Heuristic three-level Instrument combining Urban Morphology, Mobility, Service Environments and Locational Information (HIMMELI)

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Heuristic three-level Instrument combining urban Morphology, Mobility, service Environments and Locational Information (HIMMELI)

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Background

This report introduces a spatial simulation model of an urban retail system where the accessibility concept plays a key role in several aspects of interaction. Essentially, the idea is to model the cumulative effects of accessibility and the interaction of urban actors within the physical framework created by the urban structures. The study is focused on retailing which is (and has been) one the core activities of cities and which also is highly competitive and dynamic. The actors in the retail sector continuously search for new locations and modes for production and consumption in order to get comparative advantage. The behaviour and interaction in urban systems have already been interpreted as obeying the principles of complex systems (e.g. Jacobs, 1961; Schelling, 1978; Allen 1981) even before 'complexity theory' (or 'complex systems theory') has been established. The availability of computing capacity later enabled new methodologies like agent based modelling for simulating the complex phenomena.

This continuously changing and complex nature of urban development, which is emphasised in a retail sector but can also be seen in other fields, has raised new paradigms and understanding about planning problems during the last two decades. Widely used traditional planning methods are not fully able to answer the challenges of this new operational environment. This paradigm change and processual approach has created a new demand for planning tools that increase knowledge of the development process and cumulative effects of individual interactions. New planning instruments should be able to reveal causal relations and boundary conditions that can lead to system phase transitions and additionally show whether they lead to more fluctuating or stable development paths. Modelling tools can work as useful instruments in discussions between private and public sectors in planning processes and particularly in situations where tensions exist between different interest groups. The model presented here is still in a test phase and requires still improvements in order to serve in real planning contexts.

Conceptual framework and theoretical underpinnings

The focus of the modelling tool is to observe how different accessibility factors influence on a spatial organization of retail units and how this process can be simulated by using agent based modelling methodologies. The objective is to find out how the selected boundary conditions effect on the location choice of retail units on the regional scale. These boundary conditions in the model include accessibility measures, the properties of infrastructure as well as the features of urban actors and objects like households and retail units. The model emphasises the spatial aspects of the self-organising phenomena. All this is related to the network city theory in a way that the overall model structure follows Gabriel Dupuy's theoretical three level framework of urban networks (Dupuy, 1999).

The simulation model comprises all the three level elements of Dupuy's model: (1) infrastructural networks, (2) networks of production and consumption and (3) agent level networks. However, all the elements are reduced for the purposes of the retail model. Households - as the operators of level three - create the connections between the operators on level two by forming their spatial territories. As the focus of the model is on the dynamics between the three elements it also gains from the tradition of spatial interaction modelling (e.g., Batty 1976; Wilson, 1985). Approaches from different theoretical backgrounds are combined and the interest lies on the process in which the competing retail units act as independent agents and locate themselves in urban structure. The objective is to approach the concept of accessibility not only by reducing problems into smaller parts but observing it as a part of a larger entity.

Since the model approaches the retail system as spatial and morphological phenomena, accessibility is also mainly defined in terms of the structural properties of the urban environment. However within the model different components of accessibility (Geurs & Wee, 2004) are related to interactions, namely land use, transportation and individual components. The accessibility is taken into account when defining the agglomeration advantages of retail units and when households select their shopping destinations based on utility measures. The accessibility measure which is based on network properties is utilised in the process of locating new retail units generated during the simulation process.

Operational aspects

The model consists of two major modules: (1) an initialisation module and (2) a simulation module. The initialisation module includes all functions that read all the input data for the model. The input data includes information concerning households, retail services and transportation system. The actual processing of the data then happens in the simulation module which runs the given number of simulation cycles.

A more accurate description of the model can be seen in a model flow chart represented in Figure 1. The model utilizes accessibility measures in multiple ways during the simulation cycle. At first it calculates the accessibility measure from every retail unit to every other retail unit (Acc R-R) which indicates the degree of clustering of each retail unit. In the second step, the model calculates the utility of each retail unit for every household and their shopping orientation is based on this ranking of retail units (ordinal utility). The utility function includes an accessibility factor which is based on the travel cost from household location to the retail unit locations (Acc Hh-R). After every household has selected their shopping destinations, the purchasing power of every household is allocated to retail units and retail unit accounts are updated. Every retail unit type has a certain revenue limit that they have to reach in order to survive to the next simulation cycle. If a retail unit does not achieve the revenue limit, it goes bankrupt and is removed. At the end of each simulation cycle new retail units are created to replace the unit that went bankrupt. The location of the new retail units is based on the accessibility of the network (Acc Network) within a given radius. The new generation of retail units created at the end of each simulation cycle initialises the next cycle and the series of these generations form the development path of the system.

The formulas for calculating the accessibility and the utility measures

Accessibility from a retail unit to every other retail unit is defined as:

$$Acc_{R-R} = A_u = \frac{1}{n}\sum_{u=1}^{n} T_{uv} \qquad (1)$$

where T_{uv} is travel cost from retail unit *u* to retail unit *v*.

The clustering indicator of the retail unit *u* is then defined as

$$C_u = c_t A_u \qquad (2)$$

where c_t is coefficient which controls the magnitude of clustering for each retail type. The effect of the size of each retail unit is defined as

$$R_u = s_t S_u \qquad (3)$$

where s_t is coefficient depending on the unit type and S_u is size of the retail unit. Similarly the accessibility for a household in segment *i* to retail unit in segment *j* can be formulated as follows

$$Acc_{Hh-R} = A_{ij} = t_t T_{ij} \qquad (4)$$

where t_t is coefficient depending on unit type and T_{ij} is travel cost from segment *i* to segment *j*. Finally these can be combined into utility function. The utility of a household in segment *i* for retail unit *u* in segment *j* is defined as

$$U_u = \frac{C_u R_u}{A_{ij}} \qquad (5)$$

New retail units generated at the end of every simulation cycle are located on the basis of network level accessibility within a given radius *R.* The network accessibility measure for each segment *i* is defined as

$$Acc_{Network} = A_i = \frac{1}{n}\sum_{i=0}^{n} T_{ij} \quad (i, j \in R) \qquad (6)$$

where the T_{ij} is the travel cost from segment *i* to segment *j*.

The case study of the test phase is executed in the Helsinki City region in Finland. The model currently uses the census database of households. The original database includes the number of households (three income brackets) in grid format but for the model the information is linked to the road network database. The model also utilizes a company register database which includes the classification of companies based on the company size and branch. The retail typology is derived from the classification which is based on the national version of Statistical classification of economic activities in the European Community NASE Rev.2. Hitherto the model has been tested only with the data sets from Finnish sources, but there are no restrictions to use other data sources available.

At the more general level, the urban environment is represented in this study as a set of discrete spaces including information from one discrete space to every other discrete space. This representation can be defined also as a generalized travel cost matrix. As it can be noticed from above that the travel cost matrix used in current simulations is based on the representation of the topological road network structure where one road segment corresponds to one discrete space. However, the model structure allows the travel cost matrix to be based on any other relevant transportation means or spatial entities e.g. public transportation or lots.

Technically, the model is running in 64-bit Windows environment with Microsoft .Net Framework and MapInfo GIS-software. The actual code is written in MapBasic (programming language for MapInfo) and in C#. The calculation time for the dataset of ~ 20000 road segments is currently about 50 minutes and the memory usage is approximately 6 GB. Thus the implementation of the model requires some basic knowledge about MapInfo software and some general understanding of programming.

Relevance for planning practice

The model increases knowledge about the relationship of retail dynamics and the structural properties of the urban physical environment e.g. transportation networks. The simulations will produce the series of different development paths of spatial self-organisation of retail units. These development paths can reveal the phase transitions that are related to the boundary conditions defined in the model. The model enables the observation of factors behind the location choice that take into account consumers' shopping strategies as dependent on urban structure. Thus, it enables observation how the distribution of retail units emerges from individual agents' decisions which are based on several accessibility measures.

The model will also help the assessment of planning scenarios e.g. how new road alignments or new residential growth affect service locations. Generally, the tool can avail planners to approach their task of controlling the development as a process instead of an attempt to define the end result without knowing the process.

Strengths and limitations

From the scientific point of view the model offers new methodology to analyse interaction within an urban system as a self-organising far-from-equilibrium phenomena instead of using the equilibrium based land-use transportation models or spatial interaction models. The agent based modelling methodologies and the availability of more detailed data enable less aggregated representation of the system objects and more powerful tools for representing behavioural mechanisms compared with the tradition of spatial interaction models.

Currently, the model is still in a development phase and needs more testing and validation in order to serve as a serious and credible tool in real planning contexts. One of the next steps should be development of a calibration process through which a "best fit" parameter combination that corresponds to a historical development in a given area can be found. One of the strengths in real planning contexts is the knowledge that the model can produce concerning the feedback loops and causal relations between changes in infrastructural or other attributes and the reactions or the behaviour of urban actors from individuals to institutions.

One of the key future improvements of the model would be the inclusion of public transportation. The travel cost matrix which currently is based on a road network (i.e. private transportation) could be extended to cover public transportation services. This requires the data of public transportation and the methodology how this data can be processed into travel costs.

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Figures

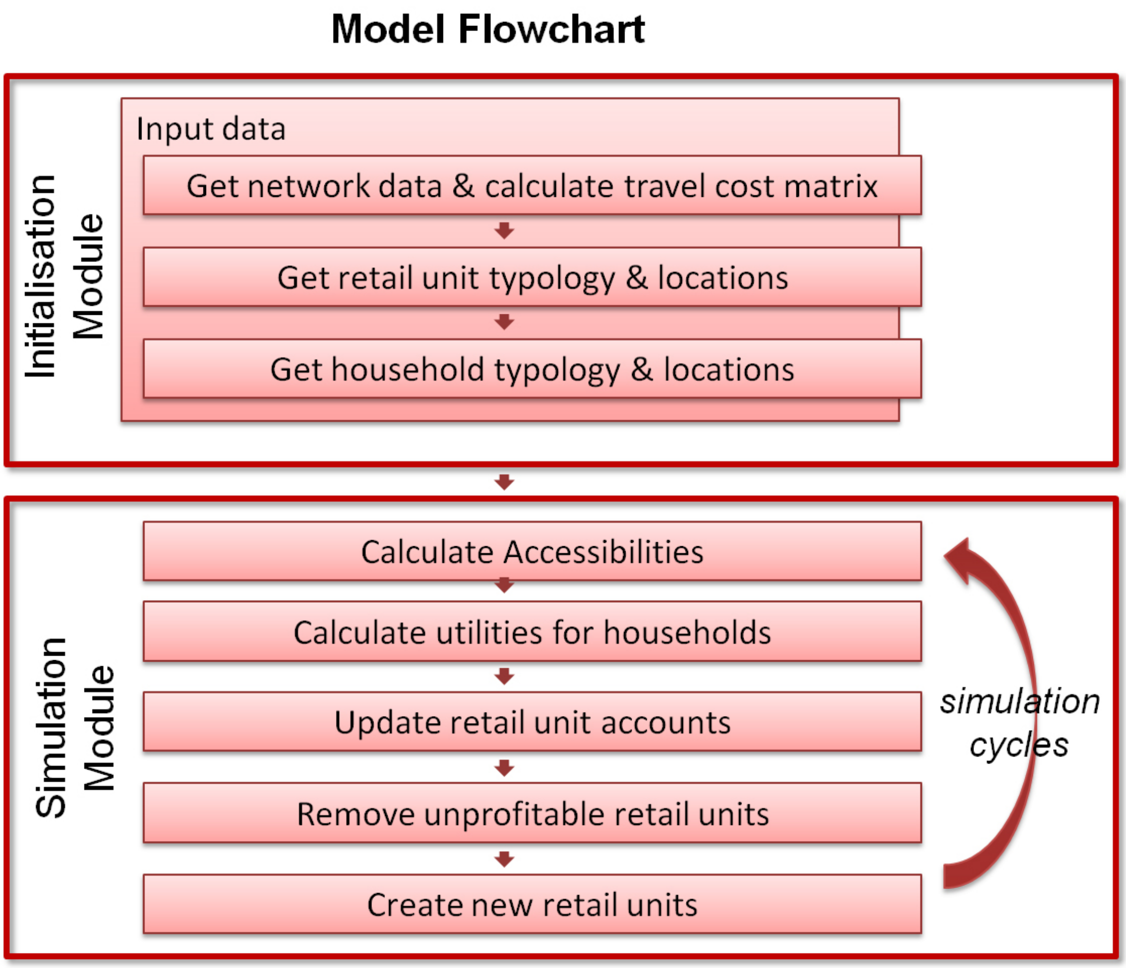

Figure 1 The simplified model flowchart

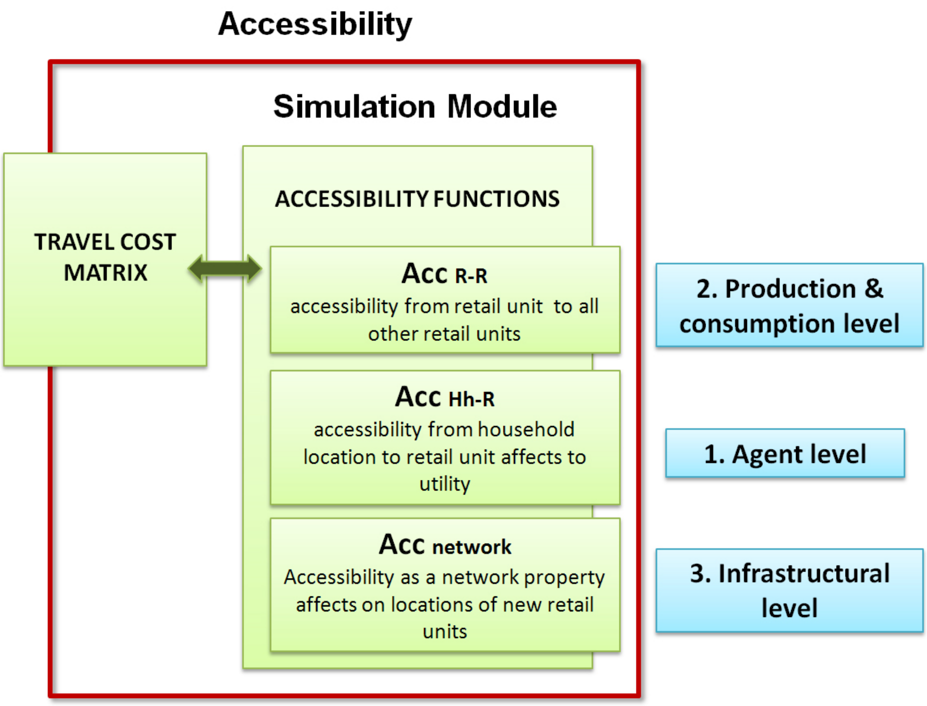

Figure 2 Different accessibility functions of the simulation module

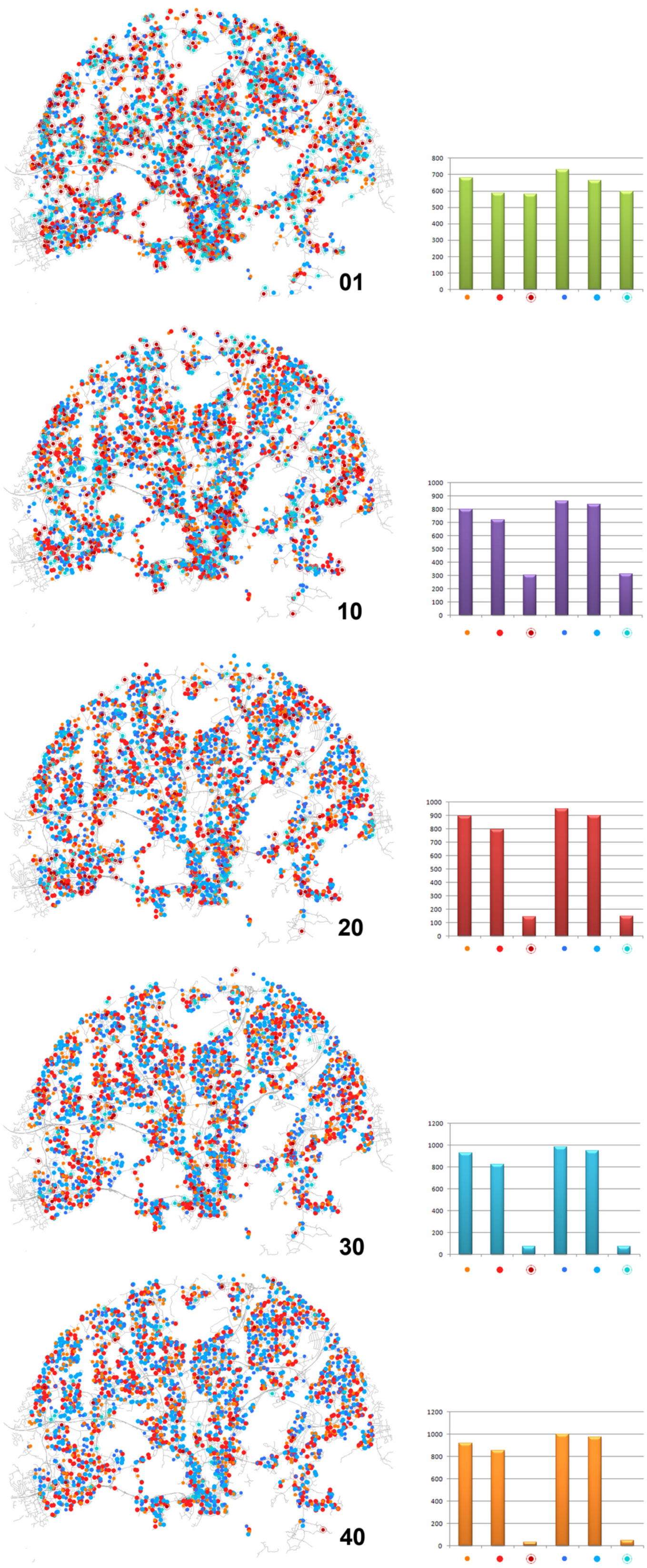

Figure 3 An exemplar of the simulation development path in Helsinki city region. Starting from a hypothetical random distribution of retail unit types, the charts (right) show the quantity by type