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Simulating pedestrians through the inner-city: an agent-based approach

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***Abstract*—This paper describes an agent-based model for the simulation of pedestrian movement in city centers for various types of visitors. It takes into account preferences of different types of pedestrians. The model is tested and calibrated using GNSS data of pedestrians collected during a field experiment in the city of Delft. Although the model as presented here is not yet fully validated it showed to be able to generate plausible patterns of movements making the model potential useful for urban design studies.**

I. Introduction

To design, plan and manage the use and accessibility of inner-city centers insight in the movement behavior and utilization of the public space is essential. This paper presents an agent-based model which simulates movements of the people in city centers based on their spatial preferences. So far, few frameworks exist that included the knowledge on pedestrian movement which preferences for places to visit [1], [2]. From a viewpoint of urban planning and design this combination may be of great value, as such a model gives the opportunity to explore various scenarios related to the design of city centers, road networks, and access points to cities. Future changes in urban structure may be checked in the model on possible effects on pedestrian behavior.

Most agents-based models which simulate movement behavior of pedestrian focus on applications in the field of crowd management [3], or the movement of tourists in nature areas [4], [5]. Only a few agent-based simulation models are known that concentrate on the behavior of pedestrians in city centers who are shopping or sightseeing, one exception of is the work of [6], [7].

In this research we present an agent-based simulation in which 3 different types of users are being distinguished, accounting for the majority of inner city users: inhabitants, regional visitors, and visitors from outside the region [8]. Inhabitants mostly combine non-leisure activities with leisure, either knowingly or not. This is the group having the most differentiated agenda but will mostly spend the least time in the city center. The regional visitor has one main purpose and that is shopping. Visitors from outside the urban region tend to spend more time with the more touristic activities like sightseeing. Like [9] also noticed, this group, the more touristic oriented leisurist, claims to do "very vaguely formulated activities such as sightseeing, wandering about, taking in the city and getting among the people". With the goal of modeling this behavior, more is needed than these vague notions of activities. Other research is more detailed and point out how this group is attracted to the obvious tourist attractions but are also is interested in shopping. Although maybe not the main purpose of the visit, most touristic visitors go shopping during their trip [10].

The goal of the research presented here is to explore the use and accessibility of streets in city centers by using an agent-based model which explicitly represents the individual behavior of people roaming around the city trying to fulfill individual desires. The simulated patterns are verified by comparing them with tracking data collect using GNSS devices during a field experiment in the city of Delft. It tries to go a bit beyond models by explicitly including attractiveness of areas, streets, and facilities in a decision-making model.

II. Methodology

The model is based on the assumption that pedestrian movement behavior is defined by two aspects: 1) a goal oriented behavior which influences the agents to choose places to visit and 2) the movement behavior which determines the routes to follow in order to visit the places it wants to visit. The movement behavior of the agents depends on the type of visitor and the activities its wants to carry out. The movement behavior may vary from a "wandering" type of movement in which the followed route is chosen to accomplish a satisfying experience till an purely optimizing behavior aimed to reach the place(s) to visit as quick as possible.

The most important assumptions of the presented model are:

- People are constrained in space and time;
- people move forward until a crossing is reached. Crossings are points where people make decisions about the route to take;
- pedestrians avoid to move on the same part of the network multiple times as much as possible;
- destinations may change as a function of their current position and are therefore often determined on an ad-hoc basis;
- pedestrians may have different levels of knowledge on the area, based on different sources. This will influence the behavior and show different levels of distance- or effect minimizing behavior;

- route choice is influenced by the characteristics of the network as well as different elements of attractions;
- agents operate independent of other agents i.e. aspects as overcrowding are currently not take into account.

A. elements of the model

Based on this the basic elements of the model are defined as follows:

- agents representing pedestrians;
- access points;
- a representation of the network;
- representation of decision points i.e. crossings;
- specific areas of interest for the various agent types i.e. shopping areas, cultural areas etc.;
- preference rules.

The agents represent individual pedestrians belonging to a certain group i.e. inhabitants, urban region visitors, or visitors from outside the region. Each agent type has different preferences about the network and their preferred destinations as well as a varying time budget.

Access points mark locations where agent start and end their movements. Mostly they represent parking lots or public transportation hubs. Each access point seeds a predefined number of agents distributed in time on to the network.

The network represents the street network of an inner-city. Each node in the network represents a crossing. Each edge in the network is characterized by values indicating the attractiveness for that street based on four types of functions: tourist attractions, shops, drinking and dining facilities, and cultural attractions. Additionally edges have an id, name, and a zone identifier which is used to demarcate areas of interest for the three groups of agents.

B. decision-making

The decision-making of the agents is implemented following a two-step procedure:

- After being “released” from their access point agents take an optimized (shortest) route over the network to their preferred areas of interest. The characteristics of the individual edges is not taken into account during this phase. If more than one preferred areas of interest is available to an agent group one of them is chosen randomly.
- When an agent reaches the area of interest it starts to exhibit roaming behavior based on the attractiveness of the network edges. At each crossing a value is calculated indicating the probability the agent will choose this road:

$$P_{ae} = h_{ae}(Azone_{za} * \sum_{f=1}^{n}(w_{af} * Aedge_{ef}))$$

Where P_{ae} is the probability of agent a to take edge e, $Azone_{za}$ is the attractiveness of zone z to agent a, h_{ae} is the history factor, w_{af} is the weight agent a assigns to function f, and $Aedge_{ef}$ is the attraction value for edge e for function f. The history factor h depends on the number of times an agent passes an edge and is currently simply defined as a exponentially decreasing function.

TABLE I
INITIAL WEIGHTS FOR THE AGENTS

type	shops	tourist.	cult.	drinking dining
inhabitants	0.5	0.0	0.9	0.5
reg. visitors	0.9	0.0	0.2	0.4
other visitors	0.4	0.9	0.1	0.2

Each agent moves around in the city center until its time-budget is used. The time budget is determined by drawing from a normal distribution based on measured time people spend in the city during the field-experiment that people spend in the city center. Larger differences exist between local inhabitants who spend on average 4500 seconds in the city center than for example visitors from outside the region who spend on average about 8200 seconds in the city.

III. Preliminary Results

A case study of the municipality of Delft is used for this research. In 2009 a tracking research has been carried out. Students of Delft University collected GPS recordings of visitors starting from 2 parking garages near the center. A brief interview was carried out to determine the type of visitor. The participants were given a GPS-tracking device. Due to urban-canyoning effects and people continuously walking in and out shops, the quality of the GPS-tracking data varied. Assigning pedestrian to specific streets was therefore not very accurate. Instead a kernel density analysis was carried out to generate heatmaps indicating the density of visitors for the various areas in the center. For example Fig. 3 shows the most visited areas by inhabitants.

The ABM was implemented in GAMA, an agent-based development environment specifically designed for geographical systems [11]. For the model a network data set containing all streets as well as all crossings of Delft was compiled. Based on a field visit each street was assigned an attractiveness value for each of the 4 aspects (shops, tourist attractions, cultural attraction, and drinking and dining facilities) (see for example Figs. 1 and 2).

The weights each agent assigns to the attractiveness of a specific function w_{af} was initially based on first estimations according table I and needs to be calibrated. As starting points the location of the parking garages near the center were used, which are the same as used for the GPS-tracking research. The number of agents leaving each parking garage was also based on the data of the field experiment.

Fig. 4 shows the results of the simulation for inhabitants. Currently these results are preliminary. However a quick visual comparison shows that the simulated patterns coincides with the measure pattern of Fig. 3 although the extend in which the pedestrian move seem to be more spread out. To thoroughly test the presented approach currently a sensitivity analysis is carried out as well as and calibration and an extended Monte

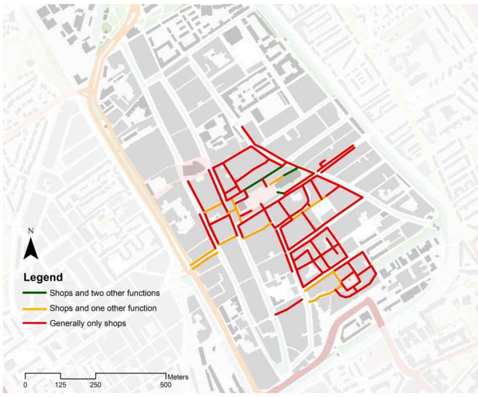

Fig. 1. Streets with having a high attractiveness for shopping

Fig. 2. Areas indicated with a high attractiveness for cultural activities

Fig. 3. Recorded GPS tracks of inhabitants visiting the city center of Delft

Carlo analysis to account for the probabilistic nature of the model.

IV. Conclusion and Discussion

Although the model up till now have not been calibrated and validated yet it already shows that it is possible to generate plausible pedestrian movement patterns for specific types of visitors of city centers with the use of existing GPS-tracking data. Patterns of movement emerge from relative simple decision-making based on attractiveness of individual

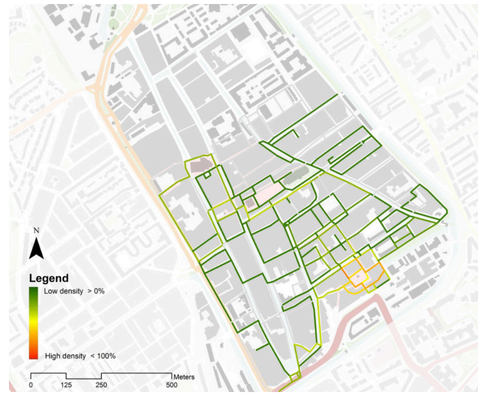

Fig. 4. Simulated movement of local inhabitants visiting the city center of Delft

roads and area to agents. A point-to-point based decision making procedure seem to realistically capture movement behavior of pedestrians in a situation were people exhibit a more exploration based behavior aimed on gathering "best experiences" in the city. The agents are currently implemented as purely reactive agents. This means that *a-priory* knowledge about for example the best shops and attractions are not known to the agent. So no means of developing intentional behavior is currently possible something which especially might influence the movement patterns of inhabitants as they are assumed to show a more goal directed behavior to shopping or visiting points of interest. A next step in the development of this model therefore could be to give agents knowledge on a larger area than only the crossings. This will enable agents to combine goal oriented behavior with the *ad-hoc* exploration of the city center thus broadening the pallet of possible movement strategies.

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