Multi-Method Analysis of the Relationship Between Individual's Space-Time Behavior, Built Environment and the Evolution of Cognitive Representations: Application of Tracking Technologies and Internet Surveys

Anastasia Moiseeva
Faculty of Architecture, Building and Planning
Eindhoven University of Technology
PO Box 513, Vertigo 8.16
5600 MB Eindhoven, the Netherlands
A.Moiseeva@tue.nl
Tel: +31 40 247 3044

Harry Timmermans
Faculty of Architecture, Building and Planning
Eindhoven University of Technology
PO Box 513, Vertigo 8.16
5600 MB Eindhoven, the Netherlands
H.J.P.Timmermans@tue.nl
Tel: +31 40 247 5096

ABSTRACT
This paper summarizes some key concepts and data collection methods used in a study which aims at better understanding how cognitions of urban environments evolve over time as individual learn about the environment by executing activity patterns. A GPS device is used to trace respondents over a longer period of time. These traces are semi-automatically interpreted to derive data on activity-travel patterns. A Web-based survey serves to complement these behavioral data with data on cognitions.

Author Keywords
Cognitive process, learning component, GPS tracking, space-time behavior.

INTRODUCTION
Research in urban planning and design, environmental psychology and related disciplines suggests that often the relationship between characteristics of the built environment and comfort, satisfaction, behaviour etc are less strong than one would like to believe [6]. It can be argued that the built environment is the spatial manifestation of human decision making. Many of these decisions are related to the way in which we perceive space, evaluate the elements of space, and imagine its potential use [1, 4]. It is important to realize that all experiences with elements of environments external to the individual take place within a framework of space and time. Although there is a wealth of studies on travel and spatial behaviour in general, much less studies have focused on space-time behaviour in public and semi-public spaces. There is a literature in environmental psychology, but this tends to focus on psychological concepts; hence the specific time-space relationship is typically not the core of analysis.

A fundamental assumption in this study is that the cognitive processes (such as perceiving, learning, formation of cognition, evaluation and cognitive maps) operate to produce in people an individual spatiotemporal awareness about environments, and mediate the relation between urban environment and behaviour. The approach taken in this study is to combine qualitative and quantitative analyses for systematically analyzing space-time behaviour and underlying psychological factors such as development of personal cognitions and value judgments (overall evaluation) toward a number of public and semi-public spaces.

We are trying to capture the dynamic evolution of the cognitive process (learning component) because learning has a major influence on the type, complexity and intensity of cognitive representations.

METHOD

GPS Tracking and Automatic Imputation of the Behavioral Patterns
In the context of our study it is crucial to understand the level of interaction (behavioral component or experience) one has had with all of the choice locations in order to determine associated cognitions and value judgments, their intensity and dynamic development. Tracking technology such as GPS logger Bluetooth A+ is utilized to collect data during 3 months on choice locations and activity-travel patterns.

The authors have developed a system, called TraceAnnotator and a prompted recall instrument, which

was designed for semi-automatic imputation of activity-travel patters [5]. The system has been developed to process automatically multi-week GPS traces. For the purpose of this project, the configuration of TraceAnnotator has been designed in a way that two main processes are handled: (*i*) imputation of transportation modes and activity episodes, whereas a Bayesian belief network is a core of the imputation process; (*ii*) imputation of an activity type where GPS data are fused with personalised and general land use data. The core of the TraceAnnotator is a Bayesian belief network that uses a network of input variables, such as speed, acceleration, possession of a transportation mode and etc, to classify the outcome variables of interest (activity location and trips with associated transportation modes).

A total of 7 different types of transportation modes are considered: walking, running, bike, motorbike, car, bus and train. For public transport, we consider only transportation modes, which are available in the study region (bus and train). Two types of the activity stops are defined: when a person conducts an activity at a certain location (activity episode) and when a person conducts an activity inside a building (activity inside building).

To increase imputation accuracy of an activity location and type of behaviors at the location, additional variables such as time of the day, and day of the week, are added as input variables into the Bayesian belief network. The results of a pilot study have indicated that activity-travel patterns can be derived from GPS traces with a high degree of certainty.

For the validation process of modes and activities episodes generated by TraceAnnotator the Internet-based prompted recall instrument was designed. A specially designed web application allows survey participants to upload multi-days GPS traces (http://bw-dssv02.bwk.tue.nl/). After uploading multi-day GPS traces, TraceAnnotator processes the data. As a result, Activity Agendas, arranged by the date (yy-mm-dd), are generated for every day. Respondents are requested to check the information for every Agenda, make necessary changes, save these changes and confirm the Agenda.

It is essential for behavioral research that we are able to impute from the GPS tracers the locations of origins and destinations, trip length, trip duration, departure and arrival times and modes for all individual trips and their corresponding trip purposes. As a result space-time behavioral patterns are described in terms of duration, frequency, type of the behavior, sequence and temporal dynamics in the use of place.

Internet Survey

The physical attributes of the built environment as well as the cultural and social components (constructs) and aesthetic quality are fundamental in forming individual's cognitive representations and value judgments toward public locations. An internet survey was designed to measure personal awareness, perceptions, cognitions and overall evaluation of certain public locations.

To allow analyses how cognitions change as individuals learn the city, respondents were asked to complete the survey in the beginning, in the middle and in the end of the tracking study.

The first group of questions involves questions concerning cognitive processes. Several questions are related to individual awareness about location attributes, perception of the location attributes and symbolic meaning of the location. Other questions are intended to understand personal considerations (reasoning) why the location was chosen.

The second group of questions is targeting toward the evaluative component: personal satisfaction with the location in general and evaluation of certain behavior in general and at particular locations.

The third group of questions consists of questions related to the learning component such as frequency of visiting and degree of interaction.

The web survey gives an understanding how personal evaluations and preferences toward location differ among people and between locations. Because the measurements are repeated, changes over time as people learn about their environment can be noted.

METHODS COMBINATIONS

The results of web survey combined with space-time behavioral patterns of individuals give an understanding how the level of experience and familiarity influences the formation of personal cognitions during the time hence allow to better understand and predict behavioral movement and space-time behavior.

The internet survey will provide information concerning the accuracy and range of recalling attributes (characteristic) of the location and evaluation of these attributes by participants (importance of these attributes for participants). For instance, on the question – could you identify social, physical and aesthetic attributes that strongly correspond to the image of this location, evoke the memory about this location – participants have to mark how these attributes characteristic for a specific location. The format for a five-point Likert scale is used:

1. very characteristic for this location
2. somewhat characteristic for this location
3. not characteristic for this location
4. I do not know – I do not notice
5. no opinion

The physical attributes relate to the built environment, the built environment includes land-use patterns, large- and small-scale built and natural features (e.g. architectural details, quality of landscaping) and the transportation system (the facilities and services that link one location to

another). Cultural and social characteristics relate to the social and cultural atmosphere of the location, diversity of activities, risk to meat unpleasant encounters, safety of walking around and etc. Aesthetic quality ascribes artistic value of the location, beauty of place and views on architecture.

At the same time the GPS traces will provide very detailed information how much time has been spend at these destinations (location), the transport mode used and the route followed.

Because individuals are traced for a longer period of time, these data also allow detecting temporal variation in activity travel patterns. Which destinations are visited repeatedly, which ones have been visited for the very first time. Assuming that cognitive representation evolves as a function of the execution of activity-travel patterns, the awareness of places, the accuracy of recalling attributes values and the degree of detail or lack therefore will likely change over time and these changes if any will be reflected in the web-survey data.

In addition to input to statistical analysis, a model of how cognitive representations are formed over time can be developed. Cognitive representations reflect the awareness of people of choice alternatives in their environments. This model can therefore be linked to a model of activity-travel behavior. Assuming that such behavior is context-dependent, choice heuristics can be derived from the data on activity-travel behavior, using data mining algorithms. An example is Albatross, developed for the Ministry of Transport [2]. This model is however static. The rules embedded in this system may however be made dynamic by allowing for specifying and simplification of rules.

In principle, alternative tree induction algorithms may be used for this purpose. However, we have found the best results for Chaid-based methods. This tree induction method allows one to identify the rules that describe which choices are made under which conditions. It relies on the *Chi-square* test to determine the best next split at each step, and generates a decision tree by splitting subsets of the space into two or more nodes repeatedly, beginning with the entire data set. To find the best split at any node, it evaluates each predictor variable and merges any allowable pair of categories of that predictor variable if there is no statistically significant difference within the pair with respect to the target variable. The process is repeated for each newly created group until no more significant splits are found. This process of extracting the rules is the same as the one used in the original ALBATROSS model.

Arentze and Timmermans [3] have suggested a method to derive elasticity information from the rule-based models to facilitate interpretation.

The principle is to use the model to predict for each condition variable a frequency crosstable of the levels of the condition variables versus the levels of the target variable in columns. The frequency table for a given condition variable is generated by applying the model as many times as there are levels of the condition variable. The frequency distribution across actions of the action variable predicted under that setting is recorded. Repeating this process for each level of the condition variable yields a frequency cross table of the condition variable against the action variable. The impact of the condition variable is then measured as the Chi-square for this frequency table. Apart from impact size, they also suggested a measure of the direction of impact.

Creating dynamic rules, which would represent a shift in the scripts people use to use the city, can be done by consistently checking whether a specification or detailing of the condition states would improve the descriptive accuracy of the choice rules. Similarly, simplification can be handling by testing whether a merge of conditions states would not lead to any statistically significant reduction accuracy.

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