BEHAVIORAL IMPEDANCE FOR ROUTE PLANNING TECHNIQUES FROM THE PEDESTRIAN'S PERSPECTIVE: THEORETICAL CONTEXTUALIZATION AND TAXONOMY

Hernane Borges de Barros Pereira
Durval Lordelo Nogueira
Lluíz Pérez Vidal
Universitat Politècnica de Catalunya
Departament Llenguatges i Sistemes Informàtics

RESUMO
Atualmente, são identificados contínuos avanços tecnológicos em análises topológicas usadas em sistemas de informação geográfica para transporte. Uma das técnicas de análise topológica é o planejamento de rotas, na qual o gerenciamento de restrições deve ser considerado. O objetivo deste artigo é fornecer uma contextualização teórica sobre a identificação e gerenciamento de restrições para conhecer o domínio da impedância comportamental sob a perspectiva do pedestre. O método da teoria de base foi usado para desenvolver a taxonomia proposta. Um meta-modelo foi usado para (1) definir a estrutura o domínio da estrutura da impedância comportamental, (2) dar suporte à coleta de datos comportamentais e (3) verificar o desenho da árvore taxonômica proposta. A contribuição principal deste artigo é a taxonomia da impedância comportamental sob a perspectiva do pedestre, a qual deverá ser usada para implementar um algoritmo de gerenciamento de restrições. Dentro deste contexto, a taxonomia proposta poderia ser usada para modelar mais precisamente as funções de custo.

ABSTRACT
Nowadays, continuous technological advances are identified in topological analysis techniques used in geographic information systems for transportation. One of the topological analysis techniques is route planning, in which constraint management must be considered. The goal of this paper is to provide a theoretical contextualization on identification and management of constraints to ascertain the behavioral impedance domain from the pedestrian perspective. The grounded theory method has been used to develop the proposed theory. A meta-model was used to (1) define the behavioral impedance domain structure, (2) support behavioral data collection and (3) verify the design of the proposed taxonomic tree. The main contribution of this article is the behavioral impedance taxonomy from the pedestrian perspective, which would be used to implement a constraint management algorithm. Within this context, the proposed taxonomy could be used to model cost functions more precisely.

1. INTRODUCTION

The interest of researchers for analyzing best routes and shortest paths allows a continuous technological advance in topological analysis techniques (e.g. route planning) used in geographic information systems for transportation (GIS-T). Topological analysis techniques can be applied to different agents such as car, bus, train (underground), aeroplane, boat, etc. In this way, Route planning considering the behavioral constraint management must be considered for each agent. Regarding that, the context of the present research focuses on urban transportation, giving attention to the pedestrian agent. However, an explicit definition of constraint domain for a pedestrian in a urban transportation system is an open approach. Consequently, some questions such as the use of only time and distance criteria for route selection, the study of spatio-temporal accessibility indicators and the study of dynamic network flow problems should be analyzed regarding a different focus, with which a complete study on the causes that lead a pedestrian to select his/her route can be carry out.

The intention or desire of traveling entails a spatial separation that is a natural constraint regarding urban public transportation scope. In this way, Morris *et al*. (1979, p. 94) commented that "spatial separation may be measured in terms of travel time, distance, cost, or some combination of these or other characteristics of the transport system". The spatial separation from the pedestrian's perspective has implications on in the behavioral impedance (BI) study that can be used to solve constraint satisfaction problems, and it is the main approach of the present research.

Several researchers in the operations research (OR) and artificial intelligence (AI) fields study constraint satisfaction problems. Raghunathan (1992) commented that OR models and AI systems can be used as techniques to do planning with constraints, and can be integrated to allow the management of a wide variety of situations in an effective manner. Cheng *et al.* (1999) commented on six approaches to increase the efficiency of constraint solving and discuss the redundant constraints approach. Kilby *et al.* (2000) presented a comparison of traditional and constraint-based heuristics methods for vehicle routing problems, and suggested that "constraint programming can be an effective way of solving routing problems" (p. 412).

On the other hand, there have been few studies where the constraint domain for a pedestrian in an urban transportation system was clearly stated. In this context, Ahern (2001) presented a similar study on decision-making process where the Theory of Planned Behaviour plays an important role. Schwartz *et al.* (1999) analyzed the various methods accorded to four major purposes (i.e. demand estimation, relative demand potential, supply quality analysis and supporting tools and techniques) to predict pedestrian's travel demand behavior, which can be applied to land use and indicators of transportation trip studies. Shriver (1997) argued that the pedestrian environment aspects constrain or facilitate a pedestrian trip. The author also commented on the limited analysis of travel distance and critical aspects of pedestrian behavior in research on walking.

Although several works on constraint issues have been published until now, more studies need to be carried out to ascertain the behavioral impedance domain in transportation network systems from the pedestrian perspective, which is an open approach yet. The goal of this paper is to provide a theoretical contextualization on identification and management of constraints regarding the behavioral impedance domain from the pedestrian's perspective within the urban public transportation context. The theoretical contextualization is based on the taxonomy proposed from a meta-model used to define the BI domain, and it will be the foundation for implementing a BI algorithm. The theoretical contextualization on the behavioral impedance domain may lead to better structuring of cost functions and algorithms used in route planning techniques.

The structure of the paper is as follows. Section 2 surveys the methodology of the present study where the philosophical position and methodological structure of the research are commented. Section 3 analyzes the main approaches on behavioral impedance domain, which is composed of a meta-model, the proposed taxonomy, and some considerations about the implications of the present proposal. Section 4 provides the conclusions and points out future research activities.

2. METHODOLOGICAL ASPECTS

The research on behavioral impedance for route planning techniques is organized in two big parts. The first part is summarized in this article, which represents a theoretical contextualization and has been basically carried out taking into account qualitative research methods. In the second part, several implementation activities will be carried out.

Consequently, quantitative methods such as formal methods, mathematical modeling and laboratory experiments will take place, and hence another methodological approach will be used.

The interpretative approach suggested by Chua (1986) was assumed to analyze the scope of the research problem. Several authors such as Orlikowski and Baroudi (1991) and Klein and Myers (1999) comment on the use of the interpretative philosophical perspective in information systems. Moreover, the research method used in determining of the meta-model and taxonomic tree elements of behavioral impedance has been grounded theory (Glaser and Strauss, 1967; Strauss and Corbin, 1990). The grounded theory method is mainly used because in this part of the research, the aim has been to construct a theory on behavioral impedance domain in order to understand the route selection phenomenon. For this, the four macro-processes have been adapted. Figure 1 depicts the relationships (i.e. chronological organization) among the grounded theory macro-processes: research design, the systematic data collection and analysis, and the theory generation.

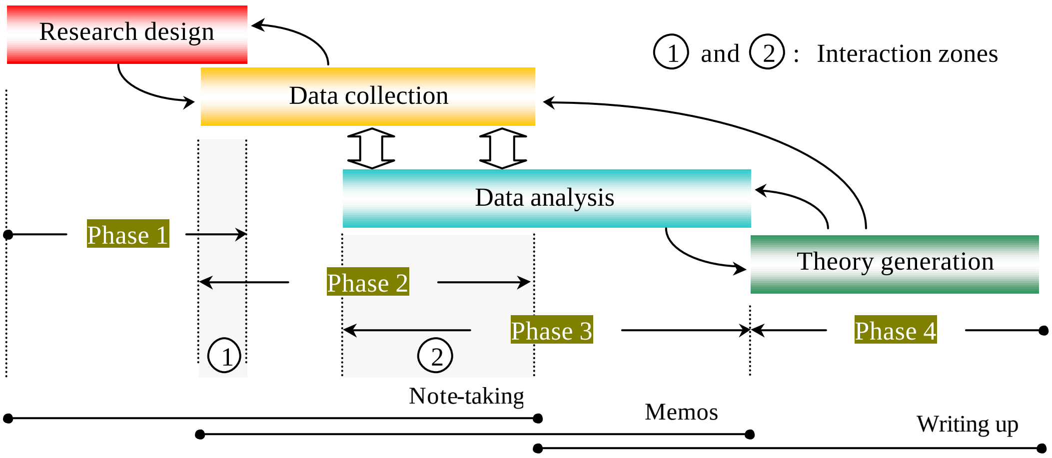

Figure 1: Grounded theory macro-processes.

In the first phase, there are basically two processes (the definition of the problem and the initial analysis of specialized literature) which are carried out in order to state the general research design (i.e. research scope). In the next phase, data collection, the types of data defined in the previous phase are collected regarding the selection criteria. The third phase, in which the theoretical sampling process takes place, is responsible for the accurate coding, sorting and analyzing of gathered data. Simultaneously, in all phases, sub-processes such as note-taking, memos (i.e. memo-writing) and constant comparison are also performed to avoid loosing important data. In the third phase the writing process is started until the fourth phase.

The two intersection zones identified in the Figure 1 represent the interactions among the processes. The first intersection zone identified between phase 1 and phase 2 represents the beginning of data collection using the initial analysis of the specialized literature as the starting point. The second intersection zone identified between phase 2 and phase 3 represents the normal and accurate data collection and analysis.

This section presents the philosophical position (i.e. interpretative approach) and the research method (i.e. grounded theory) used to carry out the acquisition and analysis of the data collection.

3. BEHAVIORAL IMPEDANCE

The term Behavioral impedance (BI) is used to refer to the constraints universe related to route planning techniques. In spite of the fact that most of the algorithms (and techniques) proposed to solve shortest and best path problems usually regard the distance and time criteria as constraints, which are applied to cost function, BI is proposed to take into account other types of criteria such as environmental or socio-politico-economical. Recker *et al.* (2001, p. 339-340) argued that "to extent that travel time is not merely just a surrogate for the actual economic cost of travel, the implication is that the time savings can and will be transformed by the traveler into something of intrinsic value – ostensibly either in more time spent on performing activities of economic, or other, value, or in increasing the 'capture space' of alternative locations for such activities".

Schwartz *et al.* (1999) commented on the Pedestrian Planning Process manual, which not only includes default impedance factors for the accessibility, amenities, attractiveness, physical comfort, psychological comfort, information and safety attributes; but also adjustment factors for elevation changes, traffic crossings, and crowding. Most of these impedance factors are considered in the BI domain.

Studies on the perceptual and measurable specification of accessibility for transport planning are closely related to behavioral impedance domain. According to Morris *et al.* (1979), "accessibility may be interpreted as a property of individuals and space which is independent of actual trip making and which measures the *potential* or *opportunity* to travel to selected activities" (p. 92). Furthermore, the authors comment on a possible link between accessibility and behavioral theories composed of three aspects strongly related to the scope of this research: "first, the choice of an appropriate measure of impedance to reflect the perceived cost of travel; second, assumptions about the perceived choice set of opportunities; and third, the choice of appropriate attractiveness variables to reflect the availability of opportunities at destinations to satisfy the particular wants and desires of travellers" (p. 94).

The BI domain has been developed using a meta-model as a starting point for the determination of elements of the taxonomy proposed. In this sense, the meta-model has allowed not only the classification and decomposition of those elements, but also the easy identification of several constraints related to BI approach.

3.1. Meta-Model

According to Raghunathan (1992, p. 321), a meta-model "is the primary knowledge source used in identifying appropriate constraints and dependency relations in a problem". In this regard, a meta-model that represents the BI domain structure is presented in Figure 2. This meta-model is composed of analytical and mathematical approaches. The analytical approach of the meta-model is used to define the tree of the BI taxonomy, which is presented in Section 3.2. On the other hand, the mathematical approach is used to specify the constraint values that will be applied to the cost function of route planning module, and it is clearly outside the scope of this paper.

As commented in Section 2, the grounded theory method has been used to determine the meta-model and taxonomic tree elements of behavioral impedance.

First, in order to design the research scope, the study on the behavioral impedance domain from the pedestrian's perspective has been defined as the research problem. Furthermore, an initial analysis of the literature specialized has been carried out. Research and practical experiences papers on GIS-T, transportation, route planning, accessibility and constraints have been selected according to the research proposal.

Secondly, data collection has been performed taking into account the selection criteria defined in the previous phase. Data were acquired from the specialized literature. In addition, a questionnaire is being applied in order to validate the meta-model and the proposed taxonomy. During data analysis, this meta-model has been developed using a similar structure presented by Raghunathan (1992), a lexicographical study supported by WordNet lexical dictionary developed by Princeton University Cognitive Science Lab (Fellbaum, 1998).

The meta-model has been organized as a hierarchy, which is composed of four levels (accurate coding and sorting processes of the grounded theory data analysis phase): Entity, State, Condition and Constraint. The first level is defined by **Entity**, which contains a set of **States** that are assigned to the second level. The following level is defined by **Conditions**, which entail in **Constraints** placed in the fourth level.

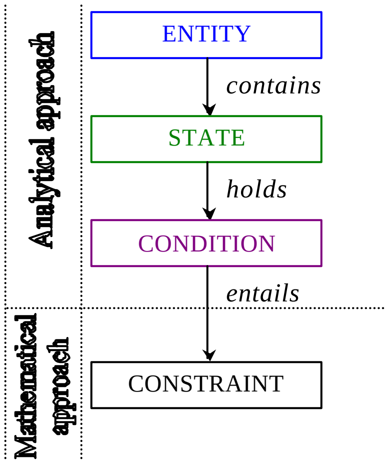

Figure 2: Meta-model of the Behavioral Impedance Domain

Finally, the proposed taxonomy allows starting the writing process, which is the basic process of theory generation. In this stage, the analytical approach of the meta-model plays a fundamental role in determining the BI tree elements that are the main focus of the proposed theory.

The determination of the entities for the BI domain regards the possible origins of influence that could produce different solutions in path selection by the user (i.e. pedestrian). The following section comments on the taxonomic structure taking into account all levels of the meta-model presented above (see Figure 2).

3.2. Proposed Taxonomy

In this research, the main interest in route planning techniques for urban public transportation from the pedestrian's perspective is not only to find the shortest path, but also the best path taking into consideration the existing impedance.

The proposed taxonomy consists of (1) some complex structural rules based on behavioral constraints of pedestrians; (2) a correspondence between the representation order from the meta-model's elements and the order observed in the real occurrences; (3) a taxonomy scheme that avoids arbitrary elements; and (4) some validation criteria initially based on research findings from the specialized literature.

The imposed resistance is produced by dynamical and/or static constraints (e.g. an irregular land or the interdiction of a road due to any incident) derived from five entities, which are basically related to the environmental, temporal, network, user and socio-politico-economic aspects. Using an inductive process as starting point, the five entities, thirteen states and thirty-six conditions have been identified in the analytical approach during the taxonomy design (see Figure 3).

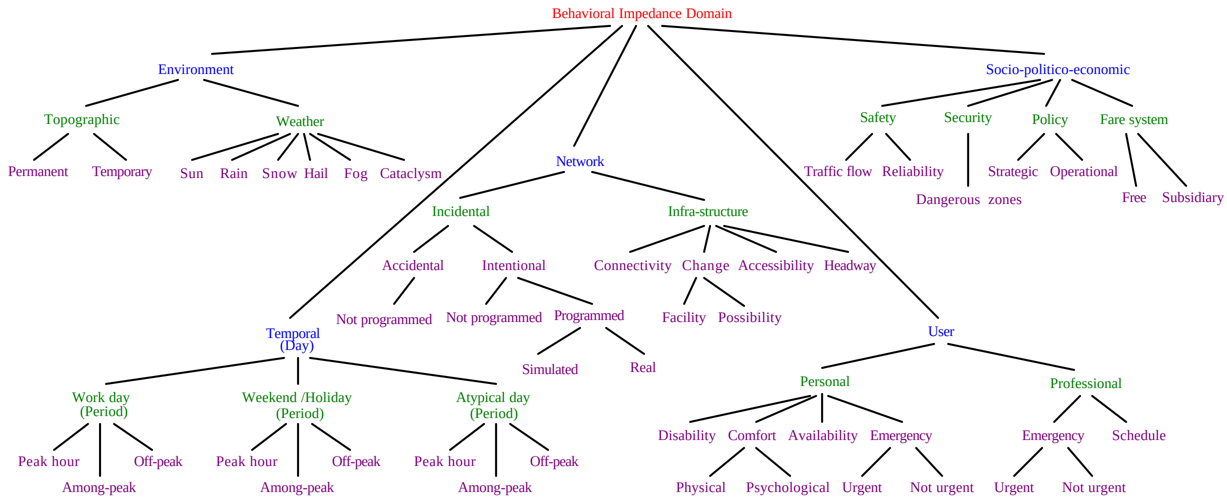

Figure 3: Taxonomy of behavioral impedance domain.

In the literature, authors such as Morris *et al.* (1979), Shriver (1997), Ercolano *et al.* (1997) and Romer and Sathisan (1997) commented on a wide group of measures (e.g. time of day, mode of travel, measure of attractiveness of opportunities, long distances, climatic conditions, pedestrian safe-access infrastructure, sidewalk, intersection corner and crosswalk) used to indicate and calculate constraint values. These measures are related to path choices, and can influence the pedestrian behavior. In addition, they can facilitate or constrain the pedestrian traffic flow, and are also identified in the present BI taxonomy.

3.3 Some Considerations

There are several relationships among the entities. Consequently, an **Entity** can influence or not the other. For instance, constraint values found in **Entity** *A* can have an influence on **Entity** *B* but cannot produce any disturbing action in **Entity** *C*. As commented before, the assignment of values to constraints is an implementation tasks and it will be described in the second part of the present research, where the mathematical modeling and the implementation of the cost function will take place.

During the grounded theory data analysis phase, four assumptions have initially been identified in order to guarantee the consistency of the relationships among the levels (i.e. **Entity**, **State** and **Condition**) of the meta-model's analytical approach. These assumptions are presented as follows:

1. This study is basically stochastic. Thus, deterministic factors such as user's availability for professional activities are not dealt with;
2. The **Conditions** establish different influences in the user's *modus operandi* and can be able to stop the pedestrian trip;
3. A **Condition** can trigger other **Conditions**;
4. The scope of the research does not involve psychological analyses, although some psychological aspects such as comfort, safety and security, are regarded as **Conditions** of the proposed taxonomy.

4. CONCLUDING REMARKS

Many studies on constraint satisfaction are carried out by researchers in OR and AI applied to transportation science. However, there have been few studies where the constraint domain for pedestrian in an urban transportation system is clearly stated. The analysis of the BI domain is carried out regarding the analytical and mathematical approaches. The former approach is the main focus of this paper and the results can visually be summarized in the Figure 3, which depicts the general taxonomy for behavioral impedance domain from the pedestrian's perspective. The later approach is clearly outside the scope of this paper and will be presented after BI module implementation.

The goal of this paper was to survey a theoretical contextualization on identification and management of constraints regarding the BI domain from the pedestrian's perspective within the urban public transportation context. Using the present BI study as a support point for the topological analyses, the transport system can offer to the pedestrian better alternatives of trip. More details on this study can be found in Nogueira *et al*. (2001).

The proposed taxonomy offers support to the implementation of the BI algorithm and some questions such as "*what information is needed to calculate the best route taking into account pedestrian's behavioral impedance?*", "*how can the behavioral impedance data be used in order to guarantee more effective route selection*?" or "*how can dynamic information systems for pedestrians be implemented taking into consideration behavioral impedance*?" should be easily answered.

The research project where this work is included is composed of six major phases. The first and second phases are summarized in Pereira and Pérez (2000). As commented before, this paper reports the partial work of the third phase, which is composed of two parts. The results of the first part are presented in this paper. Next step, second part, will be mathematically to model each restriction and to implement the behavioral impedance module that will be responsible for constraint management of a route planning prototype. The fourth (i.e. design and implementation), fifth (i.e. calibration and validation) and sixth (i.e. generalization of the results) phases are characterized by the application of the prototype regarding the multimodal network model for urban public transportation from the pedestrian's perspective.

REFERENCES

Ahern, A. A. (2001) Modal choices and new urban public transport. *Traffic Engineering & Control*, v. 42, n. 4, p. 108-114.

Cheng, B. M. W.; K. M. F. Choi; J. H. M. Lee and J. C. K. Wu (1999) Increasing Constraint Propagation by Redundant Modeling: an Experience Report. *Constraints*, v. 4, n. 2, p. 167-192.

Chua, W. F. (1986) Radical Developments in Accounting Thought. *The Accounting Review*, v. 61, n. 4, p. 601-632.

Ercolano, J. M.; J. S. Olson and D. M. Spring (1997) Sketch-Plan Method for Estimating Pedestrian Traffic for Central Business Districts and Suburban Growth Corridors. *Transportation Research Record*, n. 1578, p. 38-47.

Fellbaum, C. (ed.) (1998) *WordNet: An Electronic Lexical Database*. MIT Press, Cambridge.

Glaser, B. and A. L. Strauss (1967) *The discovery of grounded theory*. Aldine, Chicago.

Klein, H. K. and M. D. Myers (1999) A Set Principles for Conducting and Evaluating Interpretative Fields Studies in Information Systems. *MIS Quarterly*, v. 23, n. 1, p. 67-94.

Kilby, P.; P. Prosser and P. Shaw (2000) A Comparison of Traditional and Constraint-based Heuristic Methods on Vehicle Routing Problems with Side Constraints. *Constraints*, v. 5, n. 4, p. 389-414.

Morris, J. M.; P. L. Dumble and M. R. Wigan (1979) Accessibility indicators for transport planning. *Transportation Research*, Part A, v. 13A, p. 91-109.

Nogueira, D. L.; H. B. de B. Pereira and Ll. V. Pérez (2001) Study on behavioral impedance for route planning techniques from the pedestrian's perspective: Part I – Theoretical contextualization and taxonomy. *Technical Research Report LSI-01-30-R*, Departament. Llenguatges i Sistemes Informàtics - Universitat Politècnica de Catalunya, Barcelona.

Orlikowski, W. J. and, J. J. Baroudi (1991) Studying Information Technology in Organizations: Research Approaches and Assumptions. *Information Systems Research*, v. 2, n. 1, p. 1-28.

Pereira, H. B. de B. and Ll. V. Pérez (2000) Study of sidewalks in the UPC campuses of Barcelona through route planning techniques. *Technical Research Report LSI-00-43-R*, Departament. Llenguatges i Sistemes Informàtics - Universitat Politècnica de Catalunya, Barcelona.

Raghunathan, S. (1992) A Planning Aid: An Intelligent Modeling System for Planning Problems Based on Constraint Satisfaction. *IEEE Transactions on Knowledge and Data Engineering*, v. 4, n. 4, p. 317-335.

Recker, W. W.; C. Chen and M. G. McNally (2001) Measuring the impact of efficient household travel decisions on potential travel time savings and accessibility gains. *Transportation Research*, Part A, v. 35, n. 4, p. 339-369.

Romer, R. T. and S. K. Sathisan (1997) Integrated Systems Methodology for Pedestrian Traffic Flow Analysis. *Transportation Research Record*, n. 1578, p. 30-37.

Schwartz, W. L.; C. D. Porter; G. C. Payne; J. H. Suhrbier; P. C. Moe and W. L. Wilkinson III (1999) Guidebook on Methods to Estimate Non-Motorized Travel: Supporting Documentation. *Report FHWA-RD-98-166*, Turner-Fairbanks Highway Research Center – U.S. Department of Transportation – Federal Highway Administration, Georgetown Pike.

Shriver, K. (1997) Influence of Environmental Design on Pedestrian Travel Behavior in Four Austin Neighborhoods. *Transportation Research Record*, n. 1578, p. 64-75.

Strauss, A. L. and J. M. Corbin (1990) *Basics of Qualitative Reseach: Grounded Theory Procedures and Techniques*. Sage Publications Newbury Park.

The authors' addresses:

Universitat Politècnica de Catalunya
Departament de Lleguatges i Sistemes Informàtics
ETSEIB, Campus Sud – Av. Diagonal 647, 8ª planta
08028 – Barcelona – España

Tel.: +34 93 401 1954
Fax: +34 93 401 6050
E-mails:
pereira@lsi.upc.es - durval@lsi.upc.es - lpv@lsi.upc.es