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Technical Research Report

Study on behavioral impedance for route planning techniques from the pedestrian's perspective: Part I – Theoretical contextualization and taxonomy

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Abstract

The interest of researchers for analyzing best routes and shortest paths allows a continuous technological advance 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. There have been few studies where the constraint domain for pedestrian in an urban transportation system was clearly stated. Consequently, more studies need to be carried out. The aim 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. In this part of the research the grounded theory was the research method used to develop the proposed theory. A meta-model was used to (1) define the behavioral domain structure, (2) hold the behavioral data collection and (3) verify the design of the proposed taxonomic tree. The main contribution of this article is the behavioral domain taxonomy from the pedestrian perspective, which will be used to implement a module responsible for the constraint management of an experimental application, named Router. Within this context, the proposed taxonomy could be used to model cost functions more precisely.

Keywords : Behavioral impedance domain, pedestrian's perspective, constraint, route planning, geographic information systems for transportation, grounded theory

Contents

1. Introduction

The interest of researchers for analyzing the best routes and shortest paths fosters a continuous technological advance in topological analysis techniques[1] (e.g. route planning) used in geographic information systems for transportation[2] (GIS-T). One of the topological analysis techniques is route planning, in which constraint management must be considered. 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[3] 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 leads 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, Dumble and Wigan (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 leads to a behavioral impedance study, which is the main approach of the present research.

Several researchers in the operations research (OR) and artificial intelligence (AI) fields study constraint satisfaction problems. Mackworth (1977) dealt with constraint satisfaction problems as tasks that can be specified by formulating a set of variables, a specific domain for each variable, and a set of constraints associated to the values of the variables that must simultaneously satisfied. 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. Cheng, Choi, Lee and Wu (1999) commented on six approaches to increase the efficiency of constraint solving and discuss the redundant constraints approach. Comon, Dincbas, Jouannaud and Kirchner (1999) surveyed a study on the notion of constraint systems, in which methods and domains are commented. Moreover, the authors defined constraints as "an effective tool to define sets of data by means of logical formulae" (p. 337). Kilby, Prosser and Shaw (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 the pedestrian in an urban transportation system was clearly stated. In this context, Ahern (2001) presented a study on decision-making process where the Theory of Planned Behaviour plays an important role. Schwartz, Porter, Payne, Suhrbier, Moe and Wilkinson III (1999) analyzed the various methods accorded to four major purposes

[1] Topological analysis techniques can be applied to different agents such as car, bus, train (underground), aeroplane, boat, etc. Taking into account that the context of the present research focuses on urban transportation, attention is given to the pedestrian agent.

[2] Studies on geographic information systems for transportation (GIS-T technology) can be found in Thill (2000) and Oliveira and Ribeiro (2001).

[3] Morris, Dumble and Wigan (1979, p. 95) argued that "indicators of travel time, distance or cost fail unless supplemented because they reflect only one of the components of the satisfaction an individual may derive from his travel".

(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. Romer and Sathisan (1997) focused on three elements in pedestrian traffic flow analysis, which are closely related to the topographic aspects: sidewalk width, crosswalk width and corner areas. The authors commented that a balance among the aspects should improve the level of service, capacity and safety of the pedestrian transportation system.

Although several research works on constraint issues have been done 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 aim of this report 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 will be the foundation for implementing a module responsible for the constraint management of the Router application presented by Pereira and Pérez (2000). Furthermore, a meta-model and a taxonomy proposal used to define the behavioral impedance domain are presented. The theoretical contextualization on the behavioral impedance domain may lead to better structuring of cost functions and algorithms used in route planning techniques.

1.1 Organization of the report

This paper has begun with (1) a brief description of constraint management in topological analysis techniques for an urban transportation system from the pedestrian perspective, and (2) the specialized literature on constraint problems. In addition, (3) we have commented on the need for more research and (4) the main purpose has been stated. The second section will survey the methodology of the present study where the philosophical position and methodological structure of the research are commented. The third section will comment on the materials and previous work that were used in this study. The fourth section will survey the main approaches on behavioral impedance domain, which is composed of a meta-model and a proposed taxonomy; and that section will present the implications and assumptions of the present proposal. The conclusions and future research activities will be described in the fifth section.

2. Methodological aspects

The research on behavioral impedance for route planning techniques is organized in two big parts[4] (Figure 1). The first part is presented in this report, which represents a theoretical contextualization and has been basically carried out taking into account qualitative research methods. Strauss and Corbin (1990, p.17) argue that qualitative research is "any kind of research that produces findings not arrived at by means of statistical procedures or other means of qualification".

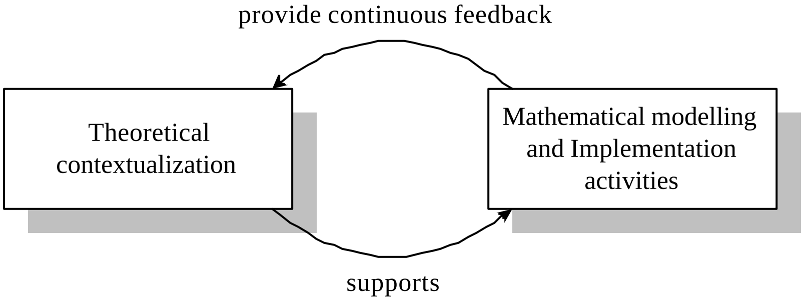

Figure 1. Parts of the research on behavioral impedance.

2.1 Philosophical positions and research method

The interpretative approach suggested by Chua (1986) was adopted to analyze the scope of the research problem. Several authors such as Orlikowski and Baroudi (1991), Klein and Myers (1999) and Caldeira (2000) comment on the use of the interpretative philosophical perspective in information systems.

Moreover, the research method used in determining 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 used mainly 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 2 depicts the relationship (i.e. chronological organization) among the grounded theory macro-processes: research design, systematic data collection and analysis, and theory generation.

[4] In the second part of the present research, several implementation activities will be carried out. Consequently, qualitative methods such as formal methods, mathematical modeling and laboratory experiments will take place, and hence another methodological approach will be used.

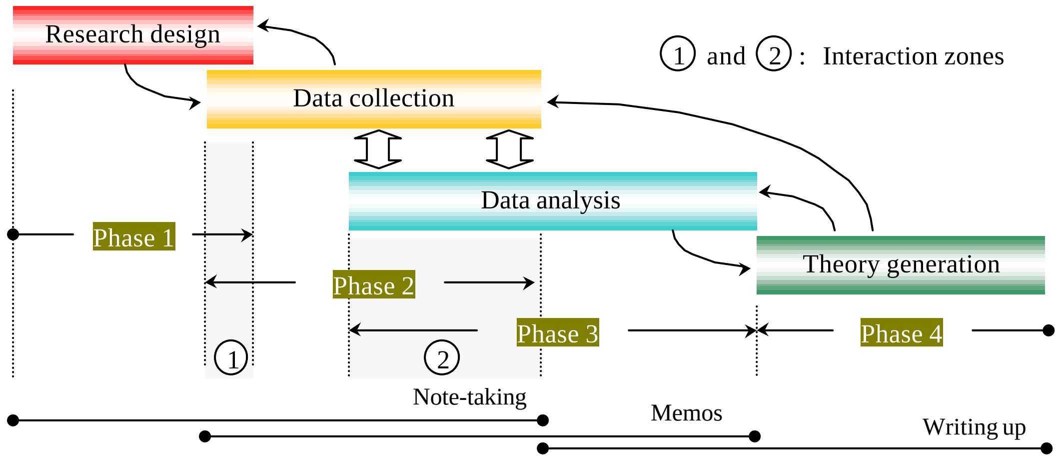

Figure 2. Grounded theory macro-processes.

In the first phase, there are basically two processes (the definition of the problem and the initial analysis of the 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 collected data. Simultaneously, in all phases, sub-processes such as note-taking, memos (i.e. memo-writing) and constant comparison are also performed not to lose important data. In the third phase the writing up 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 processes.

2.2 Questionnaire

A questionnaire is being developed in order to collect and analyze the behavioral impedance related to the decision-making process of pedestrians. Initially, the questionnaire is composed of 12 questions, which are related to mobility, public transportation modes, travel time and pedestrian behavior data. In addition, the demographic data collected have been gender, degree of study, age, professional activity, monthly income and disability.

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This section has presented the philosophical position (i.e. interpretative approach) and the research method (i.e. grounded theory) used to carry out the acquisition and analysis phases of data collection. Moreover, we have commented on the use of a questionnaire that is being used to collect the data. Section 4 provides the details about the application of the grounded theory method to the design of behavioral impedance domain.

3. Previous work

The Router 2.0 is an experimental application and works with a geographic information system. The main objective is to define the shortest path between two UPC buildings (origin and destination points) placed in the South and North campuses of the university zone of Barcelona. More details can be found in Pereira and Pérez (2000).

The initial architecture of the Router 2.0 application was composed of three modules: management, map and route modules, which are responsible for the general application management, map control and shortest path calculus with Dijkstra's algorithm (Dijkstra, 1959), respectively. Figure 3 depicts the implemented modules in solid boxes and the future modules in outline boxes (i.e. behavioral impedance, animation and simulation modules).

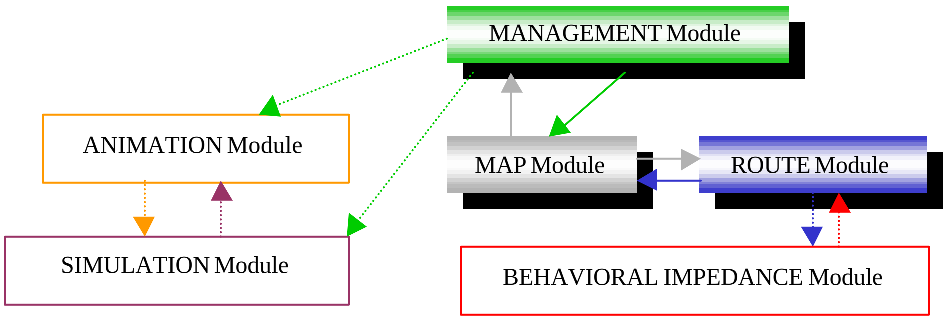

Figure 3. Router 2.0 architecture.

Router 2.0 application has been developed in ArcInfo Macro Language – AML® and C++ language. The management and map modules were developed in AML, and the route module was developed in C++. Router 2.0 application runs on a Windows NT® platform.

4. Behavioral impedance

The term Behavioral impedance (BI) is used to refer to 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 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, Chen and McNally (2001, p. 339-340) argued that "to the 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".

Using the dictionary definitions as an analysis starting point, the impedance term is proposed and used in this research. According to the dictionaries Oxford (1995), D.R.A.E. (1992) and Aurélio (1986), the word impedance arose from the study of electricity and means "the total effective resistance of an electric circuit etc. to alternating current, arising from ohmic resistance and reactance" (Oxford, 1995). Consequently, taking into account a transport network, the impedance term means a specific resistance either imposed on a part-of or whole system to the user.

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. Burns and Golob (1976) discussed the role of accessibility as a causal factor in basic transportation choice behavior from the travel by automobile and public transit perspectives. According to Morris, Dumble and Wigan (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).

In this context, Shriver (1997, p. 65) argued that "the travel-behavior approach has been sensitive to whether accessibility is determined by physical factors that induce a substitution of walking for driving trips or by personal factors that explain an individual tendency to walk".

Miller (1999) and Miller and Wu (2000) reported on the development of GIS software in which accessibility measures (i.e. rigor, realism and tractability criteria) are implemented in order to improve transportation analysis and planning. These accessibility measures are related to space-time constraints from an individual travel perspective.

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 the BI approach.

This following section presents a meta-model, which has been used as a tool to design the taxonomy proposed. In addition, some definitions of elements identified in the BI approach are presented taking into account route planning techniques used in transportation network systems for pedestrians. Finally, the proposed taxonomy is presented.

4.1 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 4. 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 4.2. On the other hand, the mathematical approach is used to specify the constraint values that will be applied to the cost function of the 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. 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 specialized literature 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 and will be validated from a questionnaire that is being performed.

During data analysis, this meta-model has been developed using a similar structure to that 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**, and then **Constraints** are placed at the fourth level.

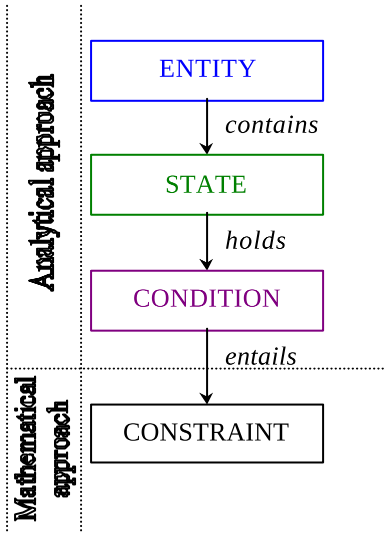

Figure 4. Meta-model of the Behavioral Impedance Domain

Finally, the proposed taxonomy allows starting the writing process, which is the basic process of theory generalization. At 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 all possible influence origins that could produce different solutions in path selection by the user (i.e. pedestrian). The following section deals with the taxonomic structure taking into account all levels of the meta-model presented above (see Figure 4).

4.2 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 actual impedance. As indicated, the taxonomy of behavioral impedance domain for pedestrian's urban transportation is proposed in this section.

The term taxonomy was chosen taking into account four arguments stated by Bloom (1956). The first argument refers to complex structural principles that allow maintaining the consistency of the taxonomy. The second argument refers to the correspondence between the order of the terms and "some 'real' order among the phenomena represented by the terms" (p. 17). The third argument refers to the fact that the taxonomy scheme may not have many arbitrary elements. Finally, the fourth argument refers to required validation "by demonstrating its consistency with the theoretical views in research findings of the field it attempts to order" (p. 17).

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[5]; and (4) some validation criteria based on research findings from the specialized literature and the results of the questionnaire[6].

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[7] as starting point, the following five entities have been identified in the analytical approach during the taxonomy design (see Figure 5).

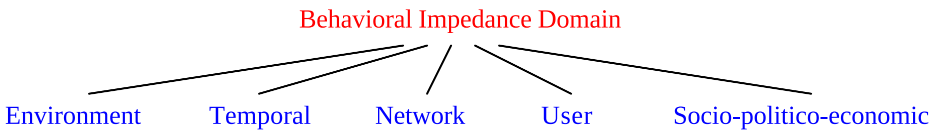

Figure 5. Main entities of behavioral impedance domain:
first level of the proposed taxonomy.

In the literature, authors commented on a wide group of measures used to indicate and calculate constraint values. Morris, Dumble and Wigan (1979, p. 94) used terms such as "unit of separation", "time of day", "mode of travel", "measure of attractiveness of opportunities", "measure of demand" and "level of disaggregation" to represent the accessibility indicators, which are related to path choices and consequently to behavioral impedance.

Khisty (1994) associated the environmental factor implications to the level of service, which should be taken into consideration in the evaluation of pedestrian facilities. The proposed performance measures are attractiveness, comfort, safety, security, system coherence and system continuity. Furthermore, Shriver (1997) commented on the importance of the walk activity characterized by accessibility influenced by spatial, environmental and individual characteristics. The first and second characteristics are related to the potential choices. The third characteristic is related to the individual behavior and demand and his/her activities. In addition, the author presented some pedestrian characteristics (e.g. weather, long distances, sufficient time, and so on). The association between the environmental factors and the pedestrian characteristics is also identified in the present BI taxonomy.

According to Ercolano, Olson and Spring (1997), pedestrian trip characteristics are composed of internal, external and extended walk trips, and aspects such as climatic conditions and pedestrian safe-access infrastructure (e.g. sidewalks, signing and refuge island) can also influence the pedestrian behavior.

Romer and Sathisan (1997) presented the main elements of urban pedestrian

[5] During the definition process of the taxonomy, it was necessary to arbitrate where some ambiguous elements should be classified. Consequently, the pertinence criterion was used to order these elements. That is, if an element is more pertinent to the entity *A* than entity *B*, then this element was included in the entity *A*.

[6] As commented, the questionnaire acquisition is being performed. Consequently, the lack of significant quantity of answers does not allow making analysis of inferences.

[7] Inductive process means that the selection of entities has been carried out taking into account the several proposed constraints in the brainstorm process.

transportation systems: sidewalk, the intersection corner and the crosswalk. In the sidewalk context, the authors argued "the effective or clear width of the sidewalk is the major determinant of the level of service and capacity of the sidewalk" (p. 31). Sidewalks characteristics are basically related to the environment and network entities and can facilitate or constrain the pedestrian traffic flow.

Fruin (1971) considered safety, security, convenience, continuity, comfort, system coherence and attractiveness as the main goals of an improvement program for the pedestrian. In addition, the author suggested a design and planning strategy in order to improve the relationship between the pedestrians and the walkways.

4.2.1 Entity of environmental aspects

As commented earlier, this research is focused on urban public transport system. This type of system is placed in a specific geographic region and affected by weather conditions. The entity of environmental aspects is characterized by (i.e. **contains**) topographic and weather states.

Topographic state (TGS) is basically characterized by (i.e. **holds**) two topographical conditions of land: permanent and temporary conditions. These conditions are related to natural (e.g. acclivities and declivities of a street) and artificial (e.g. maintenance of a street) features of the geographic region in question. Moreover, TGS can represent physical changes in the topography of land.

Weather state (WES) is basically characterized by (i.e. **holds**) six weather conditions: sun, rain, snow, hail, fog and cataclysm. The transport system does not have control on weather condition occurrences. However, 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.

Figure 6 shows a general view of the environment entity details.

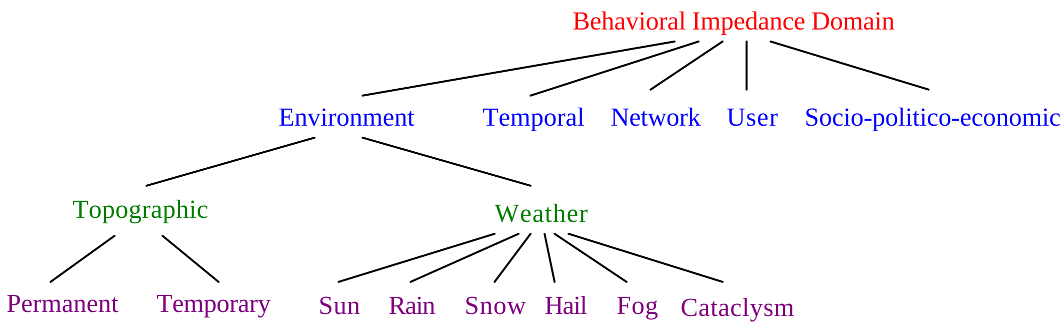

Figure 6. Environment entity details: states and conditions.

In the TGS context, elements attached to the urban topography (e.g. sidewalks) such as fire hydrants, parking meters or mailboxes constraint the capacity of pedestrian movement (Romer and Sathisan, 1997). Another important characteristic of TGS is also the direct route (i.e. directness). Sarkar, Nederveen and Pols (1997) commented that the pedestrian's preference consists of direct routes to his/her destination. Routes that would increase the distance are thus avoided.

In the WES context, climatic conditions can have an influence upon the decision-making process of the pedestrian. "Environmental conditions such as rain, fog, snow, dusk, nighttime, and glare, can limit or restrict the visibility of the crossing display" (Bailey, Jones, Stout, Bailey, Kass and Morgan, 1992, p. 69). According to Ercolano, Olson and Spring (1997, p. 42), "climate influences trip propensity".

4.2.2 Entity of temporal aspects

The quality of the urban public transport system is also dependent on the traffic flow period. The entity of temporal aspects is characterized by (i.e. **contains**) period-day states which are represented by three different types of day: work-day, weekend and holiday, and atypical day.

The three states (i.e. work-day (WDS), weekend and holiday (WHS), and atypical day (ADS)) are basically composed of (i.e. **holds**) peak hour, among-peak, and off peak conditions, which can be generally represented by intervals of hours. Obviously, each period-day has different hourly variation.

Figure 7 shows a general view of the temporal entity details.

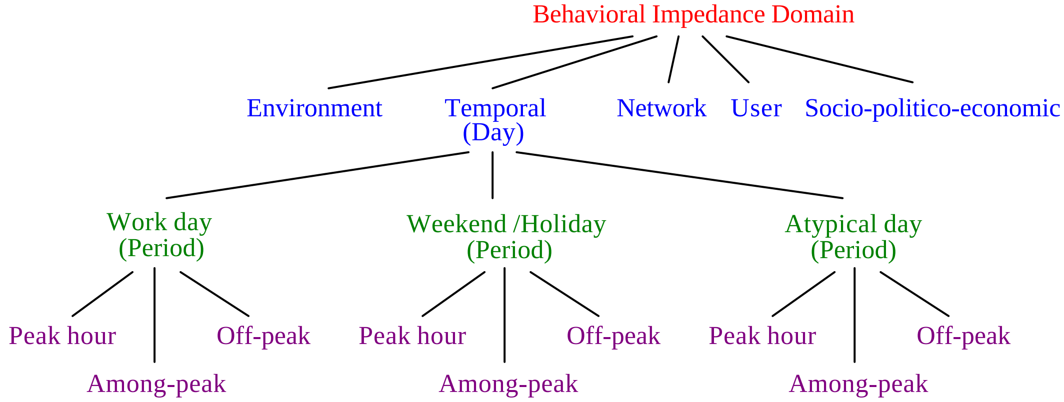

Figure 7. Temporal entity details: states and conditions.

In the literature, studies on hourly variation, traffic calming, and pedestrian volumes can be found. For instance, MT-GEIPOT (1982, p. 49-59) presented an example of "*Variação horária de viagem*" by transportation modes among traffic zones.

The improvement of road safety and of the quality of life, the reduction of the vehicle use, the encouragement of non-motorized urban transport, and the use of the street as a multi-use public place are main objectives of traffic calming (Sarkar, Nederveen and Pols, 1997). Thus, traffic calming is strongly related to the hour variation.

Schwartz, Porter, Payne, Suhrbier, Moe and Wilkinson III (1999) commented on the use of peak-hour as an input and output data used in the pedestrian demand models and pedestrian compatibility measures. In this context, Ercolano, Olson and Spring (1997) presented a method for estimating pedestrian traffic, in which the peak-hour walk-trip volumes are determined in order to guarantee a complete pedestrian safe-access infrastructure scenario.

4.2.3 Entity of network aspects

Simply stated, the graphic representation of an urban public transport system is a set of nodes (e.g. stations and stops) and edges (e.g. avenues and streets). The entity of network aspects is characterized by (i.e. **contains**) three states: incidental and infrastructure.

The incidental state (INS) is basically characterized by (i.e. **holds**) the accidental and intentional conditions. The accidental condition represents the unexpected occurrence or not programmed (e.g. unexpected blackout). The intentional condition is related to the not programmed and programmed aspects. The former aspect can be characterized by station or stop interdiction, line interruption because of climatic conditions and terroristic attack. On the other hand, the latter aspect can be characterized by general simulations (e.g. accident simulations) and transport line maintenance.

The infra-structure state (ISS) is characterized by (i.e. **holds**) the four conditions related to transport network design and operation. The first condition is connectivity, which represents the interconnections of the network. The second one is change, which represents the facility of transport line and mode change, and the pedestrian possibilities of selecting alternative routes throughout his/her trip. The third condition is accessibility, in which some services such as elevators, escalators and ramps are also related to safety aspects. The fourth condition is headway, which is related to the period of waiting between two transportation modes.

Figure 8 shows a general view of the network entity details.

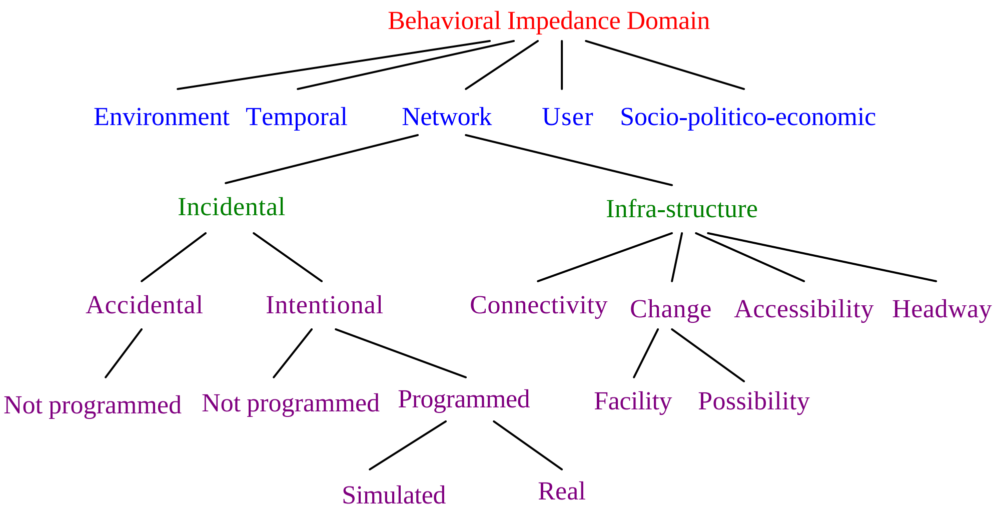

Figure 8. Network entity details: states and conditions.

Ercolano, Olson and Spring (1997, p. 42) argued that pedestrian trips "are highly dependent on pedestrian infrastructure, such as sidewalks, marked crosswalks, actuated signals, refuge islands and medians, signing, landscaping, to provide safe pedestrian access". Obstructive elements found in the pedestrian infrastructure can influence the pedestrian behavior (Fruin, 1971).

Regarding infra-structure state, authors such as Fruin (1971), Khisty (1994), Sarkar (1995) and Schwartz, Porter, Payne, Suhrbier, Moe and Wilkinson III (1999) commented on the relationships among infra-structure conditions and other conditions of the proposed taxonomy.

4.2.4 Entity of user's aspects

As indicated, topological analysis is supported by the behavior of the agents that perform trips in a transportation system. The main focus of this research is the pedestrian agent. The entity of user's aspects is characterized by (i.e. **contains**) two factors that contribute to the decision-making process in the planning of a trip. These factors are represented by two types of disjunctive demands: personal and professional states.

The personal state (PES) is characterized by (i.e. **holds**) four conditions that are not disjunctive. The first condition is disability, which is composed of physiological factors such as visual, audition and motor functions. The second one is comfort, which is related to the physical and psychological aspects for the pedestrian satisfaction. The third one is availability, which is related to the necessity of performing the trip. The fourth condition is emergency, which can determine the unconditionality of the trip. This condition is characterized by urgent and not urgent aspects.

The professional state (PRS) is characterized by (i.e. **holds**) two conditions. The first condition is emergency, which can determine the unconditionality of the trip. This condition is characterized by urgent and not urgent aspects. The second one is schedule, in which trips are programmed and several goals can be associated to them.

Figure 9 shows a general view of the user's entity details.

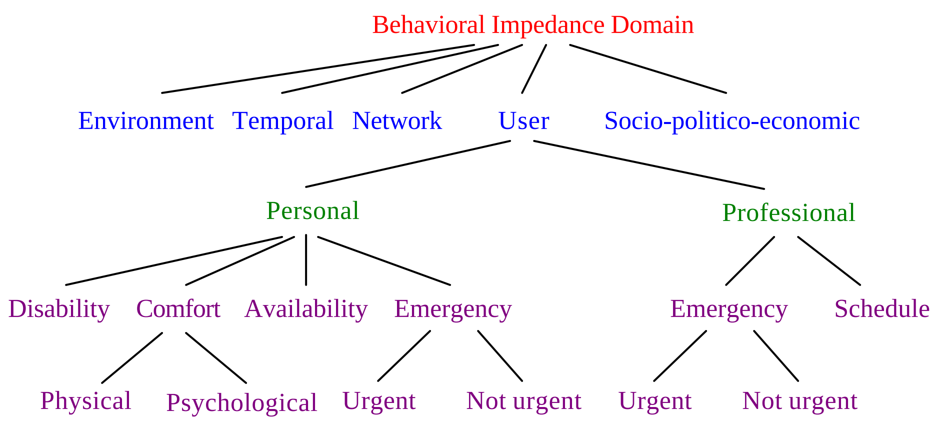

Figure 9. User's entity details: states and conditions.

In the literature, several authors describe disability and comfort as qualitative elements that should be considered for evaluating the level of service of a transport system. For instance, Khisty (1994) presented the comfort as a performance measure of a pedestrian, which is related to the other conditions within the proposed taxonomy such as weather protection, and accessibility and cleanliness of the stops and stations.

Regarding the disability condition, Bailey, Jones, Stout, Bailey, Kass and Morgan (1992) presented a study in which physiological factors of elderly pedestrians such as vision, audition, cognition and gait are pertinently surveyed.

Regarding the personal and professional states, Fruin (1971) described the necessary space for pedestrian locomotion. Fruin's study also consists of mathematical modeling based on the flow volumes and pedestrian volumes that allow determining the levels of physical and psychological pedestrian comfort.

4.2.5 Entity of socio-politico-economic aspects

There is a world tendency towards reduction in travel by private transport (e.g. travel by car) through switching or substitution by public transport (e.g. travel by walk, bike or rail). They are studied and commented by authors such as Gärling, Gärling and Johansson (2000) and Marshall and Banister (2000). The entity of socio-politico-economic aspects is characterized by (i.e. **contains**) four states: safety, security, policy and fare system.

Safety state (SFS) is basically characterized by (i.e. **holds**) two perceptions of protection. The first condition is traffic flow, in which the supports offered by the environmental and network infrastructures are closely related to the perception of safety (e.g. transportation mode speed, signing and information). The second one is reliability, where the quality of the mode of transport (e.g. in terms of waiting time and crash protection) is taken into account.

Security state (SCS) is basically characterized by (i.e. **holds**) one perception of social protection. The dangerous zones condition is related to social aspects such as police patrol, public observation and security devices, that can facilitate or constrain the performance of a pedestrian trip.

Policy state (POS) is basically characterized by (i.e. **holds**) the strategic and operational conditions. The first one represent the strategic decisions that can interfere or not in the transportation system operations (e.g. change in the network structure and fleet update). The second condition, operational policies, influences the *modus operandi* of the urban transportation system (e.g. implementation of new lines and addition of stops).

Fare system state (FSS) is basically characterized by (i.e. **holds**) market priced and subsided conditions. The first one takes into account the analysis and implementation of market prices by transportation companies. The second one, the prices subsided by the government.

Figure 10 shows a general view of the socio-politico-economic entity details.

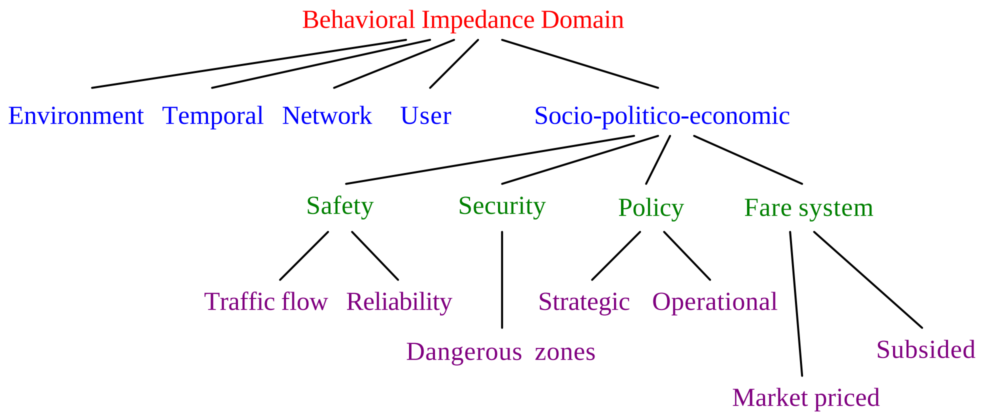

Figure 10. Socio-politico-economic entity details: states and conditions.

Regarding safety state, Shriver (1997, p. 64-65) commented that "the evaluative exploration of relationships between pedestrian behavior and attitudes has identified that characteristics of places where perception of safety is a problem include isolated areas with low visibility, broken windows and lights, graffiti, and strewn garbage; and perceptions of safety, comfort, and cleanliness are necessary for successful pedestrian activity". Within this context, Khisty (1994) also pointed out that safety and security are performance measures in order to evaluate the level of service of a transport system.

Researchers such as Fruin (1971), Sarkar (1995), Rouphail and Eads (1997), Sarkar, Nederveen and Pols (1997), Johnson (1997), Houten, Malenfant, Houten and Retting (1997) have written on pedestrian safety and the relationships between driver and pedestrian behavior in order to guarantee better integration between them by reducing the number of traffic accidents.

With regard to the economic aspects, Pendakur (1988) argued that the persons' income is the dominant factor of travel mode choice. Also, Winston and Shirley (1998) presented an extensive study on how to develop an efficient urban transportation system from the economic and political perspectives. Aspects related to strategic and operational policies, and the fare systems are discussed in order to ascertain and solve urban transportation problems.

4.3 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 influence on the entity *B* but cannot produce any disturbing action in the entity *C*. As commented before, the assignment of values to constraints is an implementation task 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. The following sections detail each entity of BI domain.

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 approached;
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.

Furthermore, it is necessary to develop matrices of correlation for each level of the meta-model analytical approach (i.e. **Entity**, **State** and **Condition**) in order to ascertain the relationships of influences among levels.

The most important and extensive matrix of correlation is characterized by the relationships among the conditions of the proposed taxonomy. To develop this matrix, we need not only the data collection from the specialized literature but also the results from the questionnaire that is being performed. Consequently, the taxonomic tree proposed in this report can be changed according to the analysis of the results of the questionnaire.

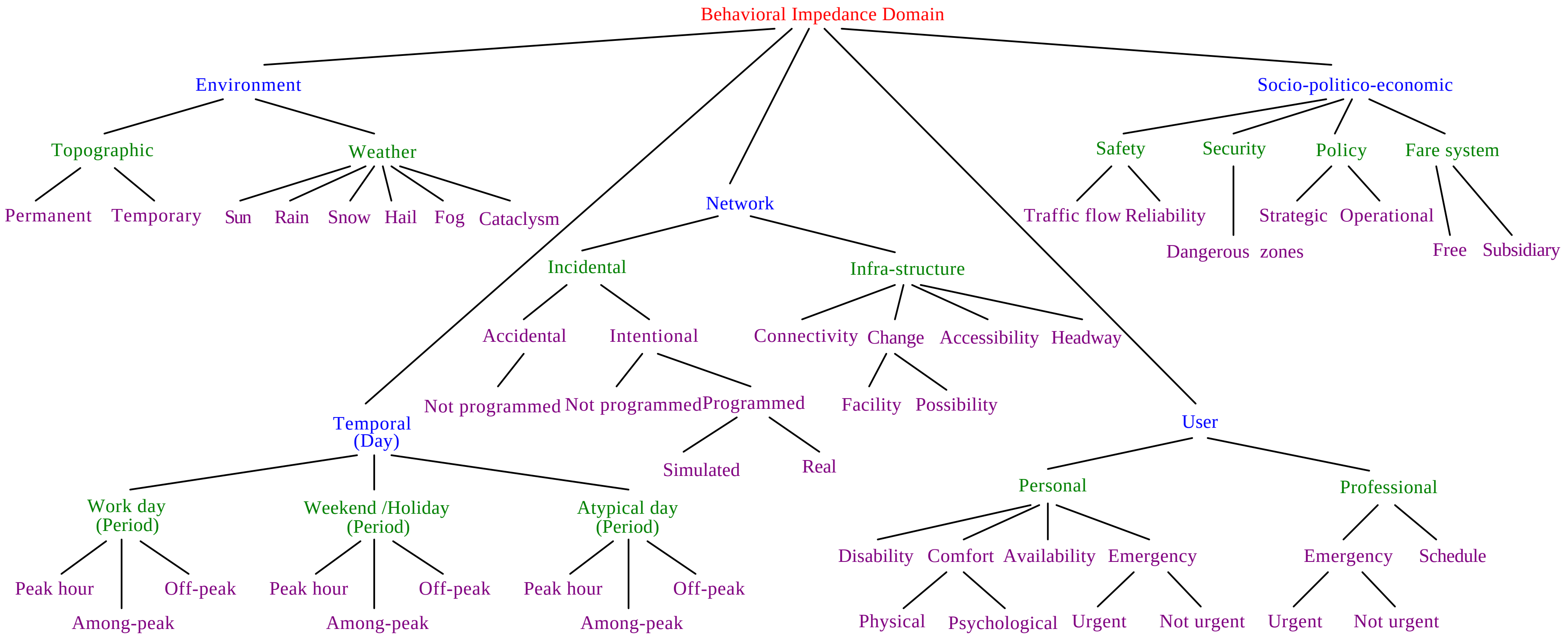

Figure 11. Taxonomy of behavioral impedance domain.

5. Concluding remarks

Many studies on constraint satisfaction are being 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 the mathematical approaches. The former approach is the main focus of this paper and the results can visually be summarized in the Figure 11, which depicts the general taxonomy for behavioral impedance domain from the pedestrian's perspective. The latter approach is clearly outside the scope of this report and will be presented after BI module implementation.

The goal of this paper is 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 could offer to the pedestrian better alternatives of trip.

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 better pedestrians' systems*?" 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 phase represents a continuous bibliographic review. The second phase was a study on sidewalks in the university zone of Barcelona (Pereira and Pérez, 2000). In this phase, an experimental application has been proposed and the management, map and route modules have been implemented.

The current phase is the analysis of behavioral impedance for route planning systems from the pedestrian's perspective, which is composed of two parts. The work and results of the first part are presented in this paper. Next step, second part, will be mathematically to model each restriction and to implement a module of the Router application responsible for constraint management.

The fourth phase is characterized by the complete design and implementation of a prototype of the multimodal network model (MNM-B[8]) for urban public transportation from the pedestrian's behavioral perspective, which must be able to solve decision-making problems using dynamic information. In the fifth phase, the calibration and validation of the MNM-B model will be performed. Finally, the analysis and generalization of the results acquired through application of the prototype to the selected case study (i.e. Barcelona) will be carried out in the sixth phase.

[8] MNM-B is an acronym for multimodal network model taking into account the pedestrian's behavioral perspective.

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