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Departament de Llenguatges i Sistemes Informàtics

TECHNICAL RESEARCH REPORT

Study on behavioral impedance for route planning techniques from the pedestrian's perspective: Some Findings and Considerations

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Abstract

The multi-disciplinary characteristics of transportation force a new design of geographic information systems, within which these characteristics are considered. In this context, geographic information systems for transportation are the result of the integration of transportation information systems and conventional geographic information systems. An interesting research area in geographic information systems for transportation is constraint management in route planning algorithms from the pedestrian’s perspective. Constraint management becomes more complex when route planning takes into account an integrated public transportation network (i.e. a multimodal network). A study on the theoretical contextualization and taxonomy of a pedestrian’s behavioral impedance has been developed in order to improve the constraint management from the pedestrian’s perspective. This study entails strategies of travel reduction by private transport (e.g. travel by car) through switching to or substitution by alternative public transport (e.g. travel by walk, bus or rail). The grounded theory method has been used to develop the proposed taxonomy. Using the partial results of a questionnaire applied to a reduced group of people from Barcelona as a starting point, important data are being collected to define the mathematical model of the behavioral impedance domain. The goal of this paper is to provide some considerations about 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 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. In this phase, an experimental application has been proposed and the management, map and route modules have been implemented on the ArcInfo GIS package and C++. This paper reports the partial work of the third phase, which is composed of two parts. The first part was a theoretical study on behavioral impedance for route planning techniques, in which taxonomy was proposed. The results of the second part are partially presented in this paper. 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. The main contribution of this article is the behavioral impedance taxonomy review from the pedestrian’s perspective, which will allow designing a mathematical model and be used to implement a constraint management algorithm. 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

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1. Introduction

The multi-disciplinary characteristics of transportation force a new design of geographic information systems (GIS), within which these characteristics are considered. In this context, geographic information systems for transportation (GIS-T) are the result of the integration of transportation information systems and conventional geographic information systems (Thill, 2000). An interesting research area in geographic information systems for transportation is constraint management in route planning algorithms from the pedestrian's perspective.

According to Vonderohe, Travis, Smith and Tsai (1993, p. 2), "GIS is much more than a tool to be applied case by case to a narrow set of specialized problems. Because of the inherent geographic nature of almost all transportation data, GIS concepts can and should serve as bases for the coherent organization of information structures and systems across the entire range of transportation applications. GIS provides a framework for moving from stand-alone isolated databases and applications to truly integrated information systems".

Several authors presented research on subjects related to constraint management, for example accessibility, mobility, and so on. Morris, Dumble and Wigan (1979) commented on accessibility indicators for transport planning, where "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). Shriver (1997), Ercolano, Olson and Spring (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.

Strothotte, Fritz, Michel, Raab, Petrie, Johnson, Reichert and Schalt (1996) comment on the MoBIC project and system, a new travel aid which "assists travellers in exploring information about the localities to which they wish to travel" (p. 140). The authors used some test participants with different abilities who even have no experience with computer. "Participants appreciated the fact that they could control the flow of information from the system" (p. 144). They put an end to their paper, commenting on the user requirements research in order to improve the mobility of the travelers.

There have been few studies where the constraint domain for a pedestrian in an urban transportation system was clearly stated. In this context, Pereira, Nogueira and Pérez-Vidal (2001) provided a theoretical contextualization on identification and management of constraints to ascertain the behavioral impedance domain from the pedestrian's perspective. Ahern (2001) presented a study on decision-making process where the Theory of Planned Behavior plays an important role. 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.

More studies need to be carried out to ascertain the behavioral impedance domain in transportation network systems from the pedestrian's perspective, which is an open approach yet. The goal of this paper is to provide some considerations about theoretical contextualization on identification and management of constraints regarding the behavioral impedance domain from the pedestrian's perspective within the urban public transportation context. For this, a questionnaire on this research approach has been designed and applied to a reduced group of people from Barcelona. Important data are being collected to define the mathematical model of the behavioral impedance domain.

1.1 Organization of the report

The structure of the paper is as follows. Section 2 presents a brief overview of GIS-T. Section 3 surveys the methodology of this research, where the philosophical position and methodological structure of the research are commented. Section 4 reviews the behavioral impedance domain, which is composed of a meta-model and the proposed taxonomy. Section 5 describes questionnaire and analyzes the results presenting the considerations on constraint management. Section 6 provides the conclusions and points out future research activities.

2. Geographic information systems for transportation: brief overview

Nowadays, geographic information systems (GIS) are computer-based applications that are used to store, manage and analyze information related to geographic characteristics. Although several authors presented GIS definitions according to their research ideologies, terms such as environment, geo-referenced data, spatial data management, manipulation and analysis, and computer-based software are used in the most of GIS definitions. GIS have been applied in many science fields, but their use in transportation area is a recent reality, thus not exhaustively researched yet.

On the other hand, several aspects such as pavement and bridge management, safety and security analysis, traffic analysis and control, travel demand analysis and cost analysis, not usually considered in conventional GIS, characterize the transportation world. Using the GIS definition structure as a starting point, transportation information systems (TIS) are applications that store, manage and analyze information related to transportation characteristics.

In this way, geographic information systems for transportation (GIS-T) are result from the union of GIS and TIS (Figure 1). According to Vonderohe, Travis, Smith and Tsai (1993, p. 11), "the necessary enhancement to existing TISs is the structuring of the attribute databases to provide consistent location reference data in a form compatible with the GIS, which in turn has been enhanced to represent and process geographic data in the forms required for transportation applications".

Within the GIS and GIS-T functional context, Vonderohe, Travis, Smith and Tsai (1993) presented six general categories of functions for data manipulation and spatial analysis: measurement, proximity analysis, raster processing, surface model generation and analysis, network analysis, and polygon overlay. Regarding constraint management in route planning and selection, this research is basically placed in network analysis category, which is composed of two analysis functions: dynamic segmentation and network overlay. On the other hand, there are other types of functions designed to analyze spatially and statistically the topology, such as shortest path analysis, optimum tour routing, location/allocation, and transportation and transshipment problems.

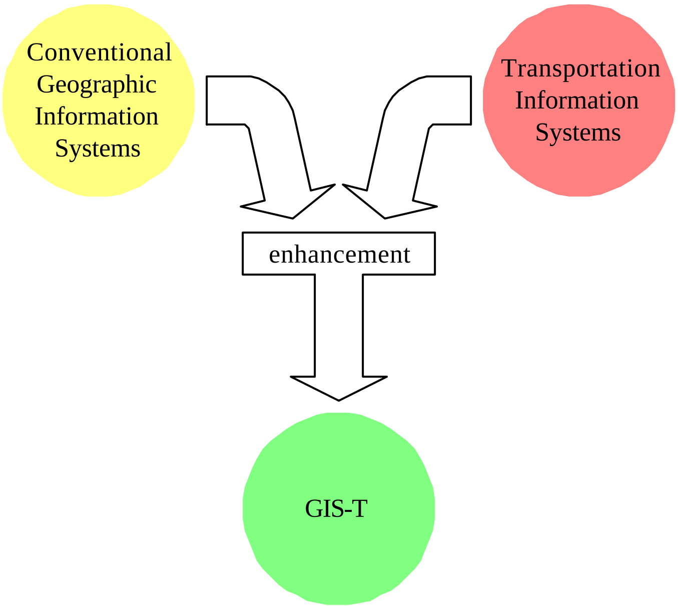

Figure 1. GIS-T as the result of the union of and enhanced TIS and an enhanced GIS. Source: Vonderohe, Travis, Smith and Tsai (1993)

Constraint management in route planning algorithms from the pedestrian's perspective is an issue for researching. Moreover, constraint management becomes more complex when route planning takes into account an integrated public transportation network (i.e. a multimodal network). A study on the theoretical contextualization and taxonomy of a pedestrian's behavioral impedance has been developed in order to improve the constraint management from the pedestrian's perspective. A previous phase to reach the constraint management module is the building of mathematical model. Therefore, some considerations on constraint management are presented in order to fit the behavioral impedance domain to GIS-T systems.

3. Research scope and methodology

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. In this phase, an experimental application has been proposed and the management, map and route modules have been implemented on the ArcInfo GIS package and C++ (Pereira and Pérez-Vidal, 2000). This paper reports the partial work of the third phase, which is composed of two parts. The first part was a theoretical study on behavioral impedance for route planning techniques, in which taxonomy was proposed. The results of the second part are partially presented in this paper. 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.

The current study is divided into two phases as shown in Figure 2. The first phase consists to identify and create the proposed taxonomy. The second phase consists of the validation of the given taxonomy, the creation of a mathematical model and then, the implementation, testing and calibrating of such model.

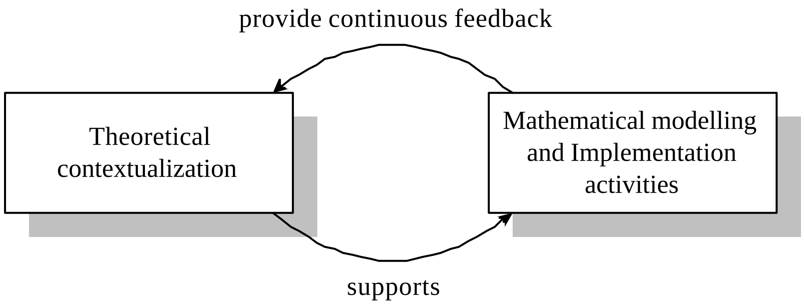

Figure 2. Parts of the research on behavioral impedance.

In this paper, some considerations on management of restrictions are presented taking into account the preliminary statistical analysis of the gathered data from a questionnaire submitted to a sample of people at the Technical University of Catalonia. Furthermore, these considerations are related to (1) the validation of the proposed taxonomy presented by Pereira, Nogueria and Pérez-Vidal (2001), and (2) the definition of the mathematical model of the behavioral impedance domain.

As commented, the research on behavioral impedance for route planning techniques is organized in two big parts. The first part has been presented in Nogueira, Pereira and Pérez-Vidal (2001), which represents a theoretical contextualization and has been basically carried out taking into account qualitative research methods. Now, statistical analysis and implementation activities are being carried out. Consequently, quantitative methods such as formal methods, mathematical modeling and laboratory experiments take place (hence another methodological approach) are used.

Within qualitative research context, 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 has been mainly used because in the first part of the research, the aim has been to construct a theory on behavioral impedance domain in order to understand the route selection phenomenon. On the other hand, quantitative research context has been used to carry out the second part of the research, which consists of quantitative methods such as statistical analysis, mathematical model design, and implementation and simulation activities.

4. Behavioral impedance domain

According to Nogueira, Pereira and Pérez-Vidal (2001), 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, socio-politico-economical, and so on.

In this sense, 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".

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.

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". This meta-model is composed of analytical and mathematical approaches. The analytical approach of the meta-model has been used to define the tree of the BI taxonomy (Pereira, Nogueira and Pérez-Vidal, 2001), and it will be briefly commented inside the scope of this paper. 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. This approach will mainly be discussed in this paper.

The meta-model has been organized as a hierarchy, which is composed of analytical and mathematical approaches and four levels: Entity, State, Condition and Constraint. The analytical approach is composed of the three firsts levels, and the fourth level characterizes the mathematical approach. 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.

Regarding the proposed meta-model, the taxonomic tree of the BI domain has been developed. 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. After analysis, some conditions were specialized in units allowing a better identification of constraints that will be used in the mathematical model. The proposed taxonomy of BI domain is shown in the Figure 3.

5. Constraint management: the beginning of the mathematical model

As commented, constraint management from the pedestrian's perspective should improve route planning techniques that take into account an integrated public transportation network. For this, it is necessary to model mathematically the BI domain from the pedestrian's perspective in order to fit the BI domain to GIS-T systems.

The building process of the mathematical model has been divided into three parts. First, a questionnaire has been prepared and a sample-panel has been established from a predefined universe, which has consisted of students and staff of the Technical University of Catalonia. Gathered data has been digitized in SPSS format, followed by the statistical inference and analysis. Second, elaboration of functions related to conditions of BI domain in order to obtain the constraints used in mathematical model.

And, finally, using the gathered data from the statistical inference and analysis and the functions of conditions as a starting point, the identified coefficients will determine the cost function during the building process of the mathematical model. This part of the mathematical model is being developed and, consequently, it is outside the scope of this paper.

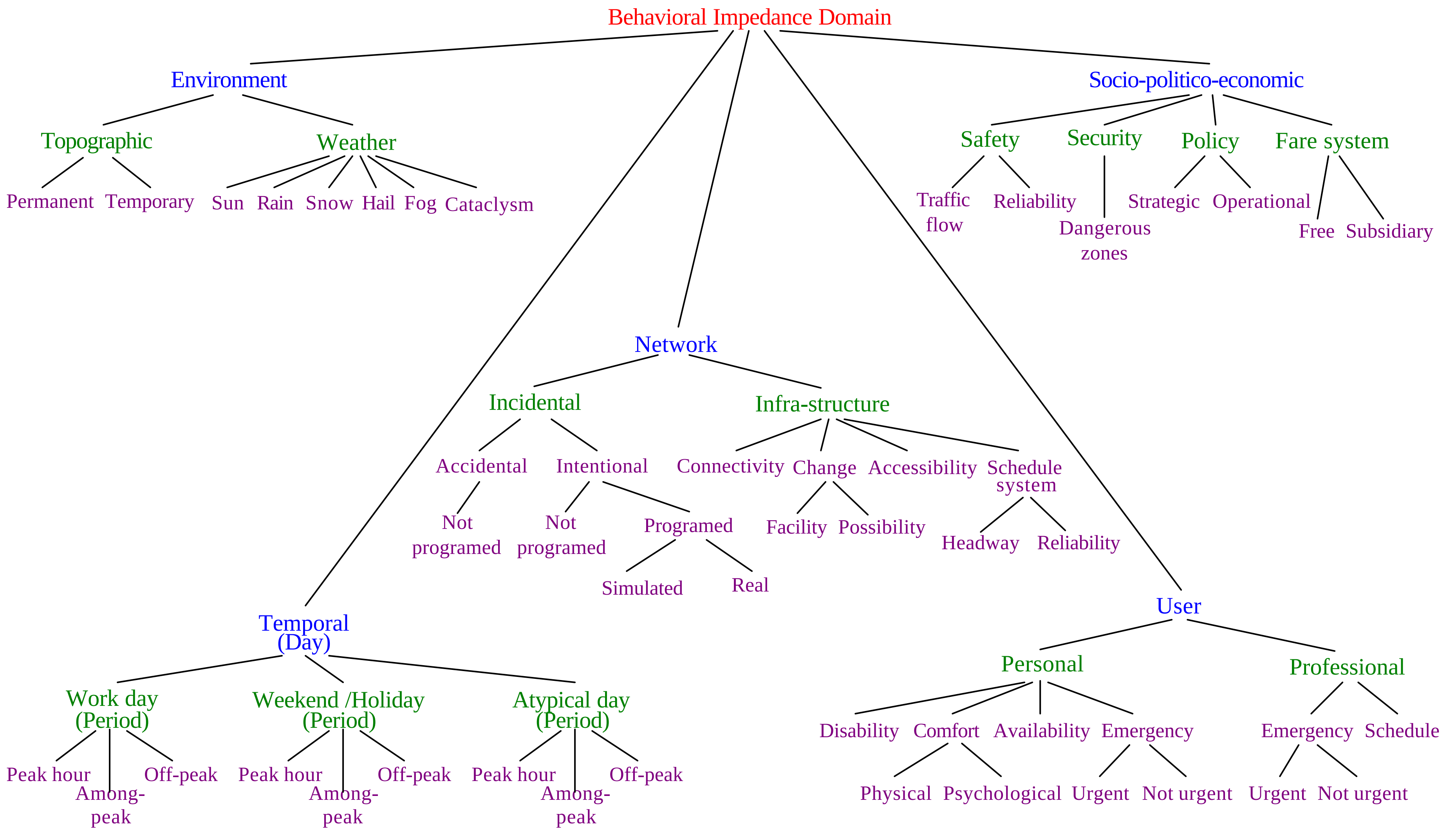

Figure 3. Taxonomy of behavioral impedance domain.

5.1. Questionnaire

At first, the main goal of the questionnaire was to validate the taxonomy, though it had to be extents one in order to enable it to capture important data for a decision-making pattern. Afterwards, more questions have been added in order to enable mathematical modeling. The questionnaire has been projected, applied and, with feedback, re-designed seven times until a final version has been accomplished. Its application has been performed between May and October, 2001. The questionnaire, whose estimated time of solving was 12 minutes, is divided into three parts:

1. **Personal data**: these data have been used in order to identify the pedestrian's profile (e.g. gender, age, study degree, incomes, disability, etc.);
2. **Transportation system data**: These data have been used in order to identify trip profile (e.g. mode, motive, trip times, headway, etc.);
3. **Behavioral impedance data**: These data (i.e. factors) have been used in order to identify the agreement level with respect to the propositions related to the conditions of the BI domain (e.g. permanent topographic, peak hour in work day, change in network infra-structure, personal comfort conditions, and subsidiary fare system). The factors have been grouped by entities of the BI domain (i.e. environment, temporal, network, user and socio-politico-economic).

The format of the scale of quantification of the factors employs a 5-point Likert scale with the following rates: 1=strongly disagree, 2=disagree, 3=not sure, 4=agree and 5=strongly agree. From the 120 questionnaires sent to a sample, which consists of students and staff of the Technical University of Catalonia, 91 were correctly filled up. Consequently, preliminary statistical analysis cannot be extrapolated to whole Barcelona because the sample has been a sectorial one. Thus, the term "user of urban public transportation" represents the sample's universe defined. Next section describes the results.

5.2. Results

The initial focus was to group the responses taking into account 5 entities of the BI domain (i.e. environment, temporal, network, user and socio-politico-economic). Frequencies of incidences grouped by entity are presented in the Table 1.

Table 1 – Frequency of incidence grouped by entity

Entity	Mean	Minimun	Maximum	Std. Deviation	N
Environment	3.3256	1	5	1.0221	75
Temporal	3.4875	1	5	1.3163	80
Network	3.8679	2	5	0.6822	90
User	3.8513	2	5	0.7550	79
Socio-politico-economic	4.0603	2.14	5	0.7475	86

The results presented in the Table 1 demonstrate the influence of each entity on the decision-making process from the pedestrian's perspective. Regarding the obtained means and standard deviation, all entities are determinant. However, network, user and socio-politico-economic entities are stronger than environment and temporal entities.

Following analysis was carried out taking into account the third part (i.e. BI data) of the questionnaire, in which the results are presented in the Table 2. Using the questions of factors as a starting point, the importance of each condition of BI domain associated to the questions of factors has been determined. Moreover, some conditions of the BI domain have been determined by trip profile into transportation system data. To obtain the pedestrian's evaluation related to his/her decision-making, the following questions of factors presented in the Table 2 have been done.

Regarding the BI domain, these questions have been fitted in three ranges or groups based on the means. First group is composed of questions of factors, where the means are less than 3 (i.e. the "strongly disagree" and "disagree" rates of). Second group is composed of questions of factors, where the means are between 3 and 3.9 (i.e. the "not sure" rate of Likert's scale). In the Table 2, this rate is called "neutral". Third group is composed of questions of factors, where the means are equal or greater than 4 (i.e. the "agree" and "strongly agree" rate of

It is observed that the questions of factors "1.1", "1.3", "3.2" and "3.7" (first group) have few relevance in the decision-making during the route selection process, because of the characteristics of the Barcelona city and the distribution of the urban transportation network.

The factors more relevant are identified (light gray rows in the Table 2) by upper means than 4 and standard deviation less than 1: "3.1", "3.3", "3.9", "3.10", "3.11", "4.2", "4.3", "5.3", "5.4", "5.5" and "5.7" (third group). This factors are strongly relevant in the decision-making during the route selection process, and highlight the importance of conditions of BI domain such as connectivity, accessibility, accidents, comfort, operational policy, subsidiary fare system, and so on.

Finally, the second group of factors has a neutral relevance in the decision-making during the route selection process. However, some factors such as "2.1", "3.5" and "5.6" are reclassified due to their trend and proximity to values of the third group.

5.3 Findings and Considerations

As commented, some considerations on management of restrictions are presented taking into account the preliminary statistical analysis. These considerations are related to (1) the validation of the proposed taxonomy and (2) the definition of the mathematical model of the behavioral impedance domain.

Regarding the validation of the proposed taxonomy, two considerations have been identified:

1. Because of the fact of there are not discrepancies between the proposed taxonomy and the results of the questionnaire, it is concluded that the proposed taxonomy of the BI domain can and should be used to improve the cost function implemented in route planning algorithms.
2. The question of factor "5.5" (i.e. reliability of the transportation system schedule) has generated a reclassification of the headway condition of the network entity. A new condition, schedule system, has been proposed. Consequently, headway changes from condition to sub-condition of the schedule system condition (Figure 4).

Table 2. Frequency of incidence by question of factor.

Ref. Number	Factor	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Valid N	Minimun	Maximun	Mean	Standard deviation
1.1	… if the streets that I use to get the transportation mode has an upward slope.	6	13	11	4	15	49	1	5	2.82	1.44
1.2	… if the streets that I use to get the transportation mode are not under construction.	19	11	14	6	12	62	1	5	3.31	1.49
1.3	… if the ways are direct ones.	8	8	14	6	12	48	1	5	2.88	1.41
1.4	… if the weather is good.	15	14	20	4	6	59	1	5	3.47	1.24
2.1	… if it is not peak hour in a work day.	35	17	10	4	10	76	1	5	3.83	1.41
2.2	… if it is not peak hour in the weekend (i.e. Saturday and Sunday).	18	10	14	10	12	64	1	5	3.19	1.48
2.3	… if it is not peak hour in an atypical day.	17	11	9	11	13	61	1	5	3.13	1.53
3.1	… if the bus, underground and rail stop are well connected.	48	13	5	3	0	69	2	5	4.54	0.81
3.2	… although frequent interruptions occur due to the maintenance of the lines and equipments.	4	1	10	13	31	59	1	5	1.88	1.18
3.3	… if there are not frequent breakdown in the transport modes.	27	13	11	2	3	56	1	5	4.05	1.15
3.4	… if there are not frequent accidents related to pedestrian	12	10	7	4	6	39	1	5	3.46	1.43
3.5	… if there are not terrorist attack scare.	27	3	8	5	4	47	1	5	3.94	1.41
3.6	… if there are not incidents in the travel zone.	25	19	11	9	4	68	1	5	3.76	1.25
3.7	… if there are not incidents outside of the travel zone.	8	7	16	10	9	50	1	5	2.90	1.31
3.8	… if the accessibility to the stop or station is good (e.g. there is elevator, mecanic stairways, etc.)	11	12	15	8	12	58	1	5	3.03	1.40
3.9	… if there is not excessive number of change.	58	14	9	3	1	85	1	5	4.47	0.91
3.10	… if the changes are not dificult ones (e.g. long corridors)	44	18	4	6	1	73	1	5	4.34	1.00
3.11	… if the headway in the stop or station is low.	53	20	4	1	2	80	1	5	4.51	0.86
4.1	… if there are not emergency situations.	18	14	17	6	2	57	1	5	3.70	1.13
4.2	… if the comfort of the transportation system is good.	29	24	14	3	0	70	2	5	4.13	0.88
4.3	… if the schedule of the transportation system is flexible.	35	15	11	4	4	69	1	5	4.06	1.20
4.4	… if I do not have professional tasks to do.	7	2	17	8	4	38	1	5	3.00	1.21
5.1	… if I do not travel through dangerous zones.	20	17	13	8	5	63	1	5	3.62	1.28
5.2	… if the traffic safety is good.	24	12	15	9	2	62	1	5	3.76	1.21
5.3	… if the transportation fare system is integrated.	41	19	8	3	2	73	1	5	4.29	1.01
5.4	… if the price of fare is not excessive.	39	15	14	5	1	74	1	5	4.16	1.05
5.5	… if the schedule of the transportation system is reliable.	41	16	10	4	3	74	1	5	4.19	1.12
5.6	… if there is not congestion of vehicles.	40	13	10	2	9	74	1	5	3.99	1.38
5.7	… if the transportation fare system is subsidiary.	24	8	6	3	3	44	1	5	4.07	1.26

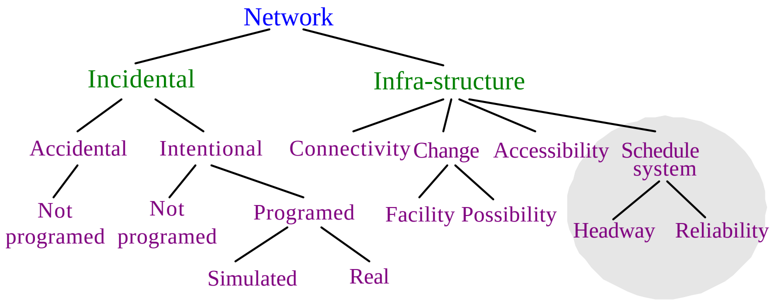

Figure 4. Schedule system condition. A reclassification of the headway.

Regarding the definition of the mathematical model of the BI domain, some relationships from the correlation matrix among the factors have been coherently identified, taking into account the Pearson correlation that are significant at the 0.01 and 0.05 levels. For this, it is arbitrarily considered the correlations greater than 0.500. For instance,

- R_1: ("traffic safety"; "dangerous zones")
- R_2: ("no terrorist attack scare"; "frequent accidents related to pedestrian")
- R_3: ("subsidiary transportation fare system"; "integrated transportation fare system")
- R_4: ("no professional task"; "peak hour in the weekend", "peak hour in an atypical day")
- R_5: ("no incidents in the travel zone"; "frequent accidents related to pedestrian")
- R_6: ("no incidents outside of the travel zone"; "frequent accidents related to pedestrian", "no terrorist attack scare").

Furthermore, other general considerations have been found:

1. All proposed conditions of BI domain influence the decision-making in the route planning process from the pedestrian's perspective.
2. Approximately, 38% of the conditions influence strongly on the decision-making.
3. Because of the fact there are strong correlations among some factors, it is concluded that ones can be functions of other. The multiple regressions among the factors that depend on more than one factor cannot be perceived yet.

6. Concluding remarks

In the constraint domain for pedestrian in an urban transportation system, few studies deal with details the pedestrian's behavioral impedance. The analysis of the BI domain is carried out regarding the analytical and mathematical approaches. Pereira, Nogueria and Pérez-Vidal (2001) presented the former approach. The later approach is being studied and some considerations are presented in this paper, but the full mathematical model will be presented after BI module implementation.

The goal of this paper was to provide some considerations about theoretical contextualization on identification and management of constraints regarding the behavioral impedance domain from the pedestrian's perspective within the urban public transportation context. For this, a questionnaire on this research approach has been designed and applied to a sample of students and staff of the Technical University of Catalonia. Consequently, some important findings and considerations related to the validation of the proposed taxonomy and the definition of the mathematical model of the BI domain were commented.

The future activities of research will be carried out taking into account three aspects: the whole statistical analysis, the design of mathematical model and the implementation process. Regarding the whole statistical analysis, the next steps will consist of (1) the stratification process of the transportation user's and trip profile; (2) the determination of the multiple regressions; and (3) the principal component analysis. Regarding the design of the mathematical model, the next steps will consist of the determination of (1) the objective function (i.e. cost function); (2) the equations of the restrictions; and (3) the coefficients of the equations. Finally, regarding the implementation process, the mathematical model of the BI domain will be incorporated to the multimodal networks for urban public transportation project.

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