Space-Time Representation of Accessible Areas for Wheelchair Users in Urban Areas

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Abstract

Providing personalized information on the accessibility of urban places for people with disabilities can significantly increase their social participation. This information should be adapted with respect to their needs at the specific time and space. Location-based technologies are considered as proper services to provide such information and encourage mobility of these people in urban areas. However, generally these services focus on the spatial conditions of the accessibility and ignore users' capabilities and time dependent constraints. This is much more challenging for people with disabilities given the diversity of their physical capabilities and preferences. To address this issue, we propose an approach to measure the space-time accessibility of urban areas considering environmental characteristics, users' capabilities, and time constraints. The proposed approach is unique and it highlights time constraint that is rooted in time geography theory. Unlike the classical time geography, which suggests a uniform travel velocity, we consider a variable travel velocity in the proposed approach, which is more relevant to the mobility of people with disabilities. To implement the proposed method, a Fuzzy approach is applied to evaluate the wheelchair speeds for the segments of a pedestrian network. The proposed approach is implemented in Saint-Roch, Quebec City for a case study and the results are presented and discussed.

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Category Short Paper

1 Introduction

The last two decades have seen a growing trend towards the space-time accessibility measures that allow geo-visualization of human activity patterns and evaluation of the accessibility for people through space and time [10]. Spatial accessibility is the result of interaction between the individual and the environment [2]. For people with disabilities, this is significant as it is in accordance with the definition of the handicap process; a path can be accessible for some while it can be inaccessible for others even if the environment is the same. People with disabilities schedule their activities considering not only spatial conditions but also temporal constraints as well as their capabilities. Hence, in order to assess the accessibility of urban areas, three main elements including environmental factors, personal factors, and the individual travel time budget should be taken into account (Figure 1).

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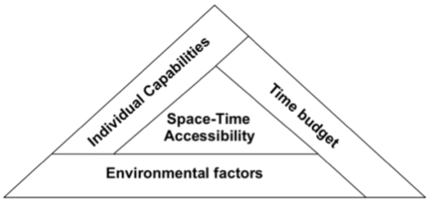

Figure 1 The main elements of space-time accessibility measure.

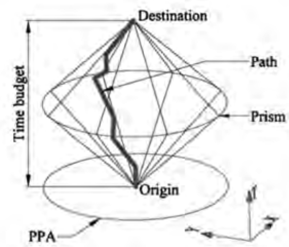

Figure 2 Time geographical concepts [10].

Time-geography concepts introduced by [3] are efficient tools to model the participation of people with different capabilities through space and time. Although this theory has a conceptual attraction and strength, very few studies have been reported on its applicability for the real world situations. This is mainly because of the difficulties of the abstraction, modeling and implementation of the real world complexities into the GIS [6]. Time geography theory relies on the concepts such as space-time prism, space-time paths, and potential path areas. The space–time prism is the package of all possible space–time paths between specified locations and times, which emphasizes on the individual ability to participate in the activities. The spatial footprint of the space-time prism is the potential path area, which is the geometric region in the space that is accessible for a moving object (for more details please refer to [8]). These concepts are visualized in Figure 2. As shown in this figure, the classical time-geography concepts suggest a uniform travel velocity, which is does not represent all the complexities of the real-world situation. For example, the travel velocity of people with disabilities and specifically wheelchair users mostly confined to the characteristics of the environment (e.g. surface quality) and their capabilities. Indeed, the accessibility level of segment (ALS), the wheelchair speed (WS), and ultimately the needed travel time (TT) of segments change from an individual to others. Therefore, these principles should be adapted for visualizing the potential travel areas (PTA) of wheelchair users. In this paper, the notion of travel area is used for an area representing a set of points reachable for a wheelchair user within a specified time, which corresponds to the potential path of traditional time geography.Although in recent years few authors have slightly adapted the time geography concepts to make it more suitable for the reflection of real-world situations [4, 5, 11, 10, 9, 7], no researches took into account the capability of people with disabilities to generate them PTA at the specified time budget. In order to address this issue, we aim to generate such areas considering time intervals for traveling of manual wheelchair users.

Following the introduction section, the paper begins with elaborating the proposed methodology in section 2. Section 3 explains the assessment of spatial accessibility of pedestrian network, which is the central part of the space-time accessibility measure process. In section 4, we employ the proposed methodology in the study area for two wheelchair users who have different level of capabilities. In this part, the spatial accessibility maps and the potential travel area through the time intervals are generated. The paper is included in section 5.

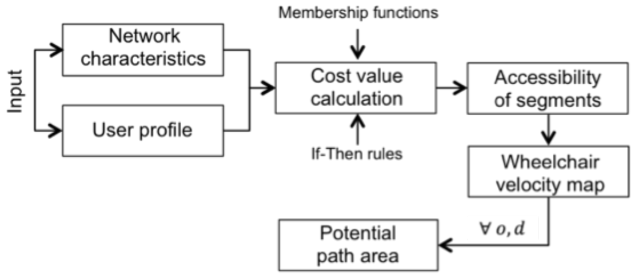

Figure 3 An overview of the proposed methodology.

2 Methodology

In reality, the WS -specially the speed of manual wheelchairs - depends on both the characteristics of the path (e.g. the surface quality and the slope) and the user capabilities. This principle should be reflected in the space-time accessibility evaluation process. Indeed, to measure the space-time accessibility, three fundamental data are required including (1) the characteristics of the travel environment; (2) the user capabilities regarding different characteristics of the environment; and (3) the WS of different ALS. In this paper, we propose a framework to measure the space-time accessibility of urban areas for manual wheelchair users. To fulfill the proposed methodology, first, we calculate the spatial ALS in the given network (i.e. study area) based on the user capabilities. To evaluate the user capabilities, the perceived ability (i.e. confidence) of a person is measured while performing a given task. Indeed, the user confidence is identified as a stronger predictor of performance than the skill itself [12]. The spatial ALS is evaluated for segments of pedestrian network by aggregating the user confidences with respect to different characteristics of the segments. To realize, If-Then rules approach in a fuzzy environment is employed. The details of this process are given in the following section. Following that, the WS of network's segments are calculated based on the calculated ALSs (i.e $WS = f(ALS)$). Finally, the TTs and consequently the PTAs are generated within the different time intervals. Figure 3 depicts the overview of the proposed methodology.

3 Evaluation of the spatial accessibility as the fundamental part of the methodology

In order to evaluate the spatial ALS, a cost value for a segment representing the ALS should be calculated. This value is computed by aggregating the user confidences with respect to the different properties of that segment. These properties are mostly determined by crisp values such 5% as the slope of a segment. However, in many cases the precise quantitative values are often inadequate to describing real-life situations and people use a more qualitative way to characterize environmental factors that affect mobility (e.g. narrow sidewalks). In our study, the fuzzy logic approach [13] is utilized to meet these requirements. To carry out the fuzzy logic approach, first, the transformation from the crisp values into a non-crisp fuzzy environment is conducted. This process is called fuzzification, which is performed by defining membership functions. A membership function is a mathematical function which maps the association of a value to a set between 0 and 1. Thus, the values of the segments' properties are transferred into fuzzy set classes using predefined membership functions [1]. Following the fuzzification process, the user confidence values should be associated to the defined fuzzy subsets. For example, high level of confidence might be associated to the gentle slope. In this

Figure 4 The spatial accessibility map for an individual.

paper, five fuzzy sets are considered to indicate the user's confidence level including Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH). These values are measured regarding three characteristics of the network's segments including Slope (S), Width (W), and Surface Quality (SuQ). The If-Then rules are subsequently defined to aggregate the user confidences and, consequently, calculate the ALS as the output variable. For example:

$If(theS.ConisVL)and(theSuQ.ConisL)Then(thesegmentisNA)$

where S.Con refers to the user confidence with respect to slope values and SuQ.Con refers to the the user confidence with respect to the surface quality values of a segment. Once the rules are defined and the aggregation step is performed, the ALS can be derived. To realize, a defuzzification technique is applied to produce exact numerical values from the fuzzy values based on the defined membership functions and defined rules. The output values are determined the ALS through four categories of Not Accessible (NA), Low Accessible (LA), Accessible (A), and Very Accessible (VA).

4 Experiments and results

Following the evaluation of the spatial ALS, The proposed methodology calculates the WS, TT, and ultimately PTA. This process is simulated for an individual who wants to travel within Saint-Roch, Quebec City. The required inputs including a graph of pedestrian network -containing nodes, edges, and their attribute tables- is collected from several data sources including collections of Ville de Québec, 2015 and web portal of Ville de Québec (i.e. S, W, SeL, and SuQ). The confidence values regarding different parameters of network (Table 1), and the WS-ALS function as s-functions (Figure 5) are simulated.The evaluation of the spatial ALS is carried out using the fuzzy approach for a part of study area. The results of this step are visualized as accessibility map in a web-based GIS tool, which is called MobiliSIG (Figure 4). Following this, the WSs for each segment based on their spatial ALS are extracted from the defined functions and ultimately the TTs of each segment for each subject are calculated. In other words, the extracted values of WSs from ALS-WS functions are used to calculate the required time for each segment (i.e.$Time = f(SegmentLength, Wheelchairspeed)$). The travel times are used as the weights of segments to calculate the time of network vertices. Figure 6 shows a simulation of ALS-WS function an individual. To understand the whole process, we illustrate the input and output data for couple of segments shown by Table 2.

Finally, the potential travel areas is generated from a given origin using the time geography concepts, which contains fundamental information about the overall directionality of the

Table 1 The confidence values regarding different parameters of network.

#	Slope			Width			Surface Quality		
Segment Attribute	Gentle	Moderate	Steep	Narrow	Moderate	Wide	Good	Fair	Poor
User Confidence	90	65	20	15	70	100	90	60	35

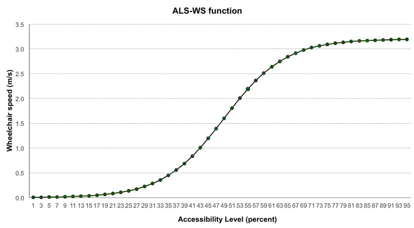

Figure 5 A simulation of ALS-WS function.

Table 2 The input and results for couple of segment examples.

Segment Id			1	2	3	4	5	6	7	8
Input	Segment Attribute	Length (m)	100	250	50	200	150	150	50	100
		S (%)	3	8	-2	4	3	2	-7	-4
		W (m)	1.5	1	2	1.5	15	1.5	1.3	1.7
		SuQ	Good	Bad	Good	Fair	Fair	Good	Bad	Fair
Results	ALS		0.8	0.25	0.85	0.5	0.68	0.68	0.35	0.7
	WS (m/s)		2.4	0.75	2.55	1.5	2.04	2.04	1.05	2.1
	TT (min)		0.7	5.6	0.3	2.2	1.2	1.2	0.8	0.8

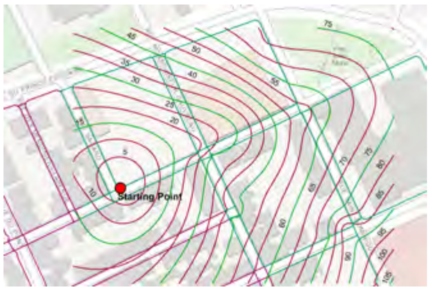

Figure 6 The potential travel area for a wheelchair user in 5s time intervals.

network and are useful for the assessment of space – time accessibility (Figure 6). In this figure, a network potential travel area is calculated in 5s time intervals. The contour lines indicate the feasible traveling parts of network in the time intervals. This knowledge on time-space accessibility would provide insights on how wheelchair users can schedule their daily activities using accessible paths and in the given time budget.

5 Conclusion

In this paper, we proposed an approach to measure the space-time accessibility of urban areas for manual wheelchair users. The originality of the method is in its focus on the people with limited mobility while considering time constraints. The approach was carried out in two steps including spatial accessibility evaluation of the pedestrian network segments, and the travel time evaluation of the segments. To perform the first step, we accounted the segments' properties (i.e. the slope, the width, and the surface quality) and the users' confidences. In this process, we were benefited from the fuzzy logic approach and defined the if-then rules to aggregate the users' confidences regarding the segments' properties. Then, the required travel time was evaluated based on the spatial accessibility levels of segments. The process was carried out for each segment employing the time geography theory. Unlike the classical time geography concepts, we considered the variable travel speeds for the manual wheelchairs. Finally the spatial accessibility map and the potential travel areas in the different time intervals were generated. The process was implemented in our study area – Saint-Roch, Quebec City – for a case study.The achievements of this research would be employed in the location-based services designed for people with disabilities to provide insights on how these people schedule their daily activities by accessible paths and in their time budget.

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