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Level of service of pedestrian facilities: Modelling human comfort perception in the evaluation of pedestrian behaviour patterns

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ABSTRACT

The paper presents a new methodology for evaluating the quality of operation of pedestrian facilities: the methodology is based on the individual level of comfort perceived by each pedestrian that moves in the area.

At each time instant, each pedestrian perceives a comfort level which is a function of the space they feel currently available and of his required space. The required space depends on the subject's walking direction as well as on physical and psychological factors. The available space depends on the current positions of pedestrians. The proposed methodology quantifies the current discomfort due to pedestrian interactions as a continuous function of the interpersonal distances.

The proposed methodology has been applied to empirical data. The experimental data are presented, discussed and compared with widely accepted level of service assessment methods.

1. Introduction

Comfortable walking is essential for pedestrian movement in modern urban transportation systems.

Good pedestrian facilities promote people to walk, whilst poor ones discourage the use of area or structure where they are. This creates the necessity of assessing the performance of pedestrian facilities (Daamen, 2002). Traditionally, the performance of pedestrian facilities is assessed on the basis of the level of service (LOS) concept. Assessing pedestrian LOS of existing facilities is useful to discover critical aspects and thus to define actions for improving them. Assessing pedestrian LOS of new facilities contributes to identify any potential problems at an early stage: mitigation measures can then be decided upon if required.

The LOS concept refers to the quality of operations of pedestrian facilities. A number of methods utilizes principles of vehicular traffic to evaluate pedestrian traffic operations. Other methodologies are more concerned with the facility design and walking environment than the actual pedestrian flows.

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This paper focuses on the interaction between a person, his desire to comfortably cross the area and the environment. That is to say, a pedestrian expects to move freely without too many disturbs due to the interactions with other pedestrians and static obstacles in the environment. Pedestrians are assumed to walk alone and have no social ties with the other pedestrians. Social groups, and the comfort of group members while walking, are out of the scope of the paper and have been considered in (Cepolina & Menichini, 2016; Cepolina, Menichini, & GonzalezRojas, 2017).

The paper is structured in the following way: Section 2 presents an overview of more common and widely accepted methods and manuals for assessing pedestrian facility LOS; Section 3 presents the proposed methodology for assessing individual comfort. Section 4 concerns the application of the proposed methodology to empirical data and compares the results with widely accepted LOS assessment methods. Conclusions follow.

2. Overview of methods for measuring the quality of operation of pedestrian facilities

A number of methods have been proposed for assessing quality of operations of pedestrian facilities. A complete picture of level of service methodologies for the pedestrian facilities has been proposed by (Sing and Jain, 2011; Sisiopiku et al., 2002; Sisiopiku, Byrd, & Chittoor, 2015).

A first classification could be done between: GROUP A *Roadway Characteristics Based Methods* and GROUP B *Capacity Based Methods*. The methods of the group A are mainly based on pedestrian environment characteristics and on how these characteristics are perceived by pedestrians. The methods of group B are based only on pedestrian flow characteristics as flow rate, speed and density and take into account pedestrian environment only giving different threshold values for the flow characteristics according to the specific pedestrian area.

A second classification could be done between aggregated and disaggregated methods, where the first ones refer to macroscopic characteristics of pedestrian flows (flow rate, speed and density) whilst the second ones refer to the individual pedestrian trajectories.

2.1. Roadway characteristics based methods: GROUP A

These methods use pedestrian perceptions and attempt to quantify the comfort level of pedestrians while encountering certain roadway characteristics. Some of the more common and widely accepted methods for determining pedestrian LOS of group A are briefly presented in the following.

SCI Model or *Landis method* (Landis et al., 2001): the model was developed through a multi-variable regression analysis based on observations. Independent variables that determine the LOS of safety (or comfort) include lateral separation elements between pedestrians and motor vehicle traffic, motor vehicle traffic mix, volumes, and speeds. The model and its pedestrian LOS predictions are based on perceived safety relative to traffic conditions and has not been correlated with actual safety data. HCM (2010) (Highway Capacity Manual, 2010) presents a method to assessing Pedestrian Level of Service which is similar to the Landis method.

Australian Method (Gallin, 2001) provides the opportunity to test the LOS provided by a pedestrian route and determines which factors contribute to low and high LOS. These factors were classified as design factors (path width, surface quality, obstructions, crossing opportunities), location factors (connectivity, path environment, potential for vehicle conflict) and user factors (pedestrian volume, mix of path users, personal security). Each factor is assigned a point on the basis of its presence and weights are assigned from the response ratings obtained from various stakeholders.

Dixon Method (Dixon, 1996) The methodology is based on the hypothesis that there is a critical mass of variables that must be present to attract non-motorized trips and defines a LOS rating that describes the degree to which facility provisions encourage pedestrian use. It considers mainly measures of pedestrian safety feature and does not take into account pedestrian flow; it is simple and easy but rather arbitrarily.

Trip Quality Method (Jaskiewicz, 2000) combines urban design architectural principles with practical safety and capacity issues to define nine qualitative parameters (enclosure of walking path by building and surrounding environment, building articulation taking account buildings flow in relation to each other, complexity and transparency of spaces relating to the ability of a pedestrian to move from public to private space, overhangs/awnings/varied rooflines, shade trees, buffer, complexity of path network and physical components/condition). A score is as-signed to each parameter and the average score is the LOS.

These methods have been calibrated for footways and pedestrian crossings and not for indoor pedestrian environments.

2.2. Capacity based methods: GROUP B

These methods use the principles of highway capacity which have been suitably adjusted to evaluate pedestrian facilities.

As it concerns aggregated methods, the most widely used one is the HCM (2000) method (Highway Capacity Manual, 2000). The method is based on the measurement of pedestrian flow rate and sidewalk space, density and speed: "as volume and density increase, pedestrian speed declines. As density increases and pedestrian space decreases, the degree of mobility afforded to the individual pedestrian declines, as does the average speed of the pedestrian stream". A planner may then look up the flow data in a reference location in a fixed period of time in a table to determine the pedestrian LOS grade. Like for