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Optimal number and location planning of evacuation signage in public space

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ABSTRACT

The smooth and fast evacuation of a pedestrian group is dependent on guidance services provided by signage systems. This paper investigates the location method of an evacuation signage system in a public space. We proposed a calculation method to determine the guidance efficiency of signage and further present a piece-wise probability function to explain interactions between pedestrians and signage. The interaction between one pedestrian and one signage was extended to the interaction between a pedestrian crowd and a signage system. A location model of the signage system was proposed to determine the minimum number of signs necessary to meet guidance demands. The location model was based on the Cooperative Location Set Cover Problem (CLSCP) and was correspondingly solved by a proposed exponential binary heuristic search algorithm (EBHS), i.e., a combined exponential binary search method and a heuristic search algorithm for solving the Cooperative Maximum Cover Location Problem (CMCLP). Finally, the proposed model was applied to determine the location of an evacuation signage system in a hall. The parameters used in the location model were calibrated based on experimental data. The model results showed that the proposed model can suggest the optimal number and best locations of signs. A sensitivity analysis showed that the guidance capacity of the signage system can be increased by improving the attractiveness of signage and pedestrian trust and familiarity with environment. The same number of signs is suggested for evacuation scenarios wherein crowd following behavior is present.

1. Introduction

1.1. Background

Signage systems are oriented visual information systems that use graphics and characters to communicate environmental information related to direction, identification, safety and regulations (Calori and Vanden-Eynden, 2015) to specific groups, ensuring safe and smooth walking experiences. These systems are typically used as a guide for passage through the physical world.

In everyday situations, as public spaces for shopping, transportation and entertainment become larger, the need for correctly designed and well-located signage becomes increasingly important (Nassar, 2011). For example, an efficient signage system produces excellent customer experience and contributes toward higher service levels, whereas an inefficient signage system confuses customers and contributes toward poorer service levels.

In emergency situations, as precautionary measures against mass accidents occurring in public facilities and to reduce any losses, evacuation signage systems play vital roles in guiding potential pedestrians to proper emergency exits. A successful signage system can indicate fast and efficient evacuation routes by simplifying the apparent complexity of a building. A poor signage system may lead to more casualties (Best, 1978; Anon., 1982; Weinspach et al., 1997; Grosshandler et al., 2005). A recent virtual reality study showed that wayfinding time can be reduced with an efficient signage system (Tang et al., 2009; Kobes et al., 2010). These systems minimize the number of wrong turns and the rate of backtracking behavior.

Because of the important role of signage systems in evacuation processes and way finding, basic international and national guidelines and standards have specified the principles and criteria of designing and locating signs to ensure that the signage system is legible, indelible and intelligible (Coté, 2011; British Standards Institution, 1990; Ministry of Public Security of the Peoples

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Republic of China, 2008; Ministry of Public Security of the Peoples Republic of China, 2005). These guidelines and standards typically contain recommendations for the sizes and colors of signs, the fonts and sizes of texts, the locations of signs, and additional lighting and materials to be used. The aims of these guidelines are to improve the cognition of signage systems so that a pedestrian can easily find them and immediately comprehend the directional guidance in emergency situations.

However, even with these guidelines, pedestrians may still become disoriented or lost during evacuation due to a number of physical and psychological factors that affect the efficiency of signage systems (Filippidis et al., 2006). A few studies have focused on a location optimization method in the design of signage systems; however, no generic solution for locating evacuation signage has been determined that satisfies all pedestrians. Few studies have attempted to explore the theory and methods for determining both the optimal locations and number of signs due to the unknown factors that affect the interactions between a pedestrian and a sign.

This paper introduces a new and quantitative method to evaluate the guidance efficiency of signage systems and the guidance demand of pedestrians. This simplifies the location optimization problem to a supply-and-demand issue. Furthermore, interaction uncertainties and microscopic pedestrian movements were incorporated in this location method to make the proposed model more reasonable and feasible. This model was applied to optimizing the location of a signage system in a hall for validation. A literature review is provided in Section 1.2, and the contributions of the paper are discussed in Section 1.3.

1.2. Related literature

Despite the importance of understanding how pedestrians and signage interact under undefined environments, previous studies have typically separately addressed the location problem of signage and the interaction between signage and pedestrians. With regard to signage location, one method considered the problem as a maximum coverage location problem (MCLP) as proposed by Church (Church and Velle, 1974; Chen et al., 2009). A higher signage coverage area would be able to better guide pedestrians and lead to more efficient pedestrian flow. The MCLP method assumes that the pedestrian can perceive the signage as long as the position of pedestrian is within the light coverage area of the closest signage. However, the signage visibility is dependent on the distance between the pedestrian and the signage; longer viewing distances hinder interactions between the signage and the pedestrian (Wang et al., 2014; Nassar, 2011). The assumption that the pedestrian at a certain position is served solely by the closest signage may not always be appropriate. This assumption ignores other signage that guides the walking direction in a building, i.e., the pedestrian can perceive information from all signage within their field of view. We believe that the probability of perceiving a signage at different positions is state dependent and that different signage can cooperate to guide the pedestrian. Therefore, it is necessary to consider interactions between the pedestrian and multiple signage systems when addressing in the signage location problem.

Another method compared and evaluated the performance of different location plans before selecting the best signage location based on simulations (Nassar, 2011). This method has obvious limitations, especially when a large amount of signage is required. Furthermore, the success of this method is dependent on a limited number of location plans. A large number of location plans may result in a complicated and time-consuming evaluation process. In Nassar (2011), the probability index for detecting three different location plans of only one sign was evaluated in a simulated environment.

Recently, the methods of "filling with tangent-circles" and "setting at hinge node" were developed to locate evacuation signage in no-obstacle and existing-obstacle pedestrian facilities, respectively. Similar to the MCLP method, the first method determines the amount of signage with assumed circle coverage area that can fully cover the space. The second method determines the hinge nodes at which signage will be located (a hinge node is an aggregation point of all imaginary routes of a pedestrian group) (Yue et al., 2013) for routes produced by a cellular automata model (Muramatsu et al., 1999). As far as the evacuation time is concerned, the location problem of evacuation signage systems in a road network has been formulated as an Evacuation Time Optimization Problem (ETOP), wherein the evacuation time decreases as the number of signs increases (Nguyen et al., 2012). Therefore, there is no universal method that addresses the location problem of evacuation signage system.

With regard to the interaction between pedestrian and signage, the interaction process has been divided into three ordered phases: perceiving the signage, interpreting the information and a decision-making phase (Xie et al., 2011). The first phase largely depends on the location and characteristics of the signage; the second phase depends on the ability for the pedestrian to understand the signage information; and the decision-making process is decided by the level of desire of the pedestrian to follow the directions of the signage.

A number of studies have investigated the first interaction phase. The probability for a pedestrian to perceive a signage has been formulated to be based on the distance the pedestrian is from the sign and the proportional area of the signage within the field of view of the pedestrian (Nassar, 2011). However, a more reasonable method incorporates the attractiveness, distance, and visibility factor of a signage to calculate the probability for perceiving the signage (Wang et al., 2014). The visible distance of a signage is dependent on its height, size (Garvey et al., 1997), color (Wong and Lo, 2007) and the viewing angle (Xie et al., 2007) and is affected by the smoke effect (Yuki et al., 2005), pedestrian age (Chrysler et al., 2001), vision level (Scott et al., 2012) and obstacles (Bo et al., 2008).

The research methods for the information interpreting phase have primarily been based on experimental data. For example, 64 participants in Sweden were invited to interpret the information of 6 types of safety signage. All of the participants were able to interpret 4 types of signage accurately because these signage appear frequently (Benthorn and Frantzich, 1999); Participants from different districts worldwide took part in an evaluation of the comprehensibility of graphical signage in an airport. The results showed that the capability to interpret and sufficiently understand a signage was not dependent on language background (Morley, 1997).

For the final decision-making phase, a pedestrian is believed to follow signage guidance based on probability. The rate of compliance with the signage direction in an evacuation has been represented by a coefficient (Liu et al., 2011). Signage directions were also found to be better followed in everyday situations than during evacuation or emergency situations (Vilar et al., 2014). This is likely due to the effects of the environmental variables, e.g., lighter and wider corridors are stronger influences on the decision-making process for a pedestrian than signage systems during emergency situations. Furthermore, the rate of compliance with signage systems is lower during emergency situations than during everyday situations. Overall, the interaction between the pedestrian and signage is affected by a number of factors, including the distance and attractiveness of the signage and the ability for the pedestrian to interpret and follow the directions on the signage.

To the best of our knowledge, few studies have performed a quantitative location analysis of signage system under the influ-