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A game theory based exit selection model for evacuation

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Abstract

How do evacuees find their way to escape from a fire zone? This will be a significant question that should be considered for modeling the evacuation process. Generally, a building consists of enclosure areas such rooms, walkways and stairs. The principal problem in wayfinding is to select the way out when occupants egress from a multi-exit area. The choice of exits will depend on how groups of evacuees interact. Non-cooperative game theory deals largely with how intelligent individuals interact with one another in an effort to achieve their own goals—to leave the fire zone as fast as possible. This article presents a game theory based exit choice model for evacuation. It has been integrated in an evacuation model and demonstrates that the evacuees' interaction can affect the evacuation pattern and clearance time of a multi-exit zone.

Keywords: Evacuation; Game theory; Selection of exits

1. Introduction

Evacuation of occupants from the hazardous region(s) is per se a way to reduce the ill effects of a fire disaster in a building and predicting evacuation pattern is useful in emergency management. Indeed, it has been considered by building maintenance professionals [1] as well as building control officers [2] that the evacuation system is the most important means for fire safety protection in buildings. In the circumstances, many evacuation models, such as EXODUS [3], SIMULEX [4,5], EGRESS [6,7], SGEM [8–10] etc have been developed to assist building designers to predict the evacuation pattern. Most of the models have focused on modeling the flow of evacuees and the behavior of crowd flow has not been comprehensively studied, especially the behavioral reaction of the evacuees during their movement.

One of the critical behavioral reactions of people that may affect the escape process is the choice of exit. Choice of exit is one of the most complex aspects of people's movement. Generally, a building consists of enclosure areas such rooms, walkways and stairs. Besides the final exits of the building, the term 'exit' here also refers to the openings of an area through which people can escape from one area to another inside the building. The principal problem in wayfinding is to select the way out when occupants egress from a multi-exit area. Therefore, choice of exit is the selection of routes from one point to another. In case of emergency, an individual's choice of escape route can be regarded as a wayfinding which involves perception and cognition. His or her decision will be affected by what has been seen in the environment and what has been formulated in his or her mind—the cognitive map. When several people are finding their ways to leave a hazardous zone, an individual's decision may be affected by other people's actions. In other words, interaction of people will be a process that should be considered in modeling the evacuation pattern in a zone of multi-exits. Non-cooperative game theory [11,12] deals largely with how intelligent individuals interact with one another in an effort to achieve their own goals—to leave the fire zone as fast as possible. This article presents a game theory-based method that can be incorporated within an evacuation model and effectively models the exit selection process in an evacuation process.

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2. Previous studies

Early engineering models used to predict people's movement, such as EVACNET [13], applied no behavioral rules. They relied on the physical movement of the population, and the physical representation of the building geometry to influence and determine occupant egress. Recently, social/architectural scientists, such as Passini [14], Ozel [15], Proulx [16,17], Sime [18] and Canter [19] have pointed out that one of the dominant factors affecting evacuation patterns is the evacuees' behavioral reactions accompanying their movement. Their studies have identified the contributing factors and provide valuable information for studying wayfinding process. On the basis of these studies, some engineering models can incorporate some psychological rules to model the response pattern of evacuees. However, how the rules can be applied in a dynamic process, especially when the reaction of an individual is affected dynamically by others, has rarely been discussed.

Garbrecht [20,21] studied the difference between random walk and random path selection strategies in normal situations. The first describes a movement in a labyrinth where a person makes a random choice at each intersection. The latter refers to an initial random choice of a complete path from origin to destination. It has been shown that the two ways of route selection will lead to different results even if the random mechanism is assumed to be uniform amongst all alternatives. This indicates that an individual has pre-select a route based on his or her knowledge of the environment, the final destination may be altered if he or she has changed the choice during the movement. The transient change of route choice is critical to the escape process in that under an emergency situation, an individual may endeavor to achieve his or her own goal—to leave the hazardous zone as fast as possible. One of the interim goals to achieve the final goal will be to avoid congestion. This will be particular obvious if the evacuees can notice the movement and reactions of the others such as in a space with large population—such as a stadium, an auditorium, etc.

Gwynne and Schneider [22,23] have also proposed exit selection behavior models. The models concern the response of occupants to exit selection and re-direction. The occupants' decision-making is adaptive according to their familiarity with the structure, the visibility of the exit and the length of queues at the exits. The exit selection behavior is mainly modeled as the passive response to the extent of the crowding and only final exits of the building is considered. In reality, however, the occupants will predict their evacuation efficiency based on others' walking direction and make a decision. Besides the final exits, the selection of exits will also occur whenever occupants egress from any enclosure inside a building.

In most evacuation models, the exit choice of an individual may be modeled by a pre-selection process on the basis of some wayfinding rules. Checking the shortest distance and the inter-person distance dynamically will be an approach to manipulate the transient situations. However, modeling the dynamic interaction of people with respect to the congestion state of the exits and the actions of other evacuees during the process is rare.

3. Model development

If the interactive decision process of the evacuees is rational, game theory can be adopted to describe the interactive behavior. In a game, several agents (the evacuees) strive to maximize their (expected) utility index by choosing particular courses of action (selecting particular route), and each agent's final utility payoffs will depend on the profile of courses of action chosen by all agents. The interactive situation, specified by the set of participants, the possible courses of action of each agent, and the set of all possible utility payoffs, is called a game. When evacuees and the congestion state of a route achieve a *Nash Equilibrium*[1] [24], the strategy[2] is optimal, i.e. all evacuees select exits based on the strategy in that the clearance time is the shortest.

Many modern buildings will comprise rooms, walkway and stairs forming a multi-zone complex. Such building system can be represented by a network system and the evacuation problem can be resolved as a network flow problem with nodes and links representing rooms and communication paths. O'Neill has commented that the network structure of nodes and their activity links is analogous to the topological paths between choice points within a building layout [25]. Choice points can occur at route (e.g. corridor) intersections and route turns [26]. An individual will select his or her route 'step by step' with the route choice point taken at every node of his evacuation path. Random path selection strategies [20,21] obviously do not represent the actual behavior. We can then define $P_{n,k}$ (D_i, L_i, B_i) as the probability that person n select the exit at time step k, for the movement from a node to another node. D_i is crowd density at exit i, L_i is distance person n to the exit i and B_i is the width of exit i. $P_{n,k}$ (D_i, L_i, B_i) will be computed on the basis of game theory at each time step with the assumption that every evacuee will select the 'best' exit based on the $P_{n,k}$ (D_i, L_i, B_i) at each time step.

4. Exit selection process

Game theory is a branch of mathematics devoted to the logic of decision-making in social interactions. The principal objective of game theory is to determine, through formal reasoning alone, what strategies the players ought

[1] If there is a set of strategies with the property that no player can benefit by changing his or her strategy while the other players keep their strategies unchanged, then that set of strategies and the corresponding payoffs constitute the Nash Equilibrium.

[2] A player's strategy is the action or the plan of actions this player chooses out of his set of strategies—a plan for playing the game.