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Planning the Building Evacuation Routes by a Spatial Network

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***Abstract*—**The previous proposed evacuation routing approaches usually divide the space into multiple interlinked zones. However, it may be harder to clearly and objectively define the margins of each zone. This paper proposes an approach that connects locations of necessary guidance into a spatial network. In doing so, evacuation routes can be constructed based on the links between starting points, turning nodes, and terminal points. This approach more conforms to the real-life evacuation behavior. The feasibility of the proposed approach is evaluated through a case of one floor in a hospital building. Results indicate that the proposed approach provides valuable suggestions for evacuation planning.

***Keywords*—**Evacuation; Spatial network; Simulation

I. Introduction

TO date, a considerable number of studies have attempted to plan evacuation routes by forming a spatial network. The buildings are usually crowded with people. If several evacuation routes all converge into the same pathway, congestion may occur and result in a slowdown of movement speed of a large number of evacuees. Besides, the buildings have a much more complicated composition of spaces in each floor. Evacuees will come to a few intersections at which they must decide which pathway to take next and take a number of turns before they can successfully evacuate the building.

Evacuation should be guided. During evacuation, evacuees spend most of their time looking for the next pathway to a safe location or the location they can wait for rescue. This paper uses previous research of guidance demand and spatial network as a foundation to propose a route planning approach based on a spatial network. This approach does not simply focus on the origins and destinations of evacuees but also stress its support for evacuees' guidance demand during evacuation.This approach estimates evacuation time and searches for an evacuation plan. The evacuation plan proposed by the approach offers optimal evacuation routes and trials for evacuees and can be a basis for laying out guidance signs.

II. Spatial Network for Evacuees

A. Turning nodes

In most previous research of evacuation routing, a space is divided into multiple zones, with each viewed as a node that evacuees may pass through. These zones are spatially interconnected, so they constitute an evacuation network.

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An evacuation route is composed of paths that link a number of nodes. However, this approach is not so applicable to floors or buildings with a more complicated spatial composition, because the boundaries of each space are hard to define.

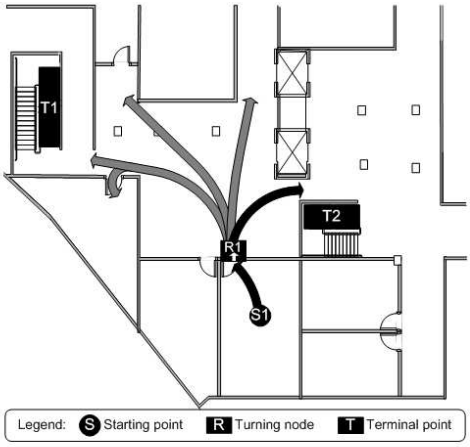
Thus, we view the locations where evacuees have to make a choice of pathway as nodes in an evacuation routing network. These locations are called "turning nodes". An example is given in Fig. 1. A group of people in this room have to move to the terminal points (either T1 or T2) to complete evacuation. As shown in Fig. 1(a), they will move from their starting point (S1) to the room's door when evacuation begins. When they get to the room's door, they have to decide which way to go next. Meanwhile, they have five choices, as shown by the arrows jetted from R1. They need proper guidance at this place so that they can take the most appropriate pathway for evacuation. This location then becomes a turning node (R1). The arrow on the turning node denotes which moving direction its guide is applicable to. The evacuees moving in the direction that the turning node is applicable to may become from the same group or different groups.

After evacuees choose the pathway marked by the black arrow, they will be guided to enter a hall on the right. At this moment, they have four choices of pathway, as shown by the arrows jetted from R2 in Fig. 1(b). R2 becomes another turning node. At R2, evacuees also need proper guidance to choose the correct route (i.e. along the wall and make a U-turn as marked by the black arrow) to finally reach the terminal point (T1). In this example, the evacuation guiding route consists of S1-R1-R2-T2.

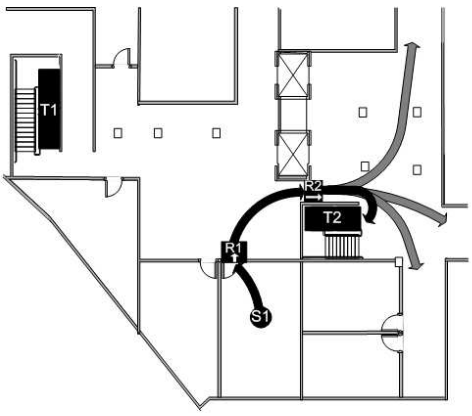
The layout of turning nodes shows where a mandatory guide is needed to direct moving evacuees. Compared with the conventional approach of dividing the space of interest into multiple zones as nodes for routing, the proposed approach can offer more practical support for design of an evacuation guidance system.

B. Evacuation Plan by Network

By linking the starting point and the terminal point along with several turning nodes between them, we can obtain an evacuation route for a group of evacuees. The spatial relationship of these points can be illustrated as a spatial network as shown in Fig. 2. The spatial links are marked by the arrows. The group of evacuees has one or multiple paths at their choice to proceed to the next point or node. As shown in Fig. 2, the evacuees complete their evacuation when they arrive at a terminal point through the guiding route S1-G1-G2-T2 (thicker arrows in black). The evacuation guiding routes of all groups of evacuees then constitute an evacuation plan, which can be used as an evacuation plan for the floor.



(a) The first turning node (R1) for routing outside the room



(b) The second turning node (R2) to the terminal point (T2)

Fig. 1 The turning and route choices for a group of evacuees

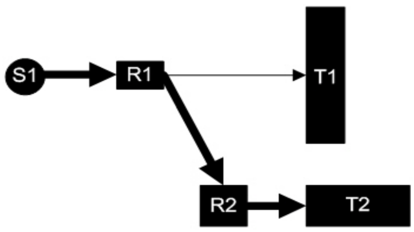


Fig. 2 The spatial network for the evacuee group at S1

III. Simulation for Clearance Time

A. Clearance Time

In the search of a near-optimal evacuation plan, a fitness value is necessary for comparison of performance of possible evacuation plans. Clearance time of evacuation is commonly used as measure of effectiveness of evacuation plans [1-3].Clearance time is typically defined as the amount of time required for 95% of all evacuees to flee the evacuation zone [4]. In this paper, we use clearance time as the fitness value and minimize the clearance time as the goal of optimizations.

B. Estimating Time by Simulation

In our proposed approach, a simulation platform is applied to estimate the clearance time of each evacuation plan. Simulation is one of the most common methods. Microscopic simulation considers the behavior of individual evacuees, so that the simulation result will be very close to real-life. Several microscopic simulation software packages have been used to simulate evacuation behavior. Compared with other software, VISSIM allows us to rewrite the coordinates to shift the turning nodes and terminal points of each evacuee group in the file and also control the simulation through the interface [5]. Thus, we apply VISSIM to assess the clearance time of evacuees under different evacuation plans.

IV. Example Problem

A. Floor Layout and Evacuees

The layout of the third floor is as shown in Fig. 3. In addition to the wards and nursing stations, there are some rooms used for providing treatment or examination to patients and some rooms available for work or rest of medical staff. We build a spatial network according to the spatial layout. The points and nodes of the proposed spatial network are also marked in Fig. 3. As there is no balcony in this floor, the four stairs (T1~T4) are the only terminal points for safety. After observing the daily activities in this floor, we pick 58 locations as the starting points of evacuee groups (S1~S58). These starting points represent the current locations of 188 evacuees who are in the rooms, on the corridors, using drinking fountains, and using the public phone. The turning nodes are key components of the spatial network. We have evaluated the spatial structure of this floor and found 57 locations where guidance is needed during the evacuation process. These locations are turning nodes (R1~R57). Most of the turning nodes are located by the doors to rooms or by the intersection between corridors and halls. The arrow on each turning node represents which direction of evacuee movement the node applies to (regardless of the group which evacuees belong to).

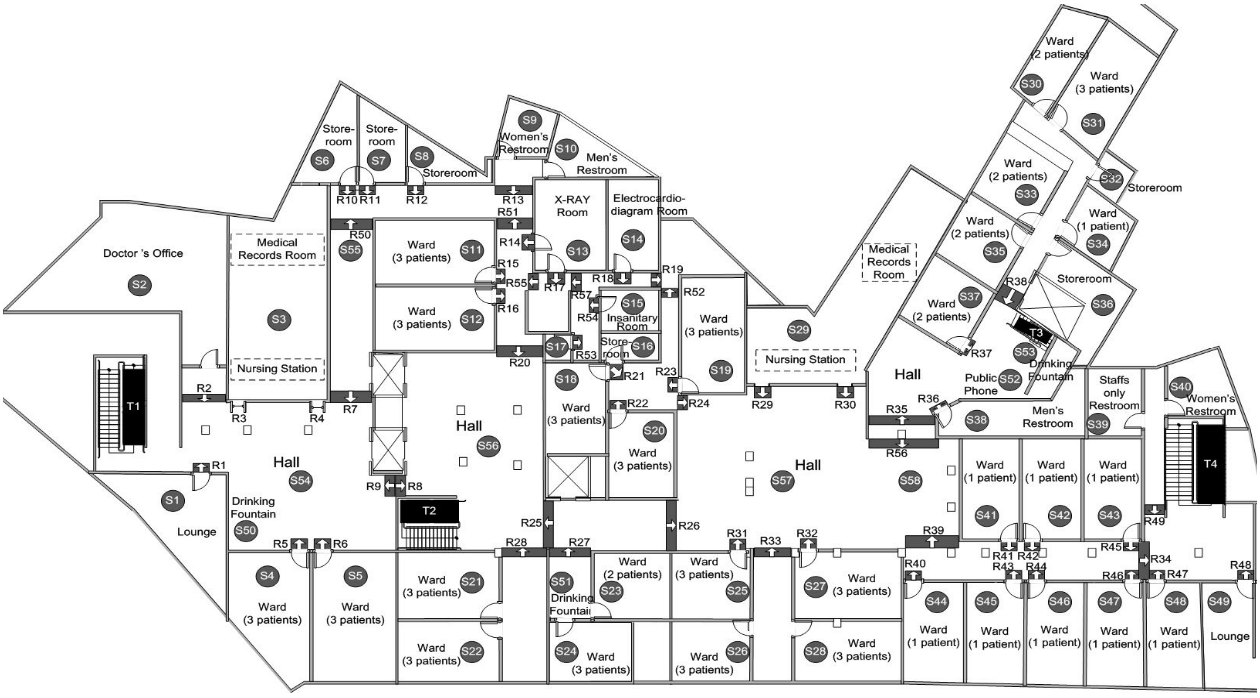


Fig. 3 The floor layout and the points/nodes

B. Forming the Spatial Network

We connect the starting points, turning nodes, and terminal points to form a spatial network. Evacuee groups located in rooms, such as S1, need to move to the turning nodes at the doors to the rooms first before they have to make a choice of evacuation guiding route. Besides, they have to go through several turning nodes before they arrive at one of the terminal points. Evacuee groups on the corridors, such as S54, have to make a choice of evacuation guiding route in the beginning. For any group from any starting point, options of evacuation guiding routes are numerous, thus resulting in a great number of possible routing portfolios in the spatial network. Our approach will use ACO to find the near-optimal evacuation plans. To simulate evacuations, we input the data of evacuee groups and evacuation parameters and construct the spatial network in VISSIM, the simulation platform of the approach. In addition to the spatial network, another factor that affects the clearance time is the average moving speed of evacuees. In this case, three random distributions are used to determine the desire speed. For evacuees who are not patients, the distribution ranges from 3.5 to 5.8 km/hr for the male, and the other ranges from 2.6 to 4.3 km/hr for the female. For patients who move more slowly, the distribution ranges from 1.6 to 3.1 km/hr.

C. Planning Results and Analysis

The goal of evacuation plan is to minimize the clearance time. After the optimization process, the best evacuation plan appears where the clearance time is 44.8 sec. Table I presents details of the proposed evacuation plan, including the number of evacuees and the evacuation guiding route for the evacuee groups at all the 58 starting points. Each evacuation route consists of no more than four turning nodes (i.e. no evacuee needs guidance more than four times to arrive at the terminal point for safety).

Finally, we simulate this evacuation plan in VISSIM to complete the evacuation routing plan. The clearance time (95% evacuees) is 44.8 sec, and the total evacuation time (100% evacuees) is 52.6 sec.

V. Conclusions

In this paper, we use mandatory guidance locations to build a spatial network for evacuation in buildings. Each location at which evacuees need to choose the next pathway to take is viewed a turning node. Thus, the spatial network consists of multiple decision nodes of evacuees. This approach avoids the difficulty of dividing a space into multiple zones and more conforms to the real-life evacuation behavior of people.

The proposed approach can not only offer valuable suggestions to planning of evacuation routes but also provide support for design of guidance signs. In the future, the approach can be further applied to evacuation of multi-floor buildings or outdoor evacuation.

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TABLE I
THE NEAR-OPTIMAL EVACUATION PLAN

Starting point	Number of evacuees	Evacuation guiding route
S1	5	S1-R1-T1
S2	4	S2-R2-T1
S3	8	S3-R3-T1
S4	6	S4-R5-T1
S5	6	S5-R6-T1
S6	1	S6-R10-R7-T1
S7	1	S7-R11-R7-T1
S8	1	S8-R12-R7-T1
S9	3	S9-R13-R20-T2
S10	3	S10-R13-R20-T2
S11	6	S11-R15-R20-T2
S12	6	S12-R16-R20-T2
S13	2	S13-R17-R55-R20-T2
S14	2	S14-R18-R57-R55-R20-T2
S15	2	S15-R54-R57-R55-R20-T2
S16	1	S16-R21-R24-R25-T2
S17	1	S17-R53-R57-R55-R20-T2
S18	6	S18-R21-R24-R25-T2
S19	6	S19-R23-R24-R25-T2
S20	6	S20-R22-R24-R25-T2
S21	6	S21-R28-T2
S22	6	S22-R28-T2
S23	4	S23-R27-R25-T2
S24	4	S24-R27-R25-T2
S25	4	S25-R31-R25-T2
S26	4	S26-R33-R25-T2
S27	6	S27-R32-R35-T3
S28	6	S28-R33-R25-T2
S29	8	S29-R30-R35-T3
S30	4	S30-R38-T3
S31	6	S31-R38-T3
S32	1	S32-R38-T3
S33	4	S33-R38-T3
S34	2	S34-R38-T3
S35	4	S35-R38-T3
S36	2	S36-R38-T3
S37	4	S37-R37-T3
S38	2	S38-R36-T3
S39	2	S39-R49-T4
S40	2	S40-R49-T4
S41	2	S41-R41-R34-T4
S42	2	S42-R42-R34-T4
S43	2	S43-R45-R34-T4
S44	2	S44-R40-R34-T4
S45	2	S45-R43-R34-T4
S46	2	S46-R44-R34-T4
S47	2	S47-R46-R34-T4
S48	2	S48-R47-T4
S49	5	S49-R48-T4
S50	1	S50-T1
S51	1	S51-R27-R25-T2
S52	2	S52-T3
S53	1	S53-T3
S54	1	S54-T1
S55	1	S55-R7-T1
S56	1	S56-T2
S57	1	S57-R35-T3
S58	1	S58-R35-T3