ARTICLE IN PRESS

Future Generation Computer Systems ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs

Centrality measures for evacuation: Finding agile evacuation routes

Marin Lujak[a],*, Stefano Giordani[b]

[a] IMT Lille Douai, 941, rue Charles Bourseul, 59508 Douai, France

[b] Dip. Ingegneria dell'Impresa, University of Rome "Tor Vergata", Via del Politecnico 1, 00133 Rome, Italy

HIGHLIGHTS

- Two novel node centrality measures for improving evacuation efficiency.
- Evacuation betweenness centrality.
- Evacuation centrality.
- Two novel evacuation-related concepts.
- Agile evacuation route
- Efficient evacuation path.
- Agile evacuation routes are found considering paths' nodes' evacuation centralities.

ARTICLE INFO

Article history:
Received 11 November 2016
Received in revised form
29 March 2017
Accepted 10 May 2017
Available online xxxx

Keywords:
Centrality measure
Betweenness centrality
Evacuation betweenness centrality
Evacuation centrality
Evacuation route
Agile evacuation route

ABSTRACT

In this paper, we study the agility of evacuation routes in relation to dynamically changing unpredictable hazardous conditions in smart space networks. Infrastructure safety conditions may unpredictably change through time. Due to unpredictability, evacuees' safety can get jeopardized at any point of the evacuation route. Thus, it is not sufficient only to find the shortest evacuation routes considering present safety conditions and evacuation flow, but we should also consider other relevant characteristics that make the evacuation routes sufficiently safe through time. With this aim, we propose two new node importance metrics: evacuation betweenness centrality and evacuation centrality, both inspired by betweenness centrality. The first metric represents the fraction of k efficient evacuation routes between all origin–destination pairs different from the given node that pass through that node, while the second represents the importance of the given node for evacuation considering the availability of alternative efficient evacuation paths (routes) from that node towards safe exits. Moreover, given a set of evacuees' positions and safe exits, we find shortest agile evacuation routes, where by agile route we mean the ability to efficiently and safely reroute from intermediate nodes in case of unpredictable safety drops through maximizing the value of the evacuation centrality of the route's intermediate nodes. In addition, we propose an algorithm for that problem and discuss its capability to react to the changes in safety circumstances along recommended routes.

1. Introduction

Emergencies and disasters occur unexpectedly and disrupt our day-to-day activities and the functioning of a community. They can strike anyone, anytime, and anywhere causing physical and/or environmental damage. Emergencies may be natural or manmade, small scale, as e.g., in a building due to an explosion or fire, or large scale, as, e.g., in a city or a region because of an earthquake, radiological accident, bombardment or dangerous weather system.

Emergency evacuation is the immediate and urgent movement of people away from the threat or actual occurrence of a hazard. In emergency, evacuees should be able to evacuate safely, rapidly, seamlessly, and in a coordinated way following an evacuation route while avoiding hazardous conditions.

To facilitate the efficiency of evacuation, conventional evacuation approaches are based on a static evacuation plan. In the case of building evacuation, it is usually positioned on a limited number of positions within a building. If the evacuation safety conditions permit it, a trained evacuation personnel is usually introduced at a predefined set of critical evacuation points.

* Corresponding author.
E-mail addresses: marin.lujak@imt-lille-douai.fr (M. Lujak), stefano.giordani@uniroma2.it (S. Giordani).

http://dx.doi.org/10.1016/j.future.2017.05.014
0167-739X/© 2017 Elsevier B.V. All rights reserved.

Each evacuee should reach his/her exit by following the signs that are attached on the floor or walls in a building. These signs represent the direction of the evacuation route shown on the evacuation plan. If the primary escape route is blocked, there is usually a secondary escape route that is marked on the evacuation plan. In the case both routes are blocked and there is no updated information available, the evacuees are left with no alternative route.

The difficulty with this evacuation approach is that it provides static evacuation routes that do not adapt to real-time changes in evacuation network topology nor to safety changes along the evacuation routes due to the hazard dynamics. Moreover, the static evacuation route information is seldom available to evacuees due to the fact that the evacuation plans are present only at a limited number of positions in a building. This may result in further casualties caused by the ongoing hazard and/or irrational panic-related behaviors.

The objective of this paper is, thus, to study coordination approaches for evacuees responsive to unpredictable dynamically changing hazardous conditions throughout the evacuation area. These approaches should be able to increase evacuees' safety by providing evacuation routes that in the case of an unforeseen hazard along the way will give an evacuee a possibility to reroute to an alternative safe route and thus respond seamlessly to the hazard dynamics and avoid further evacuation casualties.

The concepts of rapidness and seamlessness, which are necessary in this evacuation scenario, are closely related to the concept of agility. Oxford dictionary (2016) describes the term agile as "the ability to move quickly and easily" and "the ability to think and understand quickly". It is a well known concept in many areas, such as, e.g., manufacturing, software development, and business organization, see, e.g., [1–3]. In terms of outcomes, agility is a means of a system to swiftly and easily handle continuous and unanticipated change by adapting its initial stable configuration and to effectively manage unpredictable external and internal changes, e.g., [2,3]. Based on this conceptualization and paradigms of agile manufacturing and agile business systems, in this work we propose the concept of agility in evacuation routes and related route recommendation systems.

Agility of an evacuation route assures to an evacuee a high real-time reactivity to safety changes possibly occurring along the route. It requires the ability to reroute from intermediate nodes of a proposed evacuation route to alternative routes towards safe exits. Agile route recommendation systems, hence, should be capable to run in real time in the cycle sense–analyze–decide–act. To achieve it, we need complete, accurate and up-to-the-minute situational awareness along the route. While in the open spaces, GPS and, e.g., 3G and 4G communication can be used, in inner spaces, this requirement can be fulfilled by, e.g., the interaction of ambient intelligence and smartphone technologies. Hence, an agile evacuation route recommendation system should respond quickly in inner and open spaces to sudden changes in evacuation safety conditions caused by a hazard, crowdedness or any other type of requirement or disruption. To the best of our knowledge, the literature on such route recommendation systems is very scarce (Section 2).

We can model evacuation agility of a route (path) in terms of the characteristics of its intermediate nodes. For this scope, in Section 3, we first propose an evacuation network model and then examine relevant centrality measures related with finding agile evacuation routes. In Section 4, we propose two new node importance metrics called evacuation centrality and evacuation betweenness centrality, both inspired by (node) betweenness centrality. Evacuation betweenness centrality represents the fraction of k efficient evacuation paths between all origin–destination (O–D) pairs different from the given node that pass through that node, while evacuation centrality represents the importance of a node for evacuation considering the availability of alternative efficient routes from that node towards safe exits.

Given an evacuation network with a set of evacuees' positions and safe exits, in Section 5 we find agile evacuation routes, where, by agile, we mean the ability to efficiently and safely reroute from intermediate nodes of a route in case of unpredictable safety drops.

An evacuation route computation solution should be scalable and robust. We propose an algorithm that dynamically computes agile evacuation routes. An application example of the algorithm is shown on a realistic small network in Section 6. We conclude the paper and give future research directions in Section 7.

2. Related work

Building evacuation has been studied over the last decades from different perspectives such as, e.g., evacuees' behaviors, traffic control strategies, sheltering site selection, and route finding for displacement. For example, Pursals and Garzón in [4] considered the building evacuation problem and developed a model for selecting the proper routes for movement of people in a building during an emergency situation. Abdelghany et al. in [5] present a simulation-optimization modeling framework for the evacuation of large scale pedestrian facilities with multiple exit gates. The framework integrates a genetic algorithm (GA) and a microscopic pedestrian simulation assignment model. The GA searches for the optimal evacuation plan, while the simulation model guides the search through evaluating the quality of the generated evacuation plans. Evacuees are assumed to receive evacuation instructions in terms of the optimal exit gates and evacuation start times. The framework is applied to develop an optimal evacuation plan for a hypothetical crowded exhibition hall. A mixed-integer programming solver is used to derive routing plans for sample networks.

Hamacher and Tjandra in [6] give an overview of mathematical modeling of evacuation, while a survey of optimization approaches for macroscopic emergency evacuation planning can be found in, e.g., [7].

Choi et al. in [8] model building evacuations by network flows with side constraints. They consider flow dependent arc capacities and propose greedy algorithms for solving maximum flow, turnstile cost, and minimax problems in some specially structured building networks, as, e.g., path or convergent trees.

Hamacher et al. in [9] represent building evacuation as a dynamic network-flow problem. They show that lexicographical optimization is applicable in handling multiple objectives as, e.g., minimizing the total evacuation time while avoiding cyclic movements in a building.

In [10], Luh et al. consider the crowd guidance optimization problem while considering the effect of narrow passages on human behavior. Based on advanced microscopic pedestrian models and simulations, they establish a macroscopic network-flow model introducing a desired flow rate in relation to these factors. They propose a divide-and-conquer approach to reduce computational complexity and to reflect psychological findings. Moreover, they optimize egress routes by using a combination of stochastic dynamic programming and the rollout scheme, and coordinate them a posteriori to meet the total need for joint movement respecting passage capacities.

Conventional emergency evacuation plans often assign evacuees to fixed routes or destinations based mainly on geographic proximity. Such approaches can be inefficient if the roads are congested, blocked, or otherwise dangerous because of the emergency. Han and Yuan proposed in [11] the concept of *most desirable destination* for evacuees while exploring the options that allow evacuees flexibility in selecting their exit routes and destinations. This concept recognizes that municipalities responsible for large-scale evacuation have routinely assigned evacuees to routes and destinations based on limited experience and intuition rather than methodical optimization processes. Even with the implementation of

Please cite this article in press as: M. Lujak, S. Giordani, Centrality measures for evacuation: Finding agile evacuation routes, Future Generation Computer Systems (2017), http://dx.doi.org/10.1016/j.future.2017.05.014