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# A Risk-based Model of Evacuation Route Optimization under Fire

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## Abstract

Emergency evacuation plan plays a key role for fire risk management and successful evacuation. In this work, a topological model of evacuation routes is established and the corresponding matrix function is also proposed in order to evaluate evacuation ability. Simultaneously, risk assessment of fire scenarios is made based on numerical simulation. And on this basis, the variation laws of risk indicators such as temperature, thermal radiation, the concentration of toxic gas are analyzed in details and dynamic risk assessment of evacuation routes is made. Introducing the concept of equivalent routes, the scheme of the best route for evacuee at each location is the one along with the shortest time and minimal risk and suggested based on the Dijkstra algorithm. And then, one case is presented and result indicates that this model can aid people to avoid crowdedness and evacuate as soon as possible under fire accident. The risk-based model is also useful for the evacuation planning.

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*Keywords:* evacuation routes, graph theory, risk, optimization, fire

## Nomenclature

$D_{ij}$	dimensionless length of the shortest route
$E_{ij}$	connectivity between two points
$E(G)$	connectivity of network
$FED$	personnel exposure coefficient under fire
$G$	network graph of evacuation routes
$K_l$	type coefficient of evacuation passageway
$K_i$	risk coefficient of the area
$l_{ij}$	dimensionless length of the route
$N$	numbers of nodes
$Q$	evacuation routes
$Q_0$	optimal evacuation route between two points
$W_{FED}$	impact coefficient of fire
$W_{ij}$	weight of the route
$W_p$	pass difficulty coefficient
$W_e$	obstacles coefficient
<i>Greek symbols</i>	
$\rho$	dimensionless parameter of evacuee density

## 1. Introduction

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Emergency evacuation becomes necessary in case of an accident such as fire [1], which can help evacuee arrive at safety gathering place. In any accident scenario, determining an optimal or near optimal evacuation plan is an important content and comprehensive design work which needs consider security and available time.

In previous works, lots of approaches have been widely used to analysis the optimal route of buildings and other public places, such as mathematical models, network flow, simulation and so on [2-3]. With the development of international technology, three-dimensional geometric structure and GIS is gradually applied. In general, emergency evacuation routing models can be divided into three categories: (1) dynamic programming models that generate optimal evacuation plans minimizing the total evacuation time or other criteria [4-6]; (2) approximation and heuristic methods [7]; (3) simulation models such as Pathfinder and STEPS [8-9]. However, the presented work less consider the risk of evacuation routes and evacuee risk caused by the accident such as fire.

In the paper, a risk-based model has been presented to evaluate the ability and analyses the evacuation route planning. Using the graph theory, the evacuation route is translated into a connective network and matrix function. The time of each route has been calculated on the basis of equivalent distance with considering the factors such as risk, route length and evacuee density. This has been done to make sure that the evacuation route is optimum with risk and time minimization. The proposed model is expected to be useful to plan strategy to avoid overcrowding.

## 2. The model of evacuation route optimization

Based on the operational research theory, the proposed model is shown as Fig 1 by taking into consideration the factors such as the routes length, evacuee density, fire risk, moving tendency. The model includes:

- (1) Topological model of evacuation routes network;
- (2) Matrix functions of evacuation routes;
- (3) Evacuation ability assessment;
- (4) Consequence analysis on accidents such as fire;
- (5) Equivalent length model of evacuation routes;
- (6) Adjustment and optimization of evacuation routes.

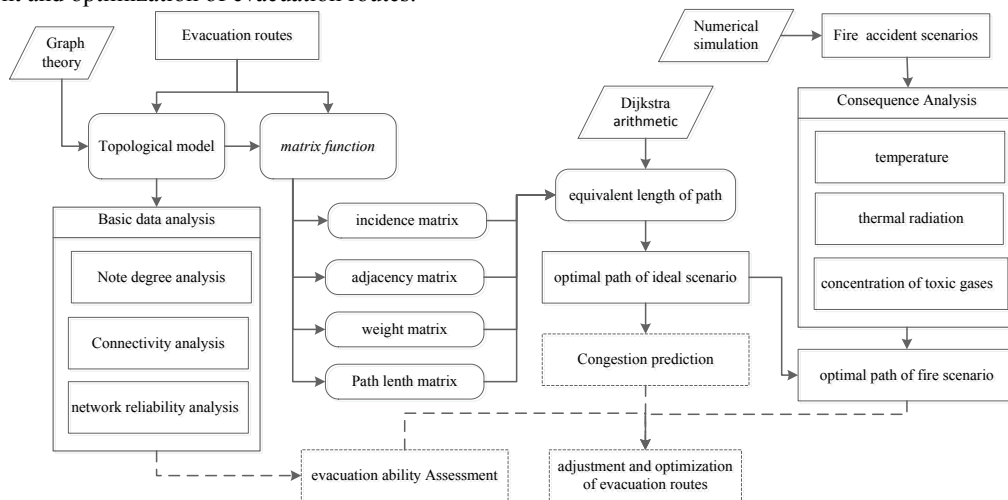


Fig. 1. The framework of risk-based model of evacuation routes optimization

### 2.1. Topological model

The evacuation route can effectively help people to escape from dangerous areas and arrive at safe areas. Using the layout of buildings as reference, the topological model of evacuation routes is made based on the principle of graph theory and it defines a relatively closed region as a separate evacuation region in the topological model. Because the moving direction of staffs is without any constraints, the topological model of evacuation routes can be treated as an undirected graph, in which the stairs, evacuation areas and the destinations are described by square, roundness and rhombus respectively. A mathematical model can be established as  $G=(V,E)=(R,S,E,M,W)$ :

- $V=R \cup S \cup E, R \cap S = \emptyset, R \cap E = \emptyset, S \cap E = \emptyset$ ;
- $R = \{R_i\} (i=1,2,\dots,n)$  is a nonempty and finite set of evacuation areas;

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