INTERNATIONAL JOURNAL OF EDUCATION AND INFORMATION TECHNOLOGIES
DOI: 10.46300/9109.2026.20.4 Volume 20, 2026

Generation and Recommendation of Personalized Routes for Evacuation

Lazar Pendov[1], Ivan Ganchev[1,2,3]
[1]Faculty of Mathematics and Informatics,
University of Plovdiv "Paisii Hilendarski",
Plovdiv,
Bulgaria

[2]Institute of Mathematics and Informatics,
Bulgarian Academy of Sciences (IMI-BAS),
Sofia,
Bulgaria

[3]TRC/ECE, University of Limerick,
Limerick,
Ireland

Received: March 19, 2025. Revised: June 25, 2025. Accepted: July 17, 2025. Published: February 24, 2026.

Abstract—This paper proposes a method for generating and recommending personalized evacuation routes in cases of natural disasters or industrial accidents—a topic of significant importance given the recent increase in such events. The utilization of the method is demonstrated on an example of a disaster/accident, having an epicenter, which is spreading radially in all directions with the same speed of onset. The web-based app, specially developed for this purpose, is briefly presented as well.

Keywords—natural disaster, industrial accident, evacuation, route generation, route recommendation, personalization

I. Introduction

Natural disasters (e.g., earthquakes, floods, wildfires, etc.) and industrial accidents (e.g., chemical leaks, explosions, etc.) may cause significant damage and casualties, including loss of human life. Some of these consequences could be prevented through timely access to sufficient information and well-coordinated actions.

Everything begins with receiving the first alert about an impending or already occurring disaster or accident. The next step is to identify the hazardous zones and assess the level of risk in each. This is followed by planning of measures to secure the affected area(s) and evacuate people located there. Recent advances in artificial intelligence (AI), geographic information systems (GIS), and real-time data fusion have enabled the development of smart systems for the generation and recommendation of evacuation routes. Principles, architecture, and methodologies for building such systems should include emphasis on safety optimization, real-time adaptability (through the use of the Internet of Things (IoT), sensor fusion, dynamic hazard modeling, etc.), crowd dynamics, and smart generation and recommendation of routes for efficient, rapid, and safe evacuation to minimize casualties and ensure public safety.

Core principles of smart generation and recommendation of evacuation routes include: (i) *safety-centric design*, e.g., to avoid hazard zones (e.g., fire, flood paths, chemical plumes), consider structural safety of bridges, roads, and tunnels used for evacuation, prioritize shortest time to safety (not just shortest distance); (ii) *route adaptability*, e.g., by real-time rerouting based on changing hazard conditions, crowd-aware path optimization to avoid bottlenecks, etc.; (iii) *data fusion* by combining data from various sources including satellite imaging, weather monitoring stations/sensors, IoT networks involving smart buildings, traffic cameras, etc., and user (mobile) devices.

Smart systems for generation and recommendation of evacuation routes consists of the following main tiers: (i) *data acquisition tier*, encompassing sensors, drones, user electronic devices, social media, and meteorological sources; (ii) *hazard mapping tier*, predicting the spread of hazards (e.g., fire/water plume models); (iii) *route generation tier*, using routing algorithms, such as Dijkstra (the classic shortest-path algorithm), A* (a heuristic-based algorithm for faster pathfinding, suitable for urban areas with predictable topologies), D* Lite (an algorithm with dynamic replanning during execution, suitable for robotic and pedestrian navigation in chaos), for real-time shortest safe path calculation; (iv) *user interface tier* containing web and/or

mobile software applications (apps) or public signage for guiding evacuees with dynamic updates; (v) *communication tier* for sending push notifications, alerts broadcasts, and evacuation route recommendations to people located in the affected areas.

An important component of smart systems for generation and recommendation of evacuation routes is the utilization of a real-time feedback loop, based on: (i) *crowd-sourcing* (via app feedback) for updating road conditions and flows of evacuating people; (ii) *edge computing* in IoT nodes (e.g., in drones, streetlights, public kiosks, etc.) for enabling low-latency updates; and (iii) use of mobile phone/vehicle *GPS data* to help avoid blocked or congested paths for evacuation.

The accompanying challenges and considerations for smart systems for generation and recommendation of evacuation routes include: (i) countermeasures in cases of *communication network outages* by using mesh networks or offline routing maps; (ii) handling *misinformation and panic behavior* by filtering crowd reports using AI and verification layers; (iii) handling *language and accessibility issues* by employing multilingual and icon-based guidance; (iv) *ethical concerns*, e.g., related to privacy and bias, i.e., to ensure anonymized data and equitable path access.

This paper presents a method for generating *personalized* evacuation routes for individuals located in disaster-affected or accident-prone areas.

II. Related Work

The problem of generating and recommending personalized context-aware (by considering user profiles and health/mobility/road constraints) evacuation routes has attracted significant attention in both academic research and applied system developers, especially with the increasing frequency of natural disasters (earthquakes, floods, wildfires) and industrial accidents (chemical spills, nuclear leaks). The core challenge lies in providing real-time, adaptive, and individualized guidance that accounts for dynamic hazards, infrastructure changes, and user-specific constraints. A short classification of these efforts is provided in the following subsections.

A. Classical Evacuation Models

Early studies focused on *static* models of evacuation planning using:

- Shortest path algorithms (e.g., static Dijkstra, A*) on road networks;
- Crowd simulation models (e.g., cellular automata, agent-based models);
- Zone-based planning using GIS.

While these methods are useful for high-level planning, they lack personalization and real-time adaptability to changing conditions.

B. Dynamic and Real-Time Route Planning

Recent works have leveraged:

- Sensor networks, mobile GPS data, social networks, and IoT networks for real-time situational awareness;
- Dynamic routing based on traffic conditions, road blockages, and evolving hazard zones (e.g., fire fronts, toxic plumes, etc.).

Examples include:

- The DASC sensing framework [1] that integrates social sensing (social media) with vehicular sensor networks to detect road damage and guide vehicles to affected areas for disaster verification and response. While not strictly evacuation routing, it illustrates how social media inputs and physical sensors can inform routing decisions during disasters.
- [2] presents a connected fire evacuation system utilizing data from various sensors and CCTV cameras inside buildings to present a real-time link for assisting trapped occupants by actively locating them and planning evacuation routes.
- The authors of [3] take advantage of IoT for intelligent route programming of crowd evacuation in metro stations to ensure crowd safety and reduce casualties in cases of emergency. A route programming model is proposed to select a suitable evacuation route and support the emergency decision-making process.

C. Personalized Evacuation Systems

Modern systems incorporate user-specific information such as:

- Mobility limitations (e.g., elderly, disabled people);
- Familiarity with terrain;
- Preferred transportation mode (walking, bicycling, driving);
- Health or safety needs.

Approaches include:

- Context-aware routing using machine learning or rule-based inference;
- Mobile applications that adapt routes based on user location, speed, and feedback.

D. Multi-Agent and Simulation-Based Systems

Some researchers explore multi-agent systems, where each agent represents a person, household, or vehicle, to:

- Run evacuation simulations to test personalized strategies in congested or blocked conditions;
- Employ game-theoretic approaches modeling competitive or cooperative behaviors in evacuation scenarios.

Examples include:

- The GIS-enabled agent-based simulation (ABS) tool [4] for aggregating information on evacuees affected by disasters, whereby the actions of agents, imitating households, are determined by decision models based on risk perception and social elements (e.g., assigning socially connected households to the same shelters to better utilize available resources);
- The model proposed in [5], whereby each evacuee is represented by an individual agent that optimizes its personalized evacuation route to reach the Nash equilibrium. The initial escape routes are generated by applying the (time-dependent) Dijkstra shortest path algorithm. Results of simulations, using the open-

source MATSim framework (www.matsim.org), give an estimate of the time it could take to evacuate an endangered area. The use of the model is demonstrated through a case study, based on a hypothetical dam-break of the Sihlsee dam near Zurich, for predicting the evacuation time and bottlenecks, showing good potential for use in large-scale scenarios.

E. AI and Machine Learning-Based Approaches

Recent works introduce deep learning and reinforcement learning (RL) for adaptive personalized routing, using:

- RL agents to learn optimal evacuation policies in dynamic environments;
- Deep Q-Networks (DQNs) and graph neural networks (GNNs) to optimize routes under evolving hazard maps.

Examples include:

- The linear function approximation-based natural policy gradient RL methodology, utilized in [6] for proposing two systems (savior and refugee) processing the environment tensor to create safe rescue and escape routes in smoke-filled or obstacle-rich environments. The proposed solution for low-visibility mapping is tested by means of a LiDAR mapping system evaluated and verified by a trust range derived from sonar and smoke concentration data.
- MultiExit-DRL [7], which uses Rainbow DQN to simulate pedestrian decisions at multiple exits. Based on environment observations, agents learn to select exits to reduce congestion and total evacuation time, outperforming conventional evacuation models.

F. Human-in-the-Loop and Ethical Considerations

Some recent studies focus on:

- Human-in-the-loop systems that allow evacuees to give feedback or adjust preferences during evacuation;
- Ethical routing, addressing questions like “Should the system prioritize children or those at greater risk?”;
- Explainability and trust in the evacuation routes generation and recommendation.

III. Methods for Delivery of Personalized Evacuation Guidance

In [8], a real-time, dynamic, intelligent, and user-specific evacuation system, named SmartEscape, is proposed with a mobile interface for use in emergency cases of fire. The system explores dynamically changing conditions measured by various sensors in buildings, uses an artificial neural network to calculate personal usage risk for each link, calculates optimum escape routes for evacuees (located by RFID technology) under existing circumstances by considering their individual features, and guides each evacuee to the exit through the calculated route with vocal and visual instructions provided on his/her smartphone.

[9] integrates Building Information Modeling (BIM) and Bluetooth Low Energy (BLE) indoor tracking to push personalized turn-by-turn evacuation guidance to mobile users via their smartphones. Routes are scored by aggregated risk factors and re-evaluated every 2 seconds in real-time. This is demonstrated in a commercial office building in Tianjin, China.

The authors of [10] propose a set of criteria for adapting emergency alerts and evacuation routes to different situations and people, along with a mechanism that can be used as a complement to traditional evacuation systems to provide personalized alerts and evacuation routes to all kinds of people during emergency situations in working places. The usability and understandability of the proposed interface for receiving and visualizing evacuation routes on smartphones is assessed through a user study performed in a fire simulation in an indoor environment.

In [11], a solution is presented involving drones flying in swarms, forming triangles to cover an area affected by a natural disaster or industrial accident. Through triangulation, the drones could detect the location of every active mobile device of people in the area. Once this information is obtained—either processed directly on drones or via an external software system—a personalized evacuation plan can be generated for each individual person and sent to his/her mobile device. The plan may take into account the positions of other persons nearby to avoid crowding. This approach allows people (mobile users) to receive information not only via a specialized mobile app, but also through a standard web browser (if access to the Internet is not affected by the disaster/accident, of course), redirected to an appropriate information page via a captive web portal.

[11] also presents the elaborated Method for EPidemic distribution of Information (MEPI), which can be used even without full drone coverage. A single drone entering or approaching the hazard zone is sufficient to distribute the necessary information based on the epidemic spreading of it through cooperating mobile devices located in the area. Measures are in place to prevent the spread of false information. The reduced need for drones is perhaps the most significant advantage of MEPI. However, a major drawback is that, since messages are relayed from one mobile device to another, significant delays in their delivery may occur.

Even though the received data appears the same, there is one crucial difference for each user device – its location. Almost every modern mobile device is equipped with a GPS receiver and thus can determine its own coordinates, but how can it use and visualize this information without Internet access? MEPI allows general information about a disaster/accident to be distributed not only in the form of messages, but also of supplementary files. This way, a static map of the affected area could be delivered to each device in the form of a graph or a structure that can easily be transformed into a graph. It is important to consider options for minimizing the file size (e.g., compression, rounding coordinates to specific decimal point positions, removing non-essential information, etc.) to facilitate transmission, which is especially important for wireless technologies and in areas with congested traffic.

Raw data from OpenStreetMap is used, processed, and converted into a suitable graph-based structure. Once the graph of the affected area is obtained, the Dijkstra algorithm is executed to calculate a suitable personalized evacuation route for each affected user. A limitation of this method, however, is the inability to predict crowding.

A web-based implementation of the method, proposed here for generating personalized evacuation routes, is described in the next section.

IV. Web-based Implementation of Proposed Method

A web-based app was designed and developed for generating personalized routes for the evacuation of people in cases of natural disasters or industrial accidents. Two roles were defined in the app: (i) *admin*, who creates, modifies, and deletes scenarios related to emerging disasters/accidents; and (ii) *user*, who uses these scenarios to generate personalized evacuation routes.

Admins are authenticated using a username and password (Fig. 1, Appendix), while user accounts do not require credentials.

When a user requests a personalized evacuation route to be generated for him/herself, the request is forwarded to a computational server or a proxy that redirects it to one of the available computational servers. The response with the generated route is returned to the app and visualized on a map using the JavaScript Library leaflet, [12]. This way, the app itself is freed from heavy computations, and the system can be scaled by adding more computational servers to handle a larger number of user requests simultaneously.

A. Creating a disaster/accident-related scenario

The sample scenario described here is for a natural disaster or industrial accident (with an epicenter) that spreads radially in all directions at a uniform rate of onset. First, the epicenter and the radius of the primary danger zone are defined by the admin. Secondary circular areas (with their own epicenters), representing other sources of danger, can also be added along with their respective radii, as depicted in Fig. 2 (Appendix).

The danger level at the epicenter and the smoothness of its decline when moving away from the epicenter are both configurable. Map data caching and calculation of danger level values at each node are performed when the created scenario is saved by the admin.

The danger level at a given point within a circular area affected by a disaster/accident is calculated as a function $f(r)$ of the respective distance r from that point to the epicenter, using the following formula:

$$f(r) = D_{ng}\left(1 - \frac{r}{R}\right)^n \quad (1)$$

where D_{ng} denotes the danger level at the epicenter (with values ranging from 1 to 100, with 100 representing the maximum possible danger), r denotes the distance from the epicenter to the given point (i.e., the user's location) for which the danger level is being calculated, R denotes the radius of the affected circular area within which the danger caused by the respective hazard source is considered effective, and n denotes the degree of danger level change from the epicenter to the periphery of the affected circular area (i.e., how fast/slow the danger level is changing). Fig. 3 illustrates the danger level distribution for different values of n.

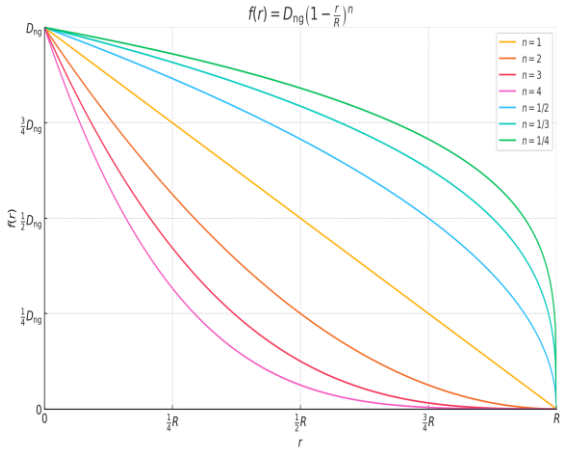

Fig. 3 The danger level distribution from the disaster/accident epicenter towards the periphery of the corresponding (circular) affected area
Source: created by the authors

If the point for calculation is located within multiple circles (of primary and secondary disasters/accidents), the danger level values, calculated for each circle, are summed together to produce the overall danger level at a particular point.

B. Generating personalized evacuation routes

For generating a personalized evacuation route, the user can choose between three modes of transportation: *walking*, *cycling*, or *driving*. Each transportation mode has different average speeds and specific restrictions regarding which types of available roads can be used. Sample personalized evacuation routes, generated by the app for a user at a given location, are shown in Appendix in Fig. 4, Fig. 5 and Fig. 6, respectively for each of these three transportation modes.

In Appendix in Fig. 4, Fig. 5 and Fig. 6, the personalized evacuation routes, shown in green, are calculated using the Dijkstra algorithm, where the route cost is determined using the following formula:

$$cost = \frac{(D_{ng1} + D_{ng2})}{2} \times time \quad (2)$$

where $cost$ denotes the cost of traversing a segment between two adjacent nodes on the map (measured in units of $danger\ level \times time$), representing how long a person would be exposed to a certain level of danger while passing through that segment); D_{ng1} denotes the danger level at node 1 (i.e., at the beginning point of the segment); D_{ng2} denotes the danger level at node 2 (i.e., at the end point of the segment); $time$ denotes the time required to traverse the segment, with a value depending on the length of the segment and the average speed for the selected transportation mode on the given type of road (a default average speed is defined for each transportation mode and road type, but the value can be configured).

V. Conclusion

This paper has presented a method, proposed for generation and recommendation of personalized routes for evacuation of people in cases of natural disasters or industrial accidents, which has been demonstrated on an example of a disaster/accident (with an epicenter), spreading radially in all directions with the same speed of onset. A specially designed and developed web-based app has been briefly presented as well.

Future research will be focused on incorporating the proposed method into a mobile app [11], whereby all computations would not be performed on a remote server, as presented here, but on drones (flying over the affected areas) using edge computing, or directly on the mobile devices of users, currently located in the area affected by the disaster/accident, without relying on existing communication infrastructures, which may be damaged or unavailable during certain types of disasters/accidents.

References

[1] M. T. Rashid, D. Zhang, and D. Wang, "DASC: Towards a Road Damage-Aware Social-media-driven Car Sensing Framework for Disaster Response Applications," *Pervasive and Mobile Computing,* vol. 67, pp. 101207. 2020. DOI: 10.1016/j.pmcj.2020.101207.

[2] V. Krishnan, G. S. Kumar, P. Anand, and M. Rajesh, "Locating and Routing for IoT-Based Fire Evacuation System," In: M. S. Thampi, P. Siarry, M. Atiquzzaman, L. Trajkovic, J. L. Mauri, (eds) Fifth International Conference on Computing and Network Communications (CoCoNet), Bengaluru (Bangalore), India. *Lecture Notes in Electrical Engineering,* vol. 1219, pp. 151-160. Springer, Singapore. 2025. DOI: 10.1007/978-981-97-4540-1_12.

[3] Y. Mei, , P. Gui, X. Luo, B. Liang, L. Fu, and X. Zheng, "IoT-based Real Time Intelligent Routing for Eemergent Crowd Evacuation," *Library Hi Tech,* vol. 37, no. 3, pp. 604-624. 2019. DOI: 10.1108/LHT-11-2017-0251.

[4] K. Padungpien, and W. Marurngsith, "Creating Social-aware Evacuation Plans based on a GIS-enable Agent-based Simulation," *Proc. 9th EUROSIM Congress on Modelling and Simulation,* pp. 452-458. Oulu, Finland. 2018.

[5] G. Lämmel, M. Rieser, and K. Nagel, "Large Scale Microscopic Evacuation Simulation," In: W. Klingsch, C. Rogsch, A. Schadschneider, M. Schreckenberg, (eds) *Pedestrian and Evacuation Dynamics,* pp. 547-553. Springer, Berlin, Heidelberg. 2010. DOI: 10.1007/978-3-642-04504-2_48.

[6] H. Srikanth, "Reinforcement Learning Based Escape Route Generation in Low Visibility Environments," arXiv, 2024. DOI: 10.48550/arXiv.2406.07568.

[7] D. Xu, X. Huang, J. Mango, X. Li, and Z. Li, "Simulating Multi-exit Evacuation using Deep Reinforcement Learning," *Transactions in GIS,* vol. 25, no. 3, pp. 1542-1564. 2021. DOI: 10.1111/tgis.12738.

[8] U. Atila, Y. Ortakci, K. Ozacar, E. Demiral, and I. R. Karas, "SmartEscape: A Mobile Smart Individual Fire Evacuation System Based on 3D Spatial Model," *ISPRS International Journal of Geo-Information,* vol. 7, no. 6, pp. 223. 2018. DOI: doi.org/10.3390/ijgi7060223.

[9] J. Zhang, J. Guo, H. Xiong, X. Liu, and D. Zhang, "A Framework for an Intelligent and Personalized Fire Evacuation Management System," *Sensors,* vol. 19, no. 14, pp. 3128. 2019. DOI: 10.3390/s19143128.

[10] I. Aedo, S. Yu, P. Díaz, P. Acuña, and T. Onorati, "Personalized Alert Notifications and Evacuation Routes in Indoor Environments," *Sensors,* vol. 12, no. 6, pp. 7804-7827. 2012. DOI: 10.3390/s120607804.

[11] L. Pendov and I. Ganchev, "Infrastructureless ICT System for Delivery of Early Warning and Notification Messages in Cases of Natural Disasters or Industrial Accidents," *International Journal of Education and Information Technologies,* vol. 19, pp. 62-70. 2025.

[12] D. Edler and M. Vetter, "The Simplicity of Modern Audiovisual Web Cartography: An Example with the Open-Source JavaScript Library leaflet.js," K*N - Journal of Cartography and Geographic Information,* vol. 69, no. 1, pp. 51-62. 2019. DOI: 10.1007/s42489-019-00006-2.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This publication has emanated from research conducted with the financial support of the European Union-NextGenerationEU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project DUECOS BG-RRP-2.004-0001-C01.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Creative Commons Attribution License 4.0 (Attribution 4.0 International, CC BY 4.0)

This article is published under the terms of the Creative Commons Attribution License 4.0
https://creativecommons.org/licenses/by/4.0/deed.en_US

APPENDIX

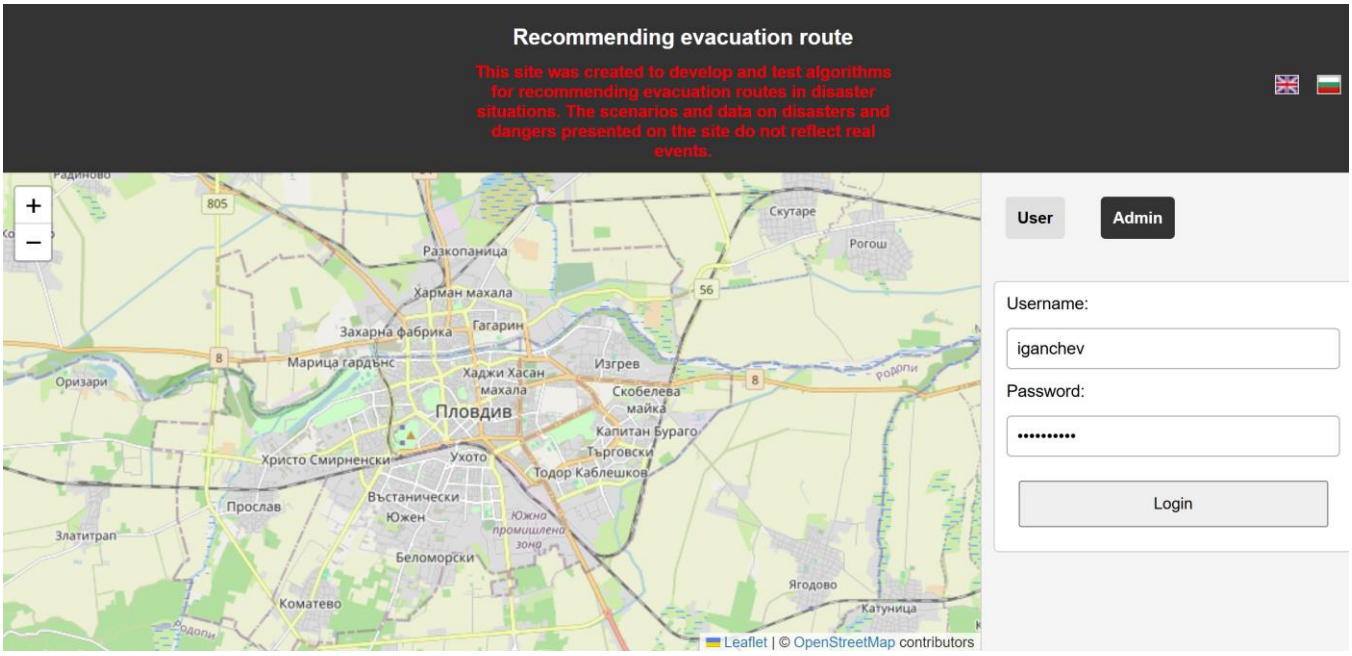

Fig. 1 The developed web-based app: admin login
Source: created by the authors

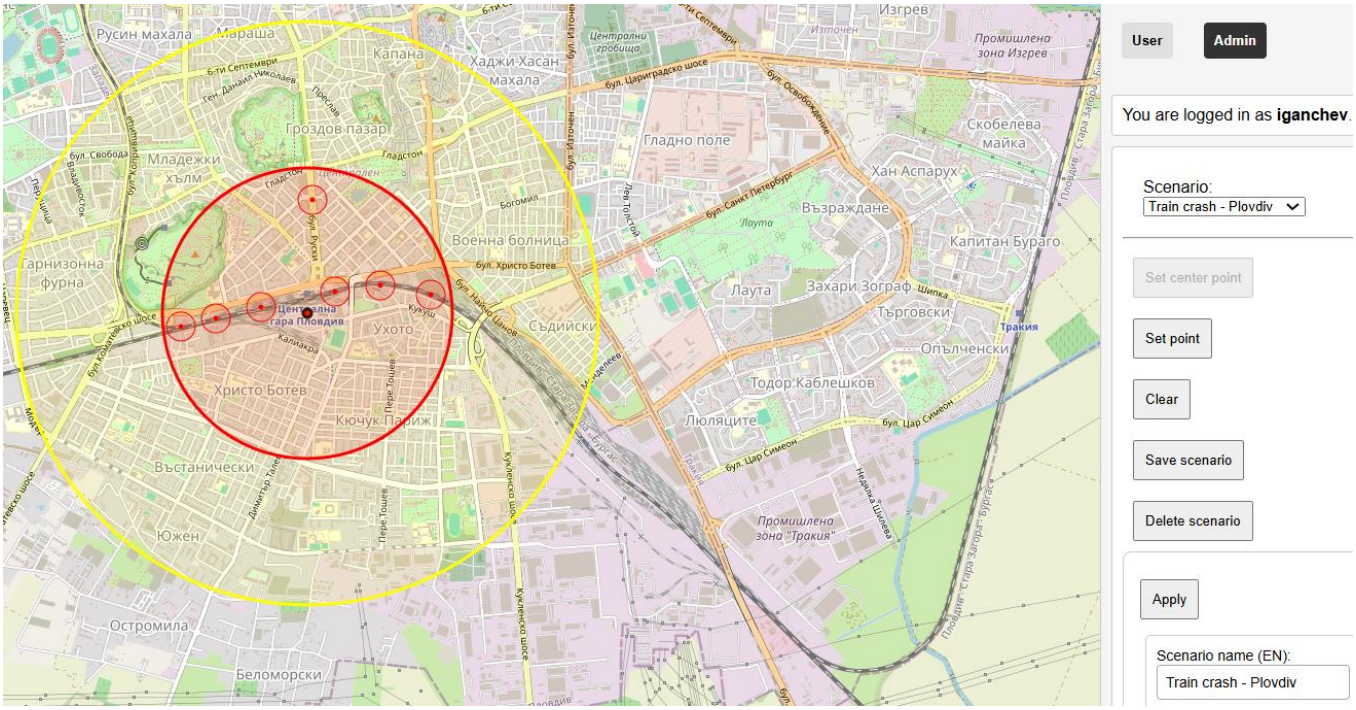

Fig. 2 The developed web-based app: danger/accident-related zone setting by admin
Source: created by the authors

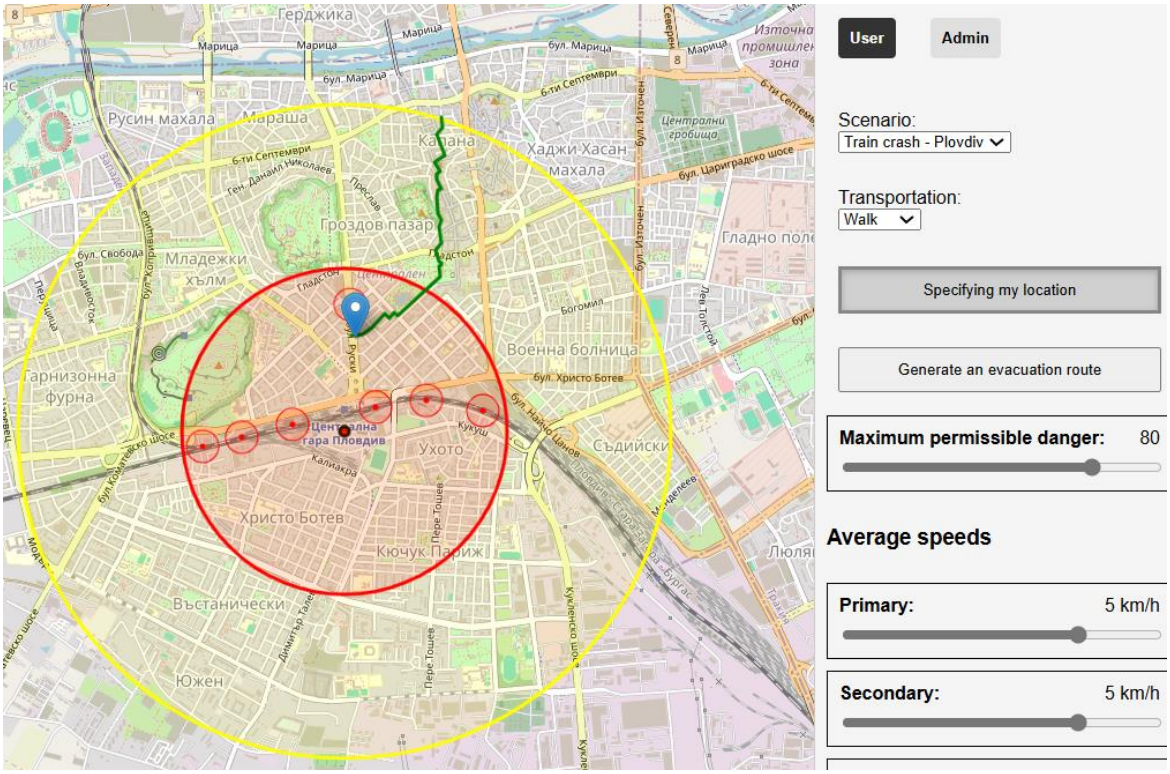

Fig. 4 The developed web-based app: the generated personalized evacuation route (in green color) for *walking*
Source: created by the authors

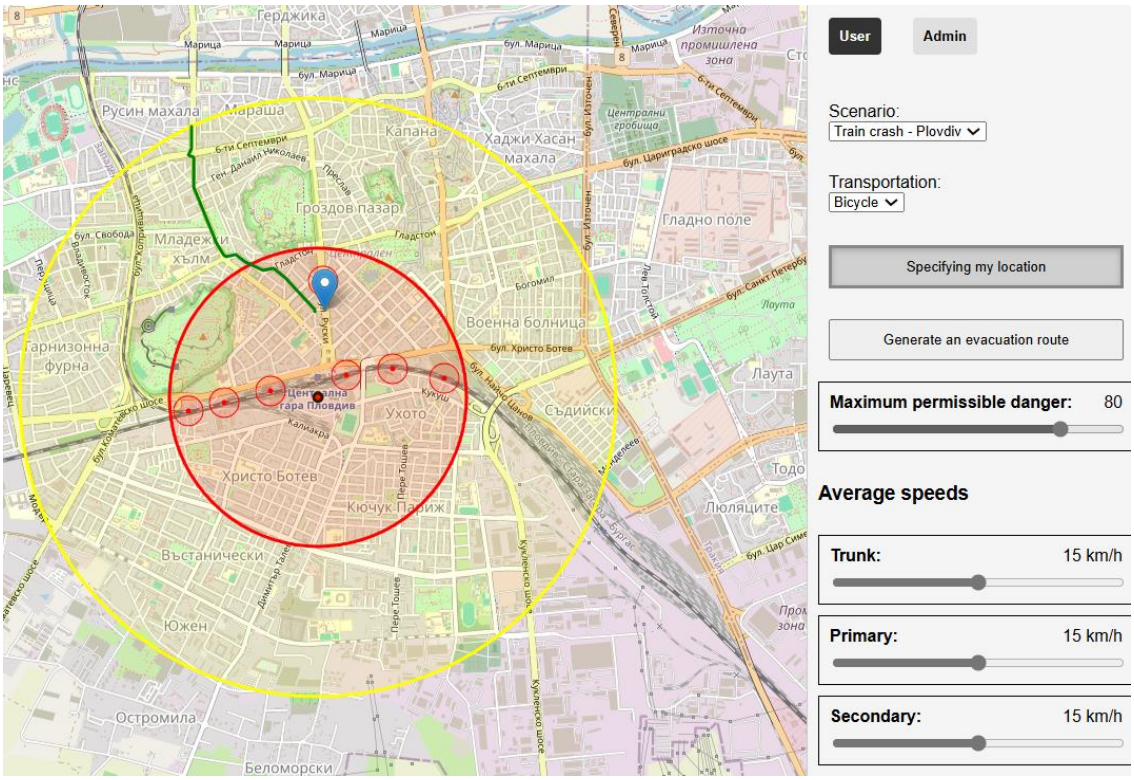

Fig. 5 The developed web-based app: the generated personalized evacuation route (in green color) for *cycling*
Source: created by the authors

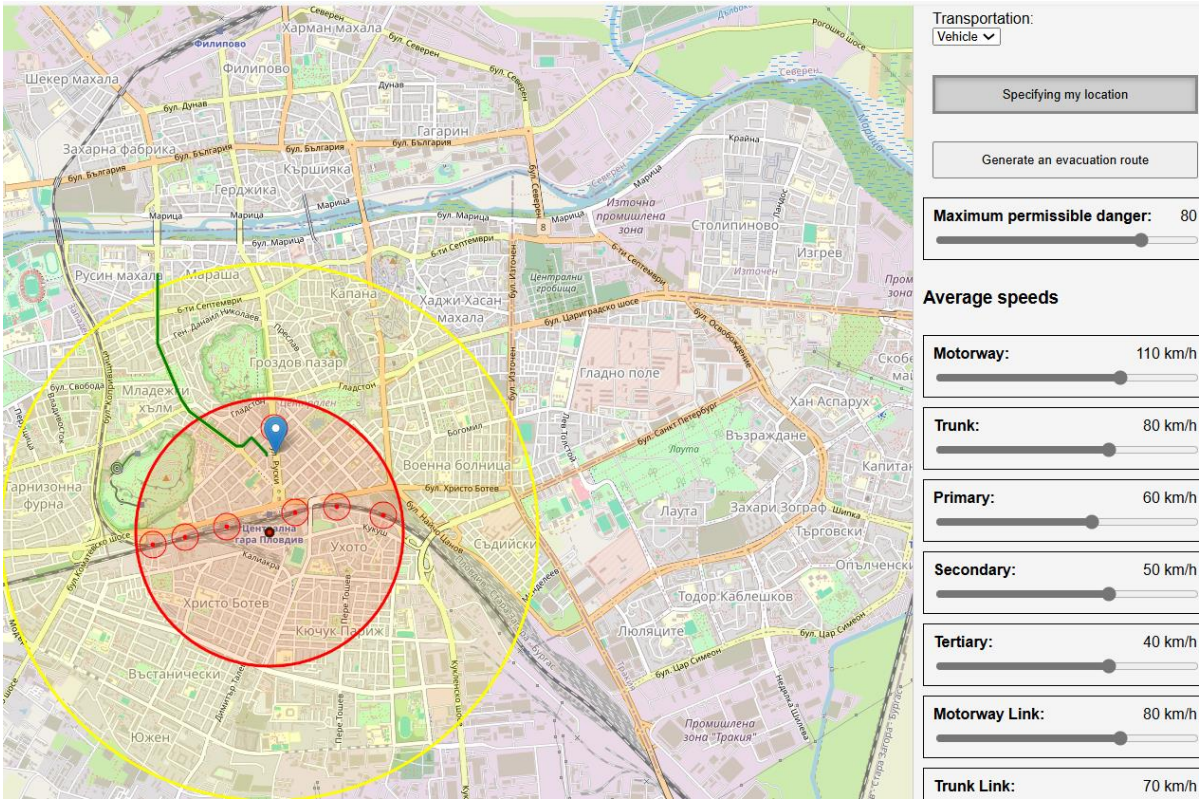

Fig. 6 The developed web-based app: the generated personalized evacuation route (in green color) for *driving*
Source: created by the authors