Toward Automatic Variations of Evacuation Simulations to Enhance Event Safety

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Abstract Mass gatherings pose significant challenges for organizers and safety authorities, as seen in past crowd disasters. Effective planning and rapid adaptation in case of danger are crucial to ensuring public safety. Our *Resilience & Event Management System (REMSY)* aims to solve a multitude of challenges surrounding event management but particularly addresses evacuation by enabling stakeholders to simulate and explore various "what-if" scenarios. Through an intuitive interface, planners can easily create and run multiple varied simulations to understand how crowd dynamics may evolve in diverging conditions. To enable data-driven decisions and optimize event planning, they are provided with various key safety indicators. A case study from Freiburg, Germany, will demonstrate the system's real-world applicability and value to stakeholders.

Keywords Event Safety, Crowd Simulation, Evacuation Planning, Emergency Preparedness, Mass Gatherings, Simulation-Based Decision Making, Crowd Management

Introduction & Motivation

Ensuring safety at open air large-scale events and mass gatherings is a complex challenge requiring a sophisticated, adaptive approach that integrates both preventive and responsive measures, such as evacuation planning. While evacuations are typically preplanned, they must be dynamically adapted to real-time conditions. Traditional static planning methods, i.e., the manual determination of evacuation routes and exits for a single event layout, often fail to account for the unpredictability of crowd dynamics and emerging hazards [6]. Unexpected factors—such as an unanticipated surge in visitors or an obstructed emergency exit—can significantly disrupt evacuation processes. Current approaches, being largely manual and scenario-specific, lack the flexibility to accommodate deviations from predefined conditions, forcing emergency responders to make rapid, high-pressure adjustments without a comprehensive situational overview. These ad hoc modifications are necessary but also come with a risk of suboptimal decisions. Therefore, an effective safety framework must encompass a broad range of potential scenarios to enhance the adaptability of evacuation plans, improve stakeholders' understanding of crowd dynamics and the impact of layout decisions during the planning phase.

The FreiburgRESIST[1] project embraces this necessity by developing a comprehensive system that supports the planning, execution, and evaluation of mass gatherings, called *REMSY* (Resilience & Event Management System). At the heart of the project is an event planning tool that allows for the simulation of multiple scenarios in relation to different event layouts. Instead of requiring the user to identify all relevant variations and run simulations individually, the tool automatically varies parameters and simulates all relevant combinations—providing a holistic overview to stakeholders and informing their decisions during event planning and execution.

From Manual to Simulation-based Event Planning

To identify the necessary key variations and decision factors, we conducted workshops and interviews with prospective system users, including Freiburg's police, fire department, department of public order, event organizers, and security services. These discussions revealed the need for an adaptive approach that allows for the evaluation of different scenarios and event layouts. Through these investigations, the following questions emerged as critical for informed decision-making:

- What happens if specific entry points or exit routes are blocked and cannot be used?

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- What if a danger emerges at location A and people start running away from it? What if it emerges at location B instead?
- How many people could be evacuated in both scenarios in a reasonable time?
- How would further or wider exit routes change the capacity?

To address these needs, *REMSY* will enable the execution of various evacuation simulations ('what-if' scenarios), providing users with in-depth insights into different situations.

Automatic Variation of Simulations

Evacuation simulations are a well-established tool for planning and assessing mass gatherings. Several models are available, each based on distinct methodologies, such as the Social Force Model ([2]) or the Optimal Steps Model [1].

For *REMSY*, we use crowd:it [3], an established tool on the market and well-validated by the tests of RiMEA [4] as well as the validation and verification tests of ISO 20414 [5]. The objective of this work is to extend the tool such that planners can easily test "what-if"-scenarios through an intuitive, user-friendly interface (see Figure 1) and receive feedback on the safety of their event layout.

A range of parameters can be adjusted to meet user requirements identified during the workshops, including visitor numbers, escape route widths, and exit availability. Users define parameter ranges (e.g., 10,000–20,000 visitors) that will be tested in multiple simulations. To exclude non-viable configurations, predefined criteria–such as a maximum evacuation time–can be applied. To maintain an overview of all variants, results are presented in a compact format, enabling users to quickly assess the validity of their layout. Figure 1 presents an exemplary simulation setup: visitor numbers and available exits are varied, discarding configurations where evacuation exceeds 15 minutes or congestion delays exceed 2 minutes. Results are displayed in a concise chart, showing that for 30,000 visitors, all exits must remain open, whereas with 20,000 visitors, the West Exit can be closed without compromising safety.

Since the multiplication and simulation of all combinations is very time-consuming, possible optimization approaches will be integrated in a next step to recognize and simulate only significant variants.

By enabling multiple simulations with varying parameters, *REMSY* users can develop a deeper understanding of the potential risks and vulnerabilities in their event planning. This allows them to make well-informed decisions and adjust their plans accordingly to ensure the safety of event visitors. The simulations can thus fundamentally alter the way events are planned and conducted.

If accepted, we will demonstrate this novel simulation approach using a real event in Freiburg, Germany, highlighting how varied simulations can enhance both safety and event planning.

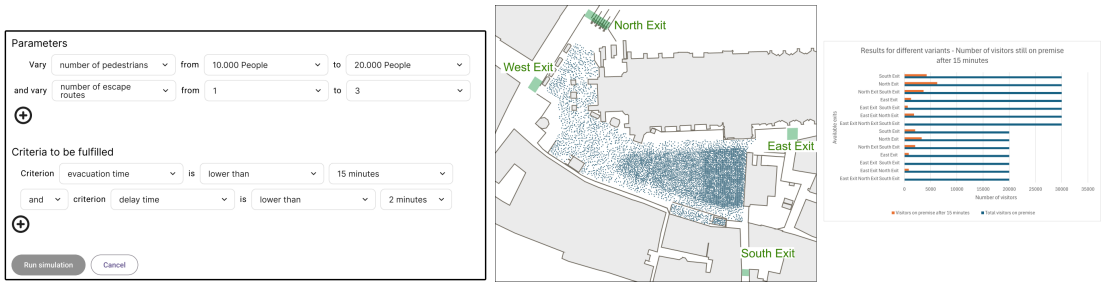

Figure 1: Left: Example mock-up of the future user interface for event planners. Right: Screenshot of one simulation run including a chart that displays the results of all parameter variation.

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