**Journal of the Operational Research Society (2008), 1–10**  0160-5682/08

www.palgrave-journals.com/jors/

# The Safest Escape problem

S Opasanon[1] and E Miller-Hooks[2]*

[1]*Faculty of Commerce and Accountancy, Thammasat University, Bangkok, Thailand; and* [2]*University of Maryland, College Park, MD, USA*

In this paper, the Safest Escape (SEscape) problem is defined for providing evacuation plans for emergency egress from large buildings or a geographical region. The objective of the SEscape problem is to determine the set of paths and number of evacuees to send along each path such that the minimum probability of arrival at an exit for any evacuee is maximized. Such paths minimize the risk incurred by the evacuees who are forced to take the greatest risk. The problem is considered in a dynamic and time-varying network, where arc capacities are recaptured over time, arc traversal times are time-varying and arc capacities are random variables with probability distribution functions that vary with time. An exact algorithm, the SEscape algorithm, is proposed to address this problem.

*Journal of the Operational Research Society* advance online publication, 3 December 2008
doi:10.1057/jors.2008.122

**Keywords:** dynamic network flows; stochastic; time-varying networks; evacuation; building egress

## 1. Introduction

A number of objectives are used in developing optimal building evacuation plans for use in evacuating a large damaged building, that is, a burning building or a building that has come under attack by enemy or natural catastrophe, or a geographic region. The primary objectives include minimizing the evacuation time (ie the time until the last evacuee exits), minimizing the total time for evacuation and maximizing the number to egress by a given time $T$. Such approaches may be useful when capacities of the passageways are known *a priori* deterministically. In emergency incidents, however, how the situation will progress is uncertain and one cannot know *a priori* the number of people who will be able to successfully pass through a given passageway at any point in time with certainty. Moreover, there may be some probability that successful egress along one or more passageways will be inhibited. Evacuees may not prefer the solution that provides the minimum evacuation time or that optimizes other functions of time, but instead may prefer a path with high likelihood of leading to successful escape. That is, a path with a long journey time, but high probability of successful egress would be preferred to a path with short journey time, but low probability of successful escape. Owing to capacity limitations, solutions will likely employ multiple paths and the likelihood of successful egress along each path will likely differ. Thus, equity issues arise. In this paper, the Safest Escape (SEscape) problem is formulated with the objective of finding the *a priori* pattern of flow that maximizes the minimum path probability of successful arrival at the sink. Solutions obtained with this objective ensure that the risk incurred by any evacuee who is forced to take the greatest risk is minimized, that is, his or her probability of successful escape is maximized. The objective is similar in nature to evacuation time or makespan objectives in that it considers the effect on the person who must endure the worst situation.

To further clarify the objective of the SEscape problem, consider the constituent paths of a given flow pattern and assess each evacuee's probability of successful arrival at a sink (eg a building exit). Among the flow pattern's constituent paths, there is one path that has the minimum probability of successful arrival at the exit (assuming no ties). The flow pattern whose minimum success probability path has the maximum success probability is optimal as illustrated in Figure 1.

Consider two possible flow patterns for shipping three supply units from node 1 to 4 in the 4-node network depicted in the figure. The minimum success probability paths are shown in bold. The flow pattern in Figure 1b (ie ship 2 units along path 1–2–4 and 1 unit along path 1–3–4) is optimal for the SEscape problem, because the associated minimum success probability (0.24 on path 1–2–4) is greater than that of the flow pattern shown in Figure 1a (0.08 on path 1–3–4).

Emergency evacuations are often characterized by dangers that strengthen and spread over time. It is not possible to know *a priori* how the situation will progress with certainty, even if the exact location and type of event that initiated the need for the evacuation is known. Moreover, there is the possibility that successful egress may be inhibited by partial or complete failure of key escape paths. In devising evacuation instructions, it is important to explicitly consider the time-varying

**Correspondence: E Miller-Hooks, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742, USA.*
E-mail: elisemh@umd.edu