Safety Science 92 (2017) 128–137

Contents lists available at ScienceDirect

Safety Science

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

Emergency evacuation capability evaluation and optimization for an offshore airport: The case of Dalian Offshore Airport, Dalian, China

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ARTICLE INFO

Article history:
Received 23 March 2016
Received in revised form 8 September 2016
Accepted 5 October 2016

Keywords:
Offshore airport
Emergency
Evacuation
Marine
Evaluation
Optimization

ABSTRACT

How to evacuate evacuees to safety from islands in disasters is an important issue for the emergency system design of an offshore airport. In this paper, a modeling framework was developed to evaluate and optimize the emergency evacuation capability of an offshore airport. With this framework, the emergency evacuation capability was evaluated and optimized in the context of the cross-sea bridge failure for Dalian International Airport, Dalian, China. With the combination of an evacuation demand analysis and a marine network analysis, a scheduling simulation was developed to evaluate the capability of the marine evacuation system plan under emergency. Based on the evaluation results, two optimization strategies were introduced to improve this plan. The evaluation results show that the emergency evacuation capability of an offshore airport is mainly limited by the marine traffic environment of the urban area in the condition of bridge failure. To improve the emergency evacuation capability, some vessels should be located at the offshore airport, and a wharf should be constructed in the nearby mainland. The current results of this study will be helpful in guiding the emergency evacuation system design of an artificial or a natural island.

1. Introduction

In recent years, many countries including China, Japan and others have attempted to overcome land-based bottlenecks with the design and construction of new offshore airports (Okuda and Hida, 2013; Plant and Oakervee, 1998). The practices (Wang et al., 2013; Yan et al., 2013) show that the construction of an offshore airport benefits the urban area (e.g., saving land resources, reducing noise problems). Because an offshore airport is located on an island, arrivals and departures of the passengers almost depend on the cross-sea bridges. However, it may be unsafe to transport passengers only through cross-sea bridges. If the cross-sea bridges fail in a disaster (Abé and Shimamura, 2014; Cheng and Wu, 2013), it is notably difficult to evacuate the evacuees from the island to safety. In this scenario, the marine evacuation system will be launched as an alternative emergency transportation system.

In fact, it is an effective method to promote the emergency evacuation capability by setting up several alternatives. Similar to the escape routes for a high-rise building, the emergency evacuation of an island depends on cross-sea bridges and other unconventional transportation systems (e.g., airports, bridges, and transit were shut down after the 9/11 attacks, while boats came to rescue persons from Manhattan) (Murray-Tuite and Wolshon, 2013). In addition, for an offshore airport that is surrounded by seawater, the marine evacuation system is the only feasible alternative if the cross-sea bridge fails. Therefore, it is particularly important to perform studies on evaluating and optimizing the capability of marine evacuation systems for an offshore airport.

As a major component of the emergency transportation system, the capability of the marine evacuation system is fully considered in design. Recently, emergency evacuation has been a hot issue for researchers as the frequency of natural disasters and terrorist attacks increases. The corresponding research findings involved high-rise buildings (Lin et al., 2008; Pursals and Garzón, 2009; Saeed Osman and Ram, 2013; Xu and Song, 2009), public entertainment (Chow and Ng, 2008; Jiang et al., 2009; Johnson, 2008; Lei et al., 2012; Reniers et al., 2007), vehicles (Miyoshi et al., 2012; Vanem and Skjong, 2006), urban communities (Abdelgawad and Abdulhai, 2012; Bish and Sherali, 2013; Chen et al., 2012; Johnstone and Lence, 2012; Lambert et al., 2013; VanLandegen and Chen, 2012), etc.; however, these studies mainly focused on terrestrial environments such as pedestrian trails, roads and railways. Studies about marine evacuation systems remain limited and underdeveloped.

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http://dx.doi.org/10.1016/j.ssci.2016.10.004
0925-7535/© 2016 Published by Elsevier Ltd.

In fact, a marine evacuation system can be treated as a maritime search and rescue (SAR) system (Breivik et al., 2012). Commonly, studies about maritime SAR can be divided into two groups (Siljander et al., 2015): operational support (Breivik and Allen, 2008; Cho et al., 2014; Guoxiang and Maofeng, 2010) and strategic planning (Azofra et al., 2007; Palm and Tornqvist, 2008; Shi et al., 2014). The former concerns methods where a real-time SAR operation is supported by computational methods to detect a missing object at sea in the minimum possible time. The second concerns strategic planning methods to evaluate the overall performance of the SAR response system, e.g., to obtain maximal coverage of a sea area with a minimum required number of rescue units. However, studies about the evacuation of an offshore airport have not been found. As aforementioned, a modeling framework was developed. Based on this framework, we focus on evaluating and optimizing the emergency evacuation capability for an offshore airport with Dalian International Airport as a case study.

2. Methodology

The goal of the evaluation and optimization is to improve the evacuation capability of an offshore airport. To fulfil this goal, studies mainly concern on the following four aspects: evacuation demand analysis, marine network analysis, scheduling simulation and plan improvement. And then the modeling framework is designed as illustrated in Fig. 1.

Evacuation demand analysis is designed to estimate the total number of evacuees in an offshore airport. Commonly, evacuees in an offshore airport can be divided into three categories (Tsui et al., 2014): air passengers, people who meet or see off the air passengers, and staff of the airport, airlines, customs, etc. To facilitate the evaluation, an adverse scenario should be set. Under this circumstance, the total number of evacuees is estimated according to an airport traffic demand analysis.

The objective of marine network analysis is to construct a marine evacuation system. A marine evacuation system mainly consists of a rescue fleet, an arrival network (through which all vessels arrive at the offshore airport from their initial positions) and a transportation network (through which the vessels can evacuate the evacuees to safety from the island). Restricted by local water depth, some vessels can be selected to construct a rescue fleet. Then the possible initial positions and the arrival routes (through which the vessels come from their initial positions to the offshore airport) of every vessel in the rescue fleet constitute an arrival network. Finally, some landing terminals in nearby mainland and transportation routes (through which the vessels can evacuate the evacuees from the offshore airport to the landing terminals) are selected to construct a transportation network.

The resultant analysis from the evacuation demand and marine network then serve as inputs to the scheduling model. The scheduling model has two individual models: an arrival model and a transportation model. The arrival model is used to simulate the process that the vessels come from their initial positions to the offshore airport. The transportation model is applied to simulate the process that the vessels evacuate the evacuees from the offshore airport to the landing terminals. And the arrival model provides the arrival time window of the vessels at the offshore airport. After the simulations, some performance measures can be collected to evaluate the evacuation capability.

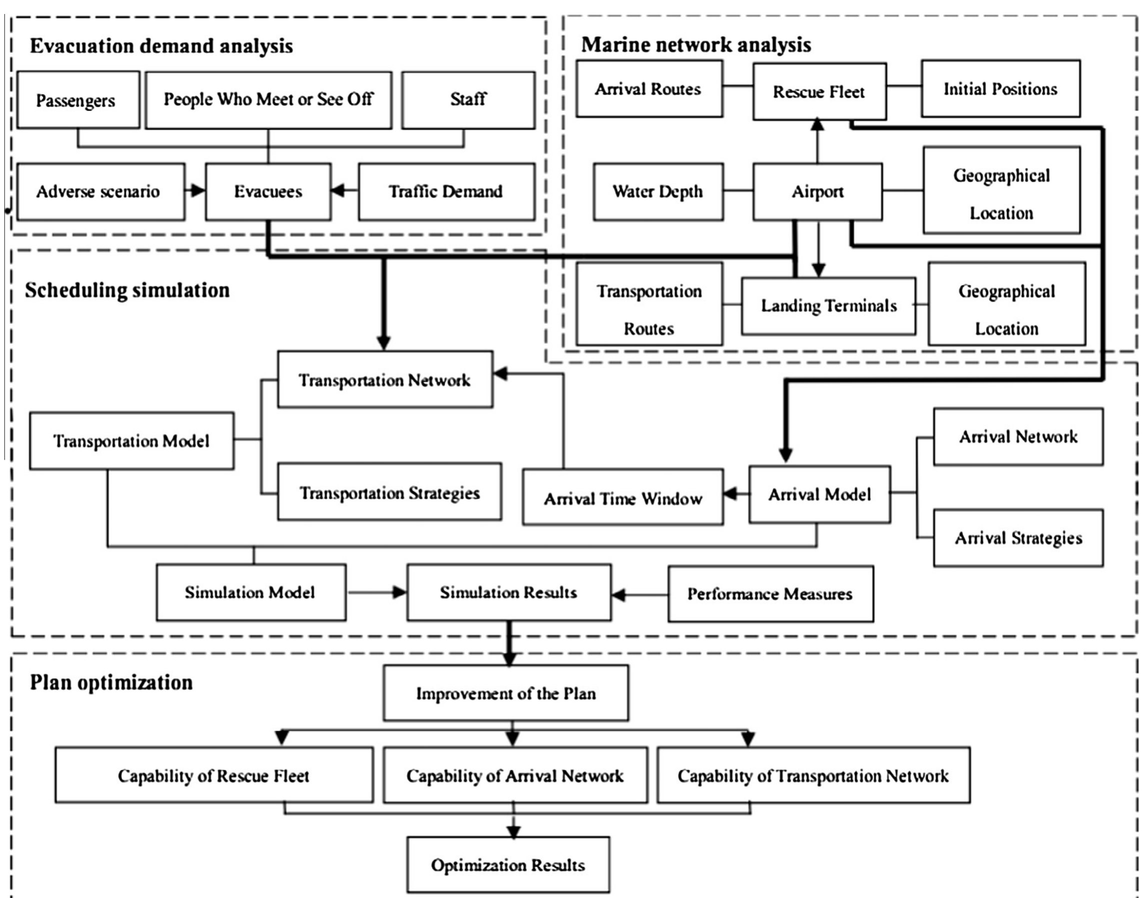

Fig. 1. Modeling framework.