Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/ijcip

A quantitative approach for assessing the critical nodal and linear elements of a railway infrastructure

Zili Zhang[a,*], *Xiangyang Li*[a], *Hengyun Li*[b]

[a]School of Management, Harbin Institute of Technology, 92 West Dazhi Street, Harbin, China
[b]School of Hotel, Restaurant and Tourism Management, University of South Carolina, 701 Assembly Street, Columbia, South Carolina 29208, USA

ARTICLE INFO

Article history:
Received 9 December 2012
Accepted 10 July 2014
Available online 29 November 2014

Keywords:
Critical infrastructure assets
Protection priority
Social network analysis
Gravity model
Mainland chinese railway infrastructure

ABSTRACT

Determining the priority of infrastructure assets is an important problem in critical infrastructure protection. However, relatively few studies have attempted to address the problem. This paper presents a quantitative approach for determining the elements of a railway infrastructure that have the highest protection priority. The train stations in a railway infrastructure (nodal elements) and railway lines (linear elements) are modeled as nodes and ties, respectively, in a social network diagram, which is used in centricity analysis to explore the relative importance of train stations. A modified gravity model is presented to assess the importance of railway lines. The feasibility of the proposed methodology is demonstrated using the railway infrastructure of Mainland China. The methodology can help practitioners and policy makers obtain a better understanding of the importance and protection priority of railway infrastructure assets as well as other critical infrastructures that have network topologies.

1. Introduction

Transportation infrastructures are of crucial importance to the economic development of a country and are important indicators of its economic growth. Railways, in particular, are the major means of transport in many developing countries. In these countries, railways constitute the backbone of the national transportation system and support the movement of passengers and goods across the country, which drives the national economy.

A railway infrastructure is composed of nodal elements such as train stations, electrical substations and telecommunications equipment rooms; and linear elements such as tracks, long metro tunnels, equipment along railway tracks and cables [15], all of which have many internal dependencies. For example, the state of one station influences or is correlated with the state of another station through a linkage or connection between the two stations. As a result, a disruption or damage to a station may negatively impact operations in the entire railway infrastructure. Each element of the infrastructure can be an accident source due to a terrorist incident or natural disaster; the disruption or damage of different elements have greater or lesser impacts on the entire system. Some damaged elements only cause the failure of one or several elements, while other damaged elements can lead to the destruction or collapse of many elements, and potentially the entire railway infrastructure. Therefore, to ensure the smooth operation of a railway infrastructure, special attention must be paid to assign more protection resources to elements that have larger impacts on the infrastructure.

A key question is how to identify critical nodal and linear elements in a railway infrastructure. Railway infrastructures

*Corresponding author.
E-mail address: n705zzl@126.com (Z. Zhang).

http://dx.doi.org/10.1016/j.ijcip.2014.11.001
1874-5482/

are large and diverse. In addition, they are geographically extended and interconnected. Clearly, damage to or the loss of certain stations and lines in a national railway infrastructure would have significant impacts. How does one identify important stations and lines and establish protection priorities? This paper proposes a methodology for answering this question. In particular, the methodology involves the analysis of a railway infrastructure to determine the most critical nodes and lines based on considerations of the criticality of train stations in cities and the economic and locational attributes of the cities.

The next section, Section 2, provides background information and an overview of the relevant literature. Section 3 describes the social network analysis approach and a modified version of the gravity model, which are used to analyze the endpoints of a railway infrastructure and the linkages or connections among them. Section 4 uses the railway infrastructure of Mainland China as a case study to illustrate the methodology. The final section, Section 5, summarizes the main results and conclusions.

2. Background

This section provides background information about critical infrastructures, critical infrastructure identification, critical infrastructure interdependencies, critical infrastructure protection prioritization and railway infrastructures.

2.1. *Critical infrastructures*

Critical infrastructure protection has become an important research field in the 21stcentury [22]. Defining the critical infrastructure is the logical first step toward protecting it; indeed, the specific definition used by a country often reflects its national priorities [25]. Although there is no universally agreed upon definition, the critical infrastructure is generally understood as comprising the facilities and services that are vital to the basic operations of society and whose disruption or destruction could greatly impair the functioning of society. The critical infrastructure is divided into a number of sectors, from traditional areas such as defense, transportation and energy, to new areas such as banking and finance, healthcare and information technology. Table 1 presents the critical infrastructure definitions used by various countries.

National definitions differ slightly in the criteria used to define the criticality of specific infrastructures. Most countries and organizations use cross-cutting criteria, which cover the infrastructures in all the sectors. Sectoral criteria are then used for each specific sector. The criteria used by some countries stress the severity and the societal effects of a disruption or destruction of a given type of infrastructure (e.g., an infrastructure is critical because its loss would be extremely disruptive). Other countries stress the finality or purpose of a given type of infrastructure (e.g., an infrastructure is critical because it performs a function that is vital to society). The latter approach is preferred by countries such as France and Canada, but the former approach is more widespread.

2.2. *Critical infrastructure identification*

Once the definition of critical infrastructure has been agreed upon, it is generally used to identify the infrastructure in the relevant jurisdiction that fits the definition and to establish

Table 1 – Critical infrastructure definitions.

Country	Definition	Sectors
United States [33]	Systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety or any combination of those matters.	Food and water systems, agriculture, healthcare systems, emergency services, information technology, communications, banking and finance, energy, transportation, the chemical and defense industries, postal and shipping entities, and national monuments and icons.
Germany [13]	Facilities and organizations of major importance to the community whose failure or impairment would cause a sustained shortage of supplies, significant disruptions to public order or other dramatic consequences.	Transport and traffic, energy, hazardous materials, information technology and telecommunications, finance, monetary system and insurance, supply services, authorities, administration and justice, and other.
United Kingdom [4]	Those facilities, systems, sites and networks necessary for the functioning of the country and the delivery of the essential services upon which daily life in the UK depends.	Communications, emergency services, energy, financial services, food, government, health, transport, and water.
France [25]	Those activities that are indispensable to the public's essential needs and the maintenance of the security and defense capabilities of the country.	Food, water, energy, transport, financial institutions, information and communications systems, and command and decision centers.
Australia [24]	Those physical facilities, supply chains, information technologies and communication networks which, if destroyed, degraded or rendered unavailable for an extended period, would significantly impact on the social or economic wellbeing of the nation or affect Australia's ability to conduct national defense and ensure national security.	Banking and finance, transport, energy, water, health, food supply and communications, key government services, manufacturing, and supply chains.
Canada [29]	Processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government.	Energy and utilities, finance, food, transportation, government, information and communication technology, health, water, safety, and manufacturing.