Decision Support Systems 54 (2013) 1580–1586

Contents lists available at SciVerse ScienceDirect

Decision Support Systems

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

Analysing the impact of disruptions in intermodal transport networks: A micro simulation-based model

Wolfgang Burgholzer [a,*], Gerhard Bauer [a], Martin Posset [b], Werner Jammernegg [a]

[a] WU Vienna University of Economics and Business, Department of Information Systems and Operations, Nordbergstraße 15, 1090 Vienna, Austria
[b] h2 projekt.beratung KG, Obere Viaduktgasse 10/7, 1030 Vienna, Austria

A R T I C L E I N F O

Available online 12 June 2012

Keywords:
Intermodal transport network
Network vulnerability
Transport network analysis
Traffic micro simulation
Supply chain disruption

A B S T R A C T

Transport networks have to provide carriers with time-efficient alternative routes in case of disruptions. It is, therefore, essential for transport network planners and operators to identify sections within the network which, if broken, have a considerable negative impact on the network's performance. Research on transport network analysis provides lots of different approaches and models in order to identify such critical sections. Most of them, however, are only applicable to mono-modal transport networks and calculate indices which represent the criticality of sections by using aggregated data. The model presented, in contrast, focuses on the analysis of intermodal transport networks by using a traffic micro simulation. Based on available, real-life data, our approach models a transport network as well as its actual traffic participants and their individual decisions in case of a disruption. The resulting transport delay time due to a specific disruption helps to identify critical sections and critical networks, as a whole. Therefore, the results are a valuable decision support for transport network planners and operators in order to make the infrastructure less vulnerable, more attractive for carriers and thus more economically sustainable. In order to show the applicability of the model we analyse the Austrian intermodal transport network and show how critical sections can be evaluated by this approach.

1. Introduction

The movement towards more and more global specialisation and consequentially increasing international trade leads to a growing amount of global transport volume [16]. More transport volume, subsequently, also creates more and more competition between transport network providers as carriers search for more (cost) efficient, flexible and reliable transport flows [16,26]. The combination of different transport modes within a single transport chain offers opportunities to improve a transport system's performance [16], not just as an effective and reliable way of transport but also regarding the public aim for more environmentally friendly and sustainable transport flows [26]. Thus, combined transportation [14], and especially intermodal freight transportation, with its main leg of the transport being operated by rail, inland waterway or ocean-going vessel [9,20], is a frequently used alternative to mono-modal transportation [14,26].

Disruptions within a transport network, caused by natural disasters, technical problems, wear and tear or human malevolence are a major threat for a network's reliability and efficiency [19,30]. Therefore, it's a goal for transport network providers, in case of a disruption, to offer time efficient alternative routes to carriers.

Based on this need for efficient transport flows in case of a disruption, we develop a model which *analyses transport flows within intermodal transport networks when a disruption occurs* in order to identify the network's strengths, and more importantly, weaknesses [21,22]. We quantitatively measure a network's *vulnerability* which, based on [8,18,31], is the amount the performance level of a network drops when individual sections, further referred to as links, of the network are disrupted [22,30]. In particular, we measure the ability of a transport network to absorb the amount of transport which cannot pass a disrupted link without considerable time delay in transportation. Thus, we identify links within a network which strongly degrade a network's performance. Such links are later referred to as *critical links* [32]. By considering terminals which allow a change of the transport mode, the model is perfectly useable for intermodal transport networks. Nevertheless, the model is also applicable to other network types.

Intermodal freight transport, which emerged as a research field in the last decade of the 20th century [1], is defined as a transport system which integrates at least two modes in a transport chain and where the handling units (mostly containers) do not change. The main leg of the transport thereby is operated by rail, inland waterway or ocean-going vessel, while the initial and final legs are operated by road [9,20]. The growing amount of global transport volume and the

* Corresponding author. Tel.: +43 1 31336 5394; fax: +43 1 31336 5610.
E-mail addresses: wolfgang.burgholzer@wu.ac.at (W. Burgholzer), gerhard.bauer@wu.ac.at (G. Bauer), mcp@h2pro.at (M. Posset), werner.jammernegg@wu.ac.at (W. Jammernegg).

0167-9236/$ – see front matter
doi:10.1016/j.dss.2012.05.060

aim for more efficient, sustainable and environmental friendly transport flows have been the drivers for research on intermodal transport [16,26]. Nevertheless, research on intermodal transport network design or performance analysis is, while developing in recent years, still scarce [16,20].

Literature on the analysis of network-disruption similarly emerged since the 1990s [29,30]. Most of the research in this field concentrates on the development of models measuring a monomodal transport network's vulnerability by means of indices [e.g.: 13,15,21,28,30,31]. These indices are based on mathematical models which depend on few input factors such as capacity utilisation, the importance of a network's links or the length of these links. The complexity of intermodal transport networks, however, with its plurality in transport modes and decision makers, makes it impossible for such mathematical models to reflect [2].

Thus, and motivated by more recent developments in the research fields of traffic assignment and traffic micro simulation [e.g.: 3,23, 29,35] as well as research on agent-based approaches in the field of transport logistics [5], our model uses a *traffic micro simulation* as its core module. A traffic micro simulation makes it possible to analyse the entities of a network individually as well as with their dependencies and relationships to other entities [24,34]. Therefore, traffic micro simulation is more and more frequently used as the method of choice for solving and analysing traffic problems [35] as it dynamically and stochastically models each traffic participant and its movements within a transport network [7,23].

This paper is structured as follows. In Section 2 we present the model in detail, i.e. its data base, assumptions and detailed operations. Section 3 gives an overview of the used network performance indicators (NPI's) in order to measure the criticality of individual network links. Furthermore, Section 4 shows the application of the model to the Austrian intermodal transport network. The network itself as well as crucial findings is outlined. Section 5 concludes the paper by pointing out the advantages and limitations of the model as well as further advancement and research opportunities.

2. The simulation model

In this chapter the *traffic micro simulation model* is described. The goal of the model is to identify critical links within an intermodal transport network. For this purpose, one link at a time is analysed by looking at the influences a disruption has on the traffic participants which normally pass this link. Therefore, the model, firstly, reproduces the intermodal transport network as well as its actual traffic before, secondly, one of the network's links is disrupted. Then, a traffic micro simulation is used in order to navigate the traffic participants through the, now disrupted, network. The criticality, thereby, is primarily measured as the total delay of all traffic participants in the network due to the simulated disruption [32].

2.1. The intermodal transport network

The intermodal transport network is modelled by *links* and *nodes*. A link of the network, on one hand, is always located between two nodes. Nodes, on the other hand, are either crossings of the underlying network or terminals which make a mode change in a fixed handling unit possible and therefore are relevant for intermodal transport (container terminals). The traffic participants are called *transport units* in this paper. These transport units are the entities of the micro simulation.

Both, the network dimensions as well as the generation of the transport units are based on collectable data of the underlying networks. Above all, these data include, both for passenger and freight traffic, capacity, throughput, utilisation and physical dimensions of each link and node. Moreover, the average speed of every passenger and freight transport unit on a specific link is provided for the model. Upon these data, the actually occurring freight and passenger transport units are simulated. The transport units are generated onto traces which serve as possible time slots for passing a specific link. The traces are simulated according to the capacity of the specific links.

A disruption is described by its duration, its time of occurrence and the capacity reduction it induces. These three variables are referred to as *disruption parameters*. In case of a disruption, each transport unit, which normally would pass the now disrupted link, chooses between three different variants (as shown in Fig. 1).

- Drive on a free trace through the disrupted link (after the end of the disruption or during the disruption when the reduction of the link's capacity is lower than 100%) (variant 1) or
- stay on the current transport mode and use a free trace on an alternative route (variant 2) or
- choose to switch the transport mode and continue on a free trace of the newly selected alternative route (variant 3).

Every transport unit will, in this juncture, decide itself for the variant and route with the *shortest transport time* [12].

2.2. The traffic micro simulation

The traffic micro simulation, which navigates the transport units through the network, is *event-driven* and *agent-based*. During the simulation, multiple events, like the assumed disruption at the beginning and later the decisions of each individual transport unit, occur. These events impact and trigger the flow of the programme [10]. As these events, in turn, are often based on individual decisions of each individual transport unit, the programming approach can also be characterised as being multi-agent-based [4,11].

R was chosen as the programming language and environment. R is especially known for its use in statistical computing and graphics [27]. Its extensive data handling, preparation and analysis tools as well as its highly flexible, array based programming language were decisive factors for our implementation.

2.3. Model assumptions

The model (as described in detail in Section 2.4) is based on the following assumptions:

- Each transport unit acts rational. The rational goal is to *minimise the transport time*.
- Each transport unit always has complete information. Thus, each transport unit knows immediately when a disruption occurs about its disruption parameters. Each transport unit also has full knowledge of the chronologically upstream transport unit's decision as well as the utilisation of the terminals and the alternative routes. In this regard, transport unit A is chronologically upstream to transport unit B when it arrives earlier at the starting point of a possible

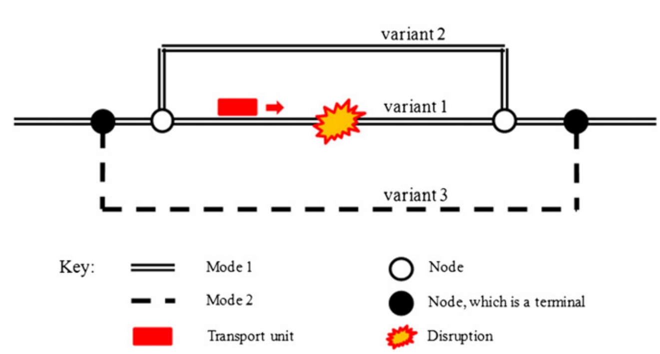

Fig. 1. A transport unit's possible choices in case of a disruption.