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Design and operation of intermodal transportation network in the Marmara region of Turkey

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ABSTRACT

This paper presents a multi-objective optimization model for integrating different transportation modes in the design and operation of an intermodal transportation network in a geographical region. The problem is formulated as a mixed-integer optimization problem that accounts for time and congestion dependent vehicle speeds. We present modeling approach, data analysis and outline the important characteristics of the mathematical programming problem for minimization of transportation cost and time simultaneously by using the augmented ϵ-constraint method. The proposed approach is illustrated on a real world case using data from Marmara region where approximately 50% industrial goods and services in Turkey are produced.

1. Introduction

Transportation related costs in typical supply chain account for approximately 5–7% of total revenue (ARC, 2008). Therefore, logistics operations started to play an important role in the extensive and complex supply networks. There is a great potential to optimize transportation costs within the supply networks since transportation links all echelons of the network having impact on the performance of each echelon. Transportation is the essential activity that links each echelon of supply networks. Intermodal transportation has been recognized as a promising concept to efficiently reduce logistics costs although it faces some operational challenges for effective usage. According to Jones et al. (2000), intermodal transportation is "being or involving transportation by more than one form of carrier during a single journey." It is necessary to integrate several transportation modes seamlessly for an effective intermodal transportation.

Most of the developed countries try to shift their transportation systems from road to rail and sea for an effective use of intermodal transportation infrastructure and eliminate congestion on the roads that are primarily designed to move passengers. This setting is not different in Turkey. The Turkish transportation sector has been facing strict reforms under the European Union regulations during the last two decades. Different industrial sectors of Turkey recognized the need for establishing a more advanced transportation infrastructure, regulations for logistics sector, and promotions or incentives to shift from road to sea and rail transportation operations (MARKA, 2013). In Turkey, domestic freight transportation is heavily dominated by road transportation (89.4%) (TUIK, 2012). This unbalanced use of transportation modes creates negative impacts on congestion, carbon emissions, and safety risks. On the other hand, intermodal transportation is a new concept for the Turkish transport industry due to lack of intermodal transportation infrastructure within the country. However,

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Turkish logistics companies use the available intermodal infrastructure in the Europe. For example, more than 125,000 trucks use RO-RO (Sea + Road modes) lines: most commonly used routes include Pendik, Turkey; Trieste, Italy or Illichecvsk, Ukraine ports and then they use either road transportation or RO-LA lines to reach their customers in Austria and Germany every year. Also, the intermodal transportation routes between Turkey and Central Europe is heavily used by more than 300,000 trucks per year and most of the trips to Germany and Austria are made on the RO-LA (Rail + Road modes) lines from Istanbul, Turkey to Wels, Austria (UND, 2013). Unfortunately, air transportation in Turkey has a negligible share in the intermodal logistics market similar to the rest of the world. The available infrastructure for intermodal transportation in Europe is heavily used by the Turkish transportation sector. Although Turkey has a very strategic location in the world trade corridors, intermodal transportation cannot be practiced in Turkey currently due to lack of required infrastructure. The main contributions of this paper is to analyze the benefits of intermodal transportation in terms of reducing the total transportation costs and delivery times and indicate the potentials of intermodal transportation within the Marmara region of Turkey. We try to obtain more effective solutions for the transport chains by integrating different transportation modes in the Marmara region. We aim to design a more balanced network to increase the transport safety and also decrease traffic congestion.

Hayuth (1987) provided a theoretical analysis on the requirements of intermodal systems and also showed that each mode has its own advantages in terms of cost, service, reliability, and safety. These advantages create separated transport systems depending on the particular characteristics of the regions. For instance, if we aim to shift the main transportation mode from road to sea in the Marmara region, then sea transportation would be the single dominant transportation mode within the region. Hayuth (1987) claims that high waiting and turnaround times of sea transportation might be eliminated with the help of intermodal systems; so transport cost, transit times, and unreliability could decrease. Therefore, we need to change our operations from single mode transportation to intermodal transportation.

Intermodal logistics has developed into a research stream in the past several decades in transportation research literature. Many papers give a general survey and definition of intermodal transportation problem. Minoux (1989), Daskin (1995), and Drezner (1995) discussed the classical facility location problem in transportation setting and their solution methodologies. Balakrishnan et al. (1997) and Raghavan and Magnanti (1997) discussed network design cases and proposed general concepts for transportation operations. Also, Melkote and Daskin (2001) combined facility location and network design problems to create an integrated solution methodology for transportation activities. In addition to these, there are many papers that examine the intermodal transportation problem and try to develop some models to address this problem. Min (1991), Barnhart and Ratliff (1993), Boardman et al. (1997), Bookbinder and Fox (1998), and Southworth and Peterson (2000) provide reviews on intermodal routing and network design. However, these papers review the state-of-art at the time that these papers were published and give a wish list of what could be done for an effective intermodal transportation. Among them, Min (1991) and Bookbinder and Fox (1998) discuss the network design of international intermodal transportation. Boardman et al. (1997) and Bookbinder and Fox (1998) think about only multiple objectives. Min (1991) examines multiple objectives and on-time service requirements.

One of the interesting studies is by Arnold et al. (2001) who developed formulations for the selection of fixed intermodal hubs among candidate locations and these formulations were improved later by Arnold et al. (2004). These studies give a demonstration of each network model as a sub graph with nodes and links. The authors also discussed connection of sub graphs via transfer links. They also focus on one of the intermodal operational issues; how an international intermodal carrier selects the best routes for shipments through the regional intermodal network.

In addition to modeling the intermodal transportation network problem, Nemhauser and Wolsey (1988) provided general information on how network design and operation problems can be solved effectively. Also, Ahuja et al. (1993) proposed models and solution algorithms for network design problems with general constraints including shortest path, minimum cost flows. Almost all of the solution methods available in the literature can be used to solve smaller cases related to sea transportation and container movement operations. For example, Chih and van Dyke (1987) developed a model for empty container distributions. There are also some models that integrate the road and rail operations into intermodal operations. Especially, Bontekoning (2006) have conducted studies on highway movements of intermodal containers or trailers. Macharis and Bontekoning (2004) and Wu et al. (2011) discussed the importance of network design in intermodal transportation.

In this paper, integration of network design and operation issues into the problem is one of our contributions. Besides, we can provide evaluation of network alternatives and testing the impact of these changes on transportation cost and travel time. Developed network designs with real world data ensure applicable plans that help organizations to take advantage of the benefits of distribution network designs.

Although there are many papers that address the intermodal transportation and intermodal network design, time dependency on intermodal transportation is not included in most of the models presented. Ziliaskopoulos and Wardell (2000) present a best-route algorithm with the objective of minimizing the transportation time in intermodal transportation network. In addition to minimizing time and cost factors, the interaction between transportation demand and supply leads to traffic congestion. Time dependency or traffic congestion is another important issue in intermodal transportation. McKinnon (1999) and McKinnon et al. (2008) provided surveys investigating the effects of traffic congestion on the supply network systems. Also, the effect of the traffic congestion on facility location of companies was analyzed by Konur and Geunes (2011). The main difference of our work from the paper by Konur and Geunes (2011) is that in our case, traffic congestion model is