Omega 45 (2014) 71–79

Contents lists available at ScienceDirect

Omega

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

Locating mobile facilities in railway construction management ☆

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ARTICLE INFO

Article history:
Received 3 December 2012
Accepted 6 January 2014
Processed by B. Lev
Available online 15 January 2014

Keywords:
Location
Allocation
Rail transport
Case study
Mathematical programming

ABSTRACT

The location problem with mobile facilities is motivated by a real-life railway construction project. In railway construction, (im)mobile concrete batching facilities are located to build viaducts and tunnels on a line over a planning horizon. The problem is to determine the number and types of facilities to be located, to schedule the movement of mobile facilities, and to make concrete production-allocation decisions, so that all requirements are satisfied, facility capacities are not violated, and the total cost is minimized. To the best of our knowledge, such a problem has not been studied in the literature before. Two mathematical models and a preprocessing heuristic are developed to solve the problem. Computational results on the real case study problem and randomly generated test problem instances show that locational decisions are important in construction management.

1. Introduction

This study introduces a location problem, motivated by a railway construction project as a part of High Speed Train Transportation Program between Ankara and İstanbul. The construction activities of the project consist of building new viaducts and tunnels, called “art buildings”, in addition to the railway itself. Concrete requirements of art buildings are satisfied by concrete batching facilities, which combine aggregate, cement, and water to form concrete. Batching facilities are in two types: mobile and immobile. It takes a week to disassemble a facility at the located site, move to a new site, and reassemble at the new site. Facilities with limited production capacities have initial opening and periodic operating costs. There is also a cost of transporting a mobile facility from one site to another, as well as material handling and transportation costs for aggregate, water, cement, and concrete. The problem is to determine the number and types of facilities to be located, to schedule the movement of facilities, and to make concrete production and allocation decisions, so that all concrete requirements are satisfied, facility capacities are not violated, and the total cost is minimized.

Railways cannot make sharp curves and must be as smooth as a straight line to satisfy technical standards in both vertical and horizontal axes. Tunnels and viaducts, called as “concrete demand sites”, are needed to keep the railway line straight. Concrete batching facilities need to be located on a line whose concrete demand sites are candidate facility locations. Fig. 1 shows an example of the vertical cross section of a planned railway construction. Material handling and transportation activities are usually performed on a temporary road that lies around the railway line and may go around hills or holes. Available water and aggregate supply sites near to the transportation line are the candidate input sources, while cement would possibly be supplied from the closest production facility. Supply sites need to be connected to the line with slip roads as shown in Fig. 2. In Fig. 2, the points W, A, and C represent alternative water sources, aggregate supply sites, and a cement facility, respectively. The points labeled with numbers represent the demand sites (of art buildings) of the railway project shown in Fig. 1. An art building can be represented with a single point. If a tunnel or a viaduct is constructed from two end points simultaneously, its concrete demand should be represented with using separate demand points. In Fig. 2, for example, the tunnel on the right is assumed to be constructed from its two end points simultaneously. Therefore, it is represented with two different demand points, point 4 and point 5. Point 1 represents the tunnel on the left, point 2 represents the viaduct and point 3 represents the tunnel in the middle. It is assumed that these three buildings are constructed starting from their right ends.

The studies in the literature on railway and road construction management mainly consider planning and scheduling issues (Hassanein and Moselhi [21]), reconstruction activities, and maintenance operations (Fazio et al. [18]). To the best of our knowledge, there is no study that considers location and allocation decisions for batching facilities. There are some studies that consider road construction and harvesting machine location in timber industry (Epstein et al. [15]), but these problems are very different from the location problem we have discussed.

☆Dedicated to the memory of Talip Demirel, who died in a work accident in the Ankara–Istanbul railway construction project.

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0305-0483/$ - see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.omega.2014.01.001

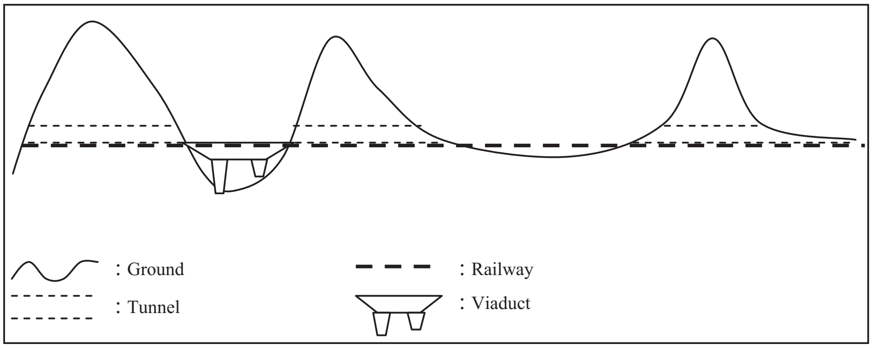

Fig. 1. A vertical cross section of a railway.

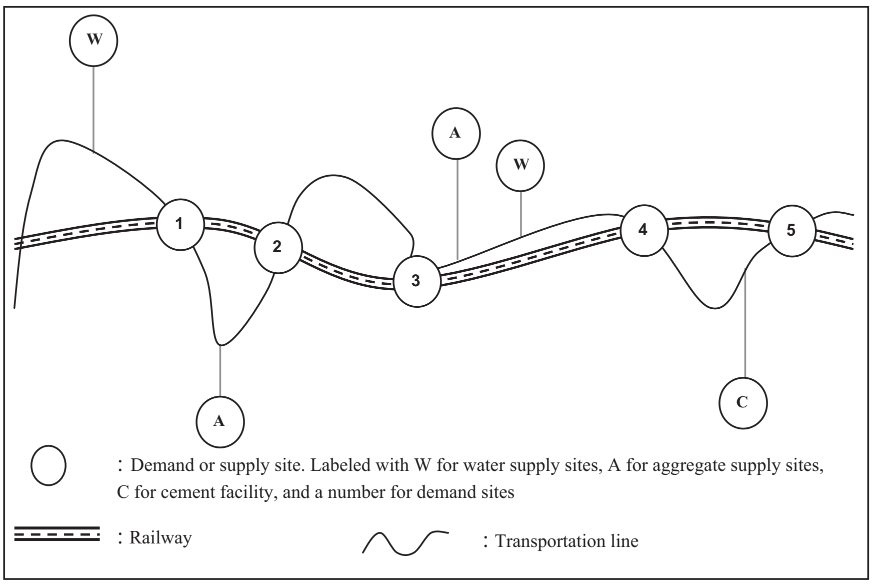

Fig. 2. Railway, transportation line, resource sites, and demand sites in a railway construction project.

In the location literature, there are some related studies incorporating features of the problem under different circumstances, such as locating facilities on a line, dynamic nature of demands, and relocation of existing facilities. There are two main properties that make the facility location problems on a line easier and results in (pseudo-) polynomial solution algorithms. The first property is eligibility of non-fractional allocations of demands to facilities and the second one is identical capacities at all facilities. Love [25], Brimberg and Revelle [10], Berberler et al. [5], and Hsu et al. [22] consider uncapacitated facilities that satisfy the first property. Brimberg and Mehrez [8] suggest an algorithm based on the first property to solve the location and sizing problems of facilities. Brimberg et al. [9], Eben-Chaime et al. [14], and Mirchandani et al. [30] consider capacitated facilities using the second property. Berman et al. [6] consider a continuous location problem on a line together with facility reliabilities and present some closed form results. None of these studies consider dynamic nature of demands and mobile facilities.

Numerous studies on dynamic location problems are published in the literature for general networks since Manne [26,27] and Ballou [4]. Decisions are mainly on opening, closure, reopening, and relocation of facilities, and capacity adjustments. Farahani et al. [16] and Arabani and Farahani [3] are two recent surveys on the dynamic facility location problem. Several varieties of dynamic location problems are reviewed in Owen and Daskin [31], Melo et al. [28], and Klose and Drexl [23].

A few studies consider the dynamic capacitated facility location problem. Facility opening times are explored in Gourdin and Klopfenstein [20] and Shulman [37]. Closing times of existing facilities are considered in Roodman and Schwarz [32]. Decisions on opening/closing times of facilities are studied in Roodman and Schwarz [33], Torres-Soto and Üster [38], Lim and Kim [24], and Antunes and Peeters [1,2]. Dias et al. [12,13] consider reopening decisions for the closed facilities in addition to opening and closure decisions. For the dynamic uncapacitated facility location problem, Blanco et al. [7] consider the railway network design (expansion) problem consisting of locating and opening time decisions for the stations. Chardaire et al. [11] and Sambola et al. [35,36] consider facility opening time, location and allocation decisions. VanRoy and Erlenkotter [39], Frantzeskakis and Watson-Gandy [19], and Saldanha-da-Gama and Captivo [34] consider opening and closing times of facilities. Wesolowsky [40], Min and Melachrinoudis [29], and Farahani et al. [17] consider the single facility location problem. Wesolowsky and Truscott [41] consider the dynamic *p*-median problems with facility relocations.

Even though "relocation" and "moving" are different in semantic and practice, the fact that both activities can be modeled in a similar way causes misuse of these terms in the location literature. We therefore revisit the related terminology in the literature. We refer to "facility relocation" if an existing facility is closed (as opposed to the building itself), but its equipment and hardware are transferred to a new or an existing open facility at another location. "Facility moving" refers to a mobile facility being entirely moved to a new location. A mobile facility may change its location more than once over the horizon. We also differentiate "abolishing" a facility from "closing" one. Although a closed facility does