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Modeling dry-port-based freight distribution planning

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ABSTRACT

In this paper we review the dry port concept and its outfalls in terms of optimal design and management of freight distribution. Some optimization challenges arising from the presence of dry ports in intermodal freight transport systems are presented and discussed. Then we consider the tactical planning problem of defining the optimal routes and schedules for the fleet of vehicles providing transportation services between the terminals of a dry-port-based intermodal system. An original service network design model based on a mixed integer programming mathematical formulation is proposed to solve the considered problem. An experimental framework built upon realistic instances inspired by regional cases is described and the computational results of the model are presented and discussed.

1. Introduction

Current trends in maritime logistics often consider the presence of inland freight terminals where consolidation of goods, custom services, information processing activities, short-term storage and value-added manufacturing services for the containerized goods take place before shipment toward the next destinations. In particular, dry ports are defined as inland freight terminals *directly connected to one or more seaports with high-capacity transport means, where customers can drop and pick up their standardized units as if directly at a seaport* (Roso et al., 2008; Leveque and Roso, 2002). The advantage of introducing one or more dry ports into freight intermodal transport was confirmed by several experiences in terms of logistics integration and port regionalization (e.g., Notteboom and Rodrigue, 2011; Roso and Lumsden, 2010). A significant economic and political effort is currently being undertaken in many countries in order to extend as much as possible the presence, number and suitability of dry ports, especially for the seaports located within the area of congested cities. Despite this increasing interest in dry-port systems, the literature on freight logistics management (Caramia and Dell'Olmo, 2008; Crainic and Kim, 2007) shows a lack of contributions addressing those optimization problems that arise from the corresponding freight distribution processes, at a strategical, tactical and operational level.

The goal of this paper is to contribute to filling this gap, by introducing and describing the freight distribution systems based on the presence of dry ports from the point of view of optimization challenges at different levels, and then developing an optimization approach for the specific problem of defining tactical plans for these distribution systems. The concurrent presence of high capacity connections among dry ports, seaports, and other terminals, as well as congested road connections between terminals and inland cargo shippers naturally yields a multi-tiered network representation, encompassing different infrastructures and classes of vehicles.

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First we present a comprehensive synthesis of the dry port concept as it is presented in the recent literature on freight transportation, identifying and classifying the optimization challenges supporting decisions in the field of optimal design and management of dry-port-based freight transportation systems.

Secondly, we consider the tactical planning problem consisting in the definition of the optimal schedule for the services operated by a fleet of high-capacity vehicles, also referred to as *shuttles* in the rest of the paper, on the railway network connecting seaport terminals and dry ports, in order to address the requested demands of containerized cargoes. An original service network design model representing the above mentioned tactical planning problem and based on a mixed integer programming mathematical formulation is introduced. The specific features of the considered problem with respect to similar cases previously presented in the literature for different applications is discussed. In particular, we consider the integration and consolidation on the vehicles of cargo flows directed from the shippers toward the seaports and vice versa, and the presence of different classes of products with different types of associated administrative and operational requirements.

We adopt a time–space network representation for service network design problems which represents a consolidated method in the scientific literature on network design (see for instance Balakrishnan et al., 1993; Powell et al., 1995). With respect to advanced approaches recently introduced in the literature on service network design for freight logistics (see Andersen et al., 2009; Crainic and Sgalambro, 2014; Crainic et al., 2009), the model proposed in this paper presents further elements of novelty related to the specific features of the considered dry-port-based distribution problem, such as:

- the integration and consolidation on the same vehicles of cargo flows directed from the shippers toward the seaports and vice versa, together with the possibility to model different classes of administrative and operational requirements and operations through the calibration of cost parameters on the dummy arcs, particularly relevant for the case of dry-port-based distribution optimization;
- the possibility to consider several candidate terminals (dry ports, seaports), in space and time, for the pick-up or delivery of each cargo demands, thus leaving the model decide which combination provides better results in terms of the overall logistics cost function.

The paper is organized as follows. In Section 2, a description of dry ports and their role in the intermodal logistics of containerized goods is provided, together with a description of related planning and decisional problems and optimization challenges. In Section 3 we describe an optimization problem introduced to support the tactical planning process for the services operated by a fleet of high-capacity vehicles on the railway network connecting the terminals. In Section 4 we propose an original service network design approach aimed to model and solve the considered optimization problem. In Section 5 an experimental framework built upon realistic instances inspired by regional cases is described and the computational results of the model are presented and discussed. Conclusions complete the paper.

2. Dry-port-based intermodal transportation

This Section starts by recalling the relevant role and evolution of the intermodal terminals in freight transportation processes. In particular, the *dry port concept* is revised, emphasizing the specific features differentiating it from a simple inland freight terminal. In the second part of the Section, optimization challenges related to the freight distribution process in presence of dry ports are introduced and discussed.

2.1. Concept and role of dry-ports

Starting from the 1960s, the traffic of goods performed through standard containers yielded a progressive increase in the importance and volumes of freight intermodal transportation. With the following impressive increase in the quantities and values associated to freight traffics, several development processes took place, yielding to the expansion and specialization of seaports, the growth of the shipping industry and the empowerment of inland logistics systems respectively, together with the progressive integration among these different components of the intermodal transportation system.

A fundamental consequence of the increase in the worldwide traffic of containers was a growth in the number and size of the vessels operating for the maritime shipping of containerized cargoes. A lot of work was done for the expansion of the seaports capacity and to increase the operational efficiency of the maritime terminals with respect to loading and unloading operations and to the transshipment of freight in proximity of the seaports.

The growth in the traffic volumes arising from the development of seaports and maritime shipping industry produced an increased level of congestion in the seaport zones due to the uncontrolled increase in road transportation of containers, which caused in turn the growth of transport times with its negative related economic fallouts, and a higher environmental and social impact interesting the people living in the seaport areas.

Cullinane and Wilmsmeier (2011) describe the development of a seaport as the results of the interactions among the economical system, the port system and the maritime shipping system: the bottleneck of seaport facilities turns out to be the port storage capacity and accessibility to the sea and the land side.

A basic feature in the recent freight distribution networks is represented by the presence of logistics platforms, designed to receive freight and vehicles, provide short-term storage, handling and consolidation, and allow the constitution of value-