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An agent-based framework for cooperative planning of intermodal freight transport chains

Angela Di Febbraro [a], Nicola Sacco [a], Mahnam Saeednia [b,*]

[a] Department of Mechanical, Energy, Management and Transportation Engineering, University of Genoa, Via Montallegro 1, Genoa 16145, Italy
[b] Institute for Transport Planning and Systems, ETH Zurich, Stefano-Franscini-Platz 5, Zurich 8093, Switzerland

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ABSTRACT

The recent development of Intelligent Transportation Systems offers the possibility of cooperative planning of multi-actor systems in a distributed framework, by enabling prompt exchange of information among actors. This paper proposes a modeling framework for cooperation in intermodal freight transport chains as multi-actor systems. In this framework, the problem of optimizing freight transportation is decomposed into a suitable set of sub-problems, each representing the operations of an actor which are connected using a negotiation scheme. A Discrete Event model is developed which optimizes the system on a rolling horizon basis to account for the dynamics of intermodal freight transport operations. This framework allows for an event driven short/medium term planning of intermodal freight transport chains. The proposed methodology is evaluated using a realistic case study, and the results are compared against the First-Come-First-Served strategy, highlighting the significance of cooperation in systems operating close to capacity.

1. Introduction

Intermodal freight transportation chains involve multiple actors such as suppliers, customers, and logistic and transportation operators. These actors are responsible for different operations, and each of them contributes to the efficient movement of freight. The just-in-time internal operation of each actor is an important factor in the management of supply-chains. Consequently, the execution of supply chains may follow the planned optimized processes (Bishop, 2002).

Previous research highlights the importance of intermodal freight transportation from economic and environmental points of view (SteadieSeifi et al., 2014). However, the competitiveness of intermodal transportation has a major role in attracting a high modal share in freight transportation. Economic efficiency and quality of service are the interdependent contributors to this competitiveness. Nevertheless, rail/road intermodal transportation options are normally not included in the first options of the companies which are under pressure to operate more efficiently and require shorter lead times (Gruppo, 1998; Bhattacharya et al., 2014).

In addition, the actors of intermodal freight transportation systems are often geographically distributed, which makes it very difficult to apply a central coordinator to manage the whole system. To deal with this issue, decentralized optimization approaches can be deployed. In such approaches, the system is decomposed into a number of sub-systems which are optimized separately. These independent decision makers cooperate to achieve a common goal. Therefore, they operate under local (internal process) constraints as well as under those imposed by the interconnection (Inalhan et al., 2002). In problems

* Corresponding author. Tel.: +41 446333199.
E-mail address: mahnam.saeednia@ivt.baug.ethz.ch (M. Saeednia).

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with a spatial distribution, decentralized approaches have proved to be fast, reliable, and extensible (Smith, 1980). This paper models one form of cooperation among multiple actors within intermodal freight transportation chains, considering a combination of cost and reliability, hereafter measured by the punctuality of deliveries in these chains. In this framework, the actors coordinate their operations using a Network Communication Coordinator (NCC), that ensures the movement toward the goal of the whole system which is transporting goods from suppliers to customers with the minimum cost and the maximum reliability. In such a scheme, a "partial cooperation" is considered, i.e. the cooperation among actors is at the level of information exchange among actors and each actor shares only a limited amount of information with others.

Such methodology exploits information technologies as a major component in the modeling process. It is worth noting that, the development of Information and Communication Technologies (ICT) provides the suitable tools which enable information exchange and system planning in real-time. This ability creates a valuable opportunity to plan, and possibly optimize, multi-actor systems in a decentralized framework efficiently. Using this possibility, the dynamics of freight handling are modeled via Discrete Event Systems (DES) modeling approach in which the freight delivery plan is determined on a rolling horizon basis. Such a choice aims at taking into account the new delivery orders continuously placed by the customers, and the stochastic phenomena which may considerably affect the performance of the system (such as delays or disruptions). The considered modeling framework enables the possibility of generating new freight delivery plans when new information is available, thus allowing an efficient planning of the considered intermodal freight transportation chain. In particular, the developed framework ensures:

- the capability of considering independent optimization processes for each actor by allowing it to decide based on its local optimal solution computed in parallel;
- the modularity of representation, i.e. the capability of adding/eliminating/modifying different elements of the system at any time;
- the possibility of modeling exogenous events that affect the system in real-time.

The paper is organized as follows: in the next Section the related previous works are discussed. Then, in Section 3, a detailed description of the global modeling framework of the system dynamics and of the relevant local optimization problems are introduced. In Section 4, the functionalities of the proposed approach are illustrated by means of a case study. Finally, Section 5 concludes the paper with some remarks and suggestions for future work.

2. Literature review

In multi-actor systems, the performance of each actor influences and depends on the performance of other actors operating in the system. Multiple studies have developed frameworks that bring together different actors involved in freight transportation to control the whole system. Many of such frameworks rely on ICT as well as agent technology. In this section, an overview of the most relevant literature with regards to the application of ICT in the planning of intermodal transportation chains, as multi-actor systems, is mentioned. This is followed by a discussion about the major methodological contributions provided by this paper.

In the literature, an agent has been introduced as an entity that is capable of autonomous performance in its environment in order to meet its design objectives (Wooldridge and Jennings, 1995). Agent-based approaches have been extensively deployed for studying multi-actor systems, including freight transportation, where one or more of the entities are modeled as agents. The related approaches have been proposed at both micro (Holmgren et al., 2012) and macro (Swahn, 2001) levels. In this framework, micro-level models appear to be more promising since they enable the possibility of capturing the details of operations and the independent decision making of the involved actors. A survey of such studies is provided by Davidsson et al. (2005) which focuses on agent-based approaches mainly from a logistic point of view. Specifically, Roorda et al. (2010) present an agent-based micro-simulation framework that illustrates multiple actors and their operations in the freight transportation system, their interactions and how these interactions are established. Dullaert et al. (2009) develop an intelligent agent-based communication support platform for multimodal transportation called MamMoeT, an agent-based software where agents are pieces of software representing a single user. The Transportation and Production of an Agent-based Simulator (TAPAS) is presented for the simulation of transportation chains in (Holmgren et al., 2012). This model can be used for analysis of transport-related policy and infrastructure measures. From the methodological point of view, many of these studies use simulation to analyze the behavior and the decisions of agents. In fact, simulation techniques provide a valuable tool for these studies to evaluate their methods, the interaction between modes, and various scenarios (Terzi and Cavalieri, 2004; Iannone et al., 2007; Zeigler et al., 1999). However, capabilities of optimization methods in producing high-quality solutions to complex problems can be deployed to develop detailed models to study this type of systems. One of the few related studies, is that of Gjerdrum et al. (2001) which combines agent-based technologies (for simulating a demand-driven supply chain) and optimization techniques (for optimizing the manufacturing component). Using this approach, the authors simulate the behavior of the supply-chain using optimization for part of its decision-making process.

Moreover, the development of ICT has provided innovative ways to deal with operational issues related to multi-actor transportation chains, such as coordination of operations across multiple actors and consideration of uncertainties of