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Integrate multi-agent planning in hinterland transport: Design, implementation and evaluation

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ABSTRACT

This paper addresses the planning issue in hinterland barge transport domain, characterized by limited information sharing, lack of cooperation and conflict of interest among different parties (terminal and barge party). The planning problem is formulated as a novel Stackelberg game to model a leader–followers bi-level optimization problem. A hybrid algorithm is developed that concerns different objectives (vessel turn around and terminal berthing capacity) simultaneously while fulling pre-defined operational constraints. The presented algorithm is outlined in a hierarchical way and embedded into dedicated agents as decision-making kernel. We describe the architecture and the implementation of the proposed mediator-based multi agent system and overall coupling framework include agent identification, coordination and decision making. A case study evaluates the performance of our approach in terms of global optimality compared with other related approach.

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1. Introduction

Container terminal is an important node in the whole supply chain. Recent port development presents the fact that its competitive position not only relies on its efficiency for serving sea-going vessels, but also on its connections with hinterland [1]. It is discussed that inland shipping has become an inexpensive and reliable link in the logistics chain [2]. This quickly growing field could offer multiple opportunities and challenges. Efficient operation of hinterland transport from sea side to inland side will be emphasized on both time and costs [3]. Stakeholders involved in the hinterland transport are eager to find new ICT technologies (e.g., automated communication and planning system) to get rid of old fashioned management system (e.g., paper-based method) and as a result achieve better efficiency and economic promotion [4].

In general, hinterland transport consists of truck transport, barge transport and rail transport. Rotterdam is located at the delta of the rivers Rhine and Meuse which makes inland barge the ideal way for reliable and cost-effective transportation of containers. It is estimated that the usage of barge will command a share of 45 percentage in the future hinterland transport (year of 2035) in the port of Rotterdam and this number is expected to keep growing [5]. Presently, a barge rotation consists of several terminal visits with loading and unloading operations at each terminal. The lack of coordination between terminal and barge party [6], inefficient communication [7] and irrational behavior [8] lead to long waiting time of barge within port region and low utilization of terminal resources [9]. The mentioned problem has already become an important and emergent issue in the Port of Rotterdam recently.

Typical scenarios of hinterland barge transport (HBT) planning problem are depicted in Fig. 1. In scenario one, the barge operator is working on issuing a rotation visit plan about when to call at which terminal. With respect to terminal operator, the primary task is to make a decision on when to serve the barge call concerning its resource availability and efficiency. From an operational research (OR) perspective, each operator has its own objective. The barge operator always satisfies result with best turn around time while the terminal operator cares more about its resources utilization. In real planning, however, a full terminal utilization (in terms of 100 percent berth occupancy) could be guaranteed only at the expense of a continuous queuing of coming vessels. Likewise, to ensure the vessel never wait before berthing is given at the cost of considerably low terminal resource utilization [10]. For an efficient plan, none of these extremes are acceptable, thus certain level of compromising between these two conditions is required.

Another scenario at right hand side of Fig. 1 reveals the challenge from an IT perspective. It often happens that the barge arrived at a terminal which has already been occupied by another activity. The barge operator has no knowledge about the terminal

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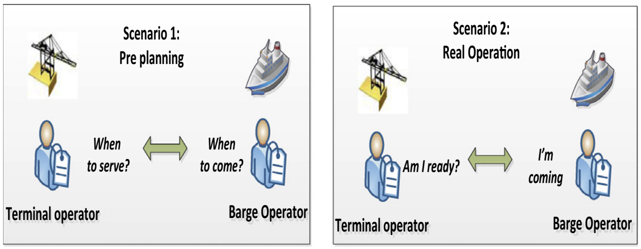

Fig. 1. HBT planning scenario.

occupation status thus lead to an unpredictable waiting time. Information sharing is a critical intrinsic factor that influent the interaction between barge operator and terminal operator. In current practice, no trusted and efficient information platform exists among joined parties (terminal and barge company). A barge visit is planned in an old-fashioned ways include telephone calls and emails. Multiple attempts are performed between barge and terminal operators as long as a feasible plan is reached which is time-consuming and error-prone. Moreover, the inherited competitive nature prevents joined parties from sharing their operational information to each other which makes an efficient planning process even more difficult.

To sum it up, the mentioned challenges stimulate two questions: how to ensure the generated plan is satisfied by both terminal operator and barge operator; how to make information sharing more efficient between terminal side and barge side.

To overcome the above mentioned problem, a variety of projects have been developed or under development to improve the overall HBT performance in industry domain. A first important initiative towards HBT planning problem in the port of Rotterdam was established in 2003 which was called APPROACH [2]. The project aimed at establishing a decentralized system that generates a rotation plan off-line. The design of the system created a multi-agent communication environment where terminal agent and barge agent could negotiate with each other to achieve a feasible plan and the system feasibility was also validated in the work of [11]. In 2007, A BTS (barge traffic system [12]) web application was put into practice in the port of Antwerp. It supported the barge operators to make appointments with terminals with announcement of their call size and estimated arrival time. The terminal operators then gave feedback regarding the terminal planning and possibly refuse or harmonize the planning. Also the terminal operators can acquire real time information regarding the position of the barge within terminal region. The supported functionaries included barge planning request, consult lock planning, request barge position and terminal planning inland barge. A new project called "Next Logic" [13] was launched since September 2013, it involved different parties includes the port of Rotterdam authority, barge company, terminal company, shipper and Dutch government. The project focused on reducing inefficiencies in inland container shipping by providing a centralized integral platform in which all of the related parties would join. Currently, the project is under feasibility study. It aims at developing a neutral and integrated planning platform where all relevant data and information gathered together, and further feed to a central decision module called "brain". The proposed platform was a good start towards centralized plan but great efforts would be taken to harmonize interest for different parties.

Apart from industrial effort, the HBT planning issue also receives attentions from scientific community recently. A so-called barge hub terminal in or near the port of Rotterdam was proposed to build in work of [14]. It will serve as a collection and distribution point for containers to and from the hinterland. The main point of the barge hub terminal (BHT) was to reduce the average terminal calls of barge by move all required containers to a dedicated position. Same concept was also discussed in [1] which explored the concept of hinterland transport with an additional barge hub terminals by focusing on the type of transport system to operate the barges. The authors overview the new transport technologies such as automated trucks, multi trailer system, automated trains and automated barge handling systems. They came to a conclusion that the innovative transport technologies will promote the efficiency of the hinterland transport and support the concept of additional inland terminals with the commercial viability. In the work of [15], the HBT alignment issues was addressed with a fully distributed MAS architecture. The author investigated how different level of information exchange influent the tardiness of barge rotation and also introduces the concept of "slack time" to increase the flexibility of terminal planning. A simulation game [16] was developed to validate the effectiveness of the proposed system which helped the potential users to get a helicopter view about the solution it provides. The system inherits the concept of multi-agent decentralized coordination between different parties. The final rotation plan will be made by barge operator according to the information (waiting profile) provided by terminal operator. The authors of [17] proposed to solve the barge rotation planning problem by means of distributed constraints optimization in a distributed agent environment. The research aimed at generating optimal plan for barge operators in terms of minimum waiting time.

In short, the state-of-art can be categorized to two folds. One by shifting the HBT operation to an inland location and it will bring great benefits and opportunities for future port construction [1,14]. It could release traffic congestion within port region and reduce waiting time of barge, thus improve the overall performance and enhance the competitive position of the port. However, this concept is a long term strategy for future port design which cannot solve the current problems immediately, thus not the scope of this paper. Another one is use IT to cope with the problem. Both centralized and distributed approaches are developed or under development. In terms of centralization [13,12], it could provide centralized control with well established technology. It is especially efficient when information flows within the domain of single organization. However, the information flow of addressed HBT problem crosses inter-organizational, it could be foreseen that convincing different parties to joint the central platform and harmonizing the conflict interests would be the major obstacles. In terms of distributed approach [15–17], it could maximumly maintain the single party autonomy by establishing self-organizing agents for negotiating and goal-pursuing. But it could bring problem that the final result considers a local best for single agent rather than the one for the group as a whole. For instance, the mentioned works focused on minimizing the barge turn-around time, which ignore the objective from terminal part. As a result, the generated plan cannot be recognized as the global optimal plan.

Continuing the discussion above, it is found that there always a decision to make whether to adapt centralized system or distributed system from practical perspective [18]. In terms of centralization, it is especially efficient when information flows within the domain of single organization. When information flows across inter-organization, distributed system is more in favor given the fact that individual business units autonomy could be optimally maintained [19]. As a result, system architecture selection is a problem-specific decision. Specifically, for our HBT planning system, four primary goals should be taken into account which include efficiency, privacy, flexibility and global optimality. They are given as follows:

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