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Collaborative framework of an intelligent agent system for efficient logistics transport planning

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ABSTRACT

In modern logistics chain, planning system which been applied for supporting daily operations, is becoming more information-intensive and technologically-dependent. Due to the growing operational complexities, the planning system is not only required to focus on ensuring the feasibility of daily plan, but also be capable of manipulating conflict of interest (COI) by exploiting efficient negotiation. This paper addresses a challenge of hinterland transport planning caused by limited information sharing, lack of collaboration and COI. We design collaboration and decision-making mechanisms for the implementation of autonomous control by means of multi agent technology and hybrid heuristics. It aims at providing quality plan to achieve high level of performance and robustness in hinterland logistics. From a system point of view, a service oriented architecture is proposed to integrate agent paradigm with a web-based planning system. From an operational point of view, special attentions are paid on establishing multi-dimensional collaborations between different stakeholders under the support of game theoretic approach. Specifically, we define how planning activities are executed, which level of collaborations are incorporated and how benefits are achieved with a global point of view. Due to the NP-hard nature of the addressed problem, an integrated NGSA-II and simulated annealing algorithm is implemented for assisting decision making. The parameters associated with the algorithm are tuned based on the Taguchi method. Case and comparative study will be presented to validate the appropriateness and performance of the approach.

1. Introduction

In current logistics chain, the efficiency and effectiveness of transport plan system has a direct connection with the satisfaction level of logistics service. The overall system tends to be increasingly complex, dynamic and distributed which makes the process of Automating Transport Plan (ATP) a challenge task (Jiménez, De La Rosa, Fernández, Fernández, & Borrajo, 2012). Conventional approach to ATP is optimization oriented by means of centralized control which aims at optimizing given objectives with the approaches from the field of operational research, includes VRP, TSP, flow job shop schedule and etc. The obtained solution primarily focuses on individual objective. In real logistics transport network, however, different entities (such as physical resources, human resources, business participants) are economically interconnected and physically distributed. It has proven to be difficult to integrate all information in any comprehensive way into an unified system (Prajogo & Olhager, 2012) due to the lack of alignment between different parties or stakeholders who posses different interests regarding the process. Therefore, it is a critical step to determine how participants with different interests could work together and what is the value of collaboration (Audy, Lehoux, D'Amours, & Rönnqvist, 2012). Confronted with the challenges, the concept of Collaborative Decision Making (CDM) has been put forward.

The concept of CDM incorporates the goal of working together in some mutually defined ways in which participants are actively sharing information and jointly making decisions in order to achieve global optimal solutions (Stadtler & Kilger, 2007; Sun, Fan, Shen, Xiao, & Hao, 2012). Recently, the use of CDM for supporting complex decision making has become popular in the domain of logistics and transport (Ramanathan, 2014). Sprenger and Mönch (2014) described a decision support system for cooperative transportation planning in the German food industry. The overall system was implemented with MAS which provides a distributed hierarchical algorithm for CDM. Hernández, Lyons, Mula, Poler, and Ismail (2014) proposed a multi-tier, negotiation-based

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Nomenclature

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i	barge unit
j	terminal unit
k	event unit in terminal plan board

Barge planning related variables

X^i_{pq}	binary variable determine whether the route from p to q is selected by i
N_b	number of barges
AT_i	arrival time of i
bcp_i	barge call profile of i
$TC_{i,j}$	terminal call of i at j
$L_{i,j}$	container load number of i at j
$UL_{i,j}$	container unload number of i at j
DT_i	latest departure time of i
$S^i_{j,j+1}$	sailing time of i from j to $j+1$
$AR_{i,j}$	arrival time of i at j
$OS_{i,j}$	operation start time of i at j
$OD_{i,j}$	operation duration of i at j
$W_{i,j}$	waiting time of i at j
$D_{i,j}$	departure time of i at j
TR_i	turn around time of i
ϵ	a very large number

Terminal planning related variables

MT_j	mooring time at j
nt	number of terminals in port region
ne	number of planned events in single terminal
tsp_j	terminal service profile of j
OR_j	operation rate, time taken to load or unload a container
α	berth occupancy level float value range between 0.0 and 1.0
E^j_k	the kth events that already been planned in j
$GT_{k,k+1}$	the gap time between two consecutive events
$TN_{k,k+1}$	the tightness value contributed by event k and $k+1$
β	the threshold for $GT_{k,k+1}$ selection
$[A^k_j, B^k_j]$	the available time window between E_k and E_{k+1}
$[a_{i,j}, b_{i,j}]$	the time window provided by j for handling i

Function

$\phi_{i,j}$	function to calculate the gap time between the i to be planned and the nearest E_k

MAS to promote the service and profit level of supply chain members by means of CDM. Panzarasa, Jennings, and Norman (2002) presented a formal model for CDM in a multi-agent environment. They identified the conditions which the self-interested agent should full filled with to increase its cooperativeness towards joint decision making. Schuldt (2012) developed coordination mechanisms for the implementation of autonomous control in logistics with MAS technology. In summary, a stream of researches select MAS technology as the way for facilitating communication and information sharing in the process of CDM within logistics domain. It is demonstrated that MAS technology provides a design-and-implementation diagram for software solutions (Pang, Zhong, & Huang, 2013) based on collective decision making in a community of autonomous, loosely coupled computational entities (Pechoucek, Kok, Warmer, Kamphuis, & Maric, 2006).

Agent technology has proven to be a sound tool for CDM, however, risk still remains that collaboration could trap into local optimal solution. It is given when each entity/agent solely concentrates on its core competencies and the sum of each is not equal to the one with global optimality (Davidsson, Persson, & Holmgren, 2007). It is a common issue for inter-organizational collaboration, such as transport planning in logistics domain where each participant holds different interests regarding the planning process. In order to achieve a win-win situation for each member, another fundamental issue for a successful CDM is to specify the mechanism for COI resolving. Game theory has proven to be a sound tool to analyze the interaction between strategic decision makers. Recent research outputs reflect the potential usage of game theoretic approach to assist the CDM process. Ohazulike and Brands (2013) applied game theoretic approach to optimally distribute traffic in a network with aim of combating some traffic externalities. Zhu et al. (2015) established a game theoretic model to coordinately manage the scheduling of appliances of consumers. Ribeiro, Weigang, Milea, Yamashita, and Uden (2015) designed a collaborative decision making system for planning aircraft departure sequence using game theory.

Based on the concept and achievement of CDM, in this research, we integrate the advantage of multi-agent system and game theoretic concept to implement a CDM system in the field of hinterland transport. It is used to facilitate the planning of hinterland barge transshipment (HBT) operations within the port of Rotterdam. A brief introduction of the problem is given as follows, a concrete explanation will be given in Section 3.

- limited information sharing: different participants (barge operator and terminal operator) involved in HBT are reluctant to share their information to each other which in turn makes coordination difficult.
- old-fashioned communication: phone calls or emails based information exchange method makes both barge and terminal operator incapable of adjusting strategy in an efficient manner.
- autonomy: each party prefers to stay autonomy, none of them allow their strategy or operation been controlled by other parties.

The objective of this paper is to design a communication and decision making system to resolve the planning difficulties in HBT, especially focusing on COI between different parties thus enable a collaborative planning process. Both conceptual and technological aspects are considered. Automated negotiation process between participants, which objective is to maintain communication efficiency and privacy, is addressed by using the MAS with a mediator based architecture. COI is resolved by means of game theoretical approach. It is implemented as a multi-level hierarchical framework which combines NSGA-II (Deb, Pratap, Agarwal, & Meyarivan, 2002) and simulated annealing algorithm, aims at searching non-dominant solutions for each participant lead to a win-win collaborative solution. The main contributions of the paper are two folds. By considering the combination of MAS framework and game theoretic approach, the designed CDM system is capable of providing win-win solutions for inter-organizational participants with efficient communication and negotiation. Secondly, the generalized framework can be beneficial for supporting complex CDM processes in other industry domains where properties include negotiation and conflict interests are presented.

The rest of paper is organized as follows: Section 2 reviews the related works towards hinterland barge transport plan and other similar field. Section 3 presents a concrete explanation about the problem and gives a discussion about obstacles from collaborative planning. Section 4 provides a leader-follower structure and a hybrid algorithm solutions. Section 5 presents the framework and main elements of proposed mediator-based MAS. Agent specification and negotiation are also discussed. Section 6 introduces