



Degrees of terminal cooperativeness and the efficiency of the barge handling process

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ABSTRACT

We study the effect of different degrees of cooperativeness on the efficiency of the barge handling process. The barge handling process is about the alignment of barge and terminal operations in a port. The efficiency of this alignment process depends on the cooperation of different players and especially terminal operators. In an earlier study we developed a Multi-Agent system assuming that terminals are fully cooperative, i.e., they provide insight in their occupation and make reliable appointments. In practice, terminals might decide to be less cooperative. We consider three degrees of cooperativeness: low, partly, and full cooperativeness. Experimental results indicate that there are two reasonable alternatives: full and low cooperativeness. In the lowly cooperative case, the lack of cooperativeness of terminals is compensated by cooperation among barge operators. We provide an extensive discussion on both alternatives. Our results provide useful insights for barge and terminal operators in the options they have to improve the barge handling process.

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1. Introduction

The barge handling problem considered in this paper is a serious problem in the Port of Rotterdam and the Port of Antwerp, and concerns the alignment of barge and terminal operations. Nowadays, the poor alignment of barge and terminal operations leads to significant and uncertain waiting times of barges at terminals and causes idle time of terminal quay resources. Although barge container transportation is an attractive mode of transportation (compared to road and rail), it is not used to its full potential due to, a.o., uncertain transit times.

Let us introduce the barge handling problem. Barges are self-propelled boats which ship containers between a port and the hinterland. In the Port of Rotterdam, barges usually visit about eight terminals to load and unload containers. The sequence in which these terminals are visited determines to a large extent the time a barge stays in the port. Currently, barge operators (companies that contract barges) and terminal operators (companies that operate a terminal) communicate by phone, email, and fax to make appointments. However, this takes much time and due to disturbances, unreliable appointments, and strategic behavior, this results in inefficient use of quays and long waiting times of barges at terminals. Complicating factor in this setting is that terminal operators compete with each other (and so do barge operators). For this reason they are not willing to give up the autonomy to plan their own operations or to share information that could undermine their competitive position.

The latter two requirements make achieving central coordination impossible. Parties are simply not willing to hand over the control of their operations to a central trusted party or to share all the required information of their operations. To provide a solution for the barge handling problem, Douma, Schutten, and Schuur (2009) developed and evaluated a Multi-Agent system. A Multi-Agent system can do justice to the specific interests of each of the parties. The idea is that every barge operator and every terminal operator gets a corresponding (software) agent. The agent represents its principal (the barge or terminal operator) and makes decisions in the best interest (and on behalf) of the principal. In the Multi-Agent system the agents of barge and terminal operators negotiate about convenient handling times. Douma et al. (2009) propose an *interaction protocol* based on waiting profiles. An interaction protocol is a protocol that prescribes the way agents communicate, the content of the communication, and the aimed outcome of the communication. The basic idea behind the waiting profile is that terminal operators give a barge insight in the maximum waiting time until its processing is started after it has arrived. This information is provided for every possible arrival moment during a certain time period. The aimed outcome of the communication between barge and terminal operators is an *appointment*. An appointment – made by a barge and a terminal operator – is an agreement from two sides. The barge promises the terminal to be present at the terminal at a certain time, i.e., the latest arrival time. The terminal in turn guarantees the barge a maximum waiting time, if the barge keeps its promise. If the barge does not keep its promise and arrives later than the announced time, it has to make a new appointment. In making appointments, the barge uses the guaranteed maximum waiting

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times at preceding terminals to calculate the arrival time at a succeeding terminal.

Starting point of the above interaction protocol is that terminals are fully cooperative in the sense that they are willing to make guaranteed agreements with barges about maximum waiting times and that they give insight in their occupation during the day. However, in practice, terminals might consider to be less cooperative, e.g., by not keeping the agreements made with barges or by providing limited insight in their occupation. The aim of this paper is to provide insight in the effect of the degree of terminal cooperativeness on the efficiency of the barge handling process.

The outline of this paper is as follows. In Section 2 we provide a discussion of related literature. Section 3 describes the assumptions we make. In Section 4 we introduce the notion 'degree of cooperativeness' and describe the different models we use. Section 5 presents the experimental settings used in the simulation study and for the off-line benchmark. In Section 6 we discuss the results and in Section 7 we complete the paper with a discussion and conclusions.

2. Related literature

In several studies ideas have been proposed to align the operations of barges and terminals by means of a Multi-Agent system. We mention [Connekt \(2003\)](#), [Melis et al. \(2003\)](#), [Schut, Kentrop, Leenaarts, Melis, and Miller \(2004\)](#). These three studies propose a Multi-Agent system that allows for making plans at one point in time for the next 24 h and supports actors to find feasible (not necessarily optimal) plans. Recently, [Douma et al. \(2009\)](#) proposed a Multi-Agent system that is able to align barge and terminals operations in a dynamic fashion, thereby enabling actors to plan their operations effectively with respect to the information available. They show that their Multi-Agent system can perform well in comparison with central coordination. Basic assumption in their study is that terminals are cooperative.

In addition to these studies, the barge handling problem relates to several other problems in the literature. We mention the berth allocation problem (see, e.g., [Cordeau, Laporte, Legato, & Moccia, 2005](#); [Stahlbock & Voß, 2008](#)), the ship routing and scheduling problem (see, e.g., [Christiansen, Fagerholt, & Ronen, 2004](#)), the attended home delivery problem (see, e.g., [Asdemir, Jacob, & Krishnan, 2009](#); [Campbell & Savelsbergh, 2006](#)), the hospital patient scheduling problem (see, e.g., [Decker & Li, 2000](#); [Paulussen, Jennings, Decker, & Heinzl, 2003](#); [Vermeulen, Bohte, & Somefun, 2007](#)), and Multi-Agent theory ([Wooldridge & Jennings, 1995](#)). We refer to [Douma et al. \(2009\)](#) for a discussion of each of these fields. For the role operations research methods play in the optimization of terminal operations we refer to an extensive literature study by [Stahlbock and Voß \(2008\)](#) and [Steenken et al. \(2004\)](#).

In this paper we focus on the concept of degree of cooperativeness. In the literature on Multi-Agent systems the concept 'cooperation' has been frequently discussed in different meanings. Cooperative agents are, e.g., considered as agents working together to achieve the same goal, in contrast to agents that are self-motivated and maximize their own benefits ([Kraus, 1997](#)). [Sandholm \(1999\)](#) states that self-interested agents can be assumed to be cooperative, if they use the strategies imposed by the designer and not choose a strategy themselves. The latter might be more likely in problems with competing self-interested agents. In these situations the design of the communication protocol becomes important, to let the agents exhibit desired behavior ([Sandholm, 1999](#)). The concept of cooperation in Multi-Agent systems is also strongly related to the field of (Cooperative) Game Theory. In a game, (self-interested) players usually have a choice to adopt a

cooperative attitude and they make a decision based on expected payoffs. This choice might be in favor of being cooperative, especially when players have long-term relationships and face each other in repeated games (see, e.g., [Mailath & Samuelson, 2006](#)).

The long-term relationships between terminals and barges might influence the decisions both actors make and the service they are willing to offer. It turns out that in the barge handling problem, the behavior of terminals is difficult to regulate within the system (see Section 4 for an explanation). However, when terminals offer better services to barges, their relationship might improve in the long run. Services can be, e.g., guarantees on waiting times ([Kumar, Kalwani, & Dada, 1997](#); [Whitt, 1999](#)).

In a previous paper ([Douma, Schuur, & Jagerman, 2008](#)) we made a first step by exploring simple decision rules so as to cope with various degrees of cooperativeness. We considered a simple port setting where every terminal has one quay. In the present paper we extend the analysis in [Douma et al. \(2008\)](#) by considering advanced decision rules, which we test in various experimental settings. We give new insights in the effect of different degrees of cooperativeness of terminals on the barge handling process. The results provide insights for barge and terminal operators on the options they have to improve the barge handling process.

3. Assumptions

We use a Multi-Agent system in which two types of decision making actors are represented, namely barge operators and terminal operators. The aim of the barge operator is to minimize the time a barge has to stay in the port. The barge operator therefore has to decide on the sequence in which a barge visits the terminals concerned. The terminal operator aims at an efficient use of the quay resources and has to decide when a barge will be handled. We assume that both terminal and barge operators are opportunistic, meaning that opportunities are exploited for their own benefit with no regard for the consequences for other players. Barges arrive over time with stochastic inter-arrival times. As in practice, we assume that each barge has a given time window within which all its activities in the port are supposed to be completed. These time windows are used to measure the performance of barges in the port. Decisions of both barges and terminals have to be made in real-time and we assume that never two barge operators plan rotations concurrently, but one after another. With respect to a terminal we assume that it handles only barges (no sea vessels), has fixed capacity, is never closed, and only has information about barges that already arrived in the port. Arrival times and other characteristics of barges that did not (yet) arrive in the port are unknown to the terminal. The time to handle a container, the mooring time, and the sailing time between terminals are deterministic. With respect to a barge we assume that, on arrival in the port, it needs to make a decision about the sequence in which it visits the terminals concerned. On arrival in the port, the barge has information about the terminals it has to visit, the number of containers it has to (un)load at each terminal, and the mooring time at and the sailing time between terminals. It has no information about the state of the network, such as waiting times at terminals, unless terminals reveal this information on request of the barge. We consider no capacity or stowage constraints for the barge. Barges visit terminals only once and preemption at a terminal is not allowed. We assume that all terminals have the same objectives and the same holds for all barges. We do not consider disturbances and the effect on the operations of barges and terminals. These assumptions allow barges and terminal operators to make reliable appointments, since unexpected delays are excluded.

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