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A framework for modelling and analysing coordination challenges in hinterland transport systems

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Abstract

Multimodal transport systems connect seaports to their hinterland and have potential economic, social and environmental advantages over road transport. However, currently this potential is realised only to a limited extent, and road transport still dominates the market. We have conducted in-depth interviews with practitioners to explore possible reasons. We find that lack of coordination at the operational level between the parties involved in transport systems leads to inefficiencies in hinterland transport systems and compromises the advantages of multimodal transport. Although academic research recognises the significance of coordination, it generally employs an economic perspective at a strategic level, but does not say much about actual implementation at an operational level. To fill this gap, we develop a framework to model coordination challenges in hinterland transport, with an emphasis on the operational level. The framework is inspired by the modelling approaches in earlier literature, and tailored based on the common characteristics of coordination challenges observed during our interviews. Further, we propose a method to analyse such models in depth and reveal specific insights such as inadequacy of contracts to facilitate coordination, the dynamics of consequential planning decisions, and shortcomings in information exchange. To demonstrate the applicability of our framework, we use it to model and analyse the particularly tenacious coordination challenge of barge congestion in the Port of Rotterdam.

Keywords Transport logistics framework · Hinterland transport · Multimodal transport · Barge congestion · Port of Rotterdam · Container transport · Contractual structures · Information exchange

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1 Introduction

The notion of coordination challenges in multimodal transport, and particularly in the hinterland of seaports, has been recognised for years. After a decade or so of contributions on the relevance of the hinterland for a port's competitive position (e.g. van Klink and van den Berg 1998; Notteboom 1997), de Langen and Chouly (2004) point out that seaports need to effectively organise access to the hinterland: the “hinterland access regime”. In 2018, the Journal of Commerce (JOC) is reporting repeatedly on coordination problems around the handling of barge traffic in the Port of Rotterdam, which accounts for about a third of hinterland transport of containers in Rotterdam. In April 2018, for instance, JOC reports on the mounting congestion of barges in the port, with delays reaching as high as 48 hours.¹ In September 2018, JOC reports on the initiatives of the port authority to remedy the situation: a dialogue with all parties. The industry association of cargo owners and shippers presents a seven-point plan that points at better agreements between barge operators and ocean terminals, better sharing of information between all parties involved, the introduction of additional decoupling points to handle overflow containers, and the general improvement of the management of the entire multimodal chain.² Meanwhile, other commentators argue that the barge traffic handling problem has been around for years, and is just particularly bad in the years 2017/2018.³

This example shows that, while there exist operational examples of multimodal hinterland transport in practice, they can be hampered by serious challenges in the coordination of parties. Many attempts to solve such challenges are fundamentally changes at operational-level planning. A prominent example of collective action in the Port of Rotterdam is NextLogic.⁴ This initiative has launched the development of a central planning tool, called *Brain*, aiming to improve the planning and handling of barges in the port. All barge operators entering the port area from the hinterland are expected to provide information on their intended pickups and deliveries of containers at various terminals, and Brain will develop a collective optimal plan, which aims to reduce turnaround time, increase utilisation rates of terminals and barges, and decrease number of calls. Van der Horst and van der Lugt (2011) report that 32% of all coordination arrangements address a lack of operational coordination. Furthermore, 33% addresses “under-utilization of assets”, which is in essence tightly related to operational-level planning. These examples emphasise the key role of operational-level planning and show its recognition by the industry and academia.

Transaction Cost Economics (TCE) (cf. van der Horst and de Langen 2008; van der Horst and van der Lugt 2011) offers key arguments for collective action (e.g. Brain) as a viable approach for addressing coordination challenges. The *need*

¹ https://www.joc.com/port-news/rotterdam-barge-congestion-still-causing-48-hour-delays_20180418.html.

² <https://www.evofenedex.nl/kennis/actualiteiten/puntenplan-moet-containerbinnenvaart-haven-rotterdam-verbeteren>.

³ <https://www.logistiek.nl/ketensamenwerking/nieuws/2017/10/heibel-de-rotterdamse-haven-door-gebrekkige-ketensamenwerking-101159195>.

⁴ <https://www.nextlogic.nl/>.

and willingness to coordinate can be established at the strategic level in companies. However, *actual coordination* (e.g. through collective action) consists of changing planning processes and related operational decisions of individual companies dynamically. Those planning processes are intricately interconnected, and only a thorough understanding of such connections can yield effective directions for redesigns that improve the overall efficiency of the hinterland supply chain. The TCE approach, however, abstracts from planning activities that make up the actual coordination effort of parties, and as such it gives little guidance on how coordination efforts (e.g. collective action) can best be implemented to address a particular issue. Consequently, while TCE provides an important tool for analysing the need and willingness for collective actions, an extension is necessary to help select the right implementation at the operational level: collective action comes in many forms, but not all forms need to be equally effective.

Therefore, in this paper we present a comprehensive *framework* for modelling coordination challenges. The framework extends existing frameworks by also considering operational-level planning explicitly, and identifies three layers of transportation processes: *contracting processes*, *planning processes* and *physical processes*, respectively, from top to bottom. This enables the development of structured *models* of (part of) the hinterland supply chain. Such a model depicts a comprehensive picture of coordination challenges in terms of contracts, planning processes and physical processes interacting with each other. It moreover illustrates the parties involved with their goals, decisions and constraints. In addition to analysing conflicting goals (as in van der Horst and van der Lugt 2011), this allows one to gain specific insights into the dynamics of coordination, and the possible mediating roles of information exchange and changes in planning paradigms, contributing to effective solutions.

Explicitly considering planning activities comes at a cost of more elaborate and in-depth models that are more burdensome to construct and analyse (compared with van der Horst and van der Lugt 2011). Further contributions of this paper are directed at alleviating this burden. We provide a step-by-step method on how to model and analyse a coordination challenge using our proposed framework. The method involves the following steps: (1) construct the model; (2) identify conflicting goals; (3) assess causality, the impact of uncertainty, and contracting requirements; (4) assess the information flow. These steps structure the subsequent analysis, though admittedly some domain expertise will still be required in the analysis. We use the barge congestion problem in the Port of Rotterdam as a case study, and show how the proposed framework leads to deeper insights.

Against this background, the remainder of the paper is organised as follows. In Sect. 2, we review the literature on coordination challenges and modelling approaches in multimodal transport. In Sect. 3, we present the research methodology. In Sect. 4, we present our proposed framework. In Sect. 5, we discuss how a specific coordination challenge can be actually modelled and analysed. In Sect. 6, we provide an application of the framework on the barge congestion problem in the Port of Rotterdam. Section 7 presents the conclusions.

2 Literature review

Hinterland connections are a key dimension of a port's competitive position (Parola et al. 2017; Rodrigue and Notteboom 2009). The importance of multimodalism for efficient hinterland transportation is widely acknowledged (e.g. van der Horst and de Langen 2008; van der Horst and van der Lugt 2011; Veenstra and Zuidwijk 2016; for a general introduction on multimodal systems in hinterland transportation we refer to Rodemann et al. 2018).

Studies of multimodal (hinterland) transport, aiming at its improvement, often employ precise mathematical models to represent planning processes. With a few notable exceptions, these works model planning problems as mathematical optimisation models with a single decision maker. Steadie Seifi et al. (2014) provide a comprehensive review of such papers. In contrast, a significant number of researchers explicitly recognise that multimodal transport networks consist of many different parties, and the resulting distributed decision-making may lead to inadequate coordination. In this section, we first review the qualitative and then the quantitative studies recognising coordination as a challenge. Finally, we discuss the relevant literature used to develop the proposed framework, which is used to model coordination challenges.

The notion of coordination challenges in multimodal transport and the multi-actor view, particularly in the hinterland of seaports, has been recognised for years. A relatively large number of papers are mainly qualitative, without mathematical modelling of planning processes. Van der Horst and de Langen (2008) study the mechanisms to enhance coordination among the actors in hinterland transport, present a data set of coordination arrangements from industry, and categorise them under four groups: incentives, changes in scope, interfirm alliance formation and collective action. Van der Horst and van der Lugt (2011) employ an updated version of the same data set to analyse the relationship between the characteristics of the problem and the specific arrangements made to increase coordination. Veenstra and Zuidwijk (2016) discuss the operational and legal consequences, the role of pricing and the role of the port authority regarding integration of multimodal networks with ports. Fransoo and Lee (2013) bring a supply chain perspective to ocean container transport. Their focus is on the ocean leg, but hinterland transport is also explicitly discussed. Based on a detailed discussion, the authors list several challenges for future research including the coordination of container shipments across the supply chain at the operational level. Bouchery et al. (2015) study intermodal transportation systems and emphasise the multi-actor characteristics of hinterland transport, and the necessity of coordinating container shipments and information exchange. Wiegman et al. (2018) also underline the need for coordination, and focus on the role of information exchange in coordinating the actors of hinterland transport.

Other works focus on governance structures (Panayides 2002), dry ports and extended gates (Roso and Lumsden 2010; Veenstra et al. 2012), comparisons of regionalisation of freight distribution and dry ports in North America and Europe (Rodrigue and Notteboom 2010, 2012), and multi-actor analysis of hinterland

strategies towards sustainability (Bergqvist et al. 2015). Like our work, these qualitative studies attempt to understand characteristics and limitations of multi-modal hinterland transport by analysing the impacts of distributed decision-making. However, our detailed and formal consideration of planning problems, focusing on the operational level, distinguishes our work from this literature. Since solutions to planning problems are the means by which coordination is achieved in practice, including them in the analysis gives deeper insights, as the application of our framework in Sect. 5 illustrates.

Coordination challenges are also studied quantitatively by explicitly including multi-actor aspects in mathematical models (e.g. Douma et al. 2009, 2011a, b; Bouchery and Fransoo 2014). In the barge planning domain, for example, Douma et al. (2009) develop a multi-agent simulation model with two groups of agents, barges and container terminals, with certain interaction protocols. The protocols can be seen as formal mathematical planning models. Douma et al. (2011a) extend this paper by allowing restricted opening times of terminals, incorporating deep sea vessel arrivals, time restrictions for containers, and terminals with unbalanced workloads. Douma et al. (2011b) further study the level of cooperativeness between the agents. Among three levels of cooperation, namely low, partial or full cooperation, they conclude that either low or full cooperation prove to be the reasonable alternatives. Bouchery and Fransoo (2014) look at network design; they propose several models to represent the objectives of the relevant actors and conclude that the non-aligned objectives necessitate a multi-actor view when designing the hinterland network. Like ours, these approaches focus explicitly on the interplay between planning problems and coordination. However, our framework is an attempt to facilitate the empirical analysis of any specific coordination challenge in a generic way. Douma et al. (2009, 2011a, b) and Bouchery and Fransoo (2014), on the other hand, address specific coordination problems. Additionally, our focus is on an in-depth analysis of contractual, informational and other aspects of an existing coordination challenge, while the work of Douma et al. (2009, 2011a, b) can be seen as a prescriptive approach for planning within a specific problem.

In this paper, we propose a novel framework with multiple layers consisting of processes, in order to model a coordination challenge. Apart from network representations widely used in operations research (Steadie Seifi et al. 2014), D'Este (1996) provides a general discussion of frameworks for intermodal systems and explains how initial attempts to generalise unimodal freight networks evolved into frameworks with multiple layers. Their study proposes an event-based container-oriented approach. However, this approach does not allow the representation of the distinct processes carried out by different actors, and the interaction between the processes remains implicit. A multilayer approach, on the other hand, allows us to distinguish between business processes explicitly. Willis and Ortiz (2004) discuss the security issues in the global container transport from a supply chain perspective using a framework that has three layers: *logistics layer*, *transaction layer* and *oversight layer*. The logistics layer is defined as the physical 'conveyor', including the road, rail and water infrastructure. The transaction layer includes all informational and financial interactions and contracts, and the oversight layer consists of law enforcement and regulatory activities imposed by national or international bodies from a

higher perspective. Van der Horst and de Langen (2008) largely ignore the oversight layer, and implicitly end up with a framework that has two layers to analyse coordination problems: an operations layer and a transactions layer. Operations include physical and planning activities, driven by transactions (i.e. contracts and financial agreements). Grefen et al. (2018) propose a four-layer framework for information systems, including *physical*, *event*, *process* and *business* layers, and apply the framework to examples in multimodal transport. Although the domains vary, a common characteristic in these approaches is the existence of a top-down hierarchical relationship. Our proposed framework is the same in this respect, except that the layers are interpreted differently to fit our scope. However, similarities are evident: the bottom layer is the physical process (as in Willis and Ortiz 2004; Grefen et al. 2018), the top layer has a regulating role (as in Willis and Ortiz 2004 and van der Horst and de Langen 2008), and the information flow (event layer in Grefen et al. 2018; transaction layer in Willis and Ortiz 2004) is represented as interactions between the processes (i.e. decisions, plans or notifications).

3 Research methodology

This research is carried out by gathering information on coordination challenges faced by hinterland transport stakeholders in practice, and by using the literature to structure the proposed approach. Initially, the issues to be discussed were not predefined by the authors and needed to be identified throughout the study. Therefore, it was necessary to explore a vast range of topics. In addition to exploring coordination issues, it was necessary to dive into the details to gain insights. Semi-structured interviews with open-ended questions were selected, as they serve both purposes and allow direct interaction with practitioners who are the natural source of such information. The downside of this method, compared with conventional surveys, is that the number of interviews was lower, making it hard to validate the findings statistically. Therefore, despite the significant number of interviews held, one concern is the objectivity and representativeness of the interviews. To overcome this, we interviewed all major actors engaged in hinterland transport, representing different perspectives. During the interviews, we disregarded subjective comments on hot topics. To prevent observation bias, at least two of the authors of the paper had to agree on removing a certain comment. Furthermore, for the findings we previously found to be of value, we cross-checked them with other actors. We shared the detailed version of the reference model provided in Sect. 4 with experts from industry for feedback on the accuracy of the observations with respect to business practices.

Twelve face-to-face interviews were held with companies located in the Netherlands: two inland terminals (also operating barges), one railroad operator, one container terminal (also operating barges and trains), a road hauler, one information technology (IT) company and the port authority of Rotterdam. The interviewees were in managerial positions with extensive experience in operations. The interviews, which varied in duration from 1 to 4 hours, started with general questions regarding operational decision-making, and continued by follow-up questions to

Fig. 1 Overview of the framework for modelling a coordination challenge

investigate coordination challenges. When allowed by the interviewee, the interviews were recorded and listened to afterwards, and key findings were compiled. Some of the coordination challenge examples discussed during the interviews were barge congestion, truck congestion at the gates, uncertainties faced by container terminals regarding the pickup time and destination of import containers, static cargo closing dates for export containers (i.e. even if the departure of a deep sea vessel is delayed, the transport operator still needs to obey initial, more restrictive cargo closing time), lack of incentive to optimise fuel consumption of barges (i.e. quite often the fuel of a barge is reimbursed by the forwarder or the shipper, and the barge operator has no incentive to optimise fuel consumption), and lost or forgotten containers due to changes in deep sea vessel calls. Among these, barge congestion was selected as a case study due to its complexity and its long history, and because it is one of the largest problems.

The findings on coordination challenges were complemented with an unstructured literature review encompassing more than 70 papers mainly in the multimodal transport domain. The papers included articles found by queries on keywords such as “coordination”, “hinterland transport”, “multimodal” and “intermodal”, and the relevant papers that were referenced in these articles. The framework was developed using modelling approaches in container logistics and intermodal transport (Grefen et al. 2018; Willis and Ortiz 2004; D’Este 1996), and tailored with respect to the common characteristics of the coordination challenges discussed during the interviews.

4 A framework to model coordination challenges

In this section, we present the framework to model coordination challenges in hinterland transport, illustrated in Fig. 1. The framework has three layers: contracting layer, planning layer and physical layer. In each of these layers, processes take place

which interact with each other via information exchange. In the physical layer, processes are mainly transportation, handling and storage. In the planning layer, these are the systematic ordering, allocation and coordination of physical processes within some kind of performance measurement (minimal costs, minimal delay, maximum volume, minimal capacity, waste, etc.). In the contracting layer, processes are the commercial negotiation and formulation of reciprocal agreements between parties. The outcomes of the various activities in the layers are interrelated; contracts determine the conditions under which the planning processes are executed. At the physical layer, capacity or other resources are often limited, and thus the need for planning arises. The commercial agreement and the planning activities determine the execution of the physical activities. Broadly speaking, an upper layer *governs* its lower layers. A lower layer, in turn, provides *feedback* on realisations that is used to make decisions in the higher layer. If operational activities have poor performance, both the content and the interaction of these three layers need to be understood in order to develop solutions.

The framework can be used to identify and relate the processes that are relevant in a coordination challenge. By subsequently looking at the processes themselves and the dynamics between the parties, the dynamics, the causal relations and motivations of parties can be identified. In that manner, the framework serves as the basis for modelling the coordination challenge.

Based on the interviews, the processes of hinterland transport are depicted as a *reference model* in Fig. 2. This is a refinement of the framework in that it presents the processes of hinterland transport that we identify within each layer of the framework based on the interviews with practitioners. Large rectangles represent the three layers, while smaller yellow boxes inside the layers represent the processes. The information flows between the processes are illustrated by dashed arrows.

4.1 Contracting Processes

Contracting processes are in place to establish contracts that govern transport. Contracts may be made for medium/long term, such as capacity agreements between forwarders and shipping lines or forwarders and barge operators, or for short-term contracts regarding a specific booking. Since we focus on the effect of contracts at the operational level, we will not get into the details of how medium/long-term agreements are formed. Our focus here is on how specific bookings lead to various *contractual structures*, and how these structures have different impacts on operational-level planning. *Contractual structure* refers to the identification of the actors, the short- and long-term contractual links and the distribution of responsibilities. The contractual structure forms as a result of a *booking process* initiated by the trade agreement between the buyer and the seller. The booking process specifies time, location and other requirements of transport. The contractual structure is characterised by two factors: the *trade agreement* between the buyer and the seller, and the *haulage type* determined by the shipper.

The *trade agreement* specifies the relevant *incoterms*. By selecting one of the incoterms, buyer and seller agree on the allocation of responsibility of transport legs

Fig. 2 A reference model of hinterland transport using the framework

and costs. In particular, the terms clarify the point at which the responsibility for the container (i.e. the shipper), and thus the risk, is transferred from the seller to buyer. The *haulage type* is selected by the shipper, and specifies the nominated party by the shipper that will actually organise the hinterland transport. If the shipping line will be responsible for arranging the hinterland transport, this is called *carrier haulage*; otherwise it is called *merchant haulage*. Within merchant haulage, two cases can be distinguished. In the first case, the shipper appoints a forwarder for organising both the hinterland and the deep sea leg. In the second case, the shipper makes the deep sea leg booking directly with the shipping line and appoints a different party (e.g. a truck operator or an inland terminal) to organise the hinterland transport. It should be noted that due to the complex procedures of import and export, in both cases, typically, an agent (e.g. a forwarder) will be hired to arrange documentation and customs duties. The different haulage types are illustrated in Fig. 3, where lines represent the contracts and boxes represent the actors. In Europe, merchant haulage is preferred, and carrier haulage accounts for only 20–30% (Wagener 2014). *Carrier-inspired merchant haulage* and *merchant-inspired carrier haulage* are two other haulage types, which for the sake of brevity we will not cover.

Fig. 3 Haulage types 1. Carrier haulage 2a. Merchant haulage with forwarder organising both deep sea leg and hinterland transport 2b. Merchant haulage with shipper making a deep sea leg booking and hinterland booking

Fig. 4 Typical contractual relations for a merchant haulage case and the Free on Board (FOB) Incoterm

Figure 4 shows an example of a typical contractual structure established for a merchant haulage case where the buyer is responsible for the deep sea leg and onwards. The figure shows that a buyer and a seller have a trade agreement. Due to the selected incoterm (e.g. FOB), the seller makes a hinterland booking at the export side, while the buyer makes the deep sea leg booking and the hinterland booking in the import side. The forwarder makes a booking at a shipping line, with whom they may already have a contractual relation, e.g. a yearly capacity-based price agreement. The forwarder also makes a booking at an inland terminal for the hinterland part of the import container. The figure illustrates a situation where the inland terminal has a long-term agreement with a barge operator and a truck operator. Hence, the inland terminal organises the hinterland leg of the import container in line with that relationship. Finally, the shipping line decides on the container terminal at which to make calls, based on their long-term agreements in the ports of the buyer's and seller's country.

Incoterms and the type of haulage are critical, as they form the contractual structure which defines the requirements parties need to fulfil while seeking their own goals. The contracting layer interacts with the planning layer in that *contracting processes* govern the *planning processes* through goals and requirements. The planning processes seek to optimise the goals of the actors, taking into account the contractual requirements. At the same time, they provide feedback to the

contracting processes on how well their goals can be achieved within the contractual structures that are in place.

4.2 Planning processes

Planning processes are in place to organise the physical transport in an optimal manner before it starts. Planning processes may be performed sequentially or in parallel, per container or in batch; they can be revisited as part of a daily or weekly routine, updated ad hoc due to changes in bookings or disturbances in physical processes, and may have overlapping timelines with each other. For convenience, we will explain the planning processes for the typical timeline of a single container.

The planning process starts after the *booking process* (a part of contracting process) with a *container allocation process*. In the latter process, the specific barge or train service that will be used for the main haul and the empty leg is determined, based on the service schedules, time requirements and disturbances. The full/empty container transport orders are sent to *main-haul planning and control*, which is performed by the transport operator. Main-haul planning and control includes all planning activities that take place regarding the execution of barge and train trips, and coordination between the deep sea port and the inland terminal. In cases where barge or train is not possible or economically not viable, trucks are used between the port and the inland location. Depending on the full/empty container orders, the transport operator makes a preliminary plan to visit the container terminals to pick up the full container via call requests. The container terminal, in turn, plans how deep sea vessels, barges, trains and trucks will be handled, which is referred to as *terminal operations planning*. As a result of the container allocation process and main-haul planning and control, the specific barge, train or truck that will handle the container is determined, providing an input to *inland terminal planning* and to the *pre/end-haul planning* process. *Inland terminal planning* involves decisions such as how to stack the containers, and schedule cranes and staff, based on the barge/train schedules and load/unload lists. *Pre/end-haul planning* relies on the execution of main haul and the bookings. It involves scheduling and routing of the trucks, drivers and chassis. Main-haul planning determines the time the container will be available to be picked up in the inland terminal, while shippers' needs determine at exactly which date and time the container will be delivered to/picked up at the inland location.

4.3 Physical processes

Physical processes are in place to execute the transport in line with schedules and load/unload lists made in planning processes. The physical processes or operational activities in the hinterland transport system are basically linear but bidirectional due to import and export flows or empty repositioning. Starting in the hinterland, cargo is loaded on a truck for the *pre/end-haul trip*, stored and loaded to a train or barge by *inland terminal operations*, transported to the seaport during the *main haul*, unloaded at a terminal, and transferred onto an ocean ship by *terminal operations*.

This is called the export process. The import process follows the same structure, but in reverse. The relevant processes are loading, unloading, transportation and storage.

The execution of these activities in practice can be complex, because neither storage facilities nor cargo handling equipment or transport means are dedicated to this one cargo consignment. Since all these operations require expensive assets that create business value by being used efficiently and not standing idle, careful planning of operational activities is necessary.

5 Modelling and analysing coordination challenges

The framework and the reference model provide a general overview of the processes that are relevant in hinterland transportation. However, a more in-depth model is required to analyse a specific coordination challenge, to gain insights in order to develop effective solutions. The first step in constructing such a model is to answer the simple question: What is the coordination challenge? Although the question is simple, the answer usually is not. The interpretation of the problem, or challenge, may depend on the actor defining it. For barge congestion, for example, the terminals tend to relate it to small call sizes, unreliable barge arrivals and ‘ghost’ call requests, while for barge operators, the problem is long waiting times, unreliable handling times and unnecessarily early notice periods. The coordination challenge we use is a broad term encompassing various elements including symptoms (e.g. poor utilisation rates, complaints) and the intricate actions of the actors and their motivations altogether. This is the actual reason why a detailed model is necessary.

This section presents the method for modelling and analysing coordination challenges using the presented framework. In Sect. 5.1, we describe how a coordination challenge can be modelled (i.e. map the processes and the flows) in detail using the framework and the reference model as the basis. After modelling, further analysis is necessary to understand the dynamics, causal relations, motivations and possible improvement points as explained in Sect. 5.2.

5.1 Modelling the coordination challenge

In theory, a model of a coordination challenge can be constructed by copying the relevant parts of the reference model from Fig. 2. In practice, however, processes, contracts and information exchanges are likely to be specific to the case in hand. Therefore, a model should be constructed for a coordination challenge as follows, while freely drawing from the reference model as desired.

1. Determine which planning processes are central to the symptoms or complaints, and insert them into the planning processes layer. Map the flow of decisions and notifications between them. Identify one-to-many (i.e. a process that affects multiple processes that are executed by different parties) and many-to-one relations (i.e. a process that is affected by multiple processes that are executed by different

- parties). These types of relations lead to snowball effects and planning difficulties, and therefore need attention.
2. Identify the actors that execute the planning processes and model the prevalent contractual structures by linking these actors with their contracts and goals. Goals can be in line with the actor's corporate strategy, such as maximising profit or minimising transit or idle times.
 3. For each planning process, determine requirements that are imposed by contracting processes. Requirements can be time requirements, such as pickup or delivery dates, demurrage and detention conditions, modality, or container quality.
 4. Identify information that is exchanged between the physical and the planning processes, such as container status or disturbances in transportation services.

The model that is constructed in this manner forms the basis for understanding and discussing the coordination challenge as it depicts: (i) the actors involved and their conflicting goals, and (ii) how the actors interact within/across the three process layers. Based on the model, a more detailed analysis can be made to explore the opportunities to improve the processes.

5.2 Analysing the coordination challenge using the model

Based on our interviews and empirical observations, we identified three main commonalities among coordination challenges: (i) conflicting and competing goals among actors, and the role of contracts; (ii) complications due to causal relations such as vicious cycles or chain reactions forming the problem, and the negative effect of uncertainty and contractual requirements; (iii) missing or delayed information flow. Coordination challenges typically emerge due to an interplay between these factors. In this section we decompose the analysis based on these three factors. These guidelines are kept generic so that they can be followed for any coordination challenge. For the same reason, domain expertise on the planning aspects is required to make the analysis.

5.2.1 Identifying conflicting and competing goals, assessing the role of contracts

Coordination challenges arise due to problematic interactions between parties, either within one layer or between layers. Principal/agent theory predicts that these interactions are characterised by *conflicts of interest*. Conflicts of interest can be resolved by contracts in which the gap between expectations and effort is closed through monetary compensation. Problems occur where interactions are required and a conflict of interest exists that is not compensated. The interests of the parties are essentially materialised in physical processes through the goals of planning processes. Therefore, a crucial step is to focus on the effects of contracting processes on planning processes. Conflicts of interest can be observed directly in the interaction (e.g. shipper's need for fast delivery versus barge's need for consolidation) or in the form of competition between the parties (e.g. logistics companies in the same region). This view fits with the industrial practices in van der Horst and de Langen (2008), where

an economic perspective is employed to improve key performance indicator (KPIs) by forming different types of coordination mechanisms. Our framework depicts a wide view on the parties who interact the most, which contracts bind them, what their goals are, and how these goals and contracts align with planning processes. Having a wider and more complete view can help understand how contracts should be made.

More specifically, the following steps are to be taken: the main actors of the planning processes and their goals are checked for conflicts or competition, and the role of contracts is assessed for improvement. For example, terminal planning and barge planning have *conflicting* goals, while different barge planning processes *compete* for the limited quays. For *conflicts*, the contracts should specify a solid base to define the obligations and limitations, so as to achieve some form of coordination between interacting parties. For example, barge operators and container terminals lack such a direct contract, which can easily be seen. For *competing* goals, collaboration opportunities can be explored to create win–win situations. For example, barges on the same corridor can consolidate their loads to cut on costs or exchange cargo (which is being done to some extent) to share the limited quay.

5.2.2 Identifying causal complications, uncertainty factors and requirements

It is important to note that processes in hinterland transport are complex and highly interdependent. As a result, in the case of delays or additional costs (e.g. additional moves while unloading a barge in a container terminal), the parties tend to blame each other. In the contracting phase, it is not practical to define and list all of the possible outcomes and address each case (Hart 1995), as this incurs transaction costs (van der Horst and de Langen 2008). Saussier (2000) states that incomplete contracts are a reality, and argues that the reason to have such contracts is to save on transaction costs. Therefore, it may be possible to focus on improving planning processes to alleviate these unwanted situations with better coordination, and avoid further arguments. Improving the planning processes necessitates a thorough understanding of causalities, which is not straightforward to keep track of. A change in a planning process may trigger another change in a different process, causing a chain reaction or snowball effect. It is also possible that the effects due to a change made by the source returns back to the origin, causing a vicious cycle. Quite often, there are one-to-many or many-to-one type of relationships, escalating the situation by increasing the number of affected parties. For instance, a change in terminal plans may lead to changes in dozens of barge rotation plans (i.e. one-to-many), which affect multiple end-haul plans. Similarly, a rotation plan involves a large number of containers in the same barge (i.e. many-to-one). Even if a single container is late due to, for instance, a delay in commercial release, the barge (and all the containers on it) may be delayed. These relationships should be exposed by detailed analysis.

When a planning process includes vicious cycles, chain reactions or snowball effects, there are two common groups of factors creating and maintaining the causal relation: *uncertainty* and *requirements*. These two factors can be considered to be the *fuel* feeding the problem, and should be reduced. *Uncertainty factors* lead to conservative plans (to ensure feasibility), short-notice changes or long-notice

periods exerted on other planning processes. One can identify uncertainty factors due to physical disturbances or planning changes, and aim to reduce the uncertainty. Due to the nature of hinterland transport, reducing uncertainty may not be possible in some cases. In such cases, methods can be developed to foresee unexpected events earlier, for instance using data science techniques, and act resiliently through fast information exchange. Another factor to check is the *requirements* imposed by contracting processes. There is a wide range of requirements. The obvious ones are container-related, for example, due dates, demurrage and detention conditions, origin–destination and mode choice. Not so obvious requirements regarding planning processes are, for example, minimum call sizes needed, notice periods for making a call request, and slot allocation in railways.

The steps to be taken are as follows: the framework provides a basis to start an initial problematic decision, say a change in the berth allocation plan. Then, one can trace back/forth the upstream or downstream flows to detect factors (i.e. uncertainty or requirement) leading to vicious cycles or chain reactions. Essentially, each step will involve causal relations between the actions created by planning processes. For each process and action, requirements and uncertainty factors are identified. Thereafter, these factors can be assessed, and challenged to avoid them or reduce the negative effects.

Challenging the contributing factors one by one may result in innovative solutions. For instance, it may seem quite straightforward that a barge has to load an import container from the terminal to which the deep sea vessel discharged. However, the Port of Rotterdam plans to improve the connectivity of container terminals in Maasvlakte2 by a project, the *Container Exchange Route*, which will make it possible for containers to be exchanged between terminals. Hence, the strict requirement of which terminal to be visited is relaxed, and barges may make fewer calls with larger call sizes. Likewise, different scaled solutions can be developed by the experts to fit to the problem and budget. Iterating in this manner, one can reduce the negative effects of vicious cycles or chain reactions, if not completely remove them, and create effective solutions.

5.2.3 Identifying missing or delayed information flow

The role of information systems in industry grows increasingly to deal with large streams of data. Wiegmans et al. (2018) emphasise the importance of information in hinterland transport, and particularly discuss the information needs of the actors under three groups: Information about containers, information about transport means and information about the container terminal. The multi-actor, dynamic and highly uncertain nature of hinterland transport necessitates a synchronisation among the actors, to be able to act together, and avoid underutilisation of resources. This synchronisation can be supported by on time exchange of information throughout the affected parties. Therefore, the actors can (i) make optimal decisions initially with more information, and (ii) act effectively and in a proactive manner in the case of disturbances that are noticed earlier. However, currently, it is common practice to communicate through manual channels such as emails and phone calls; planning is done manually by human planners. Information systems are still being used to an

extent, but even then the integration of IT systems of different actors is not mature enough. As a result, data either do not reach the affected parties or get delayed, hindering the planning process.

The steps to take to assess competence of information flow are as follows: The failures in data exchange can be detected by mapping the flow of information in terms of timing and reachability. The time an event takes place (either a planning or physical event), whether the information reaches the related process or not, and the time the data are transferred can be recorded. This way one can assess whether the data, when transferred sooner, can lead to better planning. For instance, it is possible that a shipping line decides to drop the import containers at a different port, voiding all the arrangements the barge operator has made. If this information is not shared in a timely manner, the barge may lose time before changing its rotation plan.

It should be noted that the underlying concept of information exchange is to create value for some actors, while it may not create value for the others that play a role in the exchange of information. This makes information an asset and may necessitate the establishment of an information exchange protocol through contracts.

6 Modelling and analysing barge congestion in the Port of Rotterdam with the proposed framework

In this section we show how the method from the previous section can be used to analyse the barge congestion case in the Port of Rotterdam. The section includes all of the typical coordination issues, in itself making it a good case to explain how the method can be used. The problem involves two main actors: barge operators and container terminals. Barge operators complain about the excessive waiting times in the port, idle quay cranes and unreliable call times, while container terminals complain about the small call sizes, no-shows and unreliability of the barges due to the changes in their rotation plans.

6.1 Modelling the coordination challenge: Barge congestion

Figure 5 shows the model that we created for this coordination challenge. The model was created using the framework and the reference model from Sect. 4, while following the method in Sect. 5.1.

The following steps are completed while building the model:

1. The main processes are barge planning and terminal operations planning. The main flow between processes are call requests and approvals. If necessary, changes are made (middle region with dotted pattern). One-to-many and many-to-one relations are depicted with multiple-head arrows.
2. The barge operator and the container terminal are the actors executing the main planning processes. Barge planning aims to minimise waiting time; terminal planning aims to maximise crane efficiency. The shipping line has a capacity agreement with the container terminal; its main clauses are hinterland booking

Fig. 5 Model of the barge congestion using the proposed framework

and deep sea leg booking, which determine the requirements in Step 3. These are typically in most cases independent of haulage type and incoterm. However, who will make these bookings depends on the type of haulage and incoterm, as discussed in Sect. 4. Modelling all cases is not practical for the purposes of this paper. Therefore, we assume an import activity, where the buyer is responsible for hinterland booking, and the seller is responsible for deep sea leg booking. This is also convenient for the purpose of this paper since it illustrates the conflicts of interest (i.e. multi-actor view) when hinterland and deep sea leg bookings are made by different actors. Hence, the seller makes the deep sea leg booking, the buyer makes a hinterland booking via a forwarder, and the forwarder appoints a barge operator for hinterland transport.

3. Barge planning is done in line with delivery due dates, demurrage and detention conditions as requirements, under uncertainties on call approvals/changes from

terminal operations planning. Likewise, terminal operations planning is done in line with incoming call requests/changes and prioritisation of deep sea vessels, under uncertainties on call request changes from barge planning and delays/no-shows in vessel arrivals (middle light blue region).

4. The items for physical processes are added (lower blue region). Barge planning operates under uncertainty on container availabilities (physical or customs, commercial releases). Terminal planning operates under uncertainty on vessel arrivals.

6.2 Analysis of the barge congestion

Based on the model, the analysis for improvement is provided in Sect. 6.2, using the steps in Sect. 5.2 as follows.

6.2.1 Identifying conflicting and competing goals, assessing the role of contracts

Firstly, the main goals of the planning processes (i.e. minimise waiting time of barges and maximise crane efficiency of terminals) seem to be in conflict. When we check the contractual relation between the actors carrying out the two planning processes, a direct contract is missing. This is a major problem, since it is hard to sustain a good coordination and commitment. To overcome this problem, for example Europe Container Terminals (ECT) proposes guaranteed weekly time windows for barge operators, who pay a fee, and guarantees a minimum call size of around 180 TEU. Therefore, a contract is being formed and uncertainty is reduced by manipulating the actions of actors.

The barges compete with each other for the limited quays. All sorts of collaboration such as consolidation and container exchange agreements can help barges increase their call sizes.

Forwarders play a role in commercial and customs releases, which imposes an uncertainty factor on the availability of containers. However, forwarders do not have a direct benefit from sorting out releases immediately, which could decrease associated uncertainty and increase flexibility of barge planning.

6.2.2 Identifying causal complications, uncertainty and requirements

A change in rotation plans leads to uncertainty in terminal planning, which in turn may lead to a change in berth allocation, thus causing a vicious cycle. Moreover, other barges and terminals may be affected. As a result, unless absolutely necessary, barges should stick to the original plans. This can be supported by contracting schemes.

A change in call request is undesired. Delays in container availabilities (deep sea vessel arrivals, commercial and custom releases) is an uncertainty factor. It may be possible to establish more robust procedures to ensure there will be no problems regarding commercial and customs releases.

Demurrage and detention conditions is a limiting factor in the timing and call size of barge planning. In this specific case, these conditions depend on the choice by the seller who does not have a direct interest on hinterland transport. Since the seller has no direct benefit in better D&D conditions, trucking may be necessary due to short D&D conditions.

Another limiting factor is the number of different terminals and empty depots. A barge operator deals with more than 20 different terminals/depots, which decreases the flexibility of the barge operator while planning.

The buyer may ask faster deliveries, limiting barge planning and forcing them to shift to trucking.

6.2.3 Identifying missing or delayed information flow

This step requires a more thorough study, which includes tracing the information exchange. For completeness, some observations are provided below:

The delays in deep sea vessels are best known by the shipping lines operating them. It may be possible that they delay giving info on expected delays to the container terminals, or are overly optimistic to assure that they will not wait. This is a problem since deep sea vessel delays have important negative effects.

Even if the shipping line shares the information with the container terminal, it is not guaranteed that this information will reach the barge operator. When many containers are planned to be loaded from that vessel, barge operators may waste time before changing their plans.

When a shipper makes a booking with a barge operator, there is no guarantee that this information will be shared on time with the container terminal. The terminal may thus lose the opportunity to optimise stacking operations.

When the departure of an ocean vessel is delayed, this information may not be shared with the operator. Moreover, even if this information *is* shared, the cargo closing time (i.e. the latest time that an export container should be unloaded to the terminal) is not updated, and the operator has to obey the original earlier closing time, thus limiting their flexibility.

Customs/commercial releases can be improved by push notifications among the actors through integrated IT systems, leading to early detection of problems.

As we have seen in Sect. 5.1, a typical coordination challenge is a combination of all three factors contributing to the problem. In barge congestion, this is no different:

1. The barge operators and container terminals' goals clearly conflict and the contractual links are very indirect, and thus ineffective, in resolving contracts.
2. The changes in rotation plans and berth allocation plans are tightly related, causing chain reactions or vicious cycles. The causal relations are fed by uncertainties such as deep sea vessel/feeder arrivals, commercial and customs releases, delays in the handling of barges by the terminals and delays in barge arrivals. In many terminals, stringent demurrage and detention conditions limit the action space of barges.
3. The information flow depends on manual methods, and the actors exchange information at their will, which increases uncertainty.

This case study clearly demonstrates (i) how the observations made using an economics perspective can be identified in a structured way (e.g. in van der Horst and de Langen 2008), and (ii) how the analysis decomposes the coordination challenge and enables users to spot key operational flaws that are not readily seen.

7 Conclusion

Coordination problems in hinterland transport have been studied by various authors from an economic perspective (Van der Horst and De Langen 2008; van der Horst and van der Lugt 2011). These studies discuss the growing need and intentions for collective action, and the conditions under which such actions would be successful at a strategic level; they say little, however, about how to redesign operational-level planning to realise such intentions in practice. To fill this gap, we propose a framework to model and analyse coordination challenges in hinterland transport, with an emphasis on operational-level planning. The framework consists of three hierarchical layers that interact with each other through govern and feedback loops, namely the physical, planning and contracting process layers. We propose a method to construct and then analyse a coordination challenge using the framework, which then helps to identify potential points for improvement. More specifically, the analysis involves checking the conflicting goals and assessing the role of contracts, assessing the causal relations to reveal vicious cycles or chain reactions, identifying uncertainty factors and requirements that reinforce the causal relations, and finally assessing the reachability and timeliness of information exchange.

The main goal of the method is to help create a better understanding of a coordination challenge, which makes effective improvements possible. We show the usefulness of the method by applying it to the barge congestion problem in the port of Rotterdam, and showing how it increases insights into the problem. Firstly, we show how the changes in rotation plans and berth allocation plans trigger each other, leading to a vicious cycle of planning updates. We identify the key uncertainty factors and show their negative impact on planning, namely uncertainty in container status, call requests and approvals, and actual arrival and handling of barges. We also discuss the inefficiencies in information exchange, such as the delayed sharing of updates in deep sea vessel arrivals, which contributes to increased uncertainty for barges. The framework reveals the misalignment of contractual relations with respect to planning. For example, the undesired demurrage and detention conditions when the seller makes the deep sea leg booking and the lack of a contractual link between the barge operator and container terminal, who interact intensively.

The framework's main contribution is that it helps to reveal new insights that could lead to improvements. Although it is not the main aim of this paper, the potential impact of the increased insights can be illustrated by studying examples from academia and the industry. For example, in the barge congestion case, we underline the negative impact of uncertainty in call handling by the container terminals. Douma et al. (2011b) show that only by sharing information and committing to the approved call reservations, container terminals can decrease the average waiting times of barges by 9%, while keeping the terminal efficiency fixed. The insights

gained have also relevance in practice. For example, in the Port of Rotterdam, many ongoing projects aim to solve inefficiencies in information exchange such as Portbase and NextLogic as pointed out in Sect. 5.

The method in this research is primarily meant to model and analyse a specific coordination challenge. Future research can be done to develop a method for identifying the coordination challenges for the whole hinterland transport using the framework. Such a study would complement ours in that the prospective study would identify the challenges, while this study could be used to model and analyse the identified cases specifically. As discussed earlier in the methodology section, the findings in this paper can be converted into structured surveys to check whether they can be generalised for different hinterlands.

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