MEDITYA WASESA

Agent-based Inter-organizational Systems in Advanced Logistics Operations

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Agent-based Inter-organizational Systems in Advanced Logistics Operations

Agent-gebaseerde interorganisationele systemen in geavanceerde logistieke operaties.

Thesis

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To Mama, Papa, and My Beloved Family

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Chapter 1
Introduction

1.1 Motivation

The rapid advances of information and communication technology have brought the world into an open networked economy (Barabasi et al. 2000; Eagle et al. 2010; Borgatti & Halgin 2011). To align the market demand with the supply of sources, global value chain actors have to cope with increasingly complex challenges (Lee 2004; Chopra & Sodhi 2004; Gunasekaran et al. 2008). The increasing demand's unpredictability, the product's short life-cycle, and frequent disruptions carry two major issues namely, the risk of losing the opportunity to sell products due to supply shortages and the risk to marking down the product's selling price due to oversupply cases (Chopra & Sodhi 2004). In correspondence, the ability to adapt to unexpected changes in quick and cost effective manners becomes increasingly important (Ketikidis et al. 2008; Lee 2004).

The emerging networked business are strongly associated with a developing web of people and organizations, bound together in a dynamic way, creating novel outcomes from quick evolving links among networks of business actors, etc (Konsynski & Tiwana 2005; van Heck & Vervest 2007; Pau 2013). Businesses might possess the ability to conducting quick and effective inter-organizational coordination with both direct and indirect business partners (Lee 2004; Gunasekaran et al. 2008). Inter-organizational systems (IOS) play a pivotal role in embracing the new wave of networked business interactions (Vervest, Preiss, et al. 2004; Chi et al. 2010; Venkatesh & Bala 2012). These systems mediate the coordination of multiple and independent actors, with objectives and interests that may not be aligned (Cash & Konsynski 1985; Johnston & Vitale 1988; Zhu et al. 2006; Venkatesh & Bala 2012). These multiple and independent actors are often constrained by the limited capabilities of their IOS.

In the digital age of exchanges large volumes of digital data, the classical IOS function to mediate data and information exchange purposes becomes obsolete. Notwithstanding the importance of informational exchange in coordination initiatives, the ability to synthesize those information into useful business insights has an increasing importance. To help businesses in exceling in this era of fast and flexible coordination conducts, IOS with intelligent information synthesis ability are highly demanded.

1.2 Research Questions and Objectives

This dissertation focuses on the topic of *Agent-Based Inter-organizational Systems (the ABIOS)*. In the age of information ubiquity, ABIOS might empower its users with intelligent information synthesis features (Simon 1969; Russell & Norvig 2003). Agent-based features include the ability to sense, learn, and predict patterns out of large and rich information sources (Sinur et al. 2013).

How ABIOS supports business inter-organizational coordination becomes a relevant question. Thus, the main research question (i.e. *RQ*) of this dissertation is defined as follows:

> ***RQ:*** *"In the networked business context, what is the impact of agent-based inter-organizational systems (ABIOS) on inter-organizational coordination?"*

To answer the main research question, we decompose the central question into a number of sub-research questions. In each of the following chapters, we answer each of the derived research question. In the ultimate chapter, the chapters' findings are then synthesized to answer this dissertation's main research question. We begin by elaborating a conceptual discussion concerning the fundamental role of the IOS in supporting inter-organizational coordination. We define the first sub-research question (i.e. RQ_1) as follows:

RQ$_1$: *"Why do we need inter-organizational systems in inter-organizational coordination?"*

In response, Chapter 2 aims to provide an explanation theory (Gregor 2006) on the role of the ABIOS in improving inter-organizational coordination. The chapter presents theoretical explorations and syntheses on three important aspects namely: (1) the conceptual and practical contexts of inter-organizational coordination that urge the need for IOS, i.e. the IOS demand side, (2) the conceptual and practical definitions on IOS functionalities (the IOS supply side) as the corresponding solutions to the IOS demand side, and (3) the alignment between the IOS demand and the IOS supply. The chapter also provides explanations on how ABIOS differs with conventional IOS in the way that ABIOS empower its users with the capabilities for intelligent coordination initiation, execution, and assurance processes.

In Chapter 3, we present an empirical study analyzing the implementations of ABIOS in real-life business settings. Here, we execute a cross-case analysis to investigate the impact of ABIOS on the performance of business networks. The underlying sub-research question is defined as follows:

RQ$_2$: *"What is the impact of the agent-based inter-organizational systems (ABIOS) on business network performance?"*

The objective of Chapter 3 is to provide a theory for explaining and predicting (Gregor 2006) on the impact of ABIOS applications on business network performance. This chapter provides a theoretical conceptual model portraying the ABIOS' influence on the actors' coordination structure and information architecture; and the impact of those structural alterations on business network performance in terms of the coordination, agility, and informational dimensions. To validate the model, a cross-case analysis was conducted in three real-life ABIOS implementations in three logistics sector, namely warehousing, freight forwarding, and intermodal transportation.

Chapter 4 and 5 approach the main research question from a design science perspective (March & Smith 1995; Gregor & Hevner 2013). We design

ABIOS artefacts. Chapter 4 and 5 investigates two important design aspects of ABIOS namely, the design of an auction-based coordination mechanism and the design of a predictive-analytics coordination support system. The objective of the last two chapters is to provide theory for design and action (Hevner et al. 2004; Gregor 2006) on ABIOS artefact design. For Chapter 4, we define the third sub-research question (i.e. RQ_3) as follows:

> ***RQ_3:*** *"How to design an ABIOS coordination mechanism that facilitates the coordination of self-interested actors?"*

Analysing the use of the existing seaport appointment systems to facilitate the containers pick-up/delivery coordination operations, Chapter 4 aims to offer an alternative based on a modified auction mechanism. Agent-based experimentations were conducted to assess the impact of the proposed auction mechanism on the coordinating actors' operational performance. Chapter 5 focus on the largely unexplored field of predictive analytics ABIOS development using "big" geospatial sensor-based data (Watson & Wixom 2007; Negash 2004; Chen et al. 2012). In this chapter, we define the last sub-research question (i.e. RQ_4) as follows:

> ***RQ_4:*** *"How to design a predictive-analytics ABIOS that uses large-sized geospatial sensor-based data to predict the seaport terminal service rates performance?"*

Chapter 5 investigates how stakeholders can overcome the IOS information access limitations by utilizing their internal data assets with predictive analytics techniques. We develop the seaport service rate prediction system that can help drayage operators to improve their predictions of the duration of the pick-up/delivery operations at a seaport by using trucks' trajectory data.

1.3 Theoretical Contribution and Managerial Relevance

In positioning the dissertation's theoretical contribution, we adopt the Information Systems (i.e. IS) perspective (Benbasat & Weber 1996a) as the theoretical discipline foundation. IS is a discipline that focuses on the centrality of information technology (i.e. IT) in socio-economic life (Orlikowski & Iacono 2001). This dissertation's discussions aim to enrich the IS academic body of knowledge on this very relevant topic, the ABIOS artifact. In the following chapters, the reader will also learn that dissertation will shed light to other emerging technologies such as the internet of things (IoT), big data, predictive analytics, and intelligent machines.

Table 1-1. *Research Questions, Theory Types, and Research Methods.*

Sub-research Question	Theory Type	Research Method
RQ_1: "Why do we need inter-organizational systems in inter-organizational coordination?"	Theory for Explaining	Theoretical Synthesis
RQ_2: "What is the impact of the agent-based inter-organizational systems (ABIOS), on the business networks' performance?"	Theory for Explaining & Predicting	Multiple Case Studies
RQ_3: "How to design an ABIOS coordination mechanism that facilitates the coordination of self-interested actors?"	Theory for Design & Action	Coordination Mechanism Design /Agent-based Simulations
RQ_4: "How to design a predictive-analytics ABIOS that uses large-sized geospatial sensor-based data to predict the seaport terminal service rates performance?"	Theory for Design & Action	Predictive Analytics Design

Table 1-1 presents the sub research question definitions, the type of theoretical contributions, and the corresponding research method. In line with Gregor's (2006) taxonomy of theoretical contributions, the chapters of this dissertation aim to provide contributions in the form of theory for explaining, theory for explaining and predicting, and theory for design and action (see Table

1-1). From a managerial relevance perspective, the dissertation will stimulate higher awareness from the industry on the importance, the role and impact, the best practices and implications of ABIOS technologies.

1.4 Research Design

As presented in Table 1-1, we apply multiple research methods (Mingers & Brocklesby 1997; Mingers 2001). The approach offers the ability to capturing contextual richness of the research topic, higher generalizability of the research findings, and openness to explore novel theoretical constructs during the study (Mingers 2001). In this dissertation, we conduct one theoretical synthesis (Grimes 1978), one multiple case study (Eisenhardt 1989), and two design science studies (March & Storey 2008). We describe each method in greater detail in each of the following chapters.

1.5 Structure of the Dissertation

Figure 1-1 presents the structure of this dissertation. In this introductory chapter, i.e. Chapter1, we presented an overview of the research motivation, research questions and corresponding research objectives, theoretical and managerial contribution objectives, research design, and dissertation's structure. Recall that this dissertation aims to understand the impact of ABIOS on business actors' inter-organizational coordination in the context of a networked-business. Four studies were executed. Chapter 2 clarifies the role of IOS in supporting inter-organizational coordination. Chapter 3 analyses the real-life business experiences from the logistics sector to clarify the impact of ABIOS on business network performance. Chapter 4 and 5 demonstrate the ABIOS design process and focus on two important ABIOS design spectrums: the coordination mechanism and predictive analytics aspect. Last but not least, Chapter 6 summarizes and synthesizes the findings of each study, highlights the theoretical and practical implications, discuss the studies' limitations, and draw directions for future research.

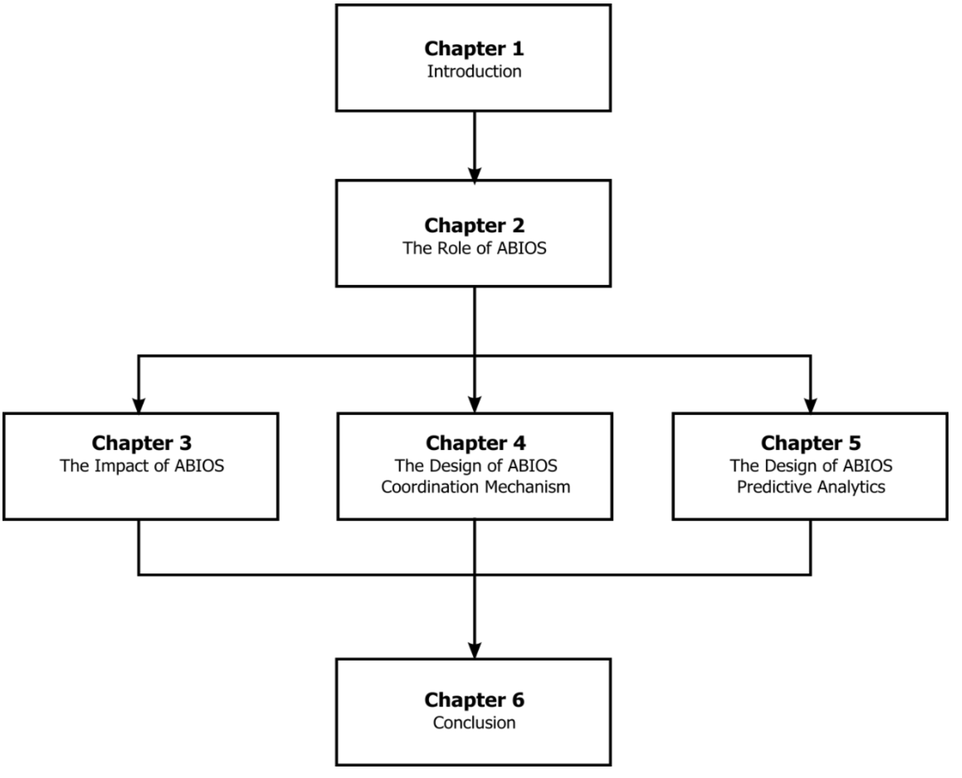

Figure 1-1. *The Structure of the Dissertation.*

Chapter 2
The Role of Inter-organizational Systems

2.1 Introduction

In the networked business era, businesses are delivering more sophisticated products and services in increasingly faster cycles than before. Customers' responsiveness becomes an important competitiveness aspect for any global value chain actor. An actor's capability to execute transactions quickly and to coordinate with any partner in the globe is the key for gaining competitive advantage. Correspondingly, large parts of IT infrastructures are developed now as networked-based platforms instead of centralistic platforms (Kambil & Short 1994; Vervest, Van Heck, et al. 2004; Bharadwaj et al. 2013; van Heck & Vervest 2007).

Inter-organizational systems (IOS) are important enablers of the networked business (Barrett & Konsynski 1982; Riggins et al. 1994; Kumar & Van Dissel 1996; Johnston & Vitale 1988; Venkatesh & Bala 2012). As spontaneous interactions in quickly evolving business networks have to be facilitated in a reliable way, IOS become more important. IOS stimulate creations of new information links that can reduce transaction and coordination costs of vertical markets, improve allocation efficiency through electronic market initiatives, reduce monopoly tendencies in differentiated markets, and so on (Bakos 1987). IOS enhance firms' capabilities and interfirm relationships which will then stimulate firms' competitive advantage in terms of increasing bargaining power and comparative advantage (Johnston & Vitale 1988; Bharadwaj et al. 2013). As example, IOS has an important role in the collaborations and competitions among airlines in airline alliances (e.g. Star Alliances, SkyTeam, Oneworld, etc). Facilitated by the IOS, the members of the airline alliances can gain benefits from joining and contributing to the alliance. Some of the benefits are extended customers' networks, cost reductions opportunities, competitive flight offerings for the costumers, etc.

While IOS became more important, many business sectors do not use these systems to its fullest potential. Despite IOS offerings such as improved business scalability, resource utilization, cost and risk sharing, etc. (Hughes & Weiss 2007; Simatupang et al. 2002), many businesses are still struggling to reap the full benefit from the IOS primary function of informational exchange facilitation. In the global logistics sector (Hausman et al. 2010), for example, the level of information sharing among coordinating partners is very limited (Ketikidis et al. 2008; Hausman et al. 2010). Moreover, many businesses still focus on and face some challenges with their internal enterprise information systems (Davenport 1998; Weill & Ross 2009).

Despite the high importance of IOS, many aspects can challenge a company's adoption IOS agenda (Grover 1993; Kurnia & Johnston 2000; Liu et al. 2010; Lyytinen & Damsgaard 2011; Kumar & Van Dissel 1996). We categorize the adoption challenges into non-functional and functional aspects. The IOS adoption non-functional challenges can exist in different dimensions: the company's vision, internal organization preparedness, institutional pressure, and risk aversion attitude. (Grover 1993; Kurnia & Johnston 2000; Liu et al. 2010; Lyytinen & Damsgaard 2011; Kumar & Van Dissel 1996). While the IOS adoption non-functional challenges have been studied extensively in the IS literatures (Benbasat & Weber 1996b; Orlikowski & Iacono 2001), the IOS adoption functional challenges have been analyzed using high level conceptual constructs such as the IOS factors (Grover 1993), support and enabling role of IOS (Kumar & Van Dissel 1996), nature of technology (Kurnia & Johnston 2000), and so on. However, these studies do not provide precise definitions on IOS functionalities. Accordingly, we define this chapter's research question as follows:

"Why do we need inter-organizational systems in inter-organizational coordination?"

2.2 Literature Review

This section introduces the readers to the foundational concepts that are used later in the theoretical synthesis. To construct an explanation theory (Gregor 2006), we utilize several important concepts such as coordination, organization, inter-organizational systems, and multi-agent systems.

2.2.1 The Concept of Coordination and Organization

Coordination initiatives aim to provide a solution on how a number of independent actors can work together to finalize tasks that exceed their individual capabilities (Durfee et al. 1989). Finalizing tasks through coordination initiatives can offer several benefits such as increased task completion rate, increased scope of achievable tasks, increased tasks' completion reliability, and improved utilization of the participants' skill specialization.

Coordination is needed due to an actor's limitation in finalizing the task at hand and thus the need to collaborate with external partners that will have the required complementary resources (Durfee et al. 1989). Four types of limitations may trigger an actor's need for coordination initiatives, namely:

(1) Cognitive limitations, an actor's limited capacity of informational access and processing ability;

(2) Physical limitations, an actor is situated in a finite physical space and will have limited resources;

(3) Temporal limitations, an actor's limited time availability,

(4) Institutional limitations, an actor's legal/political position that then specifies the actor's obligation/authorization rights (Carley & Gasser 1999).

As a term, coordination has many definitions (Axelrod & Hamilton 1981; Malone & Crowston 1990; Singh 1992; Malone & Crowston 1994). In line with the previous discussion (Durfee et al. 1989; Carley & Gasser 1999), Singh (1982) defines coordination as the integration and harmonious adjustment of individual efforts towards the accomplishment of a larger goal. Taking a different perspective, the National Science Foundation (1989) defines coordination as the emergent behavior of individuals whose actions are based on complex decision processes (Malone & Crowston 1990). In this study, we define coordination as the act of managing (inter)-dependencies between activities (Malone & Crowston 1994). Although coordination can also be associated with an orchestration of interdependent activities by a single actor, in this dissertation, we refer to the notion of coordination specifically as inter-organizational coordination, i.e., the coordination mode that involves multiple independent actors (Axelrod & Hamilton 1981).

Note that the concepts of collaboration and coordination have different abstractions. Different studies perceive both terms from different perspectives (Hahn et al. 2008; Olson et al. 2012; Gulati et al. 2012; Kumar & Van Dissel 1996). In general, the collaboration term is perceived as at a higher abstraction level than the coordination term. According to Gulati (2012) inter-organizational cooperation is defined as, "joint pursuit of agreed-on goal(s) in a manner corresponding to a shared understanding about contributions and payoffs." On the other side, "coordination is defined as the deliberate and orderly alignment or adjustment of partners' actions to achieve jointly determined goals". The emphasis of cooperation lies on "creating shared understanding about contributions and payoffs" while the emphasis of coordination is on the operational (more technical) aspect of collaboration that involves "the deliberate and orderly alignment or adjustment of partners' actions to achieve jointly determined goals". In this thesis, we will focus on the operationalization of collaboration activities i.e. coordination.

In line with the diverging definitions of coordination, the notion of organization has also different and diverging interpretations (Schelling 1978; Malone 1986; Carley & Gasser 1999). Carley and Gasser (1999) stated that, "…

there is no wide consensus on the definition of organization, and indeed theorists reason about organizations trying to answer fundamentally different questions, they construct different definitions on the basic phenomenon." Nevertheless, the organization has several generic characteristics, namely the organization as a large-scale problem solving initiative; comprised of multiple agents (human, artificial agents, or both); engaged in one or more tasks; goal directed; interacting with the environment; having knowledge; background and capabilities distinct from a single agent; and having a legal standing distinct from that of individual agents (Malone 1986; Carley & Gasser 1999). In this study, we simply define the organization as the institution that embodies coordination activities.

While organizations can be formed as an outcome of emergent behaviors (Schelling 1978), organizations often exist as a result of deliberate organizational design processes (Malone & Smith 1984). Organizational design concerns with clarifying the goal of the organization, assigning task execution and resource allocations, and defining the information architecture that will enable participating actors in achieving the organization's goal in a cost effective manner (Malone & Smith 1988; Malone et al. 1999; Malone 1986; Malone & Crowston 1994). While Malone's conception of organizational design may be applicable to organizations consisting of cooperative actors, it is not fully applicable to organizations consisting of self-interested actors. To design organizations of self-interested actors, we refer to the concept of coordination mechanism design (Decker & Lesser 1995; Shoham & Leyton-Brown 2008). The main concern in designing coordination mechanisms is how to design the interaction schemes that can bring benefits for both the coordination participants' and the mutual organization's interests. For further discussion, we present the result of designing such coordination mechanism practice in Chapter 4.

2.2.2 Inter-organizational Systems

IOS refers to the information and communication technology-based systems that transcend legal organizational boundaries (Kumar & Van Dissel 1996). Allowing informational exchange across organizational boundaries, IOS differ from regular internal information systems (Cash & Konsynski 1985; Davenport 1998). The involvement of multiple organizations whose objectives and interests may not be in rhyme will provide bigger challenges in gaining complete support for IOS implementations (Bakos 1987; Durfee et al. 1989). There are several factors that can drive an organization's decision in adopting IOS such as economic and strategic drivers (Barrett & Konsynski 1982; Johnston & Vitale 1988), transaction characteristics, and the organization's potential influence on the network (Choudhury 1997), the nature of business interactions and business environment (Teo et al. 2003), the existence of exogenous pressures, i.e. mimetic pressure (i.e. the extent of IOS adoption among competitors and the perceived success of competitor adapters), the coercive pressure (i.e. perceived dominance of suppliers/customers adapters and conformity with parent cooperation's practices), and the normatic pressures (i.e. extent of adoption among suppliers/costumers, participation in industry, business, and trade associations) (DiMaggio & Powell 2000).

In line with the concept of organizational design, the IOS design requires clarity on the coordination structure and the information architecture settings. The coordination structure refers to how the form and function of an IOS are broken down into constituent atomic subsystems (Simon 1962; Tiwana et al. 2010). The information architecture is the blueprint that defines what type of information is available to whom, or when, and how it becomes available to whom during the coordination process (Koppius & Van Heck 2002; Tiwana & Konsynski 2009). In response to the rise of networked business, where coordination will be executed by decentralized business actors that will share information both with their direct and indirect partners in a more spontaneous manner, a new generation of IOS is urgently needed (van Heck & Vervest 2005; Bharadwaj et al. 2013).

2.2.3 Multi-agent Systems

Agent-Based Inter-organizational Systems (ABIOS) is a composition of interacting software agents (multi-agent systems) that represent the coordinating actors (Jennings 2000; Zambonelli et al. 2003; Wooldridge 2009). Conceptually, software agents are positioned to carry out tasks for others, autonomously without being controlled by its master once the tasks have been delegated (Maes 1994; Wooldridge & Jennings 1995; Russell & Norvig 2003; Sinur et al. 2013). In a more technical perspective, software agents are defined as (1) identifiable problem solving entities with well-defined boundaries and interfaces; (2) situated in a particular environment (i.e. they receive inputs related to the state of their environment through sensors and they act on the environment through effectors); (3) designed to fulfill a specific objective; (4) autonomous (i.e. they have control both over their internal state and over their own behavior); (5) and capable of exhibiting flexible problem solving behavior to achieve their design objectives (Jennings 2000).

The suitability of ABIOS in supporting dynamic and flexible interactions can be traced from its primary software engineering paradigm. "Although contemporary methods (e.g., object-orientation, component-ware, design patterns, and software architectures) are a step in the right direction, when it comes to developing complex, distributed systems they fall short in two main ways: the interactions between the various computational entities are too rigidly defined; and there are insufficient mechanisms available for representing the system's inherent organizational structure" (Jennings 2000). The engineering process of agent-based software is coherent with the emerging trend in software development that is migrating from standalone-centric systems to platform-centric ecosystems (Tiwana et al. 2010; Sinur et al. 2013).

From the organizational design perspective, agent-based software engineering provides natural abstractions to translate high level organizational concepts (e.g. roles, permissions, responsibilities, etc.) to concrete artifacts. In line with the process of organizational design, there are several aspects to consider in designing the ABIOS namely, (1) modelability: the principal organizations phenomena have to be modelable; (2) performance differential: it is possible to assess/quantify the performance of the organizations both in macro and in micro individual participant level; (3) manipulability: organizations are entities that can be designed; (4) designability: organizations are entities that can be designed, re-designed, and transformed; (5) pragmatism: the cost of modeling and researching organizations using computational methods are relatively low (Wooldridge et al. 2000).

2.3 Research Method

This chapter applies a theoretical synthesis method to answer the question of why inter-organizational systems are needed in inter-organizational coordination. By conducting deliberate extensions on well-established theories as anchoring concepts, theoretical synthesis has been used in many classical studies (Astley & Sachdeva 1984; Scott 1994; Bensaou & Venkatraman 1996; Grimes 1978) to provide new explanations about a phenomenon. In conducting the synthesis, we are influenced by the literatures on information processing theory (Galbraith 1974; Tushman & Nadler 1978; Daft & Macintosh 1981; March & Simon 1993; Bensaou 1997) and inter-organizational systems (Tatarynowicz et al. 2015; Cash & Konsynski 1985; Johnston & Vitale 1988; Teo et al. 2003; Kumar & Van Dissel 1996). As the anchoring concept, we are indebted to the conceptual propositions presented in the classical literatures on inter-organizational relationship by Bensaou (Bensaou & Venkatraman 1995; Bensaou & Venkatraman 1996; Bensaou 1997) and on organizational information processing by Daft (Daft & Weick 1984; Daft & Lengel 1986; Daft & Macintosh 1981).

In constructing an explanation theory, we decompose the study's research question into three discussion points namely, (1) the conceptual and practical contexts that drive the need for IOS (the IOS demand side, Section 2.4.1), (2) the conceptual and practical definitions on the IOS functionalities (the IOS supply side, Section 2.4.2), and (3) the fit between the IOS demand and the supply side that explain what IOS is needed.

2.4 Analysis

2.4.1 IOS Demand Side

2.4.1.1 Theoretical Context

The information processing theory views organizational design as the search of the most appropriate configurations of structures, processes, and information technologies to facilitate the collection, processing, exchange and distribution of information (Galbraith 1974; Tushman & Nadler 1978; Daft & Macintosh 1981; March & Simon 1993; Bensaou 1997). The theory advocates uncertainties and equivocality as the two main factors that trigger the need for IOS (Daft & Weick 1984). According to Daft and Lengel (1986), "... two complementary forces exist in organizations that influence information processing. One force is defined as uncertainty and is reflected in the absence of answers to explicit questions ... the other force is defined as equivocality and originates from ambiguity and confusion as often seen in the messy, paradoxical world of organizational decision making ... Uncertainty is a measure of the organization's ignorance of a value for a variable in the space. Equivocality is a measure of the organization's ignorance of whether a variable exists in the space. When uncertainty is low, the organization has data that answer questions about variables in the space. When equivocality is low, the organization has defined which questions to ask by defining variables into the space (Daft & Lengel 1986)."

Uncertainties and equivocality conditions relate to different aspects of coordination. The information-processing literatures (Weick 1979; Daft & Macintosh 1981; Tushman & Nadler 1978; Galbraith 1974) identify that both constructs, i.e. uncertainties and equivocality, are present in the technological, interdepartmental relations, and environmental aspects of coordination. Using slightly different notions, Bensaou and Venkatraman (1995, 1996) identify and classify uncertainties and equivocality in three different aspects of coordination namely, (1) the task, (2) the partnership, and (3) the environmental aspects.

Uncertainties and equivocality in coordination tasks can be classified into two categories namely the task variety and the task analyzability (Daft & Lengel 1986). Task variety refers to the frequency of unanticipated tasks that require non-routine operational mitigations (Bensaou & Venkatraman 1996; Bensaou & Venkatraman 1995; Daft & Lengel 1986). Task analyzability is the extent to which there is a known procedure, that specifies steps to be followed in performing a task (Bensaou & Venkatraman 1996; Bensaou & Venkatraman 1995).

Uncertainties and equivocality in a partnership can be decomposed into two categories also, namely the inter-organizational difference and the inter-organizational interdependence. Inter-organizational differences reflect how disparate the coordinating actors are in terms of their functional specialization, objectives, and philosophical jargon. Coordination with highly similar actors tends to be less challenging compared with the ones filled with actors with different backgrounds. Inter-organizational interdependences refer to the degree of dependency among the coordinating actors (Thompson 1967). In coordination with a high interdependence degree, organizations may be trapped in a risky situation where an organization may hold other partners in hostage while coordinating (Bensaou 1997; Bensaou & Venkatraman 1996; Bensaou & Venkatraman 1995).

Next, uncertainties and equivocality in the environmental aspect can be decomposed into the cause-effect analyzability and environmental intrusiveness categories. The environmental cause-effect analyzability has a strong association with the environmental ambiguity term, i.e., whether the working rationale of the environment in terms of cause and effect relationships can be easily understood. The environmental intrusiveness element refers to the level of environmental stability. High level of environmental intrusiveness refers to rapidly changing environments and low intrusiveness refers to a more stable environment.

2.4.1.2 Practical Context

In assisting coordination, the role of IOS to reduce the partnership equivocality and uncertainties is more dominant than the role to reducing other types of equivocality and uncertainty, i.e. the task and environmental equivocality and uncertainties. Therefore, it is important to identify and classify distinct coordination activities in which partnership's equivocality and uncertainty exist. In any coordination initiative, actors are involved in the following activities: (1) finding and selecting prospective partners, (2) formulating and settling coordination arrangements, and (3) preparing, executing, and controlling coordination strategies.

Firstly, the need to find partners comes from an actor's limitation in finalizing tasks that exceed their individual capabilities (Durfee et al. 1989). Finding partners may require heavy deliberations, especially when the coordination initiative is composed of a number of unknown collaborators that possess distinctive skillsets. Secondly, the coordination arrangement consists of the coordination structure and informational architecture that governs the right, responsibility, and the information exchange of the coordination participants. It defines what an actor can do, what benefits an actor can expect, and what opportunistic behavior are considered as harmful for the sustainability of the coordination. Thirdly, coordination strategy defines how actors can extract maximum benefits from the coordination initiative without violating the predefined coordination arrangement. The coordination arrangement will have strong influence on the actor's coordination strategy selection. In short, the attractiveness of any coordination initiative is determined by those coordination elements, namely the coordinating partners, the coordination arrangement setup, and the applicable coordination strategies.

2.4.2 IOS Supply Side

2.4.2.1 Theoretical Context

Recall, that IOS refers to the information and communication technology-based systems that transcend legal organizational boundaries (Kumar & Van Dissel 1996). IOS mediate informational exchange across organizational boundaries to gain benefits (Cash & Konsynski 1985; Johnston & Vitale 1988). As equivocality and uncertainties have been defined as the theoretical constructs that triggers the demand for IOS, the type of information exchanged through the IOS will determine whether an IOS can support its users in mitigating coordination uncertainties and equivocality.

In response to the IOS demand side, i.e. equivocality and uncertainties, we introduce the concepts of information richness and information amount. We position information richness as the solution for mitigating equivocality and information volume as the corresponding solution for mitigating uncertainties. In coping with equivocality, an actor has no clear view how to fix an issue due to its incapability to define a proper problem abstraction. The ambiguous situation triggers the need for rich information types that can provide new perspectives to stimulate inventions based on novel and better problem abstractions.

In cope with uncertainties, actors cope with better-defined problems with clearer abstractions concerning the tasks at hand. As uncertainty can also refer to the deficits of the amount of information to answer a specific problem (Galbraith 1974), the positioning of the information amount concept becomes a logical solution to mitigate coordination uncertainties. Subsequent to finalizing coordination arrangements, actors will have a clearer abstractions on the coordination setup. Predicting the prospective circumstances to prepare the appropriate anticipation - to maximize the actors' utility - is the next issue. To cope with a more certain coordination setup, a small information amount is required to build an inference model of the coordination behavior. As the number of possible circumstances grows, a larger data amount is needed to build better predictions and accurate inferences.

2.4.2.2 Practical Context

As we positioned the information richness and the information amount as the conceptual solution to mitigate coordination equivocality and uncertainties, the conceptual abstractions have to be linked to practice. In line with the explanations in Section 2.3.1.2., IOS is designed to support coordination participants in at least one of the following activities: (1) finding and selecting prospective partners, (2) formulating and settling coordination arrangements, and (3) preparing, executing, and controlling coordination strategies.

To support the whole spectrums of coordination activities, three IOS functions have to be present namely, (1) the coordination initiation, (2) the coordination execution, and (3) the coordination assurance functionalities. The coordination initiation function will support users in selecting partners and settling coordination arrangements. The coordination execution function will help users in defining coordination strategies, executing, and controlling them. The coordination assurance function refers to the ability to recognize, diagnose, and repair violated expectations when external partners fail to perform their due in previously settled coordination arrangements. The assurance function relies on the system's intelligence to reason about the partners' state and intentions and to provide recommendations on the corresponding anticipations to avoid harmful coordination conducts (Sycara 1988).

2.5 Results

Figure 2-1 portrays the inter-organizational systems – inter-organizational coordination grid (the IOC-IOS-Grid) which depicts the correspondence between the IOS demand factors, i.e., the coordination circumstances that urge the *demand* for IOS, and the corresponding IOS supply factors, i.e., the IOS functionalities (see Section 2.4.1 and 2.4.2). As shown, the grid consists of two primary dimensions and four different sides. The vertical axis divides the grid into two sections, the IOS demand side (left side of the grid) and the IOS supply side (right side of the grid). The horizontal axis presents the practical (upper side of the grid) and the theoretical (bottom side of the grid) nuances of the IOC-IOS contexts.

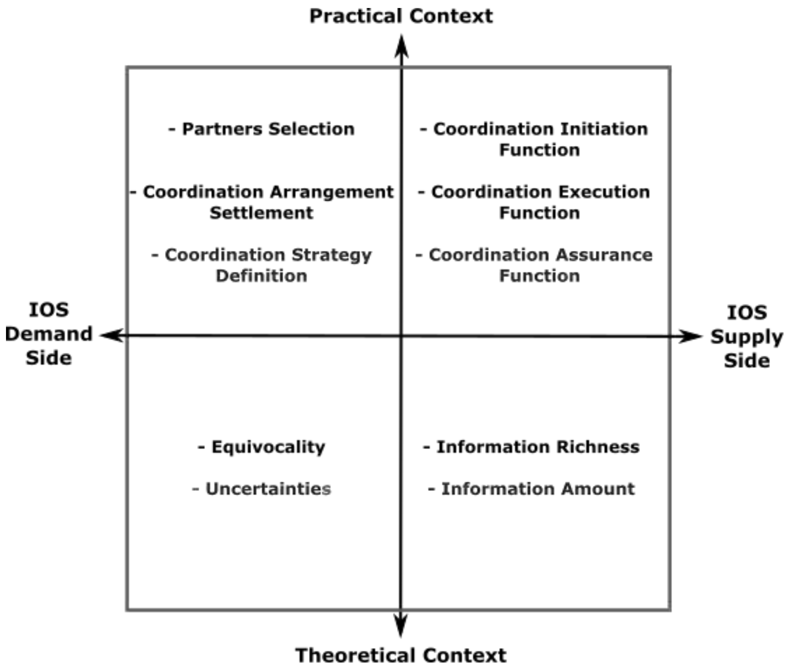

Figure 2-1. *The IOS - Inter-organizational Coordination Grid.*

The first correspondence between the practical and theoretical poles of the IOS-IOC-grid's demand side (the left side of the grid), in practice equivocality (the bottom left corner of the grid) can be observed within the partners' selection and coordination arrangement settlement activities (the upper left corner of the grid). Recall that equivocality refers to the existence of none, multiple, or conflicting interpretations about an ill-defined situations (Daft & Macintosh 1981; Weick 1979). In conducting partners' selection and coordination arrangement settlements, actors face ambiguity and require clear problem abstraction that will frame the direction of further coordination.

Coordination is still at an unstructured state and has not fully initialized without clarity on the collaborators and coordination arrangement terms. Only after the finalization of the two activities, actors can start formulating coordination strategies to anticipate future circumstances that may have direct influence on their utility.

The second correspondence between the practical and theoretical poles of the IOS-IOC-grid's demand side (the left side of the grid), the condition of uncertainties (the bottom left corner of the grid) can be observed in the context of coordination strategy definition (the upper left corner of the grid). In defining the coordination strategy, the structuring of the coordination arrangement is no longer an issue. The issue is more on how to maximize the contributions and benefits from the coordination initiative and reducing any uncertainties that may steer-out the planned coordination execution.

The third correspondence between the practical and theoretical poles of the IOS-IOC-grid's supply side (the right side of the grid), in the practical context, the information richness (the bottom right corner of the grid) concept corresponds to the coordination initiation function (the upper right corner of the grid). Rich information is needed to setting up a proper abstraction of coordination arrangement that will give structure to the coordination activities. The coordination initiation's goal to establishing clarity about the coordination goals, decision making and task execution divisions embodies the equivocality reduction concept.

The fourth correspondence between the IOS demand and supply poles of the grid's practical context side (the upper side of the grid), the need to mitigate equivocality conditions in conducting partner selection and coordination arrangement activities (the upper left corner of the grid) corresponds to the coordination initiation function of the IOS (the upper right corner of the grid). The coordination initiation function that will cope with rich types of information have to answer the demand to connect and collaborate with a wide extent of potential collaborators and to assist the users in analyzing and selecting the best coordination arrangement out of a wide array of coordination arrangement alternatives. We propose that an IOS with high coordination initiation capability can provide support in initiating contacts with potential collaborators and settling the best coordination arrangements. Conversely, an IOS with low coordination initiation capability provides limited support to contacting a handful of potential collaborators and assistance to limited array of coordination arrangement alternatives.

The need to mitigate uncertainties in defining and executing the coordination strategy (the upper left corner of the grid) will be fulfilled by the IOS coordination execution and assurance functionalities (the upper right corner of the grid). The coordination strategy that drives the execution and control of coordination is framed within a certain coordination arrangements setup. Recall that the coordination execution function provides support to defining, executing, and controlling coordination strategies and the coordination assurance function refers to the ability to recognize, diagnose, and repair violated expectations when external partners fail to perform their due (Section 3.2.2).

2.6 Concluding Remark

This chapter aims to present an explanation theory (Gregor 2006) to answer the question of why inter-organizational systems are needed in inter-organizational coordination conducts. Through the conduct of theoretical syntheses, we decompose the research question into three elements namely, (1) the conceptual and practical contexts that urge the need for IOS, (2) the conceptual and practical definitions on the IOS functionalities in response to the IOS demand side, and (3) the fit between the IOS demand and IOS supply.

At the demand side, we position equivocality and uncertainties as two theoretical constructs that urge the demand for IOS. In practice, equivocality and uncertainties are present in the following coordination contexts: (1) finding and selecting the prospective partners, (2) formulating and settling the coordination arrangements, and (3) preparing, executing, and controlling coordination strategies. At the supply side, three IOS functions have to be present to support the whole spectrum of coordination activities, namely (1) the coordination initiation, (2) the coordination execution, and (3) the coordination assurance functionalities. The coordination initiation function is required to improve the users' conducts in selecting partners and settling coordination arrangements. The coordination execution function is required to assist the users in defining, executing, and controlling coordination strategies. The coordination assurance function refers to the IOS ability to recognize, diagnose, and repair violated expectations when external collaborators fail to perform their duties. As a graphical representation of the explanation theory, we conceptualize the inter-organizational systems – inter-organizational coordination grid (Figure 2-1) that depicts the correspondences between the IOS demand and supply factors both at a theoretical/conceptual and practical dimension.

Contextualizing the theoretical synthesis results with regard to the use of Agent-Based IOS (ABIOS) in the networked business, we conclude that the role of advanced IOS in revolutionizing coordination has not reached its full potential. In an environment where instantaneous interactions among decentralized global actors quickly evolves in a spontaneous manner, businesses require IOS that can help them in finding partners, settling coordination arrangements, and conducting coordination strategies in a fast and effective manner. Agent-based technology is known for its intelligent information synthesis feature. In the age where communication of large volumes of electronic data can be done precisely, instantaneously, and effectively, ABIOS empower its users with intelligent information synthesis features (Simon 1969; Russell & Norvig 2003). The features also include the ability to sense, learn, and predict patterns out of large and rich data sets (Sinur et al. 2013). While the emphasis of the conventional IOS has been on mediating informational exchanges among organizations and not on supporting actors in their decision making processes, ABIOS empower users with an intelligent information synthesis ability that will help in finding better collaborators, setting and executing more profitable coordination arrangements, and securing coordination assurance. In the following chapters, we analyze and discuss ABIOS real-life implementations and design process examples.

Chapter 3
The Impact of
Agent-based Inter-organizational Systems[1]

3.1 Introduction

Nowadays, a business can no longer survive working as a self-contained organization that collaborates only with a handful of partners (Ghoshal and Bartlett 1990; van Heck and Vervest 2007; Tatarynowicz et al. 2015). Participating in a number of business networks can offer many opportunities, such as extended market reach, potential partnerships, and so on. In this networked era, inter-organizational systems (IOS) play an important role as technological vehicles that foster coordination activities (Bala & Venkatesh 2007; Zhao & Xia 2014; Kumar & Van Dissel 1996).

Despite the ubiquity of software agents for personal use (Wooldridge 2009), only a few, specifically agent-based inter-organizational systems (ABIOS) support coordination activities (Patel et al. 2010; Zambonelli et al. 2015; Carley & Gasser 1999). Research on the ABIOS topic is mainly categorized as design science (Gregor & Hevner 2013). Most of those studies propose coordination mechanism designs that are validated by simulation and experimentation. (Carley & Gasser 1999; Patel et al. 2010; Zambonelli et al. 2015). Recent overview articles in the field of multi-agent coordination (Cao et al. 2013; Lesser & Corkill 2014) indicate that the design of the ABIOS is still considered as the dominant research interest. Few studies evaluate ABIOS applications in a real-life situation of a dynamic business context.

[1] This chapter is based on the following journal article:
Wasesa, M., Stam, A. & van Heck, E., 2017. Investigating Agent-based Inter-organizational Systems and Business Network Performance: Lessons Learned from the Logistics Sector. *Journal of Enterprise Information Management*, 30(2), pp.226–243.

Furthermore, research of business networks is concentrated on structural aspects and the dynamics of the networks and treat the enabling technologies as exogenous (Lapiedra et al. 2004; van Heck & Vervest 2007; Pau 2013). Notwithstanding the importance of IOS in mediating practical business interactions, business networks have been explored from many theoretical perspectives such as: network structure typology (Tatarynowicz et al. 2015), competition (Ford & Håkansson 2013), innovation (Busquets 2010), and power relationships (Andersson et al. 2007). Despite the high demand for ABIOS empirical research, studies that specifically focus on the implications of ABIOS on business network performance are hard to find. This study presents a cross-case analysis that collects and synthesizes real-life evidence on the impact of ABIOS. The objective is to understand the impact of the ABIOS on the performance of business networks where organizations work together to achieve both firm and mutual goals. The main research question is defined as follows:

> *"What is the impact of the agent-based inter-organizational systems (ABIOS), on business network performance?"*

3.2 Theoretical Conceptual Model

To answer the research question, this study synthesizes theoretical concepts from the literature on smart business networks (van Heck & Vervest 2007; Busquets 2010; Pau 2013), coordination theory (Malone 1987; Williamson 2002; Olson et al. 2012), inter-organizational systems (Kumar & Van Dissel 1996; Bala & Venkatesh 2007; Zhao & Xia 2014), multi-agent systems (Wooldridge 2009; Lesser & Corkill 2014; Zambonelli et al. 2015), and coordination performance concepts (Marschak & Radner 1972; Dove 1999; Carley & Gasser 1999).

3.2.1 Coordination Structure

Coordination is the act of managing (inter)dependencies which exist due to the actor's limitations (namely cognitive, physical, temporal, or/and institutional limitations) in achieving goals (Carley & Gasser 1999). Depending on the actor's consideration of human factors (such as bounded rationality, opportunism, and the environmental atmosphere) and transactional factors (such as uncertainties, business scale, and information impact) (Williamson 2002), the goal has to be decomposed into workable activities and the activities have to be assigned either to internal or external partners at the lowest cost possible (Malone 1987; Olson et al. 2012). The coordination structure represents the decision-making and communication patterns that emerge from the actors' interactions (Malone 1987; Williamson 2002; Olson et al. 2012).

Coordination can be decomposed into three elements, namely decision rights partitioning, task execution responsibility assignment, and coordination mechanism (Williamson 2002). This research focuses on the influence of the ABIOS on the coordination structure, specifically whether introducing the ABIOS triggers the need to rearrange existing decision rights and task execution settings. Thus, the first sub-research question is defined as follows:

RQ1a: "How will the ABIOS influence the existing business networks' coordination structure?"

As information becomes ubiquitous, the ability to synthesize information content efficiently becomes increasingly important. Actors can benefit from this ability to synthesize information and play a role as intermediaries. Intermediaries can be viewed as information brokers who create value by managing information handling complexities, such as extracting information from multiple sources, synthesizing the information inputs into a comprehensive output, and delivering recommendations to their customers. With this ability, intermediaries act as information hubs which can influence the actions of others.

Depending on the ABIOS design and the client's objective, many tasks that were more efficient to be outsourced to intermediaries can now be executed internally (Wooldridge 2009). In the coordination context, the ABIOS can assist in finding partners, formulating business deals, and finalizing transactions. Using ABIOS, the dependencies for intermediaries' assistance in the mentioned coordination activities will decrease.

With ABIOS, business networks will be formed with more independent actors. Independence refers to the ability to finalize any transaction without external assistance. It portrays a condition where an actor possesses both decision rights and task execution responsibility. The presence of intermediaries indicates misalignments between decision rights partitioning and task execution responsibility assignment. The misalignment is an indication of a hierarchical coordination structure. Oppositely, an aligned condition between decision rights and task execution responsibility is characteristic for a decentralized coordination structure.

In resource allocation, intermediaries extract value (e.g. facilitating the market, matching buyers and sellers, aggregating buyers' demand/ seller products, reducing bargaining asymmetry (Malone et al. 1987; Bailey & Bakos 1997) from information asymmetries that exist between producers and consumers (Lizzeri 1999). The intermediaries' ability in accessing and synthesizing information is an important factor that drives their existence in coordination networks (Maglio & Barrett 2000). As ABIOS can provide advanced information synthesis support, the dependency on the intermediaries' informational functions will decrease. Hence, we define the proposition as follows:

P1a: "ABIOS will stimulate the migration of the extant coordination structure from the hierarchical to the decentralized structure."

3.2.2 Inter-organizational Systems Architecture

Communication is an important aspect of coordination. It is a consequence of the actors' bounded rationality in accessing and processing information. "Since, in general, the members who must take actions do not possess all the relevant information about the world, there must be some information structure that determines how members perceive and communicate information, and there must also be some decision function that determines how members decide what actions to take based on the information they receive" (Malone 1987).

IOS architecture determines how coordination participants perceive and communicate information (Malone 1987; Zhao & Xia 2014; Tatarynowicz et al. 2015). It describes what type of information is available to whom, or when and how it becomes available to whom during the coordination process. To connect the IOS architecture and the coordination constructs, one study associates the information interdependency configurations (pooled information resources, value chains, and networks) with coordination interdependence types (pooled, sequential, and reciprocal) (Kumar & Van Dissel 1996). Synthesizing the referred views, the sub research question RQ2a is defined follows:

RQ2a: "How will ABIOS influence the existing business networks' IOS architecture?"

The expected coordination structure migration from hierarchical to decentralized will have consequence on existing informational interdependencies. The transfer of task execution responsibility from intermediaries to the ABIOS will lessen the role of intermediaries and will stimulate direct communication among actors. The dominance of the pooled information structure (Kumar & Van Dissel 1996), which indicates the information is concentrated in the intermediaries, will then be reduced. The use of ABIOS will promote direct communication among actors in independent networks and will stimulate 'peer-to-peer' reciprocal information interdependencies. Thus, the answering proposition for sub-research question RQ2a is defined as follows:

P2a: "ABIOS will stimulate the migration of business network's IOS architecture from the pooled to the reciprocal information structures."

3.2.3 Coordination, Agility and Informational Performances

The cost of rearranging the existing coordination structure and the IOS architecture will be acceptable if performance improvement opportunities exist. Here, the business network performance concept is decomposed into three dimensions: the coordination performance, the agility performance, and the informational performance. Coordination performance is translated into effectiveness and efficiency. Effectiveness refers to how well a process is being performed and efficiency indicates whether a process is being performed in such a way that output is maximized relative to some input (Carley & Gasser 1999).

The capacity for fast reconfiguration in response to a highly dynamic and disruptive environment is important in the networked business environment (van Heck & Vervest 2007). Thus, agility performance is incorporated as a component to assess the performance of business networks. The agility performance construct is decomposed into: (1) the response time, as in the time needed to formulate and execute corrective actions; (2) the response cost, as in the cost to formulate and execute corrective actions; (3) the response quality/robustness, as in the ratio between the response cost and the cost of formulating and executing an action in the static scenario; and (4) the response range, as in the variety of disruptions that can be accommodated (Dove 1999).

In viewing businesses as networks of interconnected informational linkages (Bolton & Dewatripont 1994), business actors can be perceived as information processing agents who: (1) observe the environment's condition; (2) synthesize observed information into a response; and (3) execute the response (Marschak & Reichelstein 1998). Considering the actors' bounded rationality, information-related activities have to be economized. The informational performance construct is then translated into information processing performance and communication performance. Information processing performance is the total time spent synthesizing information and communication performance is the total time spent exchanging messages proportional to the number of exchanged messages in finalizing a task (Marschak & Reichelstein 1998).

Following the definitions of the performance constructs, the performance-related sub-research questions are defined as follow:

RQ1b: "How will the coordination structure alteration that the ABIOS evokes influence coordination performance?"

RQ1c: "How will the coordination structure alteration that the ABIOS evokes influence agility performance?"

RQ1d: "How will the coordination structure alteration that the ABIOS evokes influence informational performance?"

As tedious communication routines and information syntheses, which often are delegated to intermediaries, can now be conducted independently using the ABIOS, the actors' information syntheses and communication efforts can be reduced and the coordination, agility, and informational performances will improve as a result. Table 3-1 lists all propositions concerning the influence of the coordination structure alteration on the performance measures.

Table 3-1. *Coordination Structure –Performance Measures Propositions*

Independent Construct	Dependent Constructs	Research Questions – Propositions	
Coordination Structure	Coordination Performance	$RQ1_b$	*"How will the coordination structure alteration that the ABIOS evokes influence coordination performance?"*
		$P1_{b1}$	*"The evoked coordination structure alteration will increase the efficiency performance."*
		$P1_{b2}$	*"The evoked coordination structure alteration will increase the effectiveness performance."*
	Agility Performance	$RQ1_c$	*"How will the coordination structure alteration that the ABIOS evokes influence agility performance?"*
		$P1_{c1}$	*"The evoked coordination structure alteration will decrease the response time to handle disruptions."*
		$P1_{c2}$	*"The evoked coordination structure alteration will decrease the response cost to handle disruptions."*
		$P1_{c3}$	*"The evoked coordination structure alteration will increase the robustness toward disruptions."*
		$P1_{c4}$	*"The evoked coordination structure alteration will increase the response range (alternatives) in handling disruptions."*
	Informational Performance	$RQ1_d$	*"How will the coordination structure alteration that the ABIOS evokes influence informational performance?"*
		$P1_{d1}$	*"The evoked coordination structure alteration will increase the information processing performance."*
		$P1_{d2}$	*The evoked coordination structure alteration will decrease the communication performance."*

With the ABIOS application's stimulation of the coordination structure, the communication and information syntheses setup will be adjusted. The next question is whether the evoked IOS architecture alterations can stimulate better performance. The next sub-research questions are stated as follows:

RQ2b: "How will the IOS architecture alteration that the ABIOS evokes influence coordination performance?"

RQ2c: "How will the IOS architecture alteration that the ABIOS evokes influence agility performance?"

RQ2d: "How will the IOS architecture alteration that the ABIOS evokes influence informational performance?"

The conjecture is that the ABIOS will stimulate more direct collaboration among actors. As no intermediary hinders direct communication among actors, each actor will get faster information updates that enable agility performance improvements. In addition, the increasing information quality will also improve the effectiveness and efficiency of operations.

The redistribution of information concentration from intermediaries to direct communication lines among independent actors will influence informational performance. With the ABIOS, the communication and information processing intensity that each actor can handle will increase. Summarizing the discussion of the relationship between the IOS architecture alterations and the performance constructs, Table 3-2 lists the propositions.

Table 3-2. *IOS Architecture – Performance Measures Propositions*

Independent Construct	Dependent Constructs	Research Questions – Propositions	
IOS Architecture	Coordination Performance	$RQ2_b$	*"How will the IOS architecture alteration that the ABIOS evokes influence coordination performance?"*
		$P2_{b1}$	*"The evoked IOS architecture alteration will increase the efficiency performance."*
		$P2_{b2}$	*"The evoked IOS architecture alteration will increase the effectiveness performance."*
	Agility Performance	$RQ2_c$	*"How will the IOS architecture alteration that the ABIOS evokes influence agility performance?"*
		$P2_{c1}$	*"The evoked IOS architecture alteration will decrease the response time to handle disruptions."*
		$P2_{c2}$	*"The evoked IOS architecture alteration will decrease the response cost to handle disruptions."*
		$P2_{c3}$	*"The evoked IOS architecture alteration will increase the robustness toward disruptions."*
		$P2_{c4}$	*"The evoked IOS architecture alteration will increase the response range (alternatives) in handling disruptions."*
	Informational Performance	$RQ2_d$	*"How will the IOS architecture alteration that the ABIOS evokes influence informational performance?"*
		$P2_{d1}$	*"The evoked IOS architecture alteration will increase the information processing performance."*
		$P2_{d2}$	*The evoked IOS architecture alteration will decrease the communication performance."*

3.2.4 Conceptual Model

Figure 3-1 portrays the conceptual model that summarizes the sub-research questions and corresponding propositions. The model conjectures the influence of the ABIOS on clients' extant coordination structure and

IOS/information architecture, and the impact of those structural alterations on the coordination, agility and informational performance dimensions.

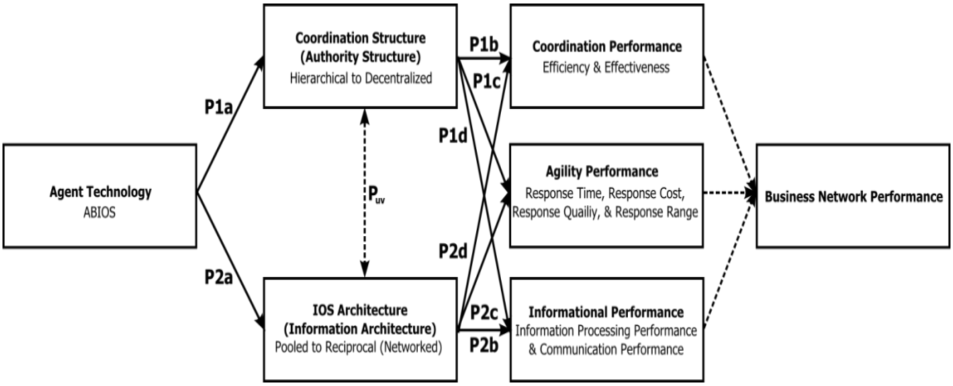

Figure 3-1. *The Theoretical Conceptual Model*

3.3 Research Method

Figure 3-2 provides an overview of this study's research design. To answer the research question, the positivist cross-case analysis method is used due to its relevance and its suitability for studying contemporary phenomenon within real life contexts in which the researchers have no control over the research objects' behavior (Yin 2009). Given the explorative nature of this research – to explore the relationship between impact of agent-based technology and performance – case study research is a logical choice. With case study research one is able to generalize with analytical generalization (not statistical generalization). The analysis of different cases (with its usage of agent-based technology) is preferable. At that the time of case selection it was not easy to get access to advanced agent-based technology cases. Most companies and networks would not like to share their advanced knowledge given the competitive advantage of these new ways of doing business.

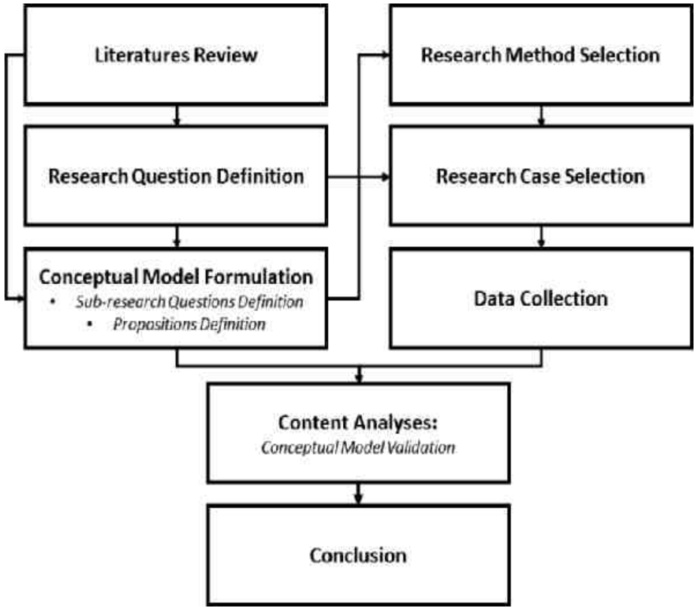

Figure 3-2. *The Research Design*

Regarding the choice of empirical cases, this study analyzes ABIOS applications in the warehousing (the Kiva system case), freight-forwarding (the Kuehne and Nagel Greece case), and intermodal-transportation (the SeaRail case) sectors. The cases comply with the following criteria: (1) the ABIOS has already been implemented in real-life situations; (2) the cases represent the perspectives of different actors that work together within a specific business network, in this case logistics; and (3) there are sufficient data sources available to analyze the cases. All three investigated cases develop and use very advanced agent-based technologies. The case of KIVA technology is analyzed with three different firms that are using this advanced technology. And in case two and three the same technology e.g. the IC-system is investigated but in a different business context. The limited access of agent-based technology cases restricted the case study design. Therefore the results of the three case studies will have a limited generalizability.

To achieve data triangulation (Runeson & Höst 2008), it is advised to use multiple sources of evidence to validate the phenomenon of interest (Yin

2009). As presented in Table 3-3, this study uses the full spectrum of first, second, and third-degree data sources (Lethbridge et al. 2005), namely project documentation, archival records, project evaluations, and press releases. The data were mainly obtained from reliable internet sites such as the company's/project's websites, European Union databases, and so on. Moreover, two phone interviews were conducted and fifteen video archives of respondent interviews from both the ABIOS developers and clients were analyzed. On the ABIOS developers' side, the respondents included company chief executive officers, technical designers, and implementation managers. On the clients' side, the respondents included chief operating officers, distribution center, transportation managers, assistant e-commerce managers, and warehouse workers.

Table 3-3. *Data Specifications*

ABIOS	Business Context	Data Source
Kiva System	Distribution centers	Technical documents, archival records, press releases, e-mail correspondences, interview archives
IC-system	Freight forwarders	Project documentations, archival records, press releases, phone interview, interviews archives
IC-system	Intermodal transportation	Project documentations, archival records, press releases, phone interview, interviews archives

In validating the conceptual model (Figure 3-1), content analysis (Weber 1990) was conducted to analyze the data sources according to all pre-defined propositions. For each proposition, a validation scale that reflects the validity power of the analyzed proposition will be assigned. A proposition will be assigned with one of the four validation scores: not valid (scale -), low validity (scale +), medium validity (scale ++), and high validity (scale +++). The validation was executed by the author of this study and might incorporate some personal bias but the results were discussed in detail with the supervisors and the associate editor and reviewers of the journal paper. The strength of this approach is that variables levels are determined in comparison with the other cases. The weakness of the approach is that not all performance sub-dimensions could be measured in great detail for all three cases. Therefore the internal validaty and the external validaty of the cases will be limited.

3.4 Case Study

3.4.1 ABIOS in the Warehousing Sector: The Kiva System

In mid-2012 the world's largest internet retailer (e-retailer), Amazon™, acquired Kiva™ Systems. As one author observed, "the only surprise about Amazon's move to acquire Kiva Systems for $775 million is that it didn't come sooner" (Wagstaff 2012). As the second-largest Amazon buy behind the $847 million Zappos™ acquisition (Kucera 2012; Ames 2015), the event has showed that agent-based empowered systems, such as the Kiva™ Systems (Wurman et al. 2008), have gained a considerable reputation in the business world.

In e-retail logistics operations, the Distribution Center (DC) controls the flow of commodities between manufacturers and end customers. DC operation is also very costly. "In a fulfillment center, 70% to 80% of the labor is devoted to picking and packing, 60% to 70% of a worker's day is spent walking among the shelves" (Mountz 2012). While manual DC operation can still be an option for small businesses, automated systems become increasingly necessary as the business size increases.

The conventional automated DC solutions (such as conveyor systems, carousels, and automated storage and retrieval system (AS/RS)) have limited flexibility. Those systems normally tie operations to a fixed set of stock keeping units, order profiles, workflows, and warehouse locations (Blair 2011). The highly dynamic e-retailing business (characterized by variability, volatility, and seasonality of order types) requires more flexible solutions. Moreover, although the market is unpredictable, extant solutions are built based on long-range forecasts. With the possibility of facility underutilization, opting for an automated DC solution is a risky task.

Kiva Systems aims to overcome the limitations of existing solutions which are either cost effective but not flexible (as in conventional automated solutions) or flexible but cost ineffective (as in the total manual approach) (D'Andrea & Wurman 2008). Using a swarm of autonomous robots, the Kiva system focuses on the pick, pack, and ship operation. The system conditions the inventory to come to the picking workers rather the other way around (Guizzo 2008). The 'reversed' pick, pack, and ship operation was made possible by the coordination of mobile inventory pods that replace the role of static inventory aisles, robotic drive units that act as the pickers, and the central computer cluster which acts as the resource allocation manager (Tam 2015).

To handle a high volume of order picking tasks, controlling the robotic picker units wirelessly through a central computer is not scalable. "Instead of relying on a single piece of software that centralizes all the decisions, they envisioned software agents that could run on the central computer, on the robots, and on PCs at the picking stations. The agents would exchange information but act independently, each trying to optimize its own tasks" (Guizo 2008).

"The software architecture reflects the fact that the Kiva system is, by its very nature, a multi-agent system" (Wurman et al. 2008). The architecture consists of the drive unit agents that represent the robotic pickers, the inventory station agents that represent the pack and ship stations, and the job manager/resource allocator agent which communicates with the warehousing management (Wurman et al. 2008). The job manager agents ensure high use of the inventory station agents and minimize the use of inventory pods and bots (Enright & Wurman 2011; D'Andrea & Wurman 2008). The task of inventory station agents is to assist the pick and ship workers in picking the articles (Wurman et al. 2008). The job manager agent determines which drive unit and which inventory station agents have to coordinate with the inventory pods to finalize the order picking tasks (Enright & Wurman 2011). Since all agents communicate with each other, the IOS architecture portrays a networked information structure.

Both computational and organizational benefits are achieved due to the adoption of a multi-agent paradigm. "The computational benefits include a natural decomposition of the computation that can be spread across as many servers as necessary. In addition, the multi-agent design makes it clear where to focus effort when making the system robust to failures ... The organizational benefits include code compartmentalization, which makes it easier to know where to put certain functionality. The multi-agent design also establishes clear boundaries of ownership among the software developers benefits" (Wurman et al. 2008).

Reviewing the customers' perspective, our study reviewed the experience of Zappos, the largest online shoe store (Mandrigal 2009); Staples, world's largest stationery retailer (Carr 2012); and von Maur, a medium sized fashion retailer (Blair 2011). Prior to opting for the Kiva system, Zappos and Staples were using conventional systems (including carrousel, conveyor-based, or AS/RS systems), while von Maur was operating a manual warehouse. The Kiva system was key to capacity expansion at von Maur. The chief operating officer at von Maur stated, "Our initial challenge was, we couldn't put more things on our website and have more offerings for the costumer because we knew we could not fulfill the orders … we knew that once we got to a point when we felt comfortable being able to continue to expand our e-commerce business online, that's exactly what would happen. Kiva really happened first for us before we could spend our energy and time expanding our selection online" (Blair 2011).

The impact of the Kiva system on clients' performance is summarized in Table 3-4. In general the respondents acknowledged the system's contribution to aspects of productivity, flexibility, and ergonomic working conditions. Different wordings were used to describe the improvements, such as reduced order-picking cycle-time, reduced personnel overhead, shorter personnel training time, increasing order-picking accuracy, reduced facility installation time, robustness against facilities and operational failures, pleasant working conditions, and so on (Durst 2007; Mandrigal 2009; Blair 2011; Carr 2012). In the words of a DC manager of Staples, "training (new employees) can be cut down three to four times: in the conveyor belt system the training may take two to three weeks while in the Kiva system it only takes two to three days". In addition, he said, "each worker is highly measurable: you can develop a metric for each individual and see how they are performing through time. In a conveyor system, depending on the technology, you cannot capture that information. You are relying on group performance rather than individual performance" (Carr 2012).

Table 3-4. *The Impact of the Kiva System on Performance*

Improvement Claim	Respondent Zappos	Staples	von Maur
Increased customer satisfaction achieved by delivering the right article in a good and timely manner	-	**Yes**	-
Increased productivity	**Yes** (Double)	**Yes** (Doubled)	**Yes** (4 times)
Decreased order-fulfilment cycle time.	**Yes** (48 min to 12 min)	-	**Yes** (1 week to 1 day)
Decreased labor overhead	**Yes** (up to 50%)	-	**Yes** (up to 15 personnel)
Improved quality assurance operations	-	**Yes**	-
Increased order-picking accuracy	**Yes** (up to 0% error)	**Yes** (less than 1% error)	**Yes** (up to 0% error)
Decreased safety incidents	**Yes** (2-3 incidents to 0 incidents)	-	-
Increased personnel and systems performance monitoring ability	-	**Yes**	**Yes**
Increased flexibility to workload fluctuations that cause operational procedure modifications	**Yes**	**Yes**	**Yes**

Short facility installation/expansion time	**Yes** (one year to 4 months)	**Yes** (half year to 6 weeks)	**Yes**
Easier in training new operators	**Yes** (4 days to .5 days)	**Yes** (2-3 weeks to 2-3 days)	**-**
Robustness against machine failures	**Yes**	**Yes**	**-**
Robustness against false order picking cases	**Yes**	**-**	**-**
More pleasant working condition	**Yes**	**Yes**	**Yes**
More quiet operation	**Yes**	**Yes**	**Yes**
Less manual load	**Yes**	**Yes**	**Yes**

3.4.2 ABIOS in the Transportation Sector: The Intelligent Cargo System

The Intelligent Cargo system (IC-system) is an ABIOS information infrastructure developed in two European projects and funded by the European Union: the Euridice project (European Inter-disciplinary Research on Intelligent Cargo for Efficient, Safe, and Environment-Friendly Logistics) (Schumacher 2008) and the i-Cargo project (Intelligent Cargo in Efficient and Sustainable Global Logistics Operations) (Paganelli et al. 2012). Both projects were carried out by universities, research centers, and industries (such as logistics, telecommunication, and consultancy) and aim to improve logistics practices through the development of an information system that applies a multi-agent system paradigm.

Unlike conventional logistics information systems (Davenport & Brooks 2004) that position cargo as passive objects, the IC-system viewed cargo as active entities (Cornelisse 2015; Schumacher 2008; Paganelli et al. 2012). In the IC-system, cargo retains the following properties: self-identification (any actor can communicate directly with the cargo); context detection (a cargo object is self-aware and can identify and interact with other cargo objects, operators, and so on); context-based access to services (an operator can ask for authorization to access a cargo object's service); automated status monitoring (a cargo object can monitor its content condition); independent behavior (a cargo object can trigger external service execution); and autonomous decisions (the cargo has self-decision making capabilities and can respond actively to its environment).

Many aspects of the IC-system differ from conventional logistics information systems (Paganelli 2009; Cornelisse 2015). In the IC-system, the data report is automatically generated by the cargo actuators. Meanwhile, the conventional system requires manual data input. Reviewing the data processing aspect, the IC-system supports data processing even at the lowest object level, namely the cargo level. Oppositely, conventional systems concentrate data processing activities in centralized servers. Note that in the conventional system cargo objects are treated as passive entities and the decision making is primarily done by the cargo owner. In the IC-system, the cargo acquires a certain level of autonomy.

Unlike the conventional system where the IOS architecture is aligned with the organization structure, the IC-system architecture is designed to support spontaneous and flexible communication among actors and active objects. Unlike conventional information systems where an organization uses different semantics for different collaborators, the IC-system uses a unified communication semantic. While in the conventional system the managers do make decisions based on periodic data updates, in the IC-system each agent makes autonomous local decisions in an event-based manner.

The IC-system is implemented as an open service platform named Orpheus (Object Recognition and Positioning Hosted European Service) (Schumacher 2008). The Orpheus platform is the layer on which the network of logistics actors and entities interact. It is connected to the client's legacy system. The two main elements of the IC-system's intelligence are the local and global services (Styczynski 2009; Paganelli 2009). The global intelligent services reside on the Orpheus platform and the local services reside on the object level. "Global intelligence is defined as the model of all cargo elements monitored by the system and the processing of available networked information ... The networked information will include data regarding the cargo itself, the global surrounding, and the current local context of each cargo object" (Styczynski 2009). The networked information is supplied in a bottom up manner from the cargo to the Orpheus platform.

The IC-system concept was implemented in several pilots. This study selected the ones that are applicable to the global sourcing context and are generalizable. Thus, this study focuses on the IC-system's role in improving coordination between a global freight forwarder's DCs and the transportation partners (the Kuehne and Nagel (K+N) Greece pilot) and improving coordination among transporters within an intermodal transportation company (the SeaRail pilot).

3.4.2.1 The IC-System in the Freight Forwarding Business

K+N Greece is a global freight forwarder that operates two main logistics hubs: one hub serves customers in the northern part of Greece and another hub serves the central and the southern region. In addition, the company works with smaller self-owned and partner hubs. A fleet of self-owned and partner trucks are also used for last-mile deliveries.

In this pilot, the objective is to improve several operational issues. The first one is the cargo content checking operation. Despite its importance for validating the integrity of cargo content, the tedious loading and unloading cargo and its checking routines consume excessive work-hours. For incoming/outcoming cargo, human operators have to do the manual barcode scanning for each cargo and do random cargo checking activities. The second one is the coordination operation between K+N Greece and external logistics partners. K+N Greece and its partners plan cargo transfers based on the estimated time of arrival (ETA) at the corresponding interchange hub. However, the ETA is often inaccurate and thus the pre-planned operations are prone to invalidations. The other aspect is transportation monitoring. As soon as the cargo was transferred to external partners, the K+N Greece could no longer monitor and control the ongoing operation. Many partners do not have the capability to automatically update the delivery's execution and cargo status. This can result in late notifications of the recipients' delivery approval, which can prevent K+N Greece from sending prompt delivery notification and billing charges.

Several features were implemented as solutions, specifically the automated cargo loading and unloading checking function for validating cargo documentation and content, the automated alerting and ETA notification function which reports any deviation from the predefined transportation plan, and the automated external third party scheduling function that improved last-mile transport coordination between K+N Greece and the logistics partners.

The use of novel sensor technology is crucial for IC-system implementation. While barcode tags were used previously for cargo identification purposes, the IC-system uses radio frequency identification (RFID) tags to store not only information about the cargo's content, sender, and recipient, but also the transportation route and transit locations. Moreover, RFID can support the transportation monitoring function and the automated ETA and arrival notification functions which inform all concerned actors whenever disruptions occur.

According to one of the K+N Greece directors, the pilot outcomes indicated that IC-system applications brought positive influences (Kyrillidis 2011). The automated checking feature improved the accuracy and the productivity of the loading and unloading routines. Moreover, the track and tracing feature increased the clients' monitoring capability. Hence, the cargo location and condition can be monitored in a nearly real-time manner while previously only the latest transit location information could be monitored (Kyrillidis 2011).

Use of the IC-system also stimulated better communication and coordination between K+N Greece and the logistics partners. The automated arrival notification function increased the ability of K+N Greece hubs and logistics partners to monitor cargo transportation progress. Both parties can anticipate upcoming operations and settle on the cargo transfer schedule in a synchronized manner. Improved communication performance has also increased the ability of K+N Greece to send prompt delivery and billing notifications. The lead time between the cargo delivery and issuing the bill can be reduced from one month to real-time.

3.4.2.2 The IC-System in the Intermodal Transportation Business

SeaRail is a Scandinavian company providing intermodal transportation services. For the pilot, we focus on the wagon transportation between the Port of Turku in Finland and the Port of Stockholm in Sweden. The process involves different organisations, namely railway operators, port operators, and ferry ship operators.

Improving the existing communication and information exchange was the project's main focus (Ahlfors 2011; Benito 2013). First, the automated notification and confirmation feature assisted the planners and operators in handling tedious notification and confirmation routines. Secondly, the automated wagon selection feature simplified the order-to-wagon assignment. Previously the planners spent most time on communication and sorting and selecting wagons for the transport assignment, but now the IC-system handles most of the workload and presents wagon recommendations to the planners, enabling the planners to focus on the core value added activity, namely selecting the best assignment recommendation.

The wagon location and condition monitoring functions present real-time information about the wagon's position and its content condition. Next, the wagon monitoring feature traces transportation progress periodically and the disruption notification function notifies concerned actors whenever deviation or disruption occurs. This improves the capacity of planners and operators to take corrective actions in response to disruptions. Finally, the wagon utilization reporting feature provides planners with real-time information on wagon utilization at the aggregate level and at the individual wagon level. With this function, the overall performance assessments and tactical decisions can be made faster.

Subsequent to the pilot trials, the SeaRail transportation manager reported several positive results (Ahlfors 2011). First, the required time to retrieve the wagon's location and condition information decreased from an average of 60-600 minutes to 5-50 minutes, an average improvement of approximately 90% in transportation information retrieval speed. Secondly, the required time to finalize the order-to-wagon assignment also decreased by a range of 75% to 93% from an average of 15-20 minutes down to 1-5 minutes. The total transportation time was reduced by approximately 20%. Next, the real-time wagon location and condition monitoring feature improved the accuracy of ETA and wagon utilization calculations. Previously the utilization rate was calculated indirectly using financial reports, however, with the IC-system the rate can be calculated automatically in real time based on information sourced directly from the wagon level.

3.5 Analysis

Table 3-5 provides an overview of the case studies analyzed with the predefined conceptual model' propositions (see Section 2). The content analysis was applied to examine and assess the coherence between the empirical findings and the model's propositions. Analyzing the impact of ABIOS on stimulating the emergence of decentralized coordination structures (proposition P1a), coordination structure alterations were significant in the Kiva system case. Decentralization of decision-making authority onto the subordinate agents was evident. With the Kiva system, misalignments between the decision-making authority and task execution responsibility are dismantled so each agent could operate autonomously.

Table 3-5. *The Overview of the Case Studies*

Unit of Analysis	Case		
	Kiva Systems	**Kuehne Nagel**	**SeaRail**
Coordination Structure	Decentralization of decision-making authority from the central computing unit to all agents (managers, drive units, inventory stations).	Delegation of the loading/unloading checking tasks. Automated last mile transport notification for external partners.	Delegation of the wagon assignment process.
IOS Architecture	The decomposition of information flow concentration from the central computing unit to all working agents.	Direct communication access to any individual cargo for any authorized actor.	Direct communication access to each individual wagon for any authorized actor.
Coordination Performance			
Effectiveness	Increased order picking and picking productivity. Shorter order fulfilment cycle time. Fewer quality inspection activities.	Increased transportation productivity (higher task completion rate/ working throughput).	Improved productivity (shorter total transportation time).
Efficiency	Decreased warehouse operational cost (labor overhead, energy).	Faster billing finalization.	Faster wagon assignment operations.
Agility Performance			
Response Time	Faster new facility's set up time. Faster new operator's training time.	All concerned actors can react to disruptions promptly due to cargo transportation monitoring features (cargo's location, condition, ETA).	All concerned actors can react to disruptions promptly due to wagon transportation monitoring features (wagon's location, condition, ETA).
Response Cost	Avoid lump sum investment with the incremental facility expansion option.		
Robustness	Increased flexibility in doing facility expansion investment.		
Response Range	Improved handling of disruptions (sales volatility, machine breakdowns).		
Informational Performance			
Information Processing	Possibility to monitor the performance of each manual worker and the performance of all working agents.	Faster execution of the loading and unloading checking routines.	Delegation of the wagon assignment tasks.

			Automation of the wagon utilization calculation. Facilitation of ETA and transportation progress information retrieval needs.
Communication	Enabling direct and intense (frequent) communication among all working agents.	Faster communication (transportation progress and bills) to external partners. Faster notifications and more accurate transportation's information.	Delegation of communication tasks to multiple transport operators for the wagon assignment purpose.

The migration of the coordination structure was more moderate both in the K+N Greece and SeaRail cases. The rearrangement of decision-making authority and task execution responsibility is limited to task delegation, namely the task transfer from an actor to the ABIOS within an actor's working scope related to communication and information synthesis. The transfer of decision-making authority and task execution responsibility across the actor's working boundaries was not found. Nevertheless, in all three cases, there was noticeable evidence that the ABIOS applications spur the migration of the coordination structure from the hierarchical to the decentralized.

The influence of ABIOS in reducing the domination of pooled information structures and in promoting the emergence of reciprocal informational structures was evident (proposition P2a). In the Kiva system case, the redistribution of decision-making authority and task execution responsibility from the warehouse management system (WMS) to the agents was obvious. In contrast to the conventional system where information flows are concentrated in the WMS, all agents in the Kiva system are actively communicating with each other.

The IC-system's conceptual design stimulates the emergence of the networked information structure. By embedding autonomy within each cargo object, direct interactions among concerned actors and cargo emerge, enabling more effective and efficient coordination activities in terms of monitoring transportation and defining corrective action. Any authorized actor can communicate directly with the cargo to access the cargo's location, and avoid tedious communication with intermediaries, as evidenced by the coordination between the main hubs of K+N Greece and the transportation partners, and by the coordination among SeaRail's fleet operators.

In the Kiva system case agility performance was identified as the system's distinctive impact (proposition $P1c_{1\text{-}4}$ and $P2c_{1\text{-}4}$). Flexible capacity expansion, faster installation time, and faster operator training enabled the clients to quickly adjust their DC operation in response to data on sales dynamics. This supports the positive impact of the ABIOS on response time and response cost measures (proposition $P1c_{1-2}$ and $P2c_{1-2}$). The role of the Kiva system in avoiding underutilized DC facilities due to inaccurate forecasts supports its positive impact on response range performance (proposition $P1c_4$ and $P2c_4$). Moreover, the system's self-organization ability in handling facility failures supports its positive impact on robustness (proposition $P1c_3$ and $P2c_3$).

The impact of the Kiva system in reducing the manual overhead and improving the order-to-ship time (by increasing order stocking and order picking productivity and increasing order picking accuracy) indicates its positive influence on efficiency and effectiveness (proposition $P1b_{1-2}$ and $P2b_{1-2}$). The system's reliability in handling high order picking volume was supported by its high informational performance, namely its ability to handle high communications and transactions data load (proposition $P1d_{1-2}$ and $P2d_{1-2}$).

For the IC-system, informational performance improvement was prominent. Communication access among all actors was opened and unnecessary information flows were trimmed (proposition $P2d_2$). The ability to directly assess the cargo's information was helpful in the cargo transfer between K+N Greece and the transportation partners. Meanwhile, SeaRail benefitted from the automated ETA and disruption notification features. In terms of computational performance, the automated loading-unloading checking feature simplified the cargo checking routines of K+N Greece (proposition $P2d_2$). In the SeaRail case, the wagon utilization calculation and the wagon selection recommendation features reduced the work-hours to finalize wagon assignments (proposition $P2b_{1-2}$).

Providing an information platform to mediate frictionless information exchange is the IC-system's main contribution (proposition $P2d_{1-2}$). However, no automated coordination mechanism was implemented in any pilot. Two IC-system implementation managers stated that the implementation of automated coordination functionalities cannot precede the development of the information platform. One implementation manager stated, "Before the basic communication and information exchange has been be established, it is premature to discuss automating coordination capabilities".

Nevertheless, the implementation of the information platform alone has stimulated noticeable coordination performance improvement (proposition $P2b_{1-2}$). The time saved by the automated wagon selection feature in the SeaRail case and faster billing routine finalization in the K+N Greece pilot case were evident (Ahlfors 2011). Despite the absence of an automated disruption handling feature, the IC-system has an indirect positive impact on agility by providing information that increases responsiveness toward disruptions (proposition $P2c_{1-2}$).

It must be understood whether the performance improvements occur due to the adjustment of the coordination structure or the information architecture. In the Kiva system case, the restructuring of decision-making authority and task execution responsibility among agents (proposition P1a) stimulated the emergence of networked informational interdependencies (proposition P2a). The coordination structure modification acted as the primary driver of the performance improvement. In contrast, the IC-system's main contribution is to the implementation of an information platform that enables direct communication among all actors (proposition P2a). The transfers of decision-making authority and task execution responsibility were limited in the task delegation forms (proposition P1a). In both IC-system pilots, the information structure adjustment was the primary cause of the performance improvements. Based on the analyses, Table 3-6 summarizes the result of the validation of the conceptual model propositions.

Table 3-6. *The Impact of ABIOS on Business Network Performance*

No	Proposition	Case: Kiva Systems		Case: Kuehne Nagel		Case: SeaRail	
P1a	The migration from the hierarchical coordination structure to the decentralized structure.	+++		+		+	
P2a	The migration from the pooled information structure to the networked structure.	+		+++		+++	
Pb	Increasing coordination performance	**Cor**	**Inf**	**Cor**	**Inf**	**Cor**	**Inf**
Pb_1	Increasing efficiency	+++	+++	+	++	+	++
Pb_2	Increasing effectiveness	+++	+++	+	++	+	++
Pc	Increasing agility performance	**Cor**	**Inf**	**Cor**	**Inf**	**Cor**	**Inf**
P_{c1}	Decreasing response time	+++	+++	-	+	-	+
P_{c2}	Decreasing response cost	+++	+++	-	+	-	+
P_{c3}	Increasing robustness	+++	+++	-	-	-	-
P_{c4}	Increasing response range	++	++	-	-	-	-
Pd	Increasing informational performance	**Cor**	**Inf**	**Cor**	**Inf**	**Cor**	**Inf**
P_{d1}	Increasing informational processing performance	+++	+++	-	+++	-	+++
P_{d2}	Increasing communication performance	+++	+++	-	+++	-	+++

Note: Not valid (scale -), low validity (scale +), medium validity (scale ++), and high validity (scale +++). Cor= coordination structure alterations, Inf= information architecture alterations.

3.6 Conclusion

This study examines the ABIOS in real-life settings. Moreover, this study proposed and validated a theoretical conceptual model that explains the influence of the ABIOS on the clients' coordination structure and information architecture that subsequently improves the business network performance: the coordination performance (effectiveness and efficiency), agility performance (response time, response cost, robustness, and response range), and informational performance (information processing and communication).

In the Kiva system case, the influence of ABIOS on the coordination structure (from centralized to decentralized) and on the information architecture alterations (from a pooled to a networked structure) improving all performance measures was remarkable. In the SeaRail and the K+N Greece pilots, ABIOS (the IC-system) evoked alterations in the information architecture but not in the coordination structure. With the information architecture adjustment, the IC-system improved its clients' informational performance and yielded modest, but still noticeable improvements to coordination and agility performances.

This study's theoretical contribution mainly centers on the empirically validated conceptual model explaining the interplay among ABIOS, the coordination structure, the business network performance. This study fills the gap in the smart business network literatures which often treat the enabling technology as exogenous (Vervest et al. 2009; van Heck & Vervest 2007; Lapiedra et al. 2004). From the perspective of ABIOS literatures, especially the ones on multi-agent coordination topic, this study fills the need for empirical works that complement the abundance of design-oriented papers (Carley & Gasser 1999; Patel et al. 2010; Zambonelli et al. 2015).

From a managerial perspective, this study explains the structural consequences of ABIOS applications. Note that IOS adoption is a strategic decision that requires support from multi-stakeholders. To implement ABIOS, organizations must be prepared to adjust their extant coordination structure, information structure, or both. Although coordination structure adjustments can lead to immediate improvements (as shown in the Kiva system case), overcoming stakeholders' resistance towards ABIOS implementation can be challenging. Alternatively, one may implement ABIOS that requires information architecture adjustments (as shown in the IC-system pilots).

Not without limitation, the assessment of the clients' performance improvement is done at the company level. Thus, analyzing performance at an aggregate network level is still open for research (Provan et al. 2007; Gunasekaran et al. 2008; Pau 2013). While this study focuses only on the logistics sector, analyzing the impact of the ABIOS on other business sectors may provide valuable insights. Lastly, this study offers a theoretical perspective for investigating the role of the ABIOS in the business network context. Alternative conceptual models explaining the role of the ABIOS in stimulating networked business practices are still rare and open for further development.

Chapter 4
The Design of ABIOS Coordination Mechanism[2]

4.1 Introduction

Hinterland transportation is an important element of intercontinental logistics (Acciaro & Mckinnon 2013). While the distance travelled over the land can weigh down to less than 5%, the cost related to hinterland transportation can reach above 80% of the total intercontinental logistics cost (van der Horst & de Langen 2008; Geweke & Busse 2011). As global trade business becomes competitive (United Nations 2015), traders are looking for high-performing partners, including the hinterland logistics channels, that can mediate fast, reliable, and cost-effective merchandise flows (Song et al. 2016; Notteboom et al. 2010).

With constantly increasing competition within the port hinterland transport chain communities (Frémont & Franc 2010; Notteboom et al. 2010), large fractions of the global hinterland regions can be classified as contestable (De Langen 2007; Notteboom & Yap 2012). Hence, coordination between the seaports and hinterland transport carriers becomes an important aspect for a region's competitiveness (Heaver et al. 2001; van der Horst & de Langen 2008). In response, many studies from different perspectives have analysed this highly

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[2] Parts of this chapter have appeared in the following publications:
Wasesa, M., Muhammad, I.H. & Van Heck, E., 2011. Improving the Container Terminal Performance by Incorporating Location Synchronization Module to the Pre-Notification Protocol. In *Proceedings of the 2nd International Conference on Computational Logistics*. Hamburg, Germany, p. 17.
Wasesa, M., Nijdam, P., Muhammad, I.H. & Van Heck, E., 2012. Improving the Pre-Notification Protocol of the Containers Pick-up Procedure: An Agent-based Approach. In *Proceedings of 4th International Conference on Agents and Artificial Intelligence*. Vilamoura, Portugal, p. 190–196.
This paper will be under review at an operations management journal and the author of this dissertation is the first author.

relevant issue, namely the coordination among hinterland logistics actors (van der Horst & van der Lugt 2011; Brooks et al. 2009; van der Horst & de Langen 2008).

Analysing the use of existing seaport appointment systems as the inter-organizational system (IOS) (Barrett & Konsynski 1982; Johnston & Vitale 1988) that facilitates the reservation process of containers pick-up/delivery operations (Morais & Lord 2006; Giuliano & O'Brien 2007), we propose the design of modified auction mechanism. With the decentralized coordination mechanism (Wellman et al. 2001; Wooldridge 2009), we offer a novel approach that incorporates the concern of resource allocation among self-interested stakeholders. As a validation method, we conduct agent-based simulations (Bonabeau 2002; Jennings et al. 1998) to evaluate the impact of the proposal on the operational performance of the coordinating actors, namely the seaports (the containers' retrieval and storage costs) and drayage operators (the appointment tardiness and reservation cost).

In Section 4.2, we review previous literatures on coordination initiatives in the road hinterland logistics sector and the use of agent-based approach in designing appointment systems. Section 4.3 presents review on existing conduct of containers' pick-up/delivery operation, problem identification and conceptual model proposition, and proposed modified auction mechanism. Section 4.4 presents the simulation setup and Section 4.5 presents and evaluates the performance of the proposed solution. Section 4.6 concludes and presents limitations and future research opportunities.

4.2 Literature Review

In terms of speed and flexibility, the road connection is still the most dominant and preferred way to reach hinterland destinations (Veenstra et al. 2012; Frémont & Franc 2010). Other alternatives such as trains and inland waterway vessels require more complex operations, namely additional handling and bundling operations, rigid schedules, and so on (Geweke & Busse 2011).

Due to the road connection's dominant position in hinterland transportation, stakeholders give more attention on issues of road hinterland logistics operation. Road congestion near seaports area are a common issue for many hinterland regions (Wan et al. 2013; Fan et al. 2012; Golob & Regan 2005). This very issue has brought negative effects not only for the coordinating stakeholders, i.e. the seaports and drayage trucking companies, but also for indirect stakeholders, namely the port authorities, business communities, and civil society (Heaver et al. 2001). Some of the negative effects are: the challenge of balancing resource allocation for the seaport operators, unproductive waiting time for the drayage trucks at over-utilized ports, and the trucks queues' spill over which lead to increasing road congestion and excessive air and noise pollution which is harmful to the port area's competitiveness and quality of life (Sathaye et al. 2010; Song et al. 2016; Wan et al. 2013).

4.2.1 Diversion and Non-diversion Initiatives

Initiatives to mitigate road congestions can be divided into two categories, namely the traffic diversion and non-diversion initiatives (Maguire et al. 2010; Acciaro & Mckinnon 2013). The objective of the diversion initiatives is re-directing the commodity traffic from the road to alternative transportation channels. The extended gateways (Veenstra et al. 2012; Acciaro & Mckinnon 2013) and dry ports initiatives (Cullinane et al. 2012; Ng et al. 2012) are two popular examples of the diversion initiatives. However, the implementation of diversion initiatives can be challenged by a number of concerns such as, market feasibility, financing, public-private support, political stability, the quality of barges and railways connections, and so on (Cullinane et al. 2012).

As an alternative to diversion initiatives, one may opt for non-diversion initiative options such as the extension of a seaport's service-hours and the development of seaport appointment systems (Maguire et al. 2010; Giuliano & O'Brien 2007). The extension of seaports' service-hours aims to deconcentrate the seaports' peak load by offering more off-peak service-hours. However, stimulating participation from the drayage operators to using the new service alternatives remains a challenge (Maguire et al. 2010). Another instance of non-diversion initiative is the seaport appointment system. The system is designed to facilitate the drayage operators' needs to arranging appointments for the container pick-up/delivery operations at seaports. In terms of the human capital and land acquisition spending, the appointment system initiative can be more beneficial if compared to the seaports' service-hours extension, dry-ports, or extended gateway initiatives (Giuliano et al. 2008; Maguire et al. 2010).

4.2.2 Seaport Appointment System

The seaport appointment systems have been implemented and supported with regulations in many hinterland regions, e.g. the Port of Long Beach, Port of Los Angeles, Port of Vancouver, etc (Giuliano et al. 2008; Morais & Lord 2006). Nevertheless, some evaluation reports found insignificant evidence of the system's positive impact on the reduction of congestion or air pollution at seaports (Giuliano et al. 2008; Giuliano & O'Brien 2007; Morais & Lord 2006). In the case of Port of Long Beach and Port of Los Angeles, the appointment system initiative failed to attract significant participations from the drayage operators (Giuliano et al. 2008; Morais & Lord 2006). The voluntary participation terms and deficiencies found in the appointment system design are two main factors that drive the low participation achievement (Morais & Lord 2006; Giuliano & O'Brien 2007).

Improving the design of the seaport appointment system has become an attractive research field. Using different perspectives, numerous studies have tried to analyse and improve the design deficiencies of the seaport appointment system (Phan & Kim 2016; Li et al. 2016; Islam & Zunder 2013; Asperen et al. 2011). Some studies adopt the seaports' perspective in analysing different scheduling aspects such as the impact of limiting truck arrivals, controlling the arrival of the trucks and other factors on the truck's turn time or the seaports operational efficiency (Chen et al. 2013; Huynh & Walton 2011; Guan & Liu 2009). Other studies use the drayage operators' lens in examining the impact of different scheduling parameterizations on inland carriers' operational efficiency namely, the number of appointments offering, the length of appointment's time window, access capacity measures, and so on (Zehendner & Feillet 2014; Namboothiri & Erera 2008; Ioannou et al. 2005).

Another stream of literatures investigate how different stakeholders can maximize their utility in relation to a fixed appointment system's specification. In this research stream, improving the design of the appointment system is not the primary objective. A number of studies examined different seaport operational strategies such as the container stacking, storage space allocation strategies, yard cranes strategies, etc (Zehendner et al. 2016; Petering 2015; Sharif & Huynh 2013; Borgman et al. 2010; Li et al. 2016) while others focus on the drayage operators' strategy to improve the conduct of container pick-up/delivery at seaports (Schulte et al. 2015; Máhr et al. 2010; Moonen 2009; Phan & Kim 2016).

4.2.3 The Agent-based Approach in the Appointment Systems Design

To the best of our knowledge, previous studies have attempted to improve the design and use of appointment systems using a specific actor's unique perspective (Carlo et al. 2014; Stahlbock & Voß 2007). However, appointment systems are essentially IOS that are used by multiple self-interested organizations. IOS enable information exchange across organizational boundaries to facilitate inter-organizational coordination conducts (Johnston & Vitale 1988; Cash & Konsynski 1985). An approach that incorporates the IOS and multi-stakeholders perspectives is needed to design better appointment systems. Our view is in-line with previous research findings that discovered low participation of the drayage operators in the appointment system initiatives (Giuliano et al. 2008; Morais & Lord 2006). The implemented system was mainly designed and implemented on behalf of the seaports for the main purpose of regulation compliance and less for satisfying the need to improve containers pick-up/delivery coordination operation (Giuliano et al. 2008; Giuliano & O'Brien 2007). As Giuliano & O'Brien (2007) stated explicitly, "terminal operators/ seaports have no incentive to employ practices that would reduce delays for truck drivers (other than to comply with the billed regulations). Rather, their incentive is to serve their customers (the steamship lines and major import/export companies) and manage dock operations within the constraints of longshore work rules and contract provisions"

In response, we adopt the agent-based approach (Bonabeau 2002; Jennings et al. 1998) that offers a mean to analyse complex, decentralized, and ill-structured coordination problems (Davidsson et al. 2005). The approach views a system's behaviour as an emerging resultant of the interactions among actors involved in the system. Each actor is modelled as having limited authority, information access, and influence on the whole system's behaviour (Bonabeau 2002; Jennings et al. 1998). This approach is in contrast with the approach applied in most previous studies which often assume decision makers have the authority and information needed to govern the behaviour of the whole system (Phan & Kim 2015; Phan & Kim 2016).

The agent-based approach has been applied in many logistics contexts (Lang et al. 2008; Mes et al. 2007; Máhr et al. 2010; Davidsson et al. 2005). While agent-based studies analysing the operation of seaports and drayage operators (Rebollo et al. 2000; Henesey 2004; Mes et al. 2007; Máhr et al. 2010; Sharif & Huynh 2013) are also plentiful, the ones specifically aiming to improve the design of seaport appointment systems are hard to find. To the best of our knowledge, currently there is only one recent article that adopted a decentralized approach in designing the appointment system (Phan & Kim 2015). The article proposes a negotiation mechanism to determine the container's pick-up/delivery appointment time.

While Phan and Kim (2015) has initiated the use of decentralized approach in designing the appointment system, many aspects are still open for improvements. Firstly, while the negotiation scheme is applicable for reserving appointments in a one to one (one seaport and one drayage operator) situation, a better coordination mechanism that can facilitate multiple reservations from multiple-drayage operators is needed. Secondly, the proposed negotiation scheme is evaluated using the drayage trucks' objective function, i.e. the appointment reschedule cost ant the truck's idling cost (Phan & Kim 2015). This is in contrary with the multi-stakeholder nature of the appointment system which must accommodate the concerns of both the drayage operators and the seaports. Thirdly, the numerical experiments were conducted in the absence of solid empirical grounding. In response, this study presents a modified auction coordination mechanism as a solution that can facilitate concurrent reservations, accommodate multi-stakeholders' interests, and conduct computational simulation based on real-life data.

4.3 Analysis

This section begins with an analysis of the existing container pick-up/delivery operations and the use of appointment systems in supporting the reservation process of the pick-up/delivery operations. Subsequently, we identify the problem of interest and propose a conceptual model that depicts our thinking in analysing the problem. Last but not least, we present a formalization of the corresponding solution: the modified auction mechanism.

4.3.1 Existing Containers' Pick-up/Delivery Operation

The seaport appointment system aims to improve the coordination conducts between the seaports and drayage operators in the context of containers' pick-up/delivery operation. The operation consists of two main conducts: the pre-arrival and on-arrival procedures. The pre-arrival procedure is the communication formalities that have to be finalized before a drayage operator can dispatch its truck to pick-up/deliver a container. The on-arrival procedure concerns with the physical execution of the pick-up/delivery operation. As an IOS, the appointment system currently concerns with the information exchange of the pre-arrival procedure.

Prior to executing the container pick-up/delivery operation, drayage operators need to finalize the pre-arrival procedure. The information exchange standard of the procedure is regulated by the United Nations Committee for Electronic Data Interchange for Administration, Commerce, and Transport (UNECE 2016). As Figure 4-1 shows, the drayage operator initiates the procedure by sending a pick-up/delivery permission request to the seaport using the COPINO format. The COPINO request includes the following information: the drayage operator's identity, the container's identity, the identity of the truck that will conduct the pick-up/delivery operation, and the proposed operation date.

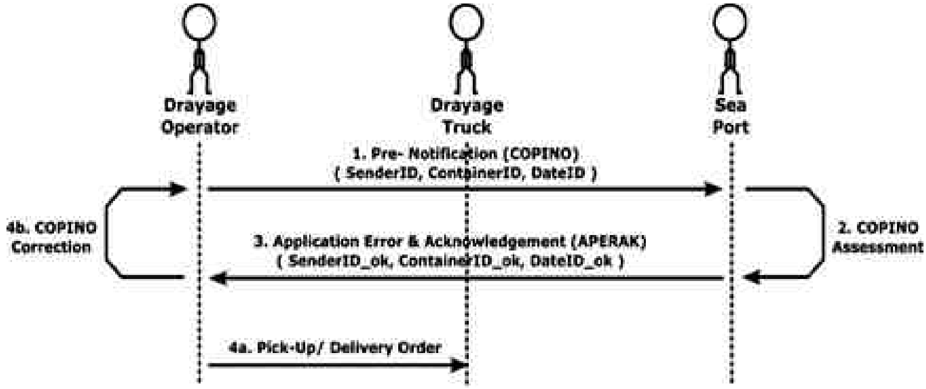

Figure 4-1. *The Existing Pre-Arrival Procedure*

Once the COPINO is received by the seaport, three main checks will be carried out, including the evaluation of the information details completeness, the presence of the container in question at the seaport's yard, and the customs clearance status. If all checks have been passed, the seaport will send a reply to the drayage operator in the form of APERAK (Application Error and Acknowledgement) message and the drayage operator can send its truck for executing the pick-up/delivery operation. If the COPINO request is rejected, a pick-up/delivery order cannot be sent. The drayage operator will review the reason for the rejection, carry out corrective actions, and re-submit the COPINO.

The pick-up/delivery on-arrival operation can only be executed after completion of the pre-arrival procedure. From the seaport's perspective, the on-arrival procedure starts when a drayage truck reaches the gate-in area. At peak hours, the trucks have to wait in a queue before receiving service at the gate. Whenever it is a truck's turn, the gate-in officer will check the truck's documentation, ensuring that the truck's pick-up/delivery service request has already been pre-registered in the seaport's EDI system via the pre-arrival procedure. Then, the officer will give permission for service and show the location of the container pick-up/delivery operation in the yard. Upon the truck's arrival at the predefined location at the seaport's yard, the truck will wait for the quay/stacker crane to come and deliver/pick-up the container. Ultimately, the truck will go to the gate-out for the final administrative formalities prior to departure.

4.3.2 The Problem Identification and Conceptual Model

In conducting the problem identification, we depart from the findings discovered during the literature review and existing system's analyses. Firstly, the appointment system facilitates the coordination of two independent actors: the seaports and drayage operators. Each actor has no dominating power to influence other's decision and each has its own objective. The drayage truck's decisions on when and how to conduct the pick-up/delivery operations are independent of the seaports' influence and vice versa. Secondly, the existing appointment system's main function is focused on clearing administrative issues, namely the truck's information detail, container's presence at the seaport, and customs and documentations clearance. The only scheduling-related information that has to be exchanged during the appointment reservation process is the drayage operator's preference on the pick-up/delivery date (Morais & Lord 2006; Giuliano & O'Brien 2007). Thirdly, most of the previous studies utilise a centralized perspective in formulating the improvement to the existing appointment system. The approach tends to omit the unaligned interests of the seaports and drayage operators (see Section 4.2.2). Fourthly, a recent study applying decentralized coordination mechanism on the seaport appointment system (Phan & Kim 2015) can still be improved from many aspects, i.e. the aspect of concurrent reservation possibilities, unaligned interest of multi-stakeholders, etc.

The research conceptual model portrays our perspective in understanding how the design of the proposed coordination mechanism will benefit the interests of participating actors (Figure 4-2). By focusing on the modified auction mechanism, we position the coordination mechanism as the independent construct. In this study, we propose two main variants of the modified auction mechanism, namely the cost-based and service-oriented schemes. Further description on each scheme can be found in Section 4.3.3.

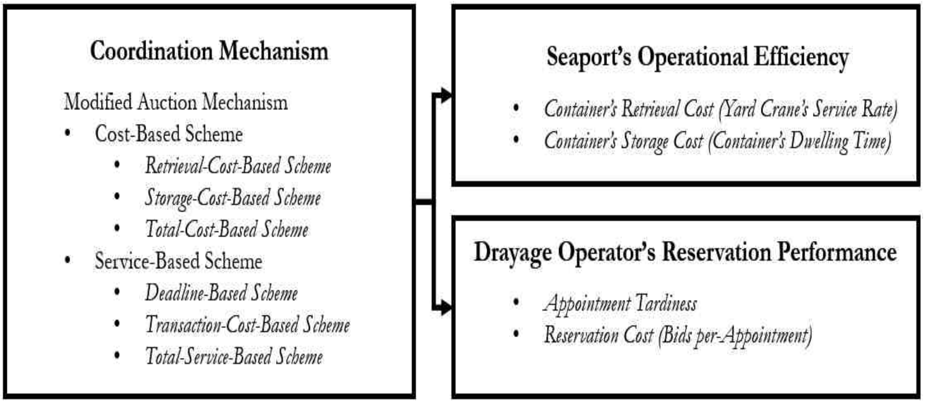

Figure 4-2. *The Research Conceptual Model*

The performance of each scheme is assessed based on two main independent constructs, namely the seaport's operational efficiency and drayage operators' reservation performance. From the seaport's perspective, we evaluate its coordination-related performance in terms of the seaport's effort to conduct a container's pick-up/delivery service (yard crane's service rate) and to store the container in the seaport's yard (container's dwelling time). From the drayage operator's perspective, we assess how well each scheme in accommodating the drayage operator's interest in getting the most preferred appointment time-slot (appointment tardiness) and the cheapest reservation costs (total bids per-finalized reservation). Detailed explanation on each evaluation criterion (i.e. yard crane's service rate, container's dwelling time, appointment tardiness, and total bids per-finalized reservation) are presented in Section 4.3.3.

4.3.3 The Modified Auction Mechanism

The modified auction mechanism is inspired by two decentralized resource allocation schemes namely the Contract Net (CNET) and the auction schemes (Wellman 1993; Smith & Davis 1981; Shoham & Leyton-Brown 2008). Known for its simplicity and clarity both schemes have become the most implemented and best-studied decentralized coordination framework (Wooldridge 2009). From the implementation perspective, applying the modified auction mechanism will require minimum adjustments on the existing Pre-Arrival procedure. We intentionally avoid radical modifications on the existing pre-arrival procedure protocol that has been regulated by the United Nations (UNECE 2016) and well accepted as the industry standard practice (Portbase 2016).

Figure 4-3 portrays a high level abstraction of the modified auction mechanism that consists of nine steps. The first two steps are in-line with the existing pre-arrival procedure (see Section 4.2.1). First, the drayage operators initiate the reservation cycle by sending the COPINO request. Second, the seaport evaluates the COPINO request in terms of the completeness of drayage operator's information, the container's presence in the seaport and custom clearance status, and the proposed date. The customization begins at step three. At the new scheme, the seaport not only sends standard APERAK message but also announces available time-slots for the requested date. Fourth, if the COPINO request is accepted, the corresponding drayage operator evaluates the time-slot alternatives and opts for the best time-slot alternative that will maximize the operator's utility (e.g. profit, service levels). Fifth, the drayage operator places a reservation request on the selected time-slot while the seaport will still receive reservation requests from other operators for the same time-slot until a specific deadline. As the deadline is reached, the seaport evaluates all reservation requests and determine the winner. Next, the seaport announces the winning reservation and remaining time-slots to the interested operators. The winning operator will then send its truck for the pick-up/delivery operation while the remaining operators will re-evaluate the remaining time-slots offering and repeat the reservation cycles.

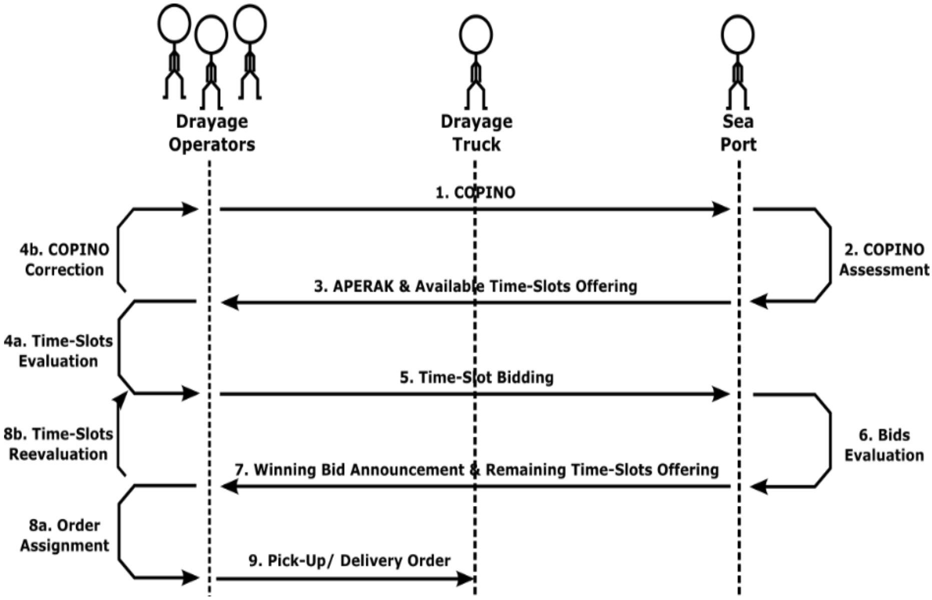

Figure 4-3. *The Pre-Arrival Procedure based on Modified Auction Mechanism*

In formalizing the modified auction mechanism, we frame the appointment reservation problem in accordance to the single-unit auction scheme (Shoham & Leyton-Brown 2008; Wellman et al. 2001). We formalize the proposed mechanism as follows:

- $O = \{o_1, \ldots, o_n\}$ is a set of n drayage operators;
- $T = \{t_1^1, \ldots, t_m^s\}$ is a set of m available time-slots in a day. The s index indicates the seaport's capacity, e.g. number of active yard blocks. Suppose the time-slot length is set to $l_t = 30$ minutes. For a single server seaport ($s = 1$) that runs 24 hours, the first time-slot t_1^1 starts at 00:00 and ends at 00:30 and the last

time-slot (m = 24 hours/0.5 Hours = 48) t_{48}^1 starts at 23:30 and ends at 24:00;

- d is the minimum period to book a time-slot and $t_{d\to j}$ is the deadline to reserve time-slot t_j^x, where $t_{d\to j} = t_j^x - (d.l_t)$. Suppose, the seaport set d = 4 and l_t = 30 minutes. At $t_{d\to j} = t_j^x - 2$ hours, the seaport will no longer accept any reservation request for t_j^x. At the same time $t_{d\to j}$, the seaport starts the evaluation of all incoming reservations for t_j^x.
- $\Theta_i = \{\Phi_{i\to 1}, \ldots, \Phi_{i\to z}\}$ is a set of pick/up delivery orders of the drayage operator o_i that have to be finalized within a specific day. The index of z in $\Phi_{i\to z}$ indicates the deadline for executing the order. For instance, $\Phi_{i\to 7}$ means the drayage operator o_i has to execute $\Phi_{i\to 7}$ at the latest at t_7^s;
- $\bar{T}, \bar{T} \subseteq T$, is a set of un-reserved time-slots (see Step 3 and Step 7 of Figure 4-3);
- $v_{i\to z}(\bar{T})$ is the valuation function of the drayage operator o_i to determine the best time-slot $\overline{t_{i\to j}^x}$ for executing $\Phi_{i\to z}$ (see Step 4a and Step 8b of Figure 4-3). The $v_{i\to z}(\bar{T})$ enumerates the utility for each $t_j^x \in \bar{T}$. The $v_{i\to z}(t_j^x)$ is defined as follows:

$$v_{i\to z}(t_j^x) = \begin{cases} r_i - \propto_{\Phi_{i-z}}.q_i, & j \le z \\ r_i - \propto_{\Phi_{i-z}}.q_i - p_i.(j-z), & z < j \end{cases} \quad \textbf{\textit{(1)}}$$

The $v_{i\to z}(t_j^x)$ consists of the drayage operator's revenue r_i from the pick-up/delivery fee, the reservation cost $\propto_{\Phi_{i-z}}.q_i$ that has to be spent each time the drayage operator place a reservation request (bid), and the penalty cost $p_i.(j-z)$ that the drayage operator pay to its costumer for conducting late pick-up/delivery operation $\Phi_{i\to z}$ where $z < j$;

- $\overline{t_{i\to j}^x}$ is the drayage operator o_i estimation of the best time-slot t_j^x to conduct $\Phi_{i\to z}$. Based on the calculation of $\overline{t_{i\to j}^x}$ (using

Equation 1), operator o_i requests for $\overline{t_j^x}$ at the bidding phase (see Step 5 of Figure 4-3);

- $c(\overline{T_j^x})$ defines the seaport's rationale to determining the winning reservation for t_j^x (see Step 6 of Figure 4-3). $c(\overline{T_j^x})$ enumerates the utility of each reservation request $\overline{t_{i\to j}^x}$ from all operators O_j that bid for t_j^x, $O_j \in O$. We consider two major schemes to determine the winning reservation request, namely the cost-based and service-based schemes. In the cost-based scheme, the winning appointment request $\Phi_{i\to z}$ is the one requiring the least operational cost $c(\overline{t_{i\to j}^x})$. We define the complete operational cost $c(\overline{t_{i\to j}^x})$ as follows:

$$c(\overline{t_{i\to j}^x}) = c_\alpha(\overline{t_{i\to j}^x}) + c_\beta\,(\overline{t_{i\to j}^x}) \qquad \textbf{\textit{(2a)}}$$

We define $c(\overline{t_{i\to j}^x})$ as a function of the container's storage $c_\alpha(\overline{t_{i\to j}^x})$ and retrieval cost $c_\beta\,(\overline{t_{i\to j}^x})$. The container's storage cost $c_\alpha(\overline{t_{i\to j}^x})$ indicates the seaport's spending in securing the storage of the container $\Phi_{i\to z}$ in the seaport's yard. The magnitude of $c_\alpha(\overline{t_{i\to j}^x})$ is a linear function of the container's dwelling duration, i.e. the duration the container remained in the terminal's yard area/ the difference between the container's time of arrival and time of departure at the yard. The container's retrieval cost $c_\beta\,(\overline{t_{i\to j}^x})$ reflects the seaport's effort to move a container inside/outside the seaport yard. We infer $c_\beta\,(\overline{t_{i\to j}^x})$ from a server's (i.e. yard crane) occupancy in serving an order $\Phi_{i\to z}$, i.e., we measure how long a crane is occupied to serve a container pick-up/delivery order; In the service-based scheme, we highlight the seaport's concern in providing better service for the drayage operators. We abstract with the drayage operator's objective to minimizing reservation costs $\propto_{\Phi_{i-z}}.\, q_i$ and late pick-up/delivery penalties $p_i.\,(z-j)$. Accordingly, we define the utility of the second scheme as follows:

$$c\left(\overline{t_{i\rightarrow j}^{x}}\right) = \propto_{\Phi_{i-z}} . q_i + p_i . (z - j) \quad \textbf{(2b)}$$

- $t_{i\rightarrow j}^{x}$ is the winning reservation for which the requested order $\Phi_{i\rightarrow z}$ gives the least cost (see Equations 2a and 2b). Note, that $t_{i\rightarrow j}^{x}$ is not the same as $\overline{t_{i\rightarrow j}^{x}}$. While $t_{i\rightarrow j}^{x}$ indicates a granted appointment, $\overline{t_{i\rightarrow j}^{x}}$ indicates an appointment request (see Step 7 of Figure 4-3).
- $\bar{T} \leftarrow \bar{T} - \{t_{i\rightarrow j}^{x}\}$ shows the updating process of the un-reserved time-slots list. This list is updated each time a reservation cycle ends (see Step 7 of Figure 4-3).

For detailed reference on the notations, Section 4.7 display the summary of notation.

4.4 Simulation Setup

To evaluate the proposed mechanisms, we select an agent-based simulation method which provides us a natural way to model, experiment, and analyse the proposed decentralized mechanisms (Bonabeau 2002; Carley & Gasser 1999). We use NetLogo (Wilensky 1999), a freeware multi-agent modelling package, to develop the simulation model. As a test case, we select one of the biggest seaports in Rotterdam (Borgman 2009; Portbase 2016; Asperen et al. 2011). We have croschecked that the analysed Pre-arrival procedure is similar with the one applied in Rotterdam (Portbase 2016).

We model the reservation proces as a single-server queuing system (Guan & Liu 2009). The objective is to put clear focus on the impact of the coordination mechanism and eliminate unintended effects, such as servers interference, load balancing, etc, that can appear if we model the system with multi-servers queuing system. For the simulation, we adopt detailed empirical data and technical specifications concerning the respondent seaport from the work of Borgman (2009). Table 4-1 enlists detailed information on the seaport's specification e.g. the containers' arrival rate from the vessel, yard crane's technical specification related to the container's pick-up/delivery service (e.g. hoist speed, trolley speed, gantry speed), and the container yard's dimension.

Table 4-1. *The Simulation Parameters.*

Parameters	Values
Containers' Arrival Rate (containers/hour)	5.44
Yard Crane Specification	
Hoist Speed with Load (m/min)	56
Hoist Speed without Load (m/min)	28
Trolley Speed (m/min)	70
Gantry Speed with Load (m/min)	130
Gantry Speed without Load (m/min)	70
Container Yard's Dimension	
Length (m)	243.84
Width (m)	24.38
Rows (containers)	20
Stack (containers)	10
Max Pile (containers)	5

The simulation experiments assess the performance of two major schemes of the proposed modified auction mechanism, namely the cost-based and service-based schemes. We decompose each scheme into three variants. Each variant has different criteria to determine the winning reservation request. For the cost-based scheme the variants are: the retrieval-cost-based (RCB, $t_{i \to j}^{x} \leftarrow$ arg.min $[c_\beta\,(\overline{t_{i \to j}^{x}})]$), storage-cost-based (SCB, $t_{i \to j}^{x} \leftarrow$ arg.min $[c_\alpha(\overline{t_{i \to j}^{x}})]$), and total-cost-based (TCB, $t_{i \to j}^{x} \leftarrow$ arg.min $[c_\alpha(\overline{t_{i \to j}^{x}}) + c_\beta\,(\overline{t_{i \to j}^{x}})]$). For the service-based scheme the variants are: the reservation-service-based (RSB, $t_{i \to j}^{x} \leftarrow$ arg.min $[\propto_{\Phi_{i-z}}.\, q_i]$), deadline-service-based (DSB, $t_{i \to j}^{x} \leftarrow$ arg.min $[p_i.\,(z-j)]$), and total-service-based (TSB, $t_{i \to j}^{x} \leftarrow$ arg.min $[\propto_{\Phi_{i-z}}.\, q_i + p_i.\,(z-j)]$) variants.

For each scheme, we also investigate the effect of the reservation deadline d setting on the performance measures. Each coordination variant is simulated in four conditions namely $d = 0$, $d = 4$ (2 hours), $d = 12$ (6 hours), and, $d = 24$ (12 hours). The appointment time-slot length is set to $l_t = 30$ minutes. For each experimentat (coordination variant -deadline pairs), we run 10 replications with a warmup period of 3 days (3*24 hours) and effective running period of 7 days (7*24 hours). We evaluate each experimentat based on four metrics namely, the container's retrieval cost (yard crane's service time), container's storage cost (dwelling time), reservation cost (number of bids), and lateness cost (appointment tardiness). Table 4-2 portrays the overview of the simulation experimental setup.

Table 4-2. *The Simulation Setup.*

Variable	Setup
Warm-up Period	3 days (3*24 hours)
Simulation Length	7 days (7*24 hours)
Simulation Replications	10
Auction Schemes	retrieval-cost-based (RCB); storage-cost-based (SCB); total-cost-based (TCB); reservation-service-based (RSB); deadline-service-based (RSB); total-service-based (TSB) schemes
Reservation Deadline, d	$d = 0$; $d = 4$ (2 hours); $d = 12$ (6 hours); $d = 24$ (12 hours)
Appointment Slot Length, l_t	$l_t = 30$ minutes
Dependent Variables	Container's retrieval cost (service time), container's storage cost (dwelling time), reservation cost (number of bids), and lateness cost (appointment tardiness)

As shown in Figure 4-4, we model a single block of containers yard served by a single yard crane (server). At the beginning of the simulation, the yard block layout is generated. During the simulation run, the simulation engine periodically generates the containers and place them on the yard. In parallel, the simulation engine also generates the drayage company's appointment requests. The appointment reservation conducts follow the modified auction mechanism as described in Section 4.3.3. Once the container is reserved, it will be picked up by the yard crane from the yard on its location on the specified appointment time. Extra work, such as reshuffling operations, might be required if the requested container sits beneath other containers. As the container is picked up, the simulation output statistics will be recorded and then both the container and corresponding reservation entities will be deleted from the simulation engine's memory.

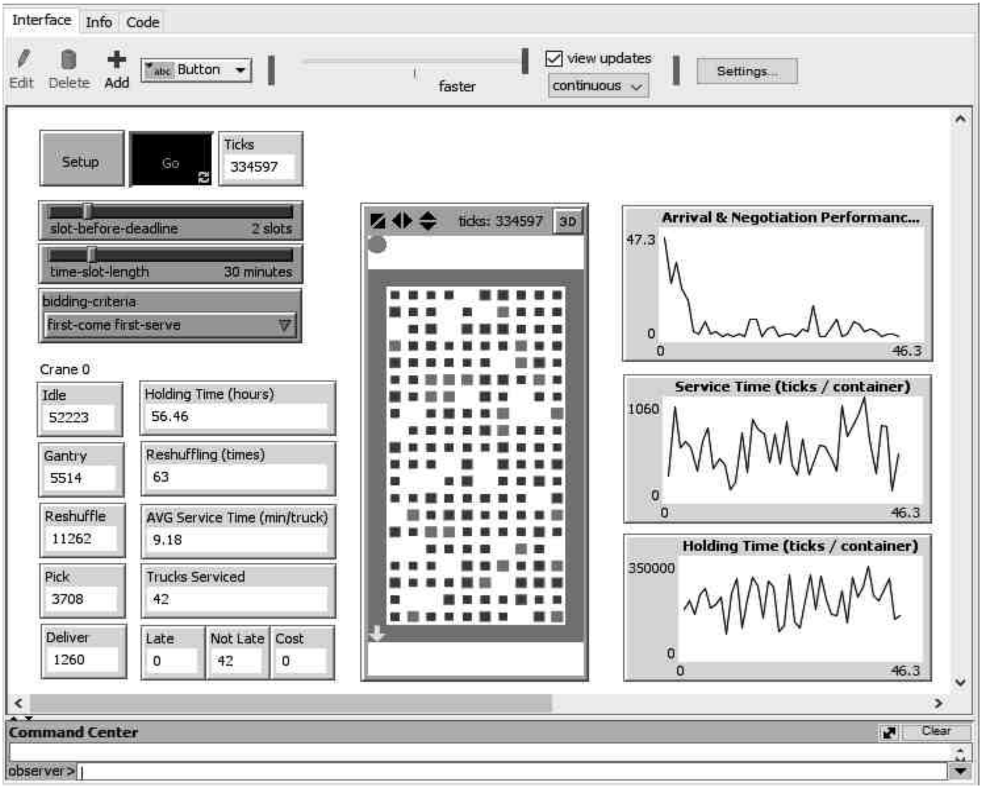

Figure 4-4. *Simulation Model Visualization.*

4.5 Results

Table 4-3 portrays the overview of the simulation results. For convenience of the reader, we illustrate the results of Table 4-3 by portraying several box-plot graphs that will make the interpretation task easier.

Table 4-3. *The Overview of the Simulation Results.*

	Retrieval Cost (Minutes)		Storage Cost (Days)		Reservation Cost (# Bids)		Appointment Tardiness (Hours)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Retrieval-Cost Based								
d = 0	8.96	4.44	3.43	2.11	7.76	11.55	33.13	39.87
d = 2	8.73	4.44	3.49	2.07	8.16	12.04	38.53	41.54
d = 6	8.72	4.33	3.38	2.06	9.36	13.85	42.21	42.35
d = 12	8.49	4.18	3.47	2.27	12.76	18.81	59.17	44.51
Storage-Cost Based								
d = 0	9.80	4.94	3.58	1.14	7.57	12.34	26.79	19.45
d = 2	10.05	5.07	3.46	1.05	8.67	14.03	28.90	17.12
d = 6	10.01	5.07	3.33	1.10	11.13	17.93	27.10	15.07
d = 12	10.03	5.03	3.50	0.99	23.00	35.23	31.35	15.65
Total-Cost Based								
d = 0	9.87	5.50	3.58	1.37	19.90	29.42	27.91	26.26
d = 2	9.93	5.24	3.63	1.35	17.40	28.12	32.92	26.05
d = 6	9.85	5.40	3.49	1.37	21.26	32.39	31.66	24.53
d = 12	9.71	5.14	3.37	1.26	40.18	52.66	33.90	25.44
Deadline Based								
d = 0	10.25	5.14	3.67	1.69	55.62	33.17	16.49	9.19
d = 2	9.68	4.97	3.50	1.65	55.62	33.17	15.27	8.71
d = 6	9.51	4.47	3.29	1.66	57.61	33.17	13.77	7.42
d = 12	9.73	5.22	3.43	1.61	80.90	34.49	13.85	7.40
Transaction Cost Based								
d = 0	10.29	5.22	3.55	1.56	55.55	33.17	16.58	9.16
d = 2	10.11	5.33	3.55	1.68	55.62	33.17	15.24	8.73
d = 6	10.22	5.20	3.38	1.63	57.61	33.17	13.77	7.45
d = 12	9.94	4.99	3.36	1.68	80.90	34.49	13.77	7.42
Total-Service Based								
d = 0	9.59	4.96	3.50	1.61	55.55	33.17	16.50	9.17
d = 2	9.81	4.89	3.50	1.61	55.62	33.17	15.25	8.71
d = 6	9.72	5.07	3.36	1.69	57.61	33.17	13.76	7.45
d = 12	9.88	4.92	3.33	1.55	80.90	34.49	13.76	7.43

In terms of the container's retrieval cost (see Figure 4-5), the best performing scheme is the retrieval-cost-based scheme (RCB). In the RCB scheme, the yard crane's occupancy can go down to less than 8.49 minutes per-single container retrieval operation (see Table 4-2). At other schemes, the yard crane's occupancy can go up to 10.29 minutes per-single service. The outcome is in line with the RCB scheme design that positions the container's retrieval cost as the main priority in determining the winning reservation requests.

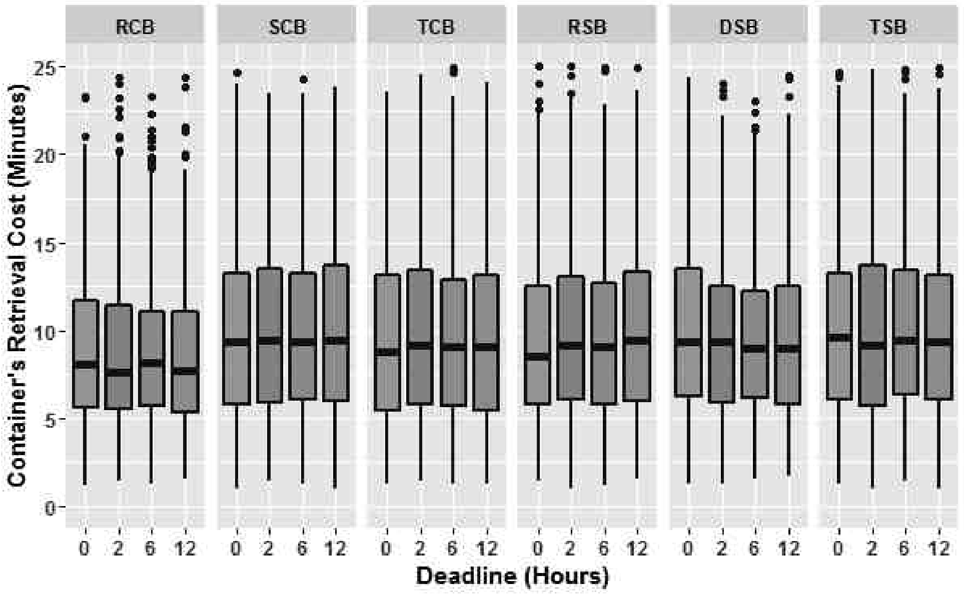

Figure 4-5. *The Retrieval Cost of the Modified Auction Mechanisms.*

In terms of the container's storage cost, the performance of all auction schemes are indistinguishable (Figure 4-6). The size of reservation slots that is set to 30 minutes is too small when compared to the increments of the dwelling time performance which variance is measured in terms of days. Thus, no reservation scheme can bring noticeable difference. Nevertheless, the SCB scheme performs the most consistent dwelling time. The standard deviation value of the SCB storage cost can go down to 0.99 days. In contrast, the storage cost records of the RCB scheme are more volatile. Its standard deviation value can go up to 2.27 days. In Figure 4-6, we can also see that the setting of the reservation deadline parameter, d, have a positive impact on the dwelling time period of the TCB and TSB schemes. In both schemes, the dwelling time tends to go lower as the reservation deadline parameter, d, is set to a higher value.

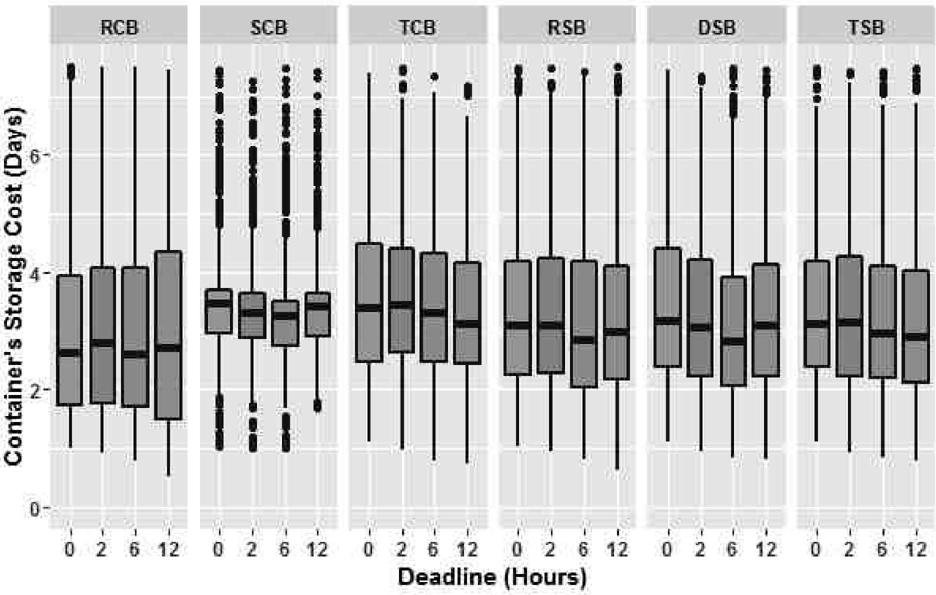

Figure 4-6. *The Storage Cost of the Modified Auction Mechanisms.*

Analysing the service metrics, we can see that all three service-based schemes, namely the RSB, DSB, and TSB, have the best performance in terms of the appointment reservations' tardiness (see Figure 4-7). In contrast, the applications of cost-based schemes, namely the RCB, SCB, and TCB, can lead to poorer and more volatile performance. Moreover, we notice that the setting of the reservation deadline parameter, d, have opposite effects if applied in the cost-based and service-based schemes. In the cost-based-schemes, the tardiness goes higher as the deadline parameter, d, is set to a higher value. Conversely, in the service-based schemes the tardiness decreases as the deadline parameter, d, is set to a higher value.

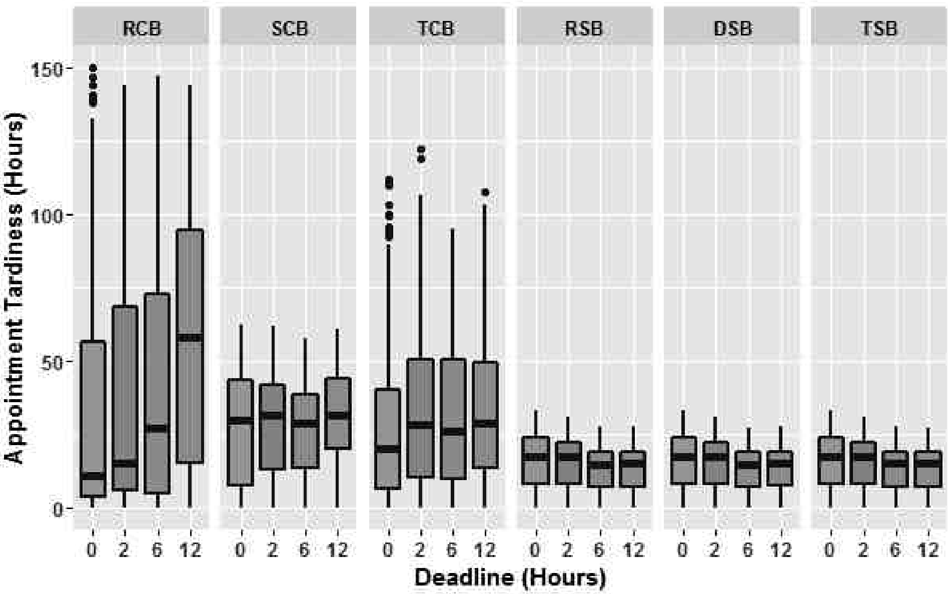

Figure 4-7. *Appointment Tardiness of the Modified Auction Mechanisms.*

While the service-based schemes have the best performance in terms of the appointment reservation tardiness, both seaports and drayage operators have to be prepared to conduct high frequency reservation operations. Figure 4-8 shows the reservation cost performance of the reservation schemes. There we can see that all service-based schemes require significantly higher number of bids to secure the most-preferred reservation time-slot. In contrast, in the cost based schemes, the drayage operators do not have to conduct many reservation iteration cycles to secure a reservation time-slot. As predicted, for any scheme the number of reservation cost goes in-line with the setting of the reservation deadline parameter, d. With higher setting of reservation deadline parameter, d, drayage operators will have more time to adjust and iterate their reservation requests in order to get the most preferred time-slot for the pick-up/delivery operation.

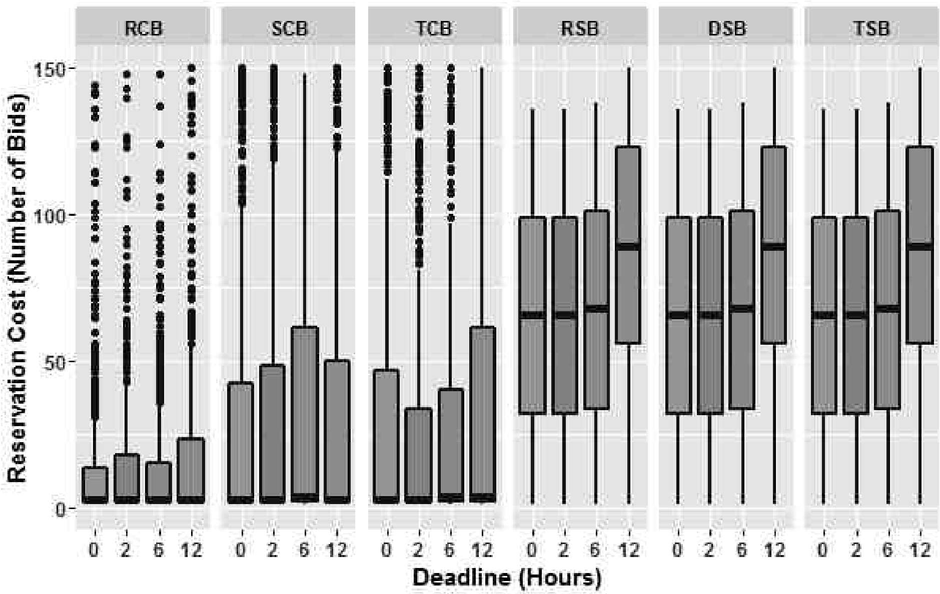

Figure 4-8. *The Reservation Cost of the Modified Auction Mechanisms.*

4.6 Concluding Remarks

This study aims to provide an alternative solution to the appointment reservation problem which concerns two self-interested business actors, namely the seaport terminals and drayage operators. We develop two major variants of the modified auction mechanism, namely the cost-based and service-oriented schemes and evaluate their performance in terms of the seaport's operational efficiency (the container's retrieval and storage costs) and drayage operators' reservation performance (the reservation costs and appointment tardiness). The applications of the retrieval-cost-based scheme offer the cheapest container's retrieval cost and the applications of the storage-cost-based scheme produce the most consistent container's dwelling time performance. On the other hand, the applications of the service-based-schemes bring superior appointment tardiness performance at the cost of high-frequency reservation cycles. The paper shows that different coordination mechanisms, that deploy different winner determination rules, will produce different performance outcomes.

From a practical point of view, the paper aims to increase the awareness of the importance of decentralized approaches in designing better coordination mechanisms facilitating collaboration among self-interested actors. While this paper has not investigated the relationships among the design of the ABIOS coordination mechanism, ABIOS adoption rate, and incentive alignments of the ABIOS users, we strongly believe, that ignoring the interests of the multiple stakeholders concern can lead to the stakeholder's low participation to the proposed appointment system initiative. Analysing the simulation results, we can see the growing potential of intelligent software agents that can assist the users in conducting high-frequency transactions. In a decentralized coordination mechanism scheme, the ability to communicate, iterate, and making decisions at a rapid pace will determine a company's competitive advantage. From a research point of view, this study corresponds to the research scarcity on the topic of decentralized approach in the design of seaport appointment systems. In response, this study offers an unexplored solution that can facilitate concurrent reservations and accommodate multi-stakeholders' interests.

This study has a number of limitations which open opportunities for further research. First, this study positions the seaport terminals as the "auctioneers" that have the right to determine the winning reservation for a time slot. This authority right may be misused for the seaport's own benefit and thus further investigations are needed to determine the best stakeholder and corresponding mechanism that can provide a win-win situation for all coordinating participants. Secondly, we simplify the modelling of the reservation schemes in accordance to the single-unit auction model. While our model offers an important milestone for the development of decentralized coordination mechanism in the seaport appointment system's context, one may model the reservation schemes using more complex models such as multi-unit auctions, combinatorial auctions, etc. In addition, one can do detailed investigations on the impact of different settings of auction parameters on varios dimensions of performance. Thirdly, our service-based auction scheme requires the disclosure of the information of the pick-up/delivery operation deadline from the drayage operators. Fourthly, we do simplify the formulation of the seaports' and drayage operators' utility functions. Notwithstanding our effort to abstract the coordinating actors' interests, the utility functions can be further refined. The enlisted limitations are surely not extensive and many opportunities can still be explored to develop better reservation schemes.

4.7 Summary of Notation

Symbol	Definition
o_i	Drayage operator i
i	The drayage operator's identifier
$O = \{o_1, \dots, o_n\}$	A set of n drayage operators
$T = \{t_1^1, \dots, t_m^s\}$	A set of m available time-slots in a day
s	The seaport's capacity (number of active yard blocks)
m	Maximum reservable time-slots in a day
t_j^x	Time-slot for period j at the yard block x
l_t	The time-slot length
d	The minimum period to book a time-slot
$t_{d\to j}$	The deadline to reserve time-slot t_j^x
j	The time-slot's identifier
$\Theta_i = \{\Phi_{i\to 1}, \dots, \Phi_{i\to z}\}$	A set of pick/up delivery orders of the drayage operator o_i that have to be finalized in a day.
z	The deadline for executing the order $\Phi_{i\to z}$
$\bar{T}, \bar{T} \subseteq T$	A set of un-reserved time-slots
$v_{i\to z}(\bar{T})$	The valuation function of the drayage operator o_i to determine the best time-slot $\overline{t_{i\to j}^x}$ for executing $\Phi_{i\to z}$
r_i	The drayage operator's revenue (pick-up/delivery fee)
$\propto_{\Phi_{i-z}} . q_i$	The total reservation cost
$\propto_{\Phi_{i-z}}$	The reservation fee
q_i	Number of bids attempted to finalize the reservation

$p_i.(z-j)$	The penalty cost for late pick-up/delivery operation $\Phi_{i\to z}$ where $j<z$;
$t^x_{i\to j}$	*T*he drayage operator o_i estimation of the best time-slot to conduct $\Phi_{i\to z}$
$c(\overline{T^x_J})$	*T*he seaport's rationale to determining the winning reservation for t^x_j
$c_\alpha(\overline{t^x_{i\to J}})$	The container's storage cost for $\Phi_{i\to z}$
$c_\beta\ (\overline{t^x_{i\to J}})$	The container's retrieval cost for $\Phi_{i\to z}$
$t^x_{i\to j}$	*T*he winning reservation for the requested order $\Phi_{i\to z}$

Chapter 5
The Design of ABIOS Predictive Analytics[3]

5.1 Introduction

In many parts of the world, road congestion near seaports is a common issue (Chen et al. 2013; Acciaro & Mckinnon 2013). This very issue has led to a number of problems, namely the challenge of balancing resource utilization for the seaport operators, unproductive waiting time for the drayage trucks at over-utilized ports, queues of trucks increasing road congestion and generating excessive pollution, and so on (Sathaye et al. 2010). The problems are becoming more severe as more shipping lines use bigger vessels (Midoro et al. 2005; Ursavas 2014) and as roads around port perimeters become more congested by commuter and freight traffic (van der Horst & de Langen 2008).

Infrastructure expansion initiatives are expensive, thus many alternatives have been proposed to mitigate the effects of congestion near seaports (Maguire et al. 2010; Acciaro & Mckinnon 2013). Existing road-traffic mitigation initiatives can be classified into two categories: diversion and non-diversion. Diversion initiatives, namely extended gate (Veenstra et al. 2012) and dry port initiatives (Roso & Lumsden 2010; Cullinane et al. 2012), aim to divert the road commodity flow onto alternative channels such as rail or inland waterways. Not without consequences, diversion initiatives are associated with

[3] Parts of this chapter have appeared in the following publications:
Wasesa, M., Stam, A. & Van Heck, E., 2014. Reinventing the Use of Vehicle Telematics Data: Using Multivariate Adaptive Regression Splines Model for Predicting the Container Terminal's Service Rate. In *Proceedings of 6th International Conference on Operations and Supply Chain Management*. Bali, Indonesia, p. 79–89.
Wasesa, M., Stam, A. & van Heck, E., 2017. The Seaport Service Rate Prediction System: Using Drayage Truck Trajectory Data to Predict Seaport Service Rates. *Decision Support Systems*, 95, p.37-48.

considerable implementation challenges such as business feasibility, public-private support, and infrastructure preparedness (Cullinane et al. 2012).

Non-diversion initiatives focus on improving the working condition of the seaport itself. In this category, popular initiatives include the extension of the seaport gate's opening hours and the improvement of the seaport gate appointment system (Maguire et al. 2010). The initiative to extend the seaport gate's opening hours aims to de-concentrate the peak load by offering more off-peak working hours. However, it is not easy to provide clear incentives to the drayage operators to use the new opening-hour alternatives and to persuade both the consignors and the consignees to accommodate the extended schedule (Maguire et al. 2010).

Alternatively, a gate appointment system can be used to monitor the arrival of trucks, mitigate load during a seaport's peak period, reduce road congestion, and improve resource utilization (Maguire et al. 2010; Giuliano et al. 2008). This initiative is less expensive than the gate extension initiative in terms of the human capital and land acquisition spending (Maguire et al. 2010; Giuliano & O'Brien 2007). However, some articles (Giuliano & O'Brien 2007; Morais & Lord 2006) have reported that existing systems deliver decent impact in mitigating the congestion of seaport roads. The systems were mainly used to retrieve information concerning commodities clearance status and were perceived as having minimum impact on improving container pick-up/delivery operations (Larsen 2009; Giuliano et al. 2008). The negative issues with appointment systems (Giuliano et al. 2008; Larsen 2009) have resulted in low participation from drayage operators.

In this study, we focus on how drayage operators can apply predictive analytic techniques to their data assets to extract better insights and improve their operational decision making (Hastie et al. 2011). Doing this, we can circumvent the need to modify the design of the existing appointment system. We approach the problem from the drayage operators' perspective that seeks to minimize the loading/unloading time at seaports, and we consider the drayage operators' wealth of trajectory data, mined from the subordinate trucks' telematics system (Baumgartner et al. 2008; Crainic et al. 2009), as a valuable resource for evaluating a seaport's service rate. The objective of this study is to present a seaport service rate prediction system that uses the trajectory data communicated through the drayage trucks' telematics devices.

In Section 5.2, we review the literature on predictive analytics and seaport appointment systems including the potential usage of predictive analytics. Section 5.3 presents the service rate prediction system framework and its step-wise approach. In Section 5.4, we present the background of the case study in the Port of Rotterdam and the used datasets and Section 5.5 presents and evaluates the results of the service-rate prediction system. Section 5.6 concludes and presents limitations and future research.

5.2 Literature Review

The use of predictive analytics (Shmueli & Koppius 2011) to improve business operations has received increasing attention from both the research and business communities (Watson & Wixom 2007; Chen et al. 2012). Technological artefacts that can access and synthesize large volumes of data to produce useful operational insights are in demand (Chen et al. 2012; Watson & Wixom 2007). On the technological side, the ubiquity of powerful sensing technologies (Kortuem et al. 2010) and the increasing use of predictive analytics (Shmueli & Koppius 2011) have stimulated the development of novel and better predictive systems. Despite the increasing development of predictive systems, studies that focus on the container pick-up/delivery operations context are rare.

5.2.1 Related Literatures on Predictive Analytics

Predictive analytics strengthen business intelligence (BI) systems' feature in providing quality inputs to support operational decision-making process by delivering the right information at the right moment, at the right place, and in the right forms (Negash 2004; Watson & Wixom 2007; Chen et al.

2012). Note that, the BI systems concept can be seen as similar to the integrated decision support systems concept which positions data warehouses as inseparable component of intelligent decision support systems (March & Hevner 2007). Predictive analytics enhance the data retrieval capabilities of BI systems through statistical models or empirical methods that are aimed at creating and assessing empirical predictions (Hastie et al. 2011; Shmueli & Koppius 2011). Unlike the conventional statistical modeling approach, predictive analytics aim to develop a prediction inference with pragmatic business relevance (Hastie et al. 2011; Shmueli & Koppius 2011).

More recently, the application of predictive analytics to novel data sources (from sensor to social media data) has received increasing interest (Watson & Wixom 2007; Chen et al. 2012). While predictive analytics development using data contents from database management systems (DBMS) or the web are plentiful, a study indicated that the underlying mobile analytics and location, and context-aware techniques for collecting, processing, analyzing, and visualizing these mobile and sensor data are largely unexplored (Chen et al. 2012). Making use of the vehicle telematics trajectory data, this study responds to the high demand for predictive analytics that process sensor-based data. While the development of data mining techniques to analyzing vehicles trajectory datasets has been well researched (Eagle & Pentland 2009; Uno et al. 2009; Zheng 2015), building predictive analytics to support operational decision making is still an under-researched field (Herrera et al. 2010; Hiribarren & Herrera 2014; Sun & Ban 2013).

5.2.2 Seaport Appointment Systems and Predictive Analytics

Many stakeholders perceived seaport appointment systems to yield a minimal improvement to container pick-up/delivery operations (Giuliano & O'Brien 2007; Morais & Lord 2006). Both seaports and drayage trucking companies are two primary users of the appointment system. Port authorities, local governments, and the people living around seaports are some of the secondary stakeholders who receive negative externalities from the system's deficiencies. Dissatisfaction with appointment system design has evoked many further research initiatives that aim to improve upon the system's design limitations (Hu & Sheng 2014; Chen et al. 2013; Giuliano & O'Brien 2007; Huynh & Walton 2011; Namboothiri & Erera 2008). Since the design of the appointment system concerns the interest of multiple stakeholders, different studies have analyzed the design factors most relevant to the interests of specific stakeholders (Bandeira et al. 2009; Li et al. 2016; Phan & Kim 2015; Huynh & Walton 2011; Namboothiri & Erera 2008).

Some studies analyzed the design from the seaport's point of view (Murty et al. 2005; Huynh & Walton 2011), focusing on the impact of limiting truck arrivals at seaports on truck turn time and yard crane utilization (Huynh et al. 2005), the impact of adjusting the number of trucks allowed to enter the seaport per period (Huynh & Walton 2011), the number of truck appointments to offer and resource allocation (Zehendner & Feillet 2014), the seaport's service line configuration (Guan & Liu 2009), the truck arrival disruption management concern (Li et al. 2016), and so on. Some studies analyzed the design from the drayage operators' perspective (Hu & Sheng 2014), focusing on how access capacity and the parameters of appointment time windows influence the productivity of drayage trucks (Namboothiri & Erera 2008), the definition of optimum pick-up/delivery time window parameters (Ioannou et al. 2005), and so on (Bandeira et al. 2009). Some studies analyzed the design of appointment systems with the goal to synchronize the operations of barges and seaports through distributed planning method (Douma 2008; Douma & Mes 2012). Other studies considered information visibility, specifically the fact that seaports have limited information about trucks before they arrive and vice versa (Zhao & Goodchild 2010; Hu & Sheng 2014). It is not trivial to achieve clear benefit propositions for all stakeholders (particularly seaports and drayage trucking companies) when modifying the design of the appointment system. Despite extensive studies on appointment system design, the affected stakeholders do not always agree to apply the recommended changes. Modifying an existing appointment system may require radical adjustments to stakeholders' existing operations. Factors such as the stakeholders' view of the prospective costs and benefits, strategic considerations, and unwillingness to invest can prevent them from supporting proposed alterations to the appointment system (van der Horst & de Langen 2008).

To circumvent the need to modify the appointment system's design, companies can explore the opportunity to use their internal data assets to extract better insights and improve their operational decision making using predictive analytics (Watson & Wixom 2007; Hastie et al. 2011; Chen et al. 2012). While predictive analytics techniques have been applied in many transportation contexts (Bin et al. 2006; Jula et al. 2008; van der Spoel et al. 2015; Fei et al. 2011; Qi & Ishak 2014), to the best of our knowledge, this approach has not been applied in any research initiative aiming to improve the container pick-up/delivery operations, especially the ones that correlated with the truck appointment system initiatives. As shown in Table 5-1, previous studies focused on predicting the productivity performance of the seaports seaside operations namely, container-handling throughput or ship working rate values (Tongzon 2001; Fung 2001; Cullinane et al. 2006; Chen & Chen 2010; Geng et al. 2015). In general, those studies used yearly/monthly statistical archives to build predictions to supporting strategic or socioeconomic decisions. In contrast, this study focuses on the seaports' landside productivity using sensor-based trajectory dataset that is updated every few minutes to supporting drayage operators' operational decisions.

Table 5-1. *Related Articles on Seaport Productivity Prediction*

Article	Predicted Variables	Predictors	Model
(Tongzon 2001)	Cargo Throughput (TEUs/year); Ship Working Rate (TEUs/hour)	Number of Cranes; Number of Berths; Number of Tugs; Service Delay (hour); Port Area (m^2); Stevedoring Labor (employees)	Data Envelopment Analysis
(Fung 2001)	Cargo Throughput (TEUs/year)	Cargo Throughput (TEUs/year); Foreign Trade Value (million USD); Port Tariff (USD)	Structural Vector Error Correction Model
(de Koster et al. 2009)	Cargo Throughput (TEUs/year)	Number of Quayside Gantry Cranes, Total Quay Length (m), Terminal area (hectare)	Data Envelopment Analysis
(Cullinane et al. 2006)	Seaport Efficiency Scale (0 - 1)	Port Length (m); Terminal Area (ha); Number of Quayside Gantry Cranes; Number of Yard Gantry Cranes; Number of Straddle Carrier	Data Envelopment & Stochastic Frontier Analyses
(Chen & Chen 2010)	Cargo Throughput (TEUs/ month)	Cargo Throughput (TEUs/month)	Genetic Programming; Decomposition Approach; Seasonal Auto Regression Integrated Moving Average
(Geng et al. 2015)	Cargo Throughput (TEUs/year)	Gross Domestic Product (CNY); Fixed Assets Investment (CNY); Imports & Exports Value (USD); Industrial Output (CNY); Primary, Secondary, and Tertiary Industrial Value (CNY); Population (people); Total Consumer Goods Retail Sales (CNY); Total Freight, Highway Freight, and Railway Volume (tons)	Robust V-support Vector Regression; Simulated Annealing Particle Swarm Optimization; Multivariable Adaptive Regression Splines

5.3 The Seaport's Service-Rate Prediction System

Figure 5-1 presents the overview of the service rate prediction system which provides a step-wise overview on how it could help the drayage operators to make use of their trucks' trajectory data asset for predicting a seaport's service time. As portrayed, users only need to provide the truck's trajectory data inputs and the prediction system will produce the seaport's service rate outputs in return. Note that the proposed framework can also be applied to predict the service rate of any service station other than seaports.

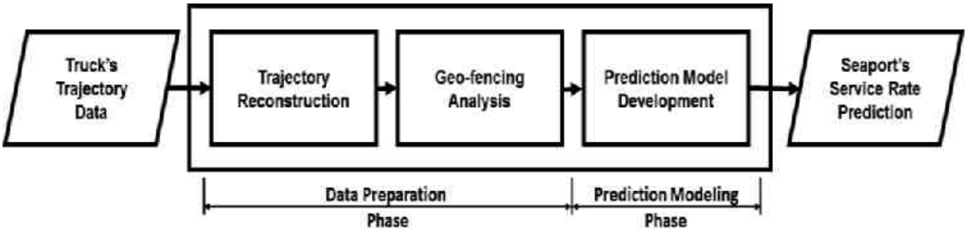

Figure 5-1. *The Framework of the Service Rate Prediction System*

This study departs from the role and limitation of the existing seaport appointment system in facilitating the container pick-up/delivery operations. In general, a seaport appointment system facilitates the pre-notification procedure, a prerequisite for drayage trucks to execute the container pick-up/delivery operation. The pre-notification procedure aims to prevent unsynchronized pick-up/delivery operations in which trucks wait at the seaport for long periods due to many possible issues such as container absence and documents clearance problems.

The existing pre-notification formalities are in accordance with the United Nations global rules for Electronic Data Interchange for Administration, Commerce and Transport/ UN-EDIFACT (UNECE 2016). The drayage operator initiates the pre-notification process by sending the pick-up/delivery permission request, known as the COPINO message, to the seaport. The seaport will then verify the information submitted by the drayage operator, the container's presence, the customs clearance status, and so on.

Subsequently, a reply (APERAK) message will be sent to the drayage operator indicating the COPINO message approval or rejection. The drayage operator's truck can conduct the pick-up/delivery at the predefined port and date only after receiving an approval of the COPINO message. If the COPINO message is rejected, the operator will review the reasons, carry out corrective actions, and re-submit a new COPINO message.

The period between the sending of the COPINO message and the receipt of the APERAK approval is the pre-arrival phase, while the period when the drivers travel to the seaport is the travel phase, and the period when the container loading/unloading execution happens is the on-arrival phase (see Figure 5-2). To speed up order delivery to the consignee/consignor, the drayage operators often dispatch their trucks to the seaport even before receiving the APERAK approval so that the pick-up/delivery execution can be conducted directly when the approval is received.

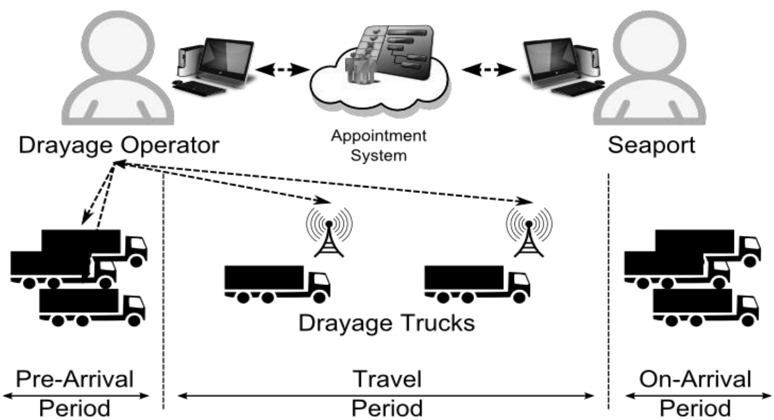

Figure 5-2. *The Container Pick-up/Delivery Operation*

The APERAK approval only contains information about a container's availability, namely whether a container can be picked up/delivered on a specific date. This information is not enough to assess the seaport's service rate, specifically the duration of the pick-up/delivery operation (Larsen 2009). Nevertheless, service rate information is important to conduct better vehicle routing that will increase trucks' productivity (Braysy & Gendreau 2005; Erera et al. 2010; Gunasekaran & Kobu 2007). Since drayage operators are commissioned based on the number of finalized pick-up/delivery services and large shares of time-dependent operational costs (such as the truck driver salary, administrative expenses) are allocated for the operation, finalizing as many orders as quickly as possible is important. Spending excessive time either in the travel phase or in the on arrival phase has to be avoided (Erera et al. 2010; Gunasekaran & Kobu 2007).

To provide the drayage operators with the required seaport's service rate predictions, we propose a service rate prediction system. We only use the truck's trajectory data as the system's primary input. Prior to the development of the prediction model, the trajectory data undergo a preparation process which includes trajectory reconstruction and geo-fencing analyses.

5.3.1 Trajectory Reconstruction

Drayage operators normally apply the temporal sampling strategy to monitor subordinate trucks (Herrera et al. 2010), such that each batch of the telematics data is uploaded from the truck's telematics system at a pre-defined time interval. The data logs can then be used to reconstruct the trucks' position (Work et al. 2008; Herrera et al. 2010). The higher the sampling frequency (or the shorter the message sending intervals), the more accurate the results of the trajectory reconstruction will be. However, higher sampling frequency is not always possible owing to high communication load and energy consumption (Herrera et al. 2010).

As shown in Figure 5-3, the output of the trajectory reconstruction process plots the trucks' historical position on a map. Note that the resolution of the reconstruction outcome is of higher quality as we magnify the trajectory reconstruction result. The trajectory reconstruction process is essential to understanding the movement of each truck. With this process, it is easier to get an overview of a drayage operator's service coverage, to analyze detailed mobility data of each truck, and to target some locations with the potential for further analysis.

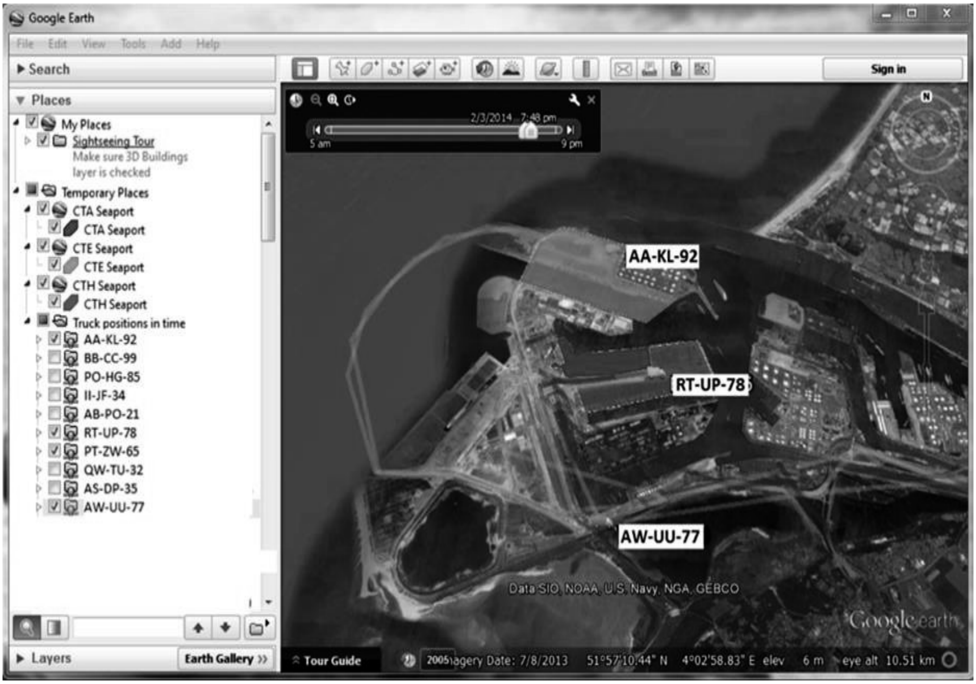

Figure 5-3. *Trajectory Reconstruction and Geo-fencing Analyses*

5.3.2 Geo-fencing Analysis

To assess a seaport's service rate performance, we apply the geo-fencing technique adopted from the wireless network research field (Sheth et al. 2009). Originally, this technique was used to define the service areas of Wi-Fi access points to a specified region (Sheth et al. 2009). In this study, we apply the geo-fencing technique and target the vehicle trajectory GPS signal area of the reviewed port (see Figure 5-3). Next, we measure the duration the truck remained in the reviewed area, specifically we record the truck's time of arrival and time of departure at the analyzed seaport. Table 5-2 shows the expected output format of this analysis.

Table 5-2. *The Format of the Geo-fencing Analysis Output*

Company	Truck ID	Time of Arrival		Time of Departure	
		Date	Time	Date	Time
LDH	AA-KL-92	10/10/2016	13:25:36	10/10/2016	13:45:22
SUP	AS-WR-1	10/10/2016	13:39:41	10/10/2016	14:09:17

Subsequent to the geo-fencing analysis, we can calculate the seaport's service rate. The service rate value is inferred from the time the truck remained at the seaport area. The service rate performance $\varphi_{t_x}^{i}$ of a certain seaport *i* at a specific time period *t* as measured by the respondent truck *x,* can be computed by subtracting the time of departure $t_{departure}$ and the time of arrival $t_{arrival}$ of the respondent truck *x*. The *t* notion in the $\varphi_{t_x}^{i}$ is set equal to $t_{arrival}$. The seaport's service rate $\varphi_{t_x}^{i}$ is then defined as follows:

$$\varphi_{t_x}^{i} = \theta_{t_{departure_x}}^{i} - \theta_{t_{arrival_x}}^{i} \qquad \textbf{(1)}$$

Note that we characterize the service rate *φ* based on three identifiers: the seaport's identity *i*; the time at which the service execution begins *t*; and the respondent truck's identity *x*. The first index *i*, the seaport's identity, is used to differentiate the performance of one seaport from another. The second index *t* is included since we conjecture that the service rate magnitude will vary based on the timing of service execution. The inclusion of the time index *t* emphasized the importance of the timing of the service execution aspect when constructing the vehicle routing plan. The service rate at one seaport may be better than another at a specific time, but the same seaport may not provide a competitive service rate at other times.

The last index *x* refers to the identity of the respondent truck whose telematics data were used to measure the seaport's service rate. It is often the case that more than one truck visited the seaport *i* at the same time period *t*. However, the measurement results may not be the same. Denoting $X = \{ x_1, x_2, \ldots x_n \}$ as the valid respondent trucks that visited the seaport *i* at a specific time period *t,* we infer the seaport's service rate φ_{t}^{i} by calculating the arithmetic mean from all measurement records of the respondent trucks. At the initial phase (i.e.

t = 0), $\varphi_{t=0}^{i}$ will be set to a constant value of c^{i} that will be entered by the user according to the user's estimation of seaport i service rate value. In a few cases, it could be that the operator's data logs do not contain any record of a truck respondent that visited the seaport i at a specific time period t (i.e. $X = \emptyset$). In this case, we infer the service rate value at time t from the service rate value of the preceding time period to capture the inertia effect from the seaport's service momentum at time t-1. As an example, the service rate of a seaport at time t = 13 ($i.e.\, \varphi_{t=13}^{i}$) will be extrapolated from the service rate of the same seaport at the preceding time t = 12 ($i.e.\, \varphi_{t=12}^{i}$) so that $\varphi_{t=13}^{i} = \varphi_{t=12}^{i}$. Formally, we state the seaport's service rate value as follows:

$$\varphi_{t}^{i} = \begin{cases} c^{i} & , t = 0 \\ \varphi_{t-1}^{i} & , \boldsymbol{X} = \emptyset \\ \frac{1}{n}\sum_{x=1}^{n}\left[\theta_{t_{departure_{x}}}^{i} - \theta_{t_{arrival_{x}}}^{i}\right] & , |\boldsymbol{X}| \geq 1 \end{cases} \tag{2}$$

5.3.3 Prediction Model Development

To predict a seaport's service rate, we adopt the generalized additive model that falls under the regression framework category. The generalized additive model technique (Hastie & Tibshirani 1986) is preferable to generalized linear models because it allows us to make inferences about associations between predicted variables and predictors without including any parametric restrictions on the associations (Ben Taieb & Hyndman 2013). We define the formalization of the seaport service rate predicted value as follows:

$$\overline{\varphi_{t}^{i}} = \alpha_{i}(t) + \beta_{i}(\gamma_{t}^{i}) + \varepsilon_{it} \tag{3}$$

where:

- $\overline{\varphi_{t}^{i}}$ denotes the predicted value of the service rate at the seaport i at time t;
- $\alpha_{i}(t)$ models the temporal effects predictor (the monthly, daily, hourly, and quarterly effects);

- $\beta_i(\gamma_t^i)$ models the inertia effects predictor of the seaport's recent performance; The γ_t^i vector consists of recent records of the service rate performance φ_{t-z}^i, the number of arriving trucks ζ_{t-z}^i, and the number of departing trucks δ_{t-z}^i; and
- ε_{it} refers to the prediction model's error.

Our choice in defining the definition of the temporal effects and inertia effects as the predictors of the seaport service rate value is motivated from the nature of the vehicle trajectory dataset that has minimum information features and by previous studies on congestion modeling (Ben-Akiva et al. 1984; Chang & Mahmassani 1988; Bando et al. 1995; Williams & Hoel 2003). Discussing the first predictor, we add the temporal effects $\alpha_i(t)$ since a seaport's service rate varies over time in the real world and we conjecture that the reversal of a seaport's performance can drive the reversal of the drayage operator's seaport preference. We translate this time-based effect into four attributes, namely the monthly, daily, hourly, and quarterly effects. The monthly effect was modelled with factor variables, adopting the month name (January, February, etc.). The daily and the hourly effects were also modelled with factor variables. The coding for the daily effects adopts the standard day values (Monday to Sunday) and the coding for the hourly effect follows the natural 24 hours discretization of a normal day. The last attribute, the quarterly effect, is coded as a factor variable and computed by discretizing the 24 hour period in 15 minutes increments. For example any service execution that started between 00.00 and 00.15 will have a quarterly index value of $t = 1$, any service execution that was started between 00.15 and 00.30 will have a quarterly index value of $t = 2$, and so on where $t \in T$ and $T = \{1, 2, \ldots, 96\}$.

By introducing the inertia effects $\beta_i(\gamma_t^i)$, we incorporate the momentum of the seaport's recent performance. Based on our previous experience in handling prediction tasks based on panel data, the inclusion of the inertia effects can significantly increase the prediction performance. The travel behavior's inertia effect has been also recognized as an important factor for modelling transport demand (Cantillo et al. 2007; Bando et al. 1995). We translate the effects into three attributes, namely the historical trace of the seaport's service rate $\varphi_{t-z}^{i} = \{ \varphi_{t-z}^{i}, \ldots, \varphi_{t-2}^{i}, \varphi_{t-1}^{i} \}$, the historical trace of the seaport's arriving trucks $\zeta_{t-z}^{i} = \{ \zeta_{t-z-1}^{i}, \ldots, \zeta_{t-2}^{i}, \zeta_{t-1}^{i} \}$, and the historical trace of the seaport's departing trucks $\delta_{t-z}^{i} = \{\delta_{t-z-1}^{i}, \ldots, \delta_{t-2}^{i}, \delta_{t-1}^{i} \}$. We incorporate the service rate trace factor φ_{t-z}^{i} to capture the seaport's recent performance in handling container pick-up/delivery requests. The prior numbers of arriving and departing trucks are incorporated as a mean for inferring the number of trucks inside the seaport area.

For the prediction task we opt for the gradient boosting method (Friedman 2002; Friedman 2001), a machine learning technique that constructs a regression prediction model by combining weak prediction models into an ensemble (Dietterich 1990; Hastie et al. 2011). "Gradient boosting constructs additive regression models by sequentially fitting a simple parameterized function (base learner) to current "pseudo"-residuals by least squares at each iteration. The pseudo-residuals are the gradient of the loss functional being minimized, with respect to the model values at each training data point evaluated at the current step" [36, p. 367]. As a boosting algorithm, the model is chosen due to its strong prediction performance records (Schapire 2003; Friedman 2001) that can be associated with its robustness towards overfitting cases (Mease 2008).

Applying the model to Equation 3, we can re-write the seaport service rate prediction in the following form:

$$\overline{\varphi_t^i} = F_i(\psi_t) + \varepsilon_{it} \tag{4}$$

ψ_t consists of all potential variables within the temporal effects $\alpha_i(t)$ and the inertia effects $\beta_i(\gamma_t^i)$ that can be incorporated as predictors in the final gradient boosting model. By learning from the supplied training dataset that consists of actual ψ_t and φ_t^i values, the goal is to find the best function $F_i: R^d \rightarrow R$ that minimizes the prediction loss function. In this study we opt for the root mean squared error (RMSE) measure for the loss function (Hastie et al. 2011; Shmueli & Koppius 2011). In essence, the RMSE indicates the sample standard deviation of the differences between the actual service rate values and the values produced by the prediction model. Thus, the prediction function F_i based on the training set $\{(\varphi_t^i, \psi_t)\}_{t=1}^T$ can be written as follows:

$$\overline{\varphi_t^i} = arg\,min \frac{1}{T}\sum_{t=1}^{T}[\varphi_t^i - F_i(\psi_t)]^2 \quad \textbf{\textit{(5)}}$$

The gradient boosting method approximates the prediction function $F_i(\psi_t)$ in a sequential manner. We denote $F_i^{(m)}(\psi_t)$ as the estimation of $F_i(\psi_t)$ at the *m*-th iteration, where *m* = 0, 1, 2, …, *M*. The approximation starts with $F_i^{(0)}(\psi_t) = \overline{\varphi_t^i}$, where for the first iteration (i.e. *m* = 0) the value of $\overline{\varphi_t^i}$ uses the mean value of the service rate performance at the seaport *i* at time *t*. Subsequently, the model can be updated using:

$$F_i^{(m)}(\psi_t) = F_i^{(m-1)}(\psi_t) + v.h_m(\psi_t, Ш_m) \quad \textbf{\textit{(6)}}$$

Whereas we denote $h_m(\psi_t, Ш_m)$ as the weak learner estimate at the *m*-th iteration with parameters $Ш_m$ and we denote $v \in [0, 1]$ as the shrinkage parameter. Given the approximation of $F_i^{(m-1)}(\psi_t)$, each additional term $h_m(\psi_t, Ш_m)$ can be computed by differentiating the loss function with the prediction $F_i(\psi_t)$ function:

$$u_t^m = -\left[\frac{{}^1\!/_2\, d\left[\varphi_t^i - F_i(\psi_t)\right]^2}{dF_i(\psi_t)}\right]_{F_i(\psi_t) = F_i^{(m-1)}(\psi_t)}$$

$$= \quad [\varphi_t^i - F_i^{(m-1)}(\psi_t)] \quad \textbf{\textit{(7)}}$$

Equation 7 produces the direction of the steepest descent step. Furthermore, a regression analysis is applied on $\{u_t^m, \psi_t\}_{t=1}^T$ by the weak learner as follows:

$$Ш_m = arg\,min \textstyle\sum_{t=1}^{T}[u_t^m - h_m(\psi_t, Ш_m)]^2 \quad \textbf{\textit{(8)}}$$

The $h_m(\psi_t, Ш_m)$ value is selected to estimate the prediction error of the prior model $F_i^{(m-1)}(\psi_t)$. Thus, the final solution can be written as follows:

$$F_i(\psi_t) = F_i^{(M)}(\psi_t) = h_0(\psi_t) + \sum_{m=1}^{M} v.h_m(\psi_t, Ш_m) \qquad (9)$$

Note that the $F_i(\psi_t)$ function is continuously updated by the addition of $v.h_m$ component at the *m*-th iteration whereas the hyper-parameter *M* denotes the maximum number of adopted components, which will prevent overfitting.

5.4 Case Study

With an annual throughput value of 465 million cargo tons, the Port of Rotterdam is currently the busiest seaport in Europe. Serving approximately 30,000 seagoing vessels and 110,000 inland vessels every year, the Port of Rotterdam is home to at least 12 container seaports and more than a hundred drayage operators (Rotterdam 2016). As a case study, we analyzed the service rate of containers pick-up/delivery operations at three anonymous container seaports. The selected seaports are some of the most prominent seaports in the region in terms of containers throughput value. To build the prediction models, we use vehicle telematics data from three different drayage operators that visit the selected terminals regularly. Two respondent operators focus on providing transportation business only while the other one provides richer spectrum of services namely transportation, warehousing, global freight forwarding, etc. In this study, we analyze the operators' trucks that conduct pick-up/deliver services for European clients located in the Netherlands, France, Germany, Switzerland, and Spain.

5.4.1 Truck Telematics System Data

Noting the appointment system's limitation in terms of information content, the availability of a large amount of truck telematics system data (Baumgartner et al. 2008) is an alternative to assess the seaport's service rate. The telematics system is used by drayage operators to monitor and communicate with their subordinate trucks. The board computer mounted on the truck's dashboard is a visible component of the system. In operationalizing the monitoring and the communication tasks, data are exchanged. The dataset contains many attributes such as the data recording's timestamp, the truck's identification, the destination's location, etc (see Table 5-3).

Table 5-3. *Specification of the Truck Telematics System's Data*

<table>
<tr><th>Attribute</th><th colspan="2">Variable</th><th>Data Type</th></tr>
<tr><td>Record Identification</td><td colspan="2">No*</td><td>Integer</td></tr>
<tr><td>Timestamp</td><td colspan="2">Timestamp*</td><td>Date and Time</td></tr>
<tr><td rowspan="4">Truck Identification</td><td colspan="2">License Plate*</td><td>String</td></tr>
<tr><td colspan="2">Affiliated Company*</td><td>String</td></tr>
<tr><td colspan="2">Driver's Name</td><td>String</td></tr>
<tr><td colspan="2">Truck's Capacity</td><td>Integer</td></tr>
<tr><td rowspan="3">Truck Status</td><td rowspan="2">Location*</td><td>Longitude*</td><td>Double</td></tr>
<tr><td>Latitude*</td><td>Double</td></tr>
<tr><td>State</td><td>Loaded/ Empty</td><td>String</td></tr>
<tr><td rowspan="3">Destination</td><td rowspan="2">Location</td><td>Longitude</td><td>Double</td></tr>
<tr><td>Latitude</td><td>Double</td></tr>
<tr><td colspan="2">Estimated Time of Arrival</td><td>Date and Time</td></tr>
</table>

* Minimum data specification

Each company may have a different policy about the information attributes that must be monitored. At a minimum, a drayage operator will monitor the trucks' position (Giannopoulos 2009; Crainic et al. 2009). This trajectory information consists of the following: the record identification number; the data recording timestamp; the truck's license plate number; the truck's affiliated company; and the truck's location, specifically longitude and latitude data.

For this study, we imported more than 15 million real-life data records logged from more than 200 drayage trucks. The data were retrieved from the drayage operator's vehicle telematics database. The imported dataset contains trajectory records for a period of more than one and a half years, during which each truck transmitted an average of 130 messages per day. Within the dataset, a few trucks were found to have inconsistent data-updating behavior. To improve the data quality, we only considered data records from the trucks with frequent and consistent data updates. For the analysis, we used two filtered datasets with different message updating threshold rates of at least 15 minutes and 7.5 minutes (see Table 5-4). In our dataset only three out of 202 trucks transmitted data updates every 5 minutes, thus we cannot set the updating-rate threshold below 7.5 minutes.

Table 5-4. *Truck Telematics System Data Description*

Variable	Metric	Raw Data	Filtered Data Update Rate	
			15 Minutes	7.5 Minutes
Number of Records	Count	15,314,614	13,918,940	7,800,648
Data Time Span	Min	21/06/2012 08:29:04 GMT+1	21/06/2012 08:29:05 GMT+1	21/06/2012 08:29:36 GMT+1
	Max	03/02/2014 15:59:44 GMT+1	03/02/2014 15:53:24 GMT+1	03/02/2014 15:53:24 GMT+1
Days	Count	592	592	592
Number of Trucks	Count	202	119	54
Daily Message Sent per Truck	Average	128.07	197.58	244.01

The dataset containing records from trucks with an updating period of 15 minutes or less provided nearly 14 million lines of high quality data from 119 respondent trucks. On average, each truck transmitted nearly 200 messages per day, or one message every 7.3 minutes. The dataset with the 7.5 minute updating threshold rate provided nearly 8 million data records from 54 respondent trucks. In the second dataset, each truck transmitted nearly 250 messages per day, or one message every 5.9 minutes.

5.4.2 Analysis

To apply the proposed framework to the dataset, we first apply the geo-fencing analysis to the dataset by treating the analyzed seaport area as the bounding area. In general, all seaport bounding areas are polygon-shaped. For each seaport, one geo-fencing analysis output sheet will be produced. Subsequently, we transform each geo-fencing output sheet into the modelling sheet format (see Table 5-5). Since we evaluate six different prediction model variants, we prepare six modelling sheets from each geo-fencing output sheet. Each modelling sheet has a different set of target and predictors variable pairs $\{(\varphi_t^i, \psi_t)\}_{t=1}^{T}$. For model 0, we only include the temporal effect variables as the predictors $\overline{\varphi_t^i} = \alpha_i(t) + \varepsilon_{it}$ where $\psi_t = (month_t,\ day_t,\ hour_t,\ quarter_t)$. For model 1, we add the inertia effect for the first time $\overline{\varphi_t^i} = \alpha_i(t) + \beta_i(\gamma_t^i) + \varepsilon_{it}$ where $\psi_t = (month_t,\ day_t, hour_t, quarter_t, \varphi_{t-1}, \zeta_{t-1}, \delta_{t-1})$. In model 2, we add the inertia effects to the second degree as predictors $\psi_t = (month_t,\ day_t, hour_t, quarter_t, \varphi_{t-1}, \zeta_{t-1}, \delta_{t-1}, \varphi_{t-2}, \zeta_{t-2}, \delta_{t-2},)$ and so on. In this study, the addition of the inertia effects goes until model 5, where we translate the predictors ψ_t as $(month_t,\ day_t, hour_t, quarter_t, \varphi_{t-1}, \zeta_{t-1}, \delta_{t-1}, \dots, \varphi_{t-5}, \zeta_{t-5}, \delta_{t-5})$.

In constructing the prediction models, we apply *k-fold* cross validation method (Hastie et al. 2011; Shmueli & Koppius 2011) with *k = 10*. The method offers lower variance than the simplistic single hold-out cross validation method and offers faster computation time compared to the leave-one-out cross validation method especially when coping with a high volume dataset like ours (Hastie et al. 2011). Since we analyze six different target and predictor variable pairs, we construct and evaluate six gradient boosting prediction models (GBM_0: GBM_5) and six generalized linear models (LM_0: LM_5) for each seaport. Note that the generalized linear models (Hastie et al. 2011) with the same target and predictors variable pairs are used as benchmarks for assessing the performance of the gradient boosting model.

Table 5-5. *The Format of the Modelling Sheet*

Construct	Attribute	Function
Temporal Effects	Month	Predictor
	Day	Predictor
	Hour	Predictor
	Quarter	Predictor
Inertia Effects	Previous Service Time *(t-n)*	Predictor
	Previous Arriving Trucks *(t-n)*	Predictor
	Previous Departing Trucks *(t-n)*	Predictor
Performance	Service Time	Target

5.5 Results and Discussion

This section presents and evaluates the predictive results using the step-wise approach that was introduced in Section 5-3, namely: the trajectory reconstruction, the geo-fencing analysis, and the prediction model development.

5.5.1 Trajectory Reconstruction

In Figure 5-4 we depict an outcome of the trajectory reconstruction process from a sample dataset (April – mid-June 2013). Through this analysis, one can plot the trucks' historical activity to better understand the trucks trajectory and service coverage during different periods (see Figures 5-4c, 5-4d, and 5-4e). The heat map plot (see Figure 5-4a) yields better insight into the mobility concentration of a drayage operator's subordinate trucks mainly around the Rotterdam area where the company's headquarters and its main costumers are located.

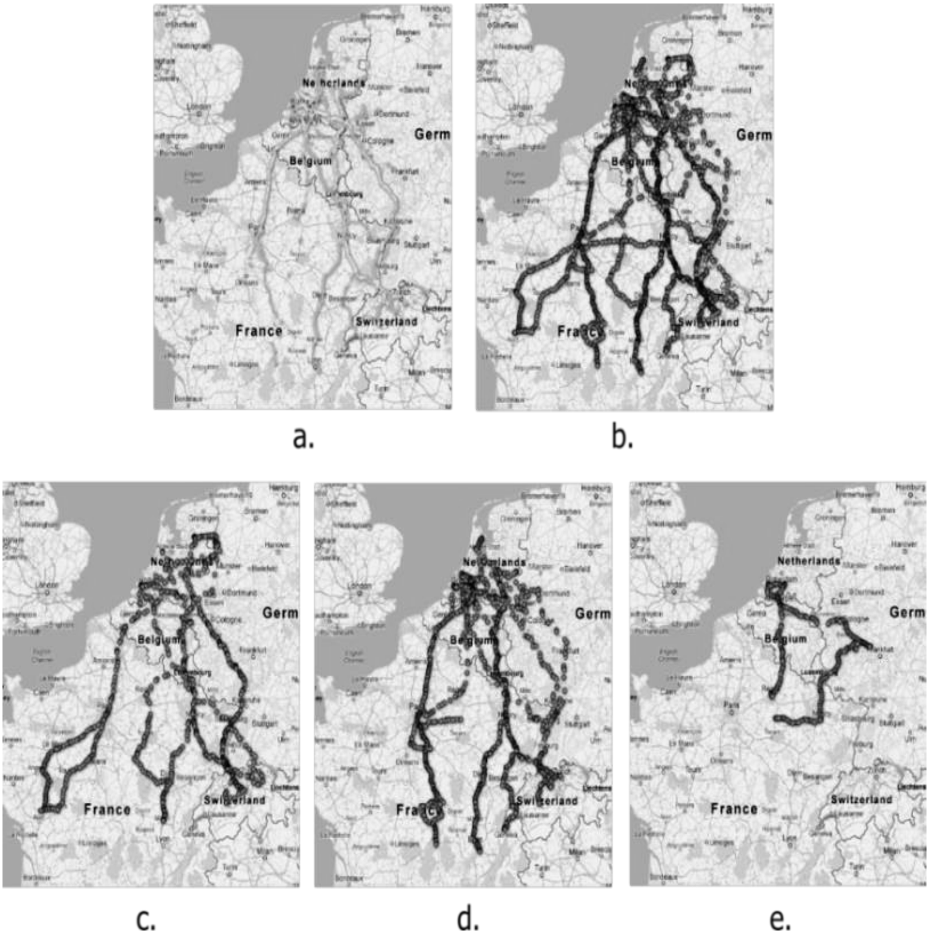

Figure 5-4. *The Trajectory Reconstruction Outcome*
(a) Heat-Plot (April-June), (b) Dot-Plot (April-June), (c) Dot-Plot (April), (d) Dot-Plot (May), (e) Dot-Plot (June)

5.5.2 Geo-fencing Analysis

Subsequent to the trajectory reconstruction process, we analyze the service rate performance of three seaports in the Rotterdam area, anonymized as CTA, CTE, and CTH. Each seaport is marked with different color namely, red (CTA), green (CTE), and blue (CTH). The application of the geo-fencing analysis to the trucks' trajectory data will produce one output sheet for each corresponding seaport. Depicting the results of the geo-fencing analysis in Figure 5-5, we notice that each seaport has unique service characteristics and the seaport service rate profile varies over time. At different hours, days, and months of service execution, the seaports perform differently.

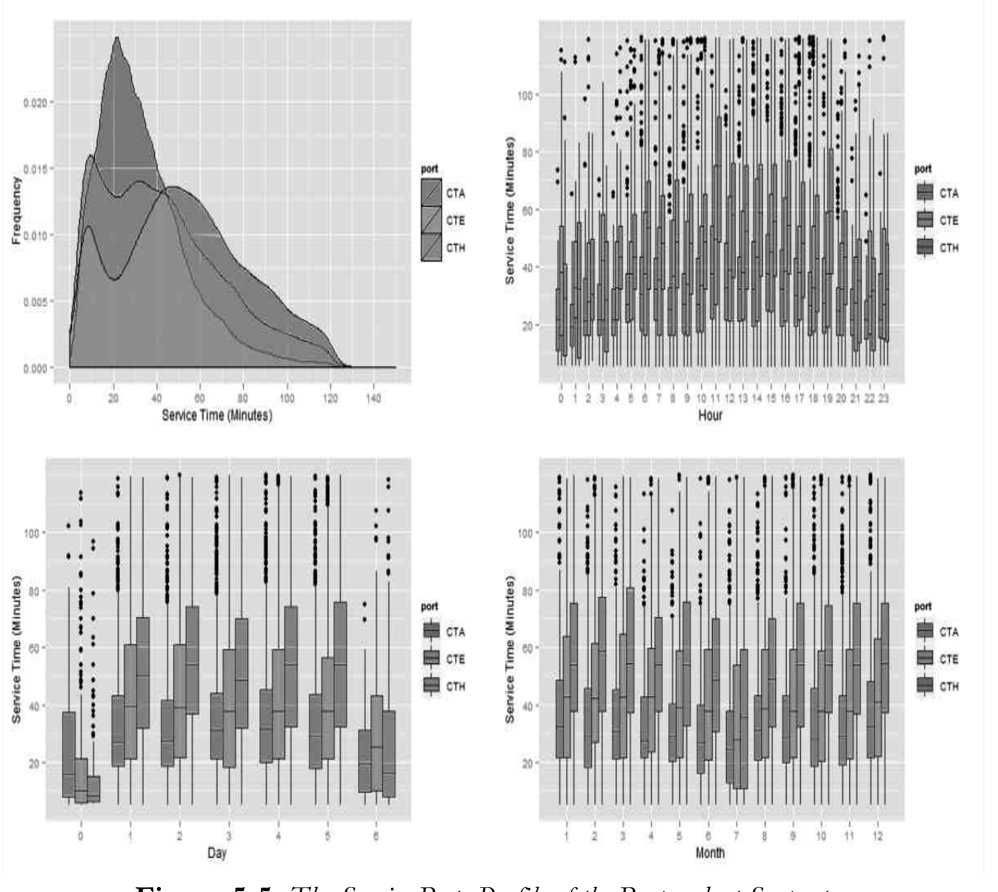

Figure 5-5. *The Service Rate Profile of the Respondent Seaports*

From Figure 5-5 we can observe that the CTA generally performs better with a lower service time than the competitors. Looking at the hourly performance, all seaports tend to deliver longer services between 11:00 and 17:00 than any other period. Looking at the monthly performance, July is the time when all seaports perform the best service rate. We can see that at Monday, Tuesday, Wednesday, Thursday, Friday, and Saturday the CTA performance is better than its competitors. However, the competitors perform better at Sunday (day 0). During this period, it is recommended to conduct pick-up/delivery service at seaports with a more competitive service rate. The findings are in line with our conjecture, namely that the service rate does indeed vary over time and the reversal of a seaport's performance can in fact drive the reversal of the preference for a particular seaport.

5.5.3 Prediction Model Development

In Table 5-6, we present the performance of the constructed prediction models in terms of the model's predictive power in RMSE form (Hastie et al. 2011). The RMSE indicates the sample standard deviation of the differences between the actual service rates and the predicted values (see Section 5.3.3. Equation 5).

For comparative purposes, we also included the descriptive statistics measures (mean and standard deviation) of each seaport's service rate. In line with the inferences that were made, we notice that in general the CTA is the best performing seaport, calculated based on the 15 minutes threshold data. Not only was the CTA found to have the shortest average service rate (CTA = 31.16 minutes compared to CTE = 39.36 minutes and CTH = 50.83 minutes), the CTA also has the lowest service rate deviation (CTA = 15.38 minutes compared to CTE = 19.73 minutes and CTH = 22.26 minutes). The low standard deviation figures indicate the seaport's consistency in conducting the containers loading/unloading service.

Table 5-6. *The Performance of the Prediction Models*

Seaport		CTA				CTE				CTH			
Update Rate		15 Minutes		7.5 Minutes		15 Minutes		7.5 Minutes		15 Minutes		7.5 Minutes	
Dataset		TR	TS	TR	TS	TR	TS	TR	TS	TR	TS	TR	TS
Mean*		31.16	31.16	31.82	31.76	39.36	39.29	39.84	39.86	50.83	50.80	51.05	51.10
St. Dev.*		15.38	15.33	15.27	15.12	19.73	19.71	20.16	20.15	22.26	22.42	23.02	23.14
Prediction Models Performance (RMSE)*	LM_0	14.93	14.89	14.97	14.83	19.30	19.29	20.01	20.03	21.15	21.25	22.60	22.77
	GBM_0	14.81	14.78	14.87	14.47	19.23	19.22	19.89	19.92	21.24	21.36	22.48	22.64
	LM_1	11.24	11.29	9.04	9.08	17.17	17.17	15.59	15.57	18.57	18.74	18.78	18.89
	GBM_1	10.45	10.56	8.23	8.25	16.40	16.44	14.98	14.99	17.73	17.91	17.33	17.50
	LM_2	11.18	11.23	8.97	9.06	17.06	17.08	15.54	15.53	18.46	18.63	18.74	18.86
	GBM_2	10.39	10.55	8.17	8.22	16.26	16.37	14.85	14.88	17.60	17.85	17.22	17.39
	LM_3	11.15	11.19	8.97	9.05	17.00	17.02	15.52	15.51	18.39	18.57	18.71	18.81
	GBM_3	10.38	10.52	8.12	8.17	16.25	16.35	14.79	14.83	17.59	17.84	17.18	17.34
	LM_4	11.14	11.16	8.97	9.05	16.96	16.98	15.50	15.49	18.34	18.51	18.68	18.79
	GBM_4	10.38	10.52	8.09	8.14	16.22	16.33	14.74	14.79	17.55	17.80	17.11	17.26
	LM_5	11.12	11.16	8.97	9.05	16.94	16.95	15.49	15.48	18.31	18.50	18.65	18.77
	GBM_5	10.35	10.51	8.08	8.13	16.22	16.34	14.73	14.80	17.50	17.74	17.08	17.26

*TR= training dataset; TS = testing dataset; *RMSE, mean, and standard deviation in minutes*

Analyzing the prediction models' performance, we observe that including inertia effects in both the gradient boosting models (GBM_{1-5}) and the linear models (LM_{1-5}) improved the prediction performance significantly (lower RMSE value). The biggest prediction improvement was achieved when we added the inertia effects for the first time (GBM_1, LM_1). For instance, the prediction performance of the GBM model for the CTA seaport improved from 14.81 minutes (GBM_{0-CTA}) down to 10.45 minutes (GBM_{1-CTA}) (see Table 5-6). As more inertia effects were added, the prediction error decreased correspondingly. Figure 5-6 highlights the prediction improvements for the 1500th quarter to the 2500th quarter. Note that the position of the prediction lines of GBM_1 and LM_1 are much closer to the yellow dots (the service rate actual value) compared to the prediction lines of GBM_0 and LM_0. This is valid for any model at any evaluated seaport (see Table 5-6). Note also that in general, the gradient boosting models performed better than the benchmark normal linear models.

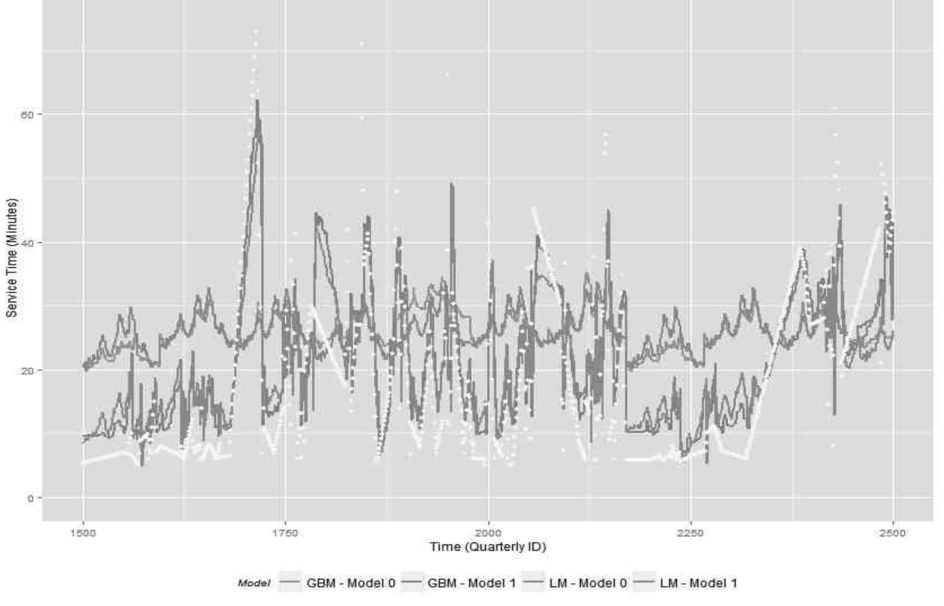

Figure 5-6. *The Impact of Inertia Effects on Prediction Performance*

Prediction models that were constructed for seaports with more consistent performance (smaller service rate standard deviation) performed better (lower RMSE) compared to models constructed for seaports with more volatile performance. Supporting the claim, we provide a snapshot of the seaports' actual service rate performance for the first week of July 2013 period in Figure 5-7. As depicted, the CTA has more consistent service rate than its competitors and the CTH has the most volatile service rate. Note that the prediction models that were constructed for the CTA also have the best predictive performance (the lowest RMSE value) and the ones for the CTH also have the poorest performance (the highest RMSE value) (see Table 5-6).

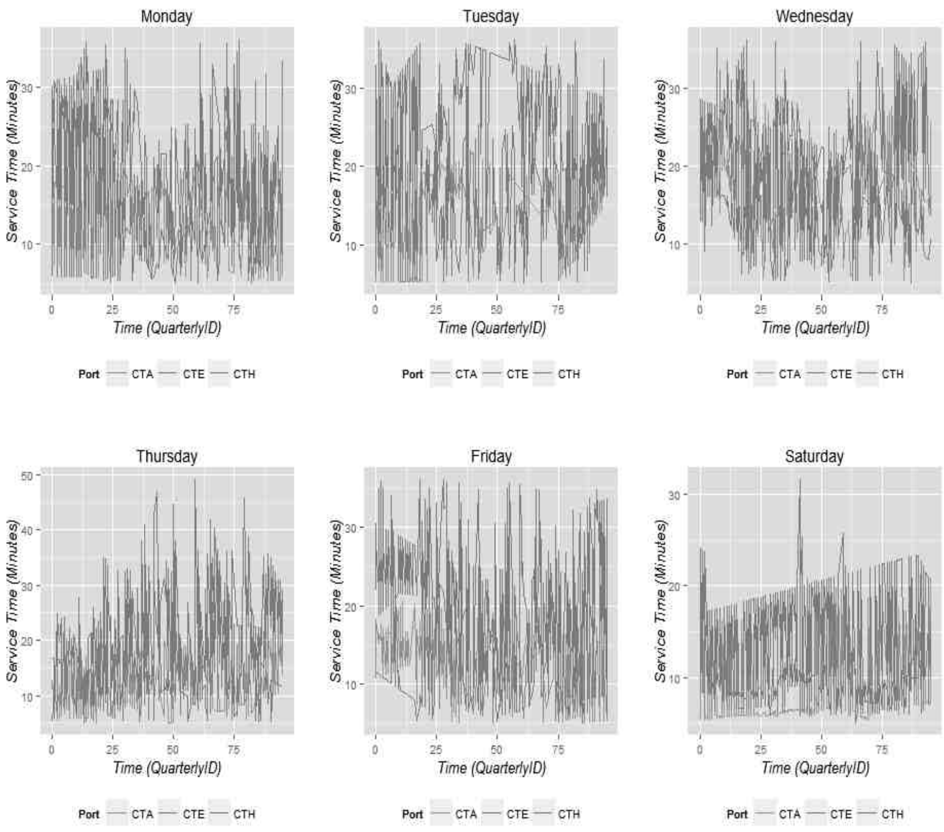

Figure 5-7. *The Seaports' Service Rate for the July 2013 Period*

Considering the high range of a seaport's service rate value that can reach up to 50 minutes (see Figure 5-7), our solution can deliver reasonably good predictions. The RMSE value can go below 17.3 minutes for CTH and below 8.2 minutes for more consistent seaports (i.e. CTA). The findings confirm the usefulness and appropriateness of our system in supporting drayage operators in predicting a seaport's service rate so that truck route planning will minimize the time spent at stop points.

5.6 Conclusion

With our seaport service rate prediction system, we provide a solution for predicting seaport service rate performance using drayage trucks' trajectory data. The proposed solution is constructed on three components, namely trajectory reconstruction, geo-fencing analysis, and prediction model development. To validate the proposed prediction analytics solution, we analyzed more than 15 million mobility records logged from more than 200 trucks over a period of 19 months. Using a high volume of data with modest information features, we incorporate the temporal and the inertia effects as the main predictors. As the final result, the proposed gradient boosting model-based solution provides better predictions than the linear model benchmark solution.

From a practical point of view, the system can support drayage operators in predicting a seaport's service rate so that truck route planning will minimize the time spent at stop points. Recall that the application of the system is not limited to predicting the service rate of seaports and can also be applied to predict any service station's service rate. In generating predictions, the system uses the vehicle telematics data logs (trajectory data), circumventing the need to modify the existing appointment system. Note, that this seaport service rate prediction needs to be considered in conjunction with the amount of landside road traffic. A seaport with low traffic at the landside can easily outperform another seaport with better service rate performance and heavy landside traffic.

From a research point of view this design science study (March & Smith 1995; Gregor & Hevner 2013) corresponds to the largely unexplored field of predictive analytics development using geospatial sensor-based data (Watson & Wixom 2007; Negash 2004; Chen et al. 2012). This study offers a new approach to the seaport congestion issue and explains how stakeholders can use predictive analytics techniques on their data assets, especially vehicle telematics data, to extract better insights to improve their decision making (Giannopoulos 2009; Herrera et al. 2010; Work et al. 2008; Hastie et al. 2011; Friedman 2002; Dietterich 1990). To the best of our knowledge, this approach has not been introduced in the research literature on seaport diversion initiatives (Maguire et al. 2010; Veenstra et al. 2012; Roso & Lumsden 2010; Cullinane et al. 2012), non-diversion initiatives (Maguire et al. 2010; Giuliano & O'Brien 2007; Giuliano et al. 2008; Morais & Lord 2006), and decision support systems on seaport hinterland operation topics (Huynh & Walton 2011; Namboothiri & Erera 2008; Hu & Sheng 2014; Bandeira et al. 2009; Murty et al. 2005; Huynh et al. 2005; Ioannou et al. 2005; Zhao & Goodchild 2010). Moreover, while many studies attempted to predict the seaports' productivity for the seaside using yearly or monthly statistics archives [43–47], this study focuses on the seaports' landside productivity using sensor-based trajectory dataset that is updated every few minutes.

This study is not without limitations, some of which open opportunities for further research. The first limitation comes from the nature of the dataset. In this study the updating rate threshold value of the trajectory dataset is limited to 7.5 minutes. Setting a lower threshold is not possible since it will filter out most of the available data records. Secondly, to produce accurate predictions, the proposed solution requires high volume trajectory data logs that are gathered from many respondent trucks. Small drayage operators with few drayage trucks may need longer time to gather adequate data. As an option, one can explore the possibility of sharing trajectory data with other operators. Thirdly, we use the trajectory data for both training and testing the prediction models. Using other data sources (surveys of stakeholders, seaport internal datasets) to test the prediction results can give more accurate predictions. Fourthly, this study aims to build a generalizable system that uses the limited specifications of truck telematics data, namely the trajectory data, as the basis for constructing the prediction models. Alternatively, one can construct better performing systems by using richer telematics data specifications and combine data sets of collaborating drayage operators. Incorporating the historical records of the landside traffic information can add even more useful and holistic predictions for the vehicle routing purposes (Kenyon & Morton 2003; Yildirimoglu & Geroliminis 2013). Next, we only focus on the gradient boosting model as an example of a robust predictive analytics method. However, one can attempt to develop better performing systems by applying alternative predictive models such as random forest, support vector regression, and so on (Mitchell 1997; Hastie et al. 2011).

Furthermore, one can aim to realize fully collaborative appointment systems that consider both the drayage operators' perspectives and the seaports' point of view. As investigated in previous studies (Douma et al. 2009; Douma 2008; Douma & Mes 2012), seaports actually have similar situations, i.e. they have limited knowledge on the arrival time of the upcoming vehicles. Hence, how to combine this study (i.e. the use of predictive analytics to predict the counterpart actions) with decentralized mechanism design research field to create better operational alignment among the coordinating business actors is a prospective research direction.

5.7 Summary of Notation

Symbol	Definition
i	Seaport's identity
x	Truck's identity
$X = \{ x_1, x_2, \dots x_n \}$	Set of respondent trucks
t	Time index
$\theta^i_{t_{arrival_x}}$	Time of arrival of respondent truck x at seaport i
$\theta^i_{t_{departure_x}}$	Time of departure of respondent truck x at seaport i
$\varphi^i_{t_x}$	Service rate performance of seaport i at a specific time period t as measured by respondent truck x

c^i	User's estimation of the seaport *i* service rate value
$\overline{\varphi_t^i}$	Predicted value of the service rate of seaport *i* at time *t*
$\alpha_i(t)$	Temporal effect predictors
$\beta_i(\gamma_t^i)$	Inertia effect predictors
ε_{it}	Prediction error
φ_{t-z}^i	Historical trace of the seaport *i* service rate, whereas $\varphi_{t-z}^i = \{ \varphi_{t-z}^i, \dots, \varphi_{t-2}^i, \varphi_{t-1}^i \}$
ζ_t^i	Number of arriving trucks at the seaport *i* at time *t*
ζ_{t-z}^i	Historical trace of the number of arriving trucks at seaport *i* at time *t*, whereas $\zeta_{t-z}^i = \{ \zeta_{t-z-1}^i, \dots, \zeta_{t-2}^i, \zeta_{t-1}^i \}$
δ_t^i	Number of departing trucks at the seaport *i* at time *t*
δ_{t-z}^i	Historical trace of the number of departing trucks at seaport *i* at time *t*, whereas $\delta_{t-z}^i = \{\delta_{t-z-1}^i, \dots, \delta_{t-2}^i, \delta_{t-1}^i \}$
z	Inertia effect index
$F_i(\psi_t)$	Prediction function
ψ_t	Potential predictors
$F_i^{(m)}(\psi_t)$	The estimation of $F_i(\psi_t)$ at the *m*-th iteration
m	Iteration index
$h_m(\psi_t, Ш_m)$	Weak learner estimate for the gradient boosting model
v	Shrinkage parameter for the gradient boosting model

Chapter 6
Conclusion

6.1 Introduction

This dissertation focuses on the topic of agent-based inter-organizational systems in supporting inter-organizational coordination in the networked-business context. The main research question of the dissertation is stated as follows:

> ***RQ:*** *"In the networked business context, what is the impact of agent-based inter-organizational systems (ABIOS) on inter-organizational coordination?"*

As information become ubiquitous, networks rise as the coordination form that offers quick informational access, flexibility, and responsiveness to highly dynamic business environment (Powell 2003). To adapt with the networked way of doing business, companies require new types of inter-organizational systems (IOS) that go beyond the conventional informational exchange functions. Conceptually, ABIOS is positioned to answer business actors' demand in finding partners, settling coordination arrangements, and conducting coordination strategies in a faster and more intelligent manner. In the age where communication of large volumes of electronic data can be done precisely, instantaneously, and cost-effectively, ABIOS empower its users with intelligence, i.e., the ability to sense, learn, and predict patterns out of large and rich information (Sinur et al. 2013). While the emphasis of the conventional IOS has focused on the informational exchanges mediation only, ABIOS empower users with an intelligent information synthesis ability that will help in finding collaborators, setting and executing profitable coordination arrangements, and securing coordination assurance.

Moreover, ABIOS decentralized coordination mechanisms can facilitate rapid and spontaneous coordination interactions among self-interested decentralized business actors (Durfee et al. 1989; Carley & Gasser 1999) that is in line with the characteristic of inter-organizational coordination practices in the networked business conducts (van Heck & Vervest 2007). We assert the level of sophistications of the networked coordination conducts will be strongly influenced by the extent to which ABIOS revolutionize inter-organizational coordination practices.

6.2 Summary of Main Findings

To answer this dissertation's research question, we conducted four independent studies. In the first study, we investigate the reason behind the emerging demand of ABIOS to support inter-organizational coordination. We recite the first sub-research question as follows:

> ***RQ_1:*** *"Why do we need inter-organizational systems in inter-organizational coordination?"*

Chapter 2 elaborates the first sub-research question by conducting theoretical exploration and synthesis on the reason behind the demand for IOS and the corresponding IOS functionalities. At the demand side, we position equivocality and uncertainties conditions as the conceptual conditions that drive the demand for IOS. The IOS is needed to support the users in the following practical contexts: (1) finding and selecting prospective partners, (2) formulating and settling coordination arrangements, and (3) preparing, executing, and controlling coordination strategies. To support the whole spectrums of coordination activities, IOS support are needed in three coordination contexts namely, (1) finding and selecting prospective partners, (2) formulating and settling coordination arrangements, and (3) preparing, executing, and controlling coordination strategies. In response, IOS must provide three main features namely, (1) the coordination initiation, (2) coordination execution, and (3) coordination assurance functionalities.

Chapter 3 presents a cross-case analysis that investigates the impact of ABIOS on its clients' business networks performance. The sub-research question for Chapter 3 is stated as follows:

> ***RQ$_2$:*** *"What is the impact of the agent-based inter-organizational systems (ABIOS) on business network performance?"*

This chapter presents a conceptual model portraying the influence of ABIOS on clients' coordination structure and information architecture; and the impact of those structural alterations on business network performance in terms of the coordination (effectiveness and efficiency), agility (response time, response cost, robustness, and response range), and informational (information processing and communication performance) performances. To validate the model, a cross-case analysis was conducted in three logistics cases, namely, warehousing, freight forwarding, and intermodal transportation. As findings, the application of ABIOS requires adjustments to the information architecture or the coordination structure, or both. Subsequently, those structural adjustments will stimulate improvements in the coordination, agility, and informational performances.

As information synthesis capability becomes an important competitive aspect in this information era, how to develop the ABIOS artefacts becomes an important issue to understand for companies that aim to excel in this networked business era. Chapter 4 and 5 present demonstrations on how companies can design ABIOS to improve their inter-organizational coordination. In Chapter 4 we present a design science study focusing on the design of ABIOS coordination mechanisms. The sub-research question of Chapter 4 is stated as follows:

> ***RQ$_3$:*** *"How to design an ABIOS coordination mechanism that facilitates the coordination of self-interested actors?"*

Chapter 4 presents two main variants of modified auction mechanism (the cost-based and service based schemes) to coordinate appointment reservations of containers' pick-up/delivery operations at seaports. The objective is to provide a solution on the appointment reservation problem which concerns self-interested actors, namely the seaports and drayage operators. For the evaluation, we develop and conduct agent-based simulations based on the empirical data of one of the biggest seaports in Rotterdam, the Netherlands. In terms of the seaport's operational efficiency, the cost-based scheme are the best. On the other side, the service-based modified auction mechanisms have the best appointment tardiness at the expense of high reservation costs.

Chapter 5 corresponds to the largely unexplored field of ABIOS predictive analytics development using large volume geospatial sensor-based data. This chapter aims to answer the following sub-research question:

> ***RQ_4:*** *"How to design a predictive-analytics ABIOS that uses large-sized geospatial sensor-based data to predict the seaport terminal service rates performance?"*

This study presents a seaport service rate prediction system that could help drayage operators to improve their predictions of the duration of the pick-up/delivery operations at a seaport by using the subordinate trucks' trajectory data. The system is constructed based on three components namely, trajectory reconstruction, geo-fencing analysis, and gradient boosting modelling. Using predictive analytic techniques, the prediction system is trained and validated using more than 15 million data records from over 200 trucks over a period of 19 months. The gradient boosting model-based solution provides better predictions compared with the linear model benchmark solution.

6.3 Contribution to Literatures

In Chapter 2, we provide explanation theory that elaborates the conceptual positioning of inter-organizational systems as a solution to mitigate partnership equivocality and uncertainties. Equivocality and uncertainties are two conceptual coordination circumstances that urge the demand for IOS. In coordination practices, equivocality and uncertainties exist in the contexts of partner selection, coordination arrangement settlement, and coordination strategy definition. We position those activities as the IOS *demand factors*. As the corresponding *supply factors*, IOS provide three main functionalities namely, the coordination initiation, coordination execution, and coordination assurance functions. To understand the correspondence between the IOS demand factors, i.e., the coordination circumstances that urge the *demand* for IOS, and the corresponding IOS supply factors, i.e., the IOS functionalities, we present *the inter-organizational systems – inter-organizational coordination grid* concept (Figure 2-1).

Chapter 3 theoretical contribution is mainly centered on the empirically validated conceptual model explaining the interplay among the ABIOS, the coordination structure, the business network performance and the informational structure, namely the coordination, agility and informational performance constructs. This study fills the gap in the smart business network literatures which often treat the enabling technology as exogenous (van Heck & Vervest 2005; Pau 2013). From the perspective of ABIOS literatures, especially the ones on multi-agent coordination topic, this study fills the need for empirical works which complement the abundance of design-oriented papers (Carley & Gasser 1999; Zambonelli et al. 2003).

Chapter 4 presents a design science artifact (Gregor & Hevner 2013), namely the modified auction mechanism for reserving appointments to execute containers' pick-up/delivery operations at seaport terminals. This chapter's research corresponds to the scarcity of agent-based research on the topic of designing seaport appointment systems. We depart from the research limitations of the research on seaport appointment systems that omit the aspect of self-interestedness of the coordinating actors. In addition most previous studies normally assume decision makers have the authority and information needed to govern the behaviour of the whole system, which is not the case. In response, we present an unexplored solution that can facilitate concurrent reservations and consider the interests of the coordinating actors, namely the seaport terminals (i.e. operational efficiency) and drayage operators (i.e. reservation performance).

Chapter 5 corresponds to the largely unexplored field of predictive analytics development using geospatial sensor-based data (Shmueli & Koppius 2011; Chen et al. 2012). This study offers a new approach to the seaport congestion issue and explains how stakeholders can use predictive analytics techniques on their internal data assets, especially vehicle telematics data, to extract better insights to improve their decision making (Herrera et al. 2010; Hastie et al. 2011). To the best of our knowledge, this approach has not been introduced in the research literature on seaport diversion initiatives, non-diversion initiatives, and decision support systems on seaport hinterland operation (Zhao & Goodchild 2011; Acciaro & Mckinnon 2013; Murty et al. 2005).

6.4 Managerial Relevance

Discussing the dissertation's managerial relevance aspect, the theoretical explanation presented in Chapter 2 can be used to understand, analyze, design, implement, and evaluate the demand conditions where the IOS would bring the maximum impact in supporting the inter-organizational coordination needs of the IOS users. With an understanding of the coordination contexts categorization (i.e., partner selection, coordination arrangement settlement, and coordination strategy definition), practitioners can pinpoint the exact IOS functionality requirement (i.e., coordination initiation, coordination execution, and coordination assurance features) to support their coordination operations. The proposed concept will be useful for organizations, in understanding the fit between their inter-organizational coordination needs and the expected functionalities of the IOS.

Chapter 3 explains the structural consequences that organizations must anticipate before confirming to ABIOS implementation projects. Note that IOS adoption is a strategic decision that requires support from multi-stakeholders. To implement the ABIOS, organizations must be prepared to modify their existing coordination structure, information architecture, or both. While ABIOS implementations with radical coordination structure modifications can lead to immediate improvements (as shown in the Kiva system case), overcoming stakeholders' resistance towards this type of ABIOS implementation can be a big challenge. Alternatively, one may choose a more moderate implementation path by implementing ABIOS that only requires information architecture adjustments (as shown in the IC-system case).

Chapter 4 highlights the importance of the agent-based approach in designing inter-organizational systems. Learning from previous failures of IOS implementations, the design of the IOS must consider the multi-stakeholder and multi-interested aspects in the IOS development. Neglecting thess very aspects will lead to low participations from the involved coordinating actors. Recall, this studies identifies high frequency communications as an important characteristic of the decentralized coordination mechanism. To cope with the emerging need of high communicational and computational load, we can see the future business need of having intelligent personal software agents. Agents can help humans' limitations in coping with highly repetitive and high informational load tasks. The use of agent-based approach which provides system designers a natural way to model, experiment, and analyse the interactions of autonomous actors is certainly of great importance, yet still an under-researched field.

In Chapter 5 copes with a challenging condition where coordination participacts use IOS with limited information availability. The chapter presents an example on how companies may re-examine and utilize their unutilized internal data assets using predictive analytics techniques to extract new insights that are useful to improve their coordination operation. Concretely, the presented system can support drayage operators in predicting a seaport terminal's service rate so that truck route planning will minimize the time spent at stop points. This chapter also shed light to the importance of utilizing emerging technologies such as the internet of things (IoT), big data, predictive analytics, and intelligent machines in developing more intelligent IOS.

6.5 Generalizability, Limitation, and Further Research

This dissertation offers a number of generalizable concepts and research insights. Chapter 2 offers the inter-organizational systems – inter-organizational coordination grid (Figure 2-1) that is applicable to analyze any IOS/ ABIOS instantiations. Chapter 3 presents a generic conceptual model (Figure 3-8) explaining the relationship among ABIOS applications, the corresponding structural adjustments requirements, and the business network performance concequences. Despite the specificity of the business context studied in Chapter 4 and Chapter 5, learning from our experience in developing ABIOS coordination mechanisms and predictive analytics, one can apply similar approach to design better performing ABIOS.

This dissertation has a number of limitations. Chapter 2 investigation on the role of IOS in supporting inter-organizational coordination were conducted based on the analyses of operational aspect of coordination activities. Many other aspects of coordination activities are not incorporated. Many aspects are still open for further study such as the legal consequences of empowering software agents with autonomous decision rights and task execution power (Smed 1998; Stuurman & Wijnands 2001; Murphy & Woods 2009), the extent to which the delegation of autonomous coordination authority can create beneficial and sustainable collaboration between the client organizations and the IOS (Friedman & Nissenbaum 1997; Norman et al. 1997), the institutional analysis on the coordination platform in which software agents can operate autonomously (Noriega & Sierra 2002; Esteva et al. 2004), etc.

In Chapter 3 the assessment of the ABIOS impact on the performance improvement is done at the company level. Analyzing performance at an aggregate network level is still open for research. While this chapter focuses only on the logistics sector, analyzing the impact of the ABIOS on other business sectors may provide valuable insights. Lastly, this study offers a theoretical perspective for investigating the role of the ABIOS in the business network context. Alternative conceptual models explaining the role of the

ABIOS in stimulating networked business practices are still rare and open for further development.

As in any design science study, Chapter 4 and 5 focus on a specific ABIOS design aspects and business context. We realize that both chapters can only explore a very limited scope off all ABIOS design aspects available. Further research limitations and prospective research opportunities are listed in detail in each chapter. Nevertheless, we believe that the selected problems studied in Chapter 4 and Chapter 5 can bring useful insights to improve the state of inter-organizational coordination between the seaport terminals and the drayage operators. Moreover, we believe that Chapter 4 and Chapter 5 offer a general design rationales (i.e. the tradeoff in designing coordination mechanisms, how to use spatiotemporal data to develop useful predictive analytics, etc.) that can be applied in other business contexts.

We hope this dissertation can pave the way for future research attempts. From the design science research perspective, we hope our work can stimulate further research development on the topic of decentralized coordination mechanism and predictive analytics in the context of seaport appointment systems designs. From the Information Systems perspective, we can see limitless opportunities in conducting fruitful studies on the applications of artificial intelligence/ agent-based technologies in the development of intelligent ABIOS in myriad business contexts.

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Summary

This dissertation explores how *Agent-Based Inter-organizational Systems (ABIOS)* play a role in enhancing future conducts of inter-organizational coordination. Investigating the impact of ABIOS on inter-organizational coordination is the central question of this dissertation. The topic has an increasing relevance as businesses need to conduct faster and more flexible inter-organizational coordination. As communication of large volumes of electronic data is no longer a problem, businesses are n constrained by the limited functionalities of their inter-organizational systems (IOS). The IOS classical function to mediating informational exchange purposes becomes obsolete. Meanwhile, the ABIOS technology with its intelligent information features is expected to revolutionize how businesses conduct coordination operations.

We conduct four independent studies in this dissertation. In the first study, i.e. Chapter 2, we conduct theoretical exploration and synthesis to provide theoretical explanations on the reason behind the demand for IOS and the corresponding IOS functionalities. At the demand side, equivocality and uncertainties conditions urge the need for having IOS. IOS support are needed in three coordination contexts namely, (1) finding and selecting prospective partners, (2) formulating and settling coordination arrangements, and (3) preparing, executing, and controlling coordination strategies. In response, IOS must provide three fundamental features namely, (1) the coordination initiation, (2) coordination execution, and (3) coordination assurance functionalities.

In Chapter 3 we investigate the impact of ABIOS on its clients' business networks performance. This chapter presents a conceptual model portraying the influence of ABIOS on clients' coordination structure and information architecture; and the impact of those structural alterations on business network performance in terms of the coordination, agility, and informational performances. To validate the model, a cross-case analysis was conducted in

three logistics cases, namely, warehousing, freight forwarding, and intermodal transportation. As findings, the application of ABIOS requires adjustments to the information architecture or the coordination structure, or both. Subsequently, those structural adjustments will stimulate improvements in the coordination, agility, and informational performances.

In Chapter 4 we present a design science study focusing on the design of ABIOS coordination mechanisms. We present two main variants of modified auction mechanism (the cost-based and service based schemes) to coordinate appointment reservations of containers' pick-up/delivery operations at seaports. The objective is to provide a solution on the appointment reservation problem which concerns self-interested actors, namely the seaports and drayage operators. For the evaluation, we develop and conduct agent-based simulations based on the empirical data of one of the biggest seaports in Rotterdam, the Netherlands. In terms of the seaport's operational efficiency, the cost-based scheme are the best. On the other side, the service-based modified auction mechanisms have the best appointment tardiness at the expense of high reservation costs.

Chapter 5 corresponds to the largely unexplored field of ABIOS predictive analytics development using large volume geospatial sensor-based data. This study presents a seaport service rate prediction system that could help drayage operators to improve their predictions of the duration of the pick-up/delivery operations at a seaport by using the subordinate trucks' trajectory data. The system is constructed based on three components namely, trajectory reconstruction, geo-fencing analysis, and gradient boosting modelling. Using predictive analytic techniques, the prediction system is trained and validated using more than 15 million data records from over 200 trucks over a period of 19 months. The gradient boosting model-based solution provides better predictions compared with the linear model benchmark solution.

To conclude, this dissertation presents novel theoretical and practical insights on the impact of ABIOS in enhancing inter-organizational coordination conducts. From the theoretical perspective, this dissertation offers new theoretical perspectives in viewing the IOS positioning in mitigating coordination equivocality and uncertainties; the interplay among the ABIOS applications, required structural adjustments, and business performance; and two important ABIOS design spectrums, the predictive analytics and coordination mechanism design. From the practical perspective, this dissertation can help businesses in understanding ABIOS' specific features, the required structural adjustments and corresponding performance improvements opportunities in applying ABIOS, the importance of two important design aspects in the ABIOS design, namely the coordination mechanism design and the value of proper utilization predictive analytics on their data asset, especially large volume data (big data), that can offer novel insights that are beneficial to improve their coordination decision making.

Nederlandse Sammenvating

Deze dissertatie onderzoekt de rol die *agent-gebaseerde interorganisationele systemen (Agent-Based Inter-Organizational Systems, ABIOS)* spelen in het verbeteren van toekomstige interorganisationele coördinatie. De centrale vraag van deze dissertatie gaat over de invloed van ABIOS op interorganisationele coördinatie. De relevantie van dit onderwerp groeit met de toenemende behoefte aan snellere en meer flexibele interorganisationele coördinatie. Nu het communiceren van grote hoeveelheden elektronische data geen probleem meer is, vormt de beperkte functionaliteit van interorganisationele systemen (IOS) de bottleneck voor bedrijven. Het belang van de conventionele functie van IOS, namelijk het bemiddelen van informatie-uitwisseling, neemt af in een tijdperk van alom tegenwoordige informatie die intelligent kan worden gesynthetiseerd om een nog betere interorganisationele coördinatie mogelijk te maken. Wij stellen dat de intelligente informatiefunctionaliteiten van deze ABIOS-technologie de manier waarop bedrijven hun operaties coördineren ingrijpend zullen doen veranderen.

Voor deze dissertatie zijn vier onafhankelijke studies uitgevoerd. De eerste studie (Hoofdstuk 2) is een theoretische verkenning en synthese die de redenen achter de vraag naar IOS en de bijbehorende IOS-functionaliteiten theoretisch verklaart. Aan de vraagkant creëren ambiguïteit en onzekerheid de noodzaak van het hebben van een IOS. Ondersteuning door IOS is nodig in drie coördinatiedimensies, namelijk (1) het zoeken en selecteren van mogelijke partners, (2) het formuleren en afstemmen van coördinatie-afspraken en (3) het voorbereiden, uitvoeren en controleren van coördinatiestrategieën. IOS moeten daarvoor drie fundamentele functionaliteiten leveren, namelijk (1) het initiëren van coördinatie, (2) het uitvoeren van coördinatie en (3) het zeker stellen van coördinatie.

In Hoofdstuk 3 wordt de impact van ABIOS op de prestaties van zakelijke netwerken van klanten bestudeerd. Een conceptueel model wordt gepresenteerd dat de invloed van ABIOS op de coördinatiestructuur en informatie-architectuur van klanten toont, alsook de invloed van die structurele wijzigingen op de prestatie van zakelijke netwerken in termen van coördinatie, flexibiliteit en informatieprestatie. Om het model te valideren, is een overschrijdende analyse uitgevoerd over drie logistieke casussen: opslagactiviteiten, vrachtvervoer en intermodaal transport. De resultaten tonen dat de toepassing van ABIOS aanpassingen zal vereisen in de informatie-architectuur, de coördinatiestructuur, of beiden. Die structurele aanpassingen stimuleren verbeteringen op het gebied van coördinatie, flexibiliteit en informatieprestatie.

In Hoofdstuk 4 wordt een ontwerponderzoek gepresenteerd gericht op het ontwerpen van ABIOS-coördinatiemechanismen. Twee versies van een gemodificeerd veilingmechanisme (een kosten-gebaseerd en een diensten-gebaseerd systeem) worden gepresenteerd om afspraakreserveringen te coördineren voor het ophalen en afleveren van containers in zeehavens. Om deze te evalueren zijn agent-gebaseerde simulaties ontwikkeld en uitgevoerd op basis van empirische data van een van de grootste zeehavens ter wereld namelijk in Rotterdam, Nederland. Op het gebied van operationele efficiëntie presteert het kosten-gebaseerde mechanisme het beste. Het diensten-gebaseerde veilingmechanisme, daarentegen, toont de minste afspraakvertraging tegen hogere reserveringskosten. De instelling van de coördinatiemechanismen heeft een grote invloed op de operationele prestatie van coördinatiedeelnemers. De deelnemers moeten daarom acht slaan op het coördinatiemechanisme dat wordt geïmplementeerd in het betreffende IOS.

Hoofdstuk 5 betreft het grotendeels onverkende gebied van voorspellende analyse met ABIOS op basis van grote volumes geo-ruimtelijke sensordata. Deze studie presenteert een dienstverleningsvoorspellingssysteem voor zeehavens dat containertransportbedrijven kan helpen om de duur van ophaal- en aflever-afhandeling op de terminal te voorspellen met behulp van de routedata van hun eigen vrachtwagens. Het systeem is gebouwd op basis van drie componenten, namelijk trajectreconstructie, analyse van *geo-fencing* en modellering op basis van *gradient boosting*. Met behulp van deze voorspellende analysetechnieken is het systeem getraind en gevalideerd op meer dan 15 miljoen gegevens van meer dan 200 vrachtwagens over een periode van 19 maanden. De oplossing op basis van het *gradient boosting model* levert betere voorspellingen op dan de benchmark op basis van een lineair model.

Deze dissertatie presenteert vernieuwende theoretische en praktische inzichten over de impact van ABIOS op het verbeteren van interorganisationele coördinatie. Ten eerste biedt deze dissertatie nieuwe theoretische perspectieven door de rol van IOS in het verminderen van organisationele ambiguïteit en onzekerheid te benadrukken; door de interactie tussen ABIOS-applicaties, de benodigde structurele aanpassingen en de zakelijke prestaties te identificeren; en door twee belangrijke ontwerpen te introduceren, namelijk het ontwerpen van en coördinatiemechanismen het ontwerpen van voorspellende analyse. Ten tweede kan deze dissertatie bedrijven helpen om specifieke eigenschappen van ABIOS te begrijpen, evenals de benodigde structurele aanpassingen en bijbehorende kansen voor prestatieverbetering door toepassing van ABIOS te onderkennen. Gebruikers zullen ook het belang van de twee belangrijke ontwerpen van ABIOS erkennen, namelijk het coördinatiemechanisme-ontwerp en de waarde van succesvol gebruik van voorspellende analyse op hun datasets, vooral bij grote hoeveelheden data (zongenaamde *big data*), waarmee nieuwe inzichten kunnen worden verworven die de coördinatiebesluitvorming tussen bedrijven zal verbeteren.

Ikhtisar Bahasa Indonesia

Pada era jaringan bisnis terintegrasi (*networked business*), koordinasi antar para pelaku bisnis harus dilakukan dengan lebih cepat dan fleksibel. Untuk mendukung kebutuhan ini, kompleksitas sistem inter-organisasi (*inter-organizational systems*/ IOS) yang diperlukanpun akan semakin meningkat. Dengan meningkatnya informasi yang dipertukarkan antar pelaku bisnis, IOS tidak hanya diharapkan dapat memfasilitasi pertukaran informasi namun juga diharapkan dapat melakukan proses sintesis informasi secara lebih pintar. IOS generasi baru ini dikenal dengan nama *Agent-Based Inter-organizational Systems*/ ABIOS. Disertasi ini memaparkan hasil dari empat penetitian terkait peran, penggunaan, dan pengaruh ABIOS dalam praktek koordinasi antar-organisasi dalam konteks operasi logistik.

Pada Bab 2 dipaparkan hasil penelitian pertama terkait eksplorasi teoretis yang menghasilkan sintesis konseptual yang menjelaskan dasar dari kebutuhan IOS dan fungsionalitas dasar IOS. Ditinjau dari sisi kebutuhan, penelitian ini memposisikan konsep ketidakjelasan (*equivocality*) dan ketidakpastian (*uncertainties*) dalam aktifitas koordinasi sebagai dua aspek yang melatarbelakangi kebutuhan akan IOS. Kedua aspek tersebut dapat diamati pada seluruh spektrum dasar aktifitas koordinasi: (1) pencarian dan pemilihan rekanan, (2) formulasi dan persetujuan skema koordinasi, dan (3) penyiapan, eksekusi, dan pengendalian strategi koordinasi. Untuk mengatasi ketidakjelasan dan ketidakpastian dalam aktifitas koordinasi, IOS mendukung pengambilan keputusan melalui tiga fungsi utamanya: (1) inisiasi, (2) eksekusi, dan (3) penjaminan aktifitas koordinasi.

Penelitian kedua (Bab 3) memaparkan pengaruh dari aplikasi ABIOS terhadap performa jaringan bisnis klien ABIOS. Bab ini memaparkan perumusan model konseptual acuan yang menjelaskan pengaruh implementasi ABIOS terhadap penyesuaian struktur koordinasi dan arsitektur informasi klien yang akan berimbas pada peningkatan performa jaringan bisnis klien. Performa jaringan bisnis dijabarkan secara lebih lanjut kedalam tiga aspek: (1) performa koordinasi (efektifitas dan efisiensi), (2) kegesitan perusahaan/ *agility* (waktu respons/*response time*, ongkos respons/ *response cost*, jangkauan respons/ *response range*, dan ketangguhan/ *robustness*), dan (3) performa informasi (performa pemrosesan informasi dan komunikasi). Rumusan model konseptual acuan kemudian divalidasi menggunakan metode studi kasus pada sejumlah implementasi ABIOS dalam domain bisnis pergudangan dan transportasi. Pada kasus implementasi ABIOS di bidang pergudangan yang diteliti, perombakan struktur koordinasi dan arsitektur informasi klien yang berujung pada peningkatan keseluruhan spektrum performa jaringan bisnis klien dapat diamati jelas. Pada implementasi ABIOS di dua perusahaan transportasi yang diteliti, ditemukan adaptasi arsitektur informasi pada sisi klien; namun tidak ditemukan adanya perubahan dari struktur koordinasi. Pada kasus kedua ini, implementasi ABIOS dijalankan dengan cara yang lebih moderat dimana performa jaringan bisnis klien tetap dapat ditingkatkan dengan menghindari perubahan terhadap struktur koordinasi yang tengah berjalan.

Penelitian ketiga (Bab 4) membahas perancangan mekanisme koordinasi ABIOS. Pada penelitian ini dipaparkan dua varian dari rancangan mekanisme koordinasi lelang (mekanisme lelang berbasis ongkos dan berbasis layanan) yang ditujukan untuk memperbaiki proses reservasi jadwal pengantaran/pengambilan peti kemas. Perancangan ini mengajukan solusi koordinasi terdesentralisasi bagi dua aktor bisnis utama yang terlibat pada proses terkait: terminal peti kemas dan operator truk. Untuk mengevaluasi rancangan koordinasi yang diajukan, dilakukan simulasi berbasis agent (*agent-based simulation*) dengan memakai acuan empiris dari salah satu terminal peti kemas terbesar di Rotterdam, Belanda. Hasil evaluasi menunjukan bahwa skema koordinasi lelang berbasis ongkos akan memiliki implikasi yang lebih baik bagi efisiensi operasi terminal peti kemas. Pada sisi lain, skema koordinasi lelang berbasis layanan memiliki implikasi positif pada ketepatan waktu reservasi meskipun biaya reservasi pada sisi operator truk akan menjadi lebih tinggi.

Penelitian keempat (Bab 5) membahas aplikasi teknik *predictive analytics* pada data geospasial berukuran besar pada rancangan ABIOS. Penelitian ini memaparkan rancangan sistem prediksi kecepatan layanan terminal peti kemas yang dapat digunakan operator truk untuk memprediksi durasi pelayanan pengantaran/pengambilan peti kemas. Melalui aplikasi teknik *predictive analytics* yang diaplikasikan pada lebih dari 15 juta baris GPS data yang diekstrak dari catatan pergerakan 200 truk selama 19 bulan. Studi ini mendemonstrasikan bagaimana pelaku bisnis dapat menggunakan data historis internal sebagai sumber berharga dalam mengekstrak berbagai perspektif baru bagi perbaikan operasi koordinasi.

Dengan membaca disertasi ini, diharapkan pembaca akan mendapatkan perspektif baru terkait peran, penggunaan, dan pengaruh ABIOS dalam praktek koordinasi antar-organisasi modern. Dari sisi teoretis, disertasi ini menjelaskan (1) posisi IOS sebagai infrastruktur informasi yang berfungsi memitigasi berbagai ketidakjelasan (*equivocality*) dan ketidakpastian (*uncertainties*) dalam aktifitas koordinasi; (2) keterkaitan antara ABIOS, adaptasi struktur koordinasi dan arsitektur informasi, dan potensi peningkatan performa jaringan bisnis; dan (3) dua spektrum perancangan ABIOS: perancangan mekanisme koordinasi dan *predictive analytics*. Dari sisi praktis, disertasi ini memberikan pemahaman terhadap fungsionalitas ABIOS, konsekuensi adaptasi struktural dan potensi peningkatan performa jaringan bisnis yang harus dipertimbangkan, demonstrasi perancangan mekanisme koordinasi sebagai jantung dari fungsi fasilitasi koordinasi ABIOS, dan aplikasi *predictive analytics* yang mampu memfasilitasi ekstraksi pengetahuan dari data berukuran besar (*big data*) yang berguna bagi perbaikan pengambilan keputusan koordinasi.

About the Author

Meditya Wasesa obtained his bachelor degree in mechanical engineering from Bandung Institute of Technology, Indonesia. He continued his study in the University of Duisburg-Essen, Germany, where he obtained his master degree in logistics engineering with the highest distinction (*sehr gut*). During his time in Germany, he worked for the after-sales logistics department of General Motors Europe GmbH. He founded and is managing the Indonesian Center for Logistics and Value Chain (ICLOV) in his hometown, Bandung, Indonesia. He has been working on numerous research and consultancy projects for several renowned private and stated owned companies. His professional interests focus on the field of logistics and information systems.

His PhD research at the Rotterdam School of Management has been funded by the Erasmus Research Institute of Management (ERIM) and Almende BV. His research focus is on the role and impact of agent-based inter-organizational systems, business intelligence systems, and predictive analytics techniques on business networks performance in the logistics sector. His research has been presented at numerous international workshops and conferences. One of research projects won the best poster paper award at the 8th Workshop on e-Business, Phoenix, USA. Two chapters of his dissertation are published in the Journal of Enterprise Information Management and Decision Support Systems respectively.

Ph.D. Portfolio

Selected Publications

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“Agent-based Inter-organizational Systems (ABIOS) in Advanced Logistics Operations” explores the concepts, the design, and the role and impact of agent-based systems to improve coordination and performance of logistics operations. The dissertation consists of one conceptual study and three empirical studies. The empirical studies apply various research methods such as a multiple-case study research, coordination mechanism design, and predictive analytics using big data. The conceptual study presents a theoretical exploration and synthesis explaining the demand for inter-organizational systems (IOS) and the corresponding IOS functionalities. The first empirical study presents a multiple-case study exploring real-life ABIOS implementations in the warehousing and transportation business. The second empirical study provides an auction based coordination mechanism design for the container’s pick-up/delivery appointment reservation problem that involves the seaports and drayage operators. The third empirical study presents a seaport service rate prediction system that could help drayage operators to improve their predictions of the duration of the pick-up/delivery operations at a seaport by using the subordinate trucks’ trajectory data. Based on these studies, the dissertation offers new insights on the role of inter-organizational systems in mitigating coordination equivocality and uncertainties; the interplay among the ABIOS applications, required structural adjustments, and the potential of business performance improvement opportunities; and the development of two ABIOS prototypes: an auction based coordination mechanism and a predictive analytics application based on big data.

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