RESEARCH AGENDA TOWARDS MARITIME INFORMATICS

by

SEYMA GUVEN KOCAK

(Under the Direction of Richard Thomas Watson)

ABSTRACT

Maritime transportation is the most efficient and cost-effective mode of transport. With the appropriate use of advanced technology, the efficiency of the industry can be improved even further. Information systems for the maritime industry have been generally ignored by the IS community. Consequently, we introduce "Maritime Informatics" as a new stream to introduce IS scholars to the many research and practice opportunities offered by the maritime industry. Our goals are to understand the characteristics, operations, and culture of the industry, as well as some major problems that need improvement. By analyzing previous studies addressing the problems of the maritime transportation industry, we aim to develop a research agenda for information system researchers, with the end goal of creating a more efficient, safe, and ecologically sustainable maritime transportation.

INDEX WORDS: maritime informatics, information systems, maritime ecosystem

# RESEARCH AGENDA TOWARDS MARITIME INFORMATICS

by

SEYMA GUVEN KOCAK

BS, Boğaziçi University, Turkey, 2011

MS, New York University, 2013

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF ARTS

ATHENS, GEORGIA

2014

# RESEARCH AGENDA TOWARDS MARITIME INFORMATICS

by

SEYMA GUVEN KOCAK

Major Professor: Richard Thomas Watson
Committee: Marie-Claude Boudreau
Mikael Lind

Electronic Version Approved:

Julie Coffield
Interim Dean of the Graduate School
The University of Georgia
December 2014

# DEDICATION

To my husband Kamil Kocak who is my greatest supporter.

ACKNOWLEDGEMENTS

I would like to extend my gratitude to my advisor, Professor Richard Thomas Watson, for his guidance, support and understanding throughout my research. He is the most inspiring professor I have ever met. I cannot imagine a better role model for academic endeavor. I am grateful for having a chance to work with such a successful academician with great personality.

I am also thankful to the members of my committee – Dr. Marie-Claude Boudreau and Dr. Mikael Lind, for their valuable suggestions. I appreciate their support and understanding throughout my thesis process.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Page

# CHAPTER 1

## DIGITIZATION OF THE SEAS

Maritime transportation is the backbone of international trade. With around 90% of the world's trade carried by sea, maritime transportation is essential for the global economy (IMO, 2013). Including indirect and induced effects, the annual economic impact of the shipping industry is $436.6 Billion (World Shipping Council, 2014b). The industry supports 13.5 million jobs (World Shipping Council, 2014b). With a 4.3% growth rate in 2012, as well as a growing trend throughout history, maritime transportation is likely to remain important in the coming years (IMO, 2013; UNCTAD, 2013). Therefore, certain problems in the industry need to be solved. Conditions should be improved in order to secure a better transportation system in the future.

Maritime transportation is the most efficient and cost-effective mode of transport. Container ships can carry several large warehouses of goods on a single journey, and they are also able to operate with a team of only thirteen people thanks to advanced computer technology (World Shipping Council, 2014a). It is also relatively fast: a journey of around 14,500 km can be completed in a mere days (World Shipping Council, 2014a). Added to that, being capable of carrying large amounts of goods decreases the unit cost of goods transported. For example, the cost of transporting a kilogram of coffee from Asia to Europe is only fifteen cents (World Shipping Council, 2014a). With the appropriate use of advanced technology, the efficiency of the industry can be improved even further.

Currently, the maritime transportation industry experiences communication problems that can inevitably result in chaos, as revealed by the following event. The Port of Felixstowe – UK's busiest port – was in 2014 in danger of losing many customers due to port congestion. The summer period has always been busy in Felixstowe, but in 2014, the unexpected growth of Asian imports worsened the situation, so much so that many companies had already diverted their ships from Felixstowe to London Gateway Port. Felixstowe was not alone: Rotterdam and Hamburg ports – Europe's two biggest ports – also had congestion problems in 2014.

Port authorities often complain that ships do not maintain announced schedules. Moreover, carriers do not always communicate with their shippers before making a diversion to a new port. Thus, exporters have difficulty whenever they try to arrange a new route from a new port. (Wackett, 2014) Serious communication problems in the maritime industry often lead to chaos, as in Felixstowe's case. Communication and congestion are two of the maritime industry's major management issues.

Information systems for the maritime industry have been generally ignored by the IS community, with a few exceptions (Cumberland, Jessup, & Valacich, 2002). Consequently, we introduce "Maritime Informatics" as a new stream to introduce IS scholars to the many research and practice opportunities offered by the maritime industry.

In this work, we first aim to understand the characteristics, operations, and culture of the industry, as well as some major problems that need improvement. By analyzing previous studies addressing the problems of the maritime transportation industry, we aim to develop a research agenda for information system researchers, with the end goal of creating a more efficient, safe, and ecologically sustainable maritime transportation. Lastly, we introduce *maritime informatics* as a research stream that studies the application of information systems in order to increase the efficiency, safety, and ecological sustainability of the world's shipping industry.

# CHAPTER 2

# MARITIME ECOSYSTEM

Maritime transportation differs from other modes of transportation due to its unique characteristics (Christiansen & Fagerholt, 2006). Throughout history, the shipping industry has had distinctive traditions, norms, and universal rules, which have formed a rooted and unique maritime culture (Lutzhoft, Grech, & Porathe, 2011). Understanding the industry, its operations, and problems requires a understanding of its ecosystem, which consists of a culture of unique characteristics and conditions (Lutzhoft et al., 2011). In this section, the components of maritime ecosystem (see Figure 1) are explained in detail.

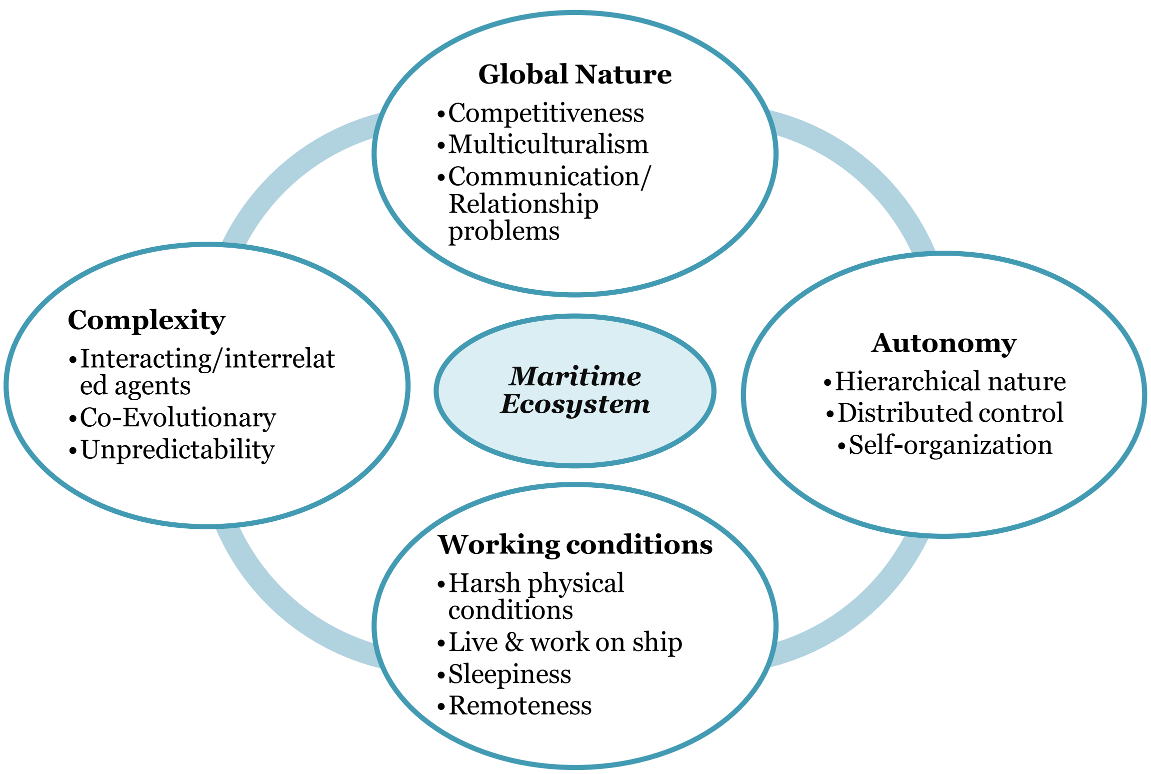


**Figure 1: The components of the maritime culture**

The distinct characteristics of a maritime ecosystem can be grouped into four main categories: working conditions, global nature, autonomy, and complexity. The working conditions of the maritime industry have many unique characteristics that affect its overall operations. It is inherently global (International Chamber of Shipping, 2009), which requires specific norms and regulations. Despite the fact it continuously interacts with different cultures, the industry still maintains distinctive traditions. One of the most notable historical characteristics is the autonomy of the captain. Also, the maritime industry has a complex nature in terms of the relationships between the agents, the operations, rules, and regulations. All four of these major components need to be collectively understood before considering the application of information systems to improve the ecosystem.

**Global Nature**

The shipping industry is global by nature, which affects the roles, regulations, and the culture of the industry. Globalization provides an opportunity to serve a more varied market, but also opens doors to a larger number of players, which usually increases competition. As the maritime industry operates in a highly competitive environment, ship owners are compelled to be cost-oriented (Lutzhoft et al., 2011). They seek economic efficiencies in their operations. For example, they hire multinational crews from developing economies to decrease their wage bills, or they reduce the number of crew members on board (Lutzhoft et al., 2011). Knowing the cost-oriented behavior of the ship owners help us to understand subsequent decisions they might make about certain issues such as employee training and technology investments.

The global nature of the industry makes multiculturalism inevitable. Crew members from different nations work and live together during long trips. Managing a multicultural crew is an important challenge for a ship's captain and its officers. While it may provide a cost reduction opportunity, it can also create many problems in the work environment (Horck, 2005).

One of the major disadvantages of multiculturalism is poor communication between crew members mainly due to their lack of linguistic skills in a common language, usually English (National Maritime Polytecnic, 2006). Not speaking the same language in a workplace can lead to problems such as misinterpretation of information and ineffective teamwork. Sometimes lack of communication can even lead to accidents (Lutzhoft et al., 2011). Even in circumstances in which all crew members speak the same language they might still have communication difficulties originating from attitude-related problems (Lutzhoft et al., 2011).

Moreover, multinational crew members often have relationship problems due to racism, cultural differences, stereotyping, prejudice, and power distance (Horck, 2005; Lutzhoft et al., 2011). When people do not recognize each other's specific cultural values, goals, and customs, they may be conflict in their working relationships (Horck, 2005). Sometimes they may not even find enough common ground to develop basic friendships. Another reason for potential conflict in a multicultural crew is the differences in power distance (Horck, 2005; Lutzhoft et al., 2011). Seafarers from high-power distance countries may accept authority more easily, while those from low-power distance countries may question their superiors directly (Lutzhoft et al., 2011). Cultural differences can also strain relationships between crew members and a ship's officers.

Despite its challenges, multiculturalism can be beneficial to the shipping industry. Some of its advantages include a diverse range of intellectual processes and patterns, maintaining a captain's authority by a broad mixture of nationalities, knowledge transfer between seafarers, and easier communication with customers from different nationalities (Horck, 2005). All in all, multiculturalism is an important facet of the industry that must be taken into account in maritime studies. With the right management tools, current disadvantages may even prove to be beneficial.

**Autonomy**

Shipboard teams are traditionally hierarchical, consisting of a combination of civil-type structures and quasi-military norms (Lutzhoft et al., 2011). The captain has full authority over everything – routes, seafarers, and operations. The captain's autonomy is revealed in Flexstowe's case, where ships often decided to change port without informing their customers or port authorities. Based on their judgment, a captain and other officers may make important decisions such as changing the route, the arrival port, or a schedule.

Shipping has traditionally had a power culture and an autocratic attitude style (Goulielmos & Gatzoli, 2012). The power culture is held and transmitted by the ship owner, while the captain has an autocratic attitude (Goulielmos & Gatzoli, 2012). In the past, the ship owners used to stay on their ships, while today their management style is different: "management by communication" (managing the ships from the shore and leading the captain). In addition, they have come to view their ships as commercial properties that can be sold anytime, which shows that there is no sentimental link between the ship and its owner (Goulielmos & Gatzoli, 2012). On the other hand, the captain is always on the ship and the one whose life is at risk in case of an accident. Thus, the communication between the captain and the ship owner is not always effective, especially in moments of distress (Goulielmos & Gatzoli, 2012). In addition, according to the IMO safety regulations, the captain has the major responsibility for safety issues, with increasing accountability in recent years (Goulielmos & Gatzoli, 2012). Having the highest responsibility on a ship may help explain the autocratic attitude of the captain.

Self-organization is another characteristic of the maritime ecosystem. In the shipping industry, the control of operations is distributed among different agents (Caschili & Medda, 2012). Even though there are international trade agreements, rules, and regulations, such as the IMO's regulations, there are also agents coordinating ports, ships, and operations. Agents pursue their own advantage in their decisions, and operations by self-organization – "*a bottom-up process arising from the simultaneous local non-linear interactions among agents*" (Caschili & Medda, 2012).

**Complexity**

The maritime industry has a complex structure with a large number of interacting independent agents. The key agents of the industry are ports, port authorities, shipping companies, terminal operators, commodity producers, and freight brokers. They are independently managed by different parties, but connect with each other on a daily basis. The presence of a large number of interacting agents makes the structure of the maritime industry (Figure 2) highly complex (Caschili & Medda, 2012).

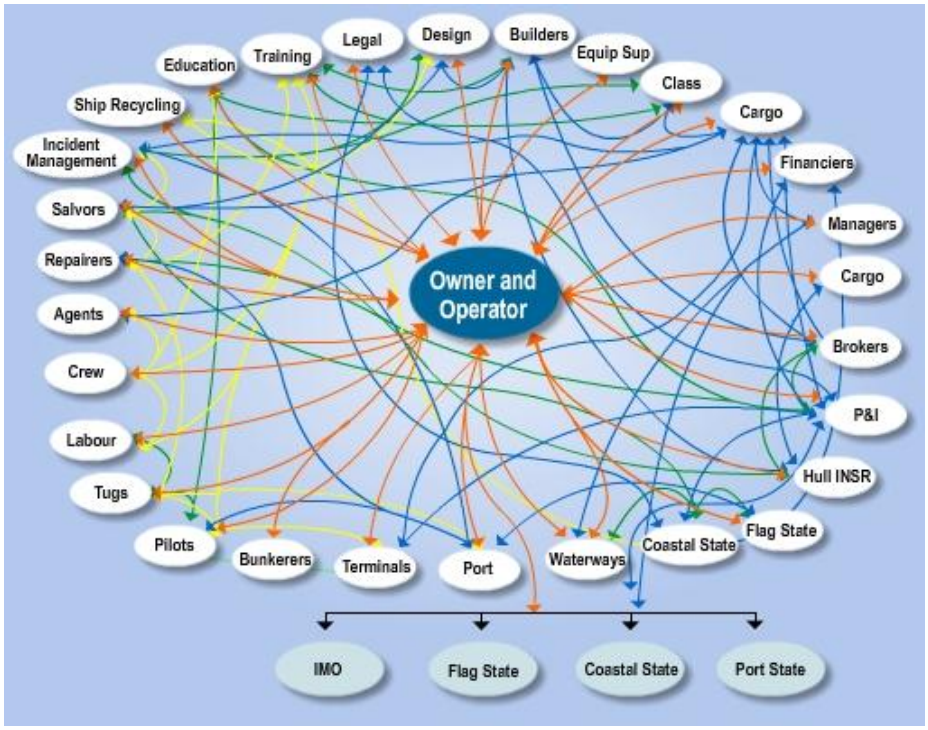


**Figure 2: Complexity of the stakeholders in maritime industry (Adopted from (Maritime Industry Foundation, 2013))**

The mutual interactions of agents generates evolution in the system. The industry is co-evolving because agents need to change their actions as they interact with other agents. For example, if a big seaport hub is damaged due to a natural disaster, then the maritime shipping network will co-evolve to maintain operations. Similarly, in the case of a financial international crisis, the maritime shipping network will co-operate with each other in order to share the investment as well as the risk. In this way, they can stay profitable. Being able to co-evolve makes the structure of the maritime transportation more complex.

The shipping industry also incorporates an element of unpredictability (Caschili & Medda, 2012; Lutzhoft et al., 2011). Planned arrival times, departure times, and sailing schedules can change on board (Lutzhoft et al., 2011). The most common reasons for unpredictable schedules are weather conditions, and port conditions (Christiansen & Fagerholt, 2006). Weather conditions may affect the sailing time, such as a ship needing to reduce its speed in bad weather. Furthermore, port conditions – mechanical problems, traffic, operating hours – can affect arrival and departure times (Christiansen & Fagerholt, 2006). Although it is not easy to eliminate the variations in shipping operations, uncertainties due to port conditions may be reduced by better communication of higher quality information between stakeholders and by more effective management.

**Working Conditions**

The maritime industry has unique working conditions. First of all, there is often a harsh physical working environment (Lutzhoft et al., 2011). Although the conditions may vary from ship to ship, the facilities are generally poor. For example, in some ships, sea water can be used for bathing, while electricity is only available to the higher grade staff (Samuels, Sultana, & Chakraborty, 2013). Crew members must deal with the varying conditions of the seas even as they try to operate safely and efficiently. Besides the often poor facilities, there are other challenges for the sailors, such as natural disasters, accidents, and robbery (Samuels et al., 2013).

Even if the conditions are relatively fair, working long hours at sea create a difficult life (NPR, 2013). A ship is not just the workplace for the crew, but also the crew's only living space. During longer trips, the ship is the place where crew live, work, entertain, and sleep - it is everything (NPR, 2013). As crew members often share their cabins with other sailors, they don't usually have privacy or a quiet room to sleep (Samuels et al., 2013). Moreover, they need to sleep in motion in a noisy surrounding, since the ship continues its operations day and night (Lutzhoft et al., 2011).  In addition, shift work makes sleeping conditions even worse as its schedule correlates with short and poor-quality sleep (Axelsson, Akerstedt, Kecklund, & Lowden, 2004; Lutzhoft et al., 2011). Consequently, sleepiness is a major problem for seafarers.

Waking hours also pose specific problems. It is very difficult for a seafarer to get away from the job and have some free time, which leads many workers to refer to their jobs as "a prison with a salary" (Alderton, Bloor, & Kahveci, 2004; NPR, 2013). An American ex-seafarer explains the dilemma as follows: *"Seafarers work tremendous hours and they have nowhere to go, either at sea or in port. One of the big innovations since I started going to sea is the video tapes, but after you've seen Terminator 3 for the four times, I am sure that it gets to them"* (Alderton et al., 2004). A Bulgarian chief officer express similar feelings: *"Being in the ship all the time gets to you. The ship is damp, it's sometimes cold. The food isn't fresh. There is voice and vibration. Where the ship goes, it vibrates. We are always on board. I work here, eat here, sleep here. Sometimes it creates psychological problems"* (Alderton et al., 2004).

As the testimonies reveal, maritime workers must deal with the reality that their workplace is far away from family, and friends. The remoteness of the working environment and limited access to communication technology often result in an isolated, difficult, and lonely environment (Lutzhoft et al., 2011; NPR, 2013). In turn, this situation affects seafarers' morale, their relationships, families, and shore-based life in a negative way (Alderton et al., 2004). Trying to communicate with one's family during stressful times, such as when a family member is ill, only serve to exacerbate an already difficult situation. During these times, lack of communication increases the seafarer's stress level, which can lead to fatigue and low levels of productivity in the workplace (Alderton et al., 2004). Since technological developments increase a seafarer's chance of communicating with family more frequently and easily, implementing the newest technologies at sea may raise a worker's morale (and hence, productivity).

# CHAPTER 3

# MARITIME TRANSPORTATION LITERATURE

## Literature Overview

Maritime transportation has received considerable attention from fields diverse as operations research, management, policy, economics, and information systems. We reviewed the literature in a broad range of fields to identify the major problems of the industry, research questions that have already been answered, and ones that remain for future studies. In the previous studies, we observe four main research domains: efficiency, safety, environment, and policy. These arenas represent the ultimate purpose of the research – improving efficiency, safety, or environmental performance. In the current research, we are not directly involved in policy studies, so we exclude this research from our review.

Each study tends to focus on one or more components of the maritime ecosystem. For example, improving efficiency requires a consideration of complex structure of the industry, and improving safety requires a consideration of working conditions on board. We have listed the most highly cited publications studying the efficiency, safety and environment domains of maritime transportation research since 2005 in Table 1. We performed a search with “maritime transportation” keyword in Web of Science and selected articles based on their citation counts. We classified them by their research domains, and noted the ecosystem components that they take into consideration.

**Table 1: List of selected publications in maritime transportation research since 2005, their research themes, and the maritime ecosystem components**

| RESEARCH THEMES | | MARITIME ECOSYSTEM | | | |
|---|---|---|---|---|---|
| | **Selected publications** | **Global Nature** | **Autonomy** | **Complexity** | **Working Conditions** |
| **Efficiency** | (Agarwal & Ergun, 2008) | | | IIA | |
| **Efficiency** | (Al-Khayyal & Hwang, 2007) | | | IIA | |
| **Efficiency** | (Bilgen & Ozkarahan, 2007) | C | | IIA | |
| **Efficiency** | (Brønmo, Christiansen, Fagerholt, & Nygreen, 2007) | | SO | IIA<br>U | |
| **Efficiency** | (Grønhaug, Christiansen, Desaulniers, & Desrosiers, 2010) | | | IIA | |
| **Efficiency** | (Hoff, Andersson, Christiansen, Hasle, & Løkketangen, 2010) | C | | IIA | |
| **Efficiency** | (Norstad, Fagerholt, & Laporte, 2011) | | | | |
| **Safety** | (Celik, Lavasani, & Wang, 2010) | M<br>CR | | IIA<br>U | |
| **Safety** | (Li, Meng, & Qu, 2012) | | | U | HPC<br>LW |
| **Safety** | (Merrick, Dorp, & Dinesh, 2005) | | | U | |
| **Safety** | (Trucco, Cagno, Ruggeri, & Grande, 2008) | M | | IIA | |
| **Safety** | (Ulusçu, Ozbaş, Altiok, & Or, 2009) | CR | | IIA | |
| **Safety** | (van de Wiel & van Dorp, 2009) | | | IIA | R |
| **Safety** | (Yip, 2008) | CR | | IIA | |
| **Environment** | (Celik, 2009) | C | DC | | |
| **Environment** | (Corbett, Wang, & Winebrake, 2009) | C | DC | | |
| **Environment** | (Eyring et al., 2010) | | DC | IIA | |
| **Environment** | (Fitzgerald, Howitt, Smith, & Hume, 2011) | C | DC | | |
| **Environment** | (Psaraftis & Kontovas, 2010) | C | DC | | |
| **Environment** | (Psaraftis & Kontovas, 2013) | C | DC | | |
| **Environment** | (Ronza, Vílchez, & Casal, 2007) | C | | U | |

*Initials used for ecosystem components: HPC: Harsh physical conditions, LW: Live & work on ship, S: Sleepiness, R: Remoteness, C: Competitiveness, M: Multiculturalism, CR: Communication/ Relationship problems, H: Hierarchical nature, DC: Distributed control, SO: Self-organization, IIA: Interacting/interrelated agents, CO: Co-Evolutionary, U: Unpredictability

Detailed literature review is provided in Appendix, where we listed the field of study, findings, methodologies, and future research suggestions of the articles. We shaped our research questions considering the limitations of the current studies. This detailed literature review shows us that majority of the prior studies have offered solutions for local problems, and have suggested an integrated approach for solving the problems of the maritime ecosystem. Therefore, in our research agenda, we focus on research questions that address the issues of the maritime ecosystem as a whole, instead of the problems of individual players.

The highlights of the detailed literature review provided insight for our research agenda. Studies on efficiency emphasize the complexity of the industry, and suggest accounting for the relationships between interacting agents. We believe that this can be achieved by an effective communication between related agents. Safety studies emphasize the importance of human factors, historical data analysis, and traffic control technologies. We believe that information systems can help gathering safety related data, help preventing human related errors, and manage port and sea traffic. Environmental studies focus on the assessment of the environmental performance, and the impact of the environmental policies. Information systems would help gathering environmental data which makes it easier to assess the environmental performance, and monitor the actions of the stakeholders.

Findings and limitations of the prior studies helped us determine our proposed research questions, which are presented in Chapter 5. We adopted a broad perspective to approach ecosystem problems.

**The Most Cited Articles**

In order to understand the main themes of the research articles in maritime transportation, we look at the five most cited articles since 2005. We selected them based on their Web of Science citation count. Table 2 lists these five articles as well as their main goals and data they use. We observe that two of them (Agarwal & Ergun, 2008; Al-Khayyal & Hwang, 2007) focus on efficiency in maritime scheduling and cargo routing, while one of them is a book chapter explaining the industry and its characteristics. The others are about strategic decision making, and risk analysis. Although their research streams are different, one common factor remains: lack of field data. None of them empirically test their ideas or hypotheses using industry data. Other articles in the literature follow the same path.

**Table 2: The five most cited articles (searched from Web of Science with the keyword "maritime transportation")**

| Article | Goal | Data |
|---|---|---|
| **(Agarwal & Ergun, 2008)** | Ship Scheduling and Network Design for Cargo Routing in Liner Shipping | Randomly generated instances simulating real life |
| **(Celik, Cebi, Kahraman, & Er, 2009)** | Utilizing fuzzy axiomatic design (FAD) and fuzzy technique to manage strategic decision-making with incomplete information in Turkish container ports | No field data are used |
| **(Christiansen & Fagerholt, 2006)** | A chapter on maritime transportation which explains the characteristics of the industry, its culture, stakeholders, problems etc. | N/A |
| **(Al-Khayyal & Hwang, 2007)** | Formulating a model for finding a minimum cost routing in a network for a heterogeneous fleet of ships engaged in pickup and delivery of several liquid bulk products | 100 test problems randomly generated and solved |
| (Trucco et al., 2008) | Integrating Human and Organizational Factors (HOF) into risk analysis | Case study |

The maritime literature mainly consists of articles that use generated data or conceptual articles. We believe that the main reason for this shortcoming is the complexity of the industry. Because of the large number of agents and inter-related relationships between the agents (Caschili & Medda, 2012), data from the industry is complex enough to make its collection and analysis difficult. However, testing ideas in the field is important for the relevancy of the research. Thus, we believe that there should be more research using industry data. The gap between the reality and the research must be narrowed if academics are to make effective contributions to the field.

## The Information Systems Literature

As the highly cited articles in Table 1 do not include any articles from the Information Systems literature, we performed a separate search of IS literature, limited to the senior scholars basket of eight journals[1] and the two main conferences of Association of Information Systems (AIS) – International Conference on Information Systems (ICIS), and American Conference on Information Systems (AMCIS). As these journals and conferences are highly recognized in the field, we believe that the list would include any high-quality research which has strong roots in IS literature.

We used the Web of Science database using the key words "maritime transportation" without any date restriction (between 1864 and 2014). We had zero results. We repeated the search with "maritime" as the keyword without any date restriction and found one article, which was not directly related to maritime industry.

---

1 http://aisnet.org/?page=SeniorScholarBasket&hhSearchTerms=%22basket+and+eight%22

With “shipping,” we obtained five results. Among these five, only two of them are (see Table 3) directly related to the shipping industry, while others merely mention the industry. In order to make sure that we didn’t miss any articles, we repeated the search in Google Scholar, and had the same results.

**Table 3: List of selected IS publications in maritime transportation research**

| Article | Goal | Data |
|---|---|---|
| **(Rai, Pavlou, Im, & Du, 2012)** | Identifying the means by which information technology helps co-create relational value in the context of interfirm relationships in the logistics industry | Archival data provided by the focal logistics supplier |
| **(Gordon, Lee, & Lucas, 2005)** | Discussing the resources, including operations and information technology that have contributed to the competitive position of the Port of Singapore | Interviews with a purpose of learning about operations and specific IS initiatives employed by the Port |

We used the AIS database to search for “maritime”, and “shipping” keywords in AMCIS and ICIS proceedings. Among a few results, none of them has the maritime industry as its main area of focus. Therefore, we conclude that the maritime industry has been ignored by the IS community. This situation confirms the need to create Maritime Informatics as a new subfield of IS.

In addition to reviewing the selected journals and conference proceedings mentioned previously, we performed a broader search to see if the maritime industry was ever mentioned in IS literature. Cumberland, Jessup, & Valacich (2002)’s work is worthwhile to mention here. The paper, which appears in the *Communication of the Association for Information Systems* in 2002, aims to introduce a comprehensive list of information systems that support the maritime industry and also to explore the research opportunities in this area. Although their purpose seems similar to ours, their paper is significantly different. First, they focus on the technologies used without analyzing the components of the maritime ecosystem. If the unique characteristics of the industry are not explained thoroughly, the need for research might not be clearly understood and key dimensions overlooked. Another important difference is that they create a research agenda for a specific information system only: Automated Identification Systems (AIS). However, we propose a research agenda for a much wider range of possible information systems used key stakeholders of the maritime industry.  Cumberland, Jessup, & Valacich (2002)'s article had little impact, and we are not aware of any citations.

# CHAPTER 4

## THE ROLE OF IS IN MARITIME ECOSYSTEM RESEARCH

Information systems can create efficiency and raise safety as well as reduce environmental problems in the maritime industry. In order to create effective information systems, it is critical to thoroughly understand the maritime ecosystem – its needs and characteristics. The information system can have a positive impact only if it is aligned with specific objectives (Henderson & Venkatraman, 1993). Therefore, the alignment of the information systems with the goals of the key stakeholders of the maritime industry is critical.

As explained in the previous chapters, the maritime ecosystem has many unique characteristics. Information systems designed for this industry need to be closely aligned with these characteristics. For example, developing an information communication system for seafarers requires that we first consider the needs, culture, and working conditions of the shipping industry. Thus, information systems designed for maritime industry need to be aligned with the goals of the stakeholders as well as with the characteristics of the ecosystem.

In this section, we propose a framework of the maritime informatics (see Figure 3), which arose from our review of the literature, and analysis of the ecosystem. In doing so, we explain the information system needs of the industry and determine ecosystem components that should be taken into consideration in developing information systems for certain industry needs. Next, we provide some examples of information systems that we think would be used in the maritime industry to achieve its goals. We also present the ecosystem characteristics that need to be taken into account in the design and management of those information systems. In this way, we aim to illustrate how to utilize the maritime informatics framework we propose.

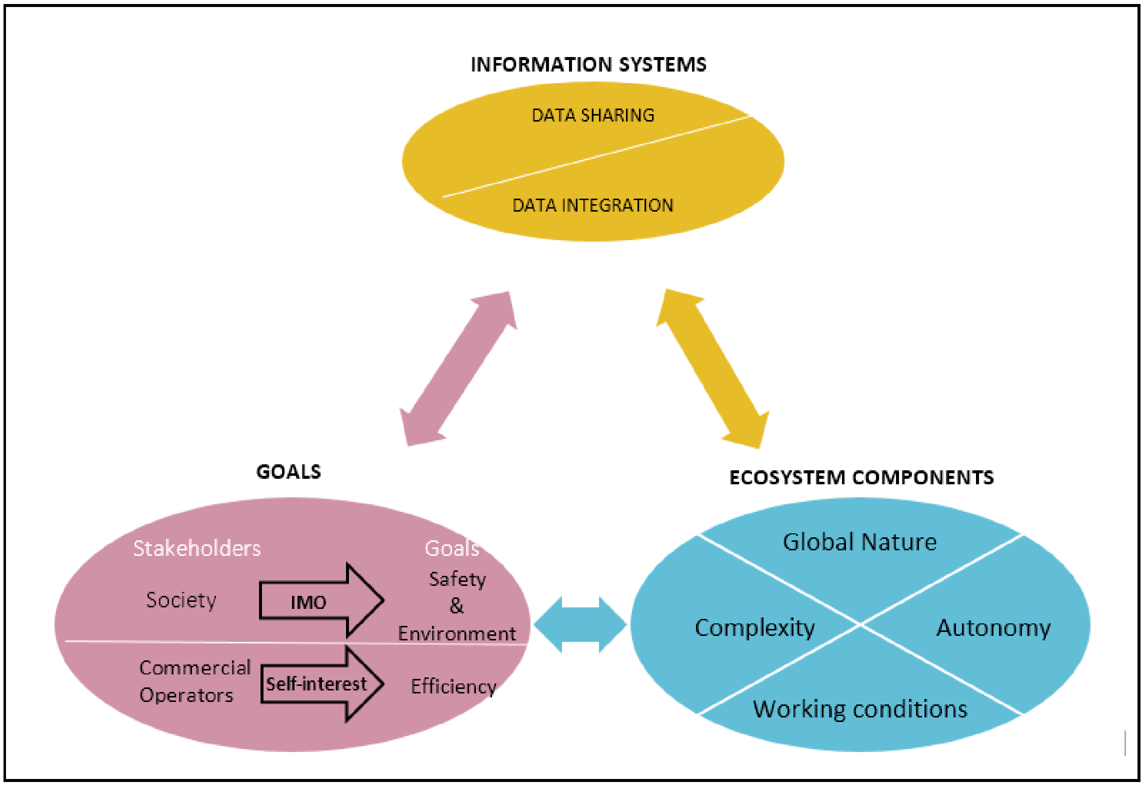


**Figure 3: Maritime Informatics Framework: The alignment between the information systems, the goals of its key stakeholders, and the characteristics of the maritime ecosystem**

In our framework, we first identified the key stakeholders of the industry and their goals. Since the maritime transportation industry is complex, there are many interacting and interrelated stakeholders (Caschili & Medda, 2012). However, it is possible to group the stakeholders into two main categories: society and commercial operators. Commercial operators include ship owners, port authorities, cargo owners, and others (see Figure 2). The main goals of the society are safety and environmental protection, while commercial stakeholders are mainly interested in profit through efficiency. Clearly, some commercial stakeholders also care about the environment and safety, but in order to survive, their main focus should be on efficiency. The International Maritime Organization (IMO) helps society achieve its goals through rules and regulations for safety and the environment (IMO, 2014). On the other hand, commercial operators' self-interest and market forces are the main drivers of efficiency.

Governments, institutions and companies recognize the importance of information systems in maritime transportation. The European Union has initiated an e-Maritime Initiative to foster the use of advanced information systems in the industry (European Union, 2012). It aims to improve the quality, efficiency of the operators, and the communication between the agents (European Union, 2012). As Dimitrios Theologitis – head of unit "Maritime Transport and Ports Policy" for the European Commission – mentioned in an interview in 2011, it also expects gains in terms of the living standards and education of seafarers (Face of Shipping, 2011). Information technology for the maritime industry also attracts many companies. As a result, many independent information systems have been developed for certain purposes, creating little standardization. As Mr. Theologitis mentions, even though integrating information between all stakeholders is not realistic, the stakeholders, at the very least, need to communicate information. Thus, developing a system that supports data sharing is critical.

There are a variety of information systems that the stakeholders can adopt to achieve safety, efficiency, and environmental goals including but not limited to the major ones we explain below. Our explanation for selecting each information system, their roles, and the ecosystem components which impact their effectiveness are explained in this section. We start with societal goals – safety and environment – and continue with efficiency goals for commercial operators.

**Safety**

Improving maritime safety necessitates decreasing the risk of accidents, improving fire protection and working conditions, and more accurate navigation and communication (International Maritime Organization, 2014b). The information system needed to achieve safety goals should be designed considering the root causes of the accidents. According to studies, human error causes around 80 percent of all accidents at seas (Berg, 2013; Goulielmos, Goulielmos, & Gatzoli, 2013; Hetherington, Flin, & Mearns, 2006; Lutzhoft et al., 2011). In order to explain the possible causes of the accidents in detail, we use the Samina express case (Goulielmos et al., 2013).

The Samina Express accident, which resulted in 82 deaths in September 2000, is a typical example of marine accidents resulting from a series of mistakes. One of the main causes of the accident was the change of the route a mere fifteen minutes before the accident (Goulielmos et al., 2013). Automatic pilot was in use, even though the specific area was not appropriate for the use of automatic pilot. Ultimately, it remained ambiguous as to whether the captain approved the change of route. In addition, at the time of the accident, critical crew members – including the radio officer, lookout man, and captain – were absent. After the accident, the ship sank very quickly because some watertight doors were open, even though it is mandatory to keep all of them closed.

Clearly, more than one mistake caused this disaster. Similar to the Samina Express case, in other marine accidents such as Titanic accident, the cause is generally a series of mistakes (Goulielmos et al., 2013).

These groupings of mistakes are generally of a human nature. As such, we define information systems that can be used to decrease the possibility of accidents. First of all, we know that there was a lack of communication between crew members. The route was changed, but it was ambiguous that the captain approved this change. Also, vital crew members were absent. Here, we suggest that an open communication system within the units would be helpful. In this way, the crew members would communicate easily in case of accidents, or important decisions such as route change. In order to design an effective open ICT, the global nature of the maritime ecosystem should be taken into consideration. As there is a great diversity in terms of the nationalities of the crew members, open ICT would include translation features for effective communication. In addition, the fact that there might be relationship problems among the crew members would be an important factor affecting the design of the system. For example, in order to encourage them to behave professionally, their interactions through the system could be recorded and tracked by their supervisors.

Being one of the most dangerous industries, maritime transportation is controlled by IMO's safety rules and regulations. However, as we see in the case of Samina Express, certain rules may sometimes be ignored by the seafarers. To deal with this problem, sensor networks can be implemented to collect data regarding the safety precautions. For example, there might be sensors measuring whether the watertight doors are open or closed. When the working conditions are considered, we know that seafarers have difficult differentiating their living places and workplace. Thus, they may not be continuously careful about rules and regulations. Realizing the harsh working conditions, a system that warns crew members when the doors are open would be one solution. In some cases, warning the seafarers may not be enough. As explained in the Samina Express case, opening the watertight doors can be the result of a certain cultural attitude among some seafarers. In this case, a system that shares all data with the company managers, and IMO would be a better solution. In sum, the components of the maritime ecosystem and culture should be taken into consideration while designing these systems. Similarly, sensor networks can be used for collecting all other safety-related data to be able to keep track of safety regulations on board.

Safety rules and regulations demand that seafarers be constantly careful about a complex number of details. Thus, a Safety Management Information System (SMIS) to manage all safety issue within the company would be useful. With SMIS, seafarers can keep track of all safety related situations with more ease. Considering the sleepiness problem of seafarers, SMIS may have alarm features just in case the seafarer on duty falls asleep. Similarly, considering the lack of distinction between the workplace and home, SMIS may force crew members to be at the right place at the right time. In addition, SMIS can provide better reporting and statistics to the operator company and enable them to analyze the causes of certain accidents.

**Environment**

Improving the environmental performance of the maritime industry is another important goal of the society, which is regulated by IMO. Maritime is the least environmentally damaging mode of transportation and in order to decrease its environmental damage even more IMO provides various rules and regulations (International Maritime Organization, 2014a). In addition, the nature of the maritime transportation makes it possible to improve the environmental performance in terms of energy efficiency and the prevention of pollution (IMO, 2013).

In order to collect environment-related data to be able to keep track of environmental regulations on board, sensor networks can be utilized. In this way, IMO can more easily audit the ships and companies in terms of their environmental performances. Similarly, environmental IT can be utilized to manage all actions. Thanks to the use of environmental IT, the operator company can analyze their environmental performance and use optimization algorithms to minimize the environmental effect. Designing environmental IT and sensor networks would require working conditions to be taken into consideration. Due to the harsh working environment, seafarers may not be able to keep track of all the environmental regulations they need to follow. These information systems would make their life easier on board.

**Efficiency**

An efficiency goal for commercial stakeholders should motivate them to implement information systems that would help them decrease the costs and maximize the profits. In order to decide on what kind of information system to use, we consider the factors increasing the cost of operations. Key variables of shipping costs include fuel costs, maintenance, port expenses, and operational costs (Gkonis & Psaraftis, 2009). Shorter routes and less waiting times at the ports would decrease the fuel costs. In order to find the shortest route with less waiting time at the port, the shipping company needs to obtain information about ship location and port traffic. To do so, Geographic Information Systems (GIS) can be utilized. With GIS, they can track the location of their ships, and generate shorter routes based on the port traffic. For example, if the expected waiting time for a port is too long, stakeholders can decide to direct their ships to another port. For an effective use of GIS, the global nature and complexity of the industry should be taken into consideration. Due to the large number of interacting agents, the mere location of the ship is not the only information that a company needs. They also need to obtain information about other ships that are close to their ships, as well as vessels planning to use the same port as their ships. In order to secure this information, companies and ports need to agree to share some of their data with the relevant stakeholders. A GIS enabling data sharing would be much more useful in this global and complex ecosystem.

Decisions regarding the routes and ports made on shore are useless unless there is a way to communicate this information with the captain on board. This communication is possible with the use of vessel-to-shore ICT. However, the autonomous nature of the ecosystem and autocratic behavior of the captains need to be taken into consideration while designing these technologies. Use of vessel-to-shore ICT that provides a way to control the captain may conflict with the maritime culture. Thus, its use should be adjusted according to the particular culture. For example, instead of direct control though out the trip, the communication may be limited to the critical situations such as route changes, and emergencies, or when the ship is approaching the port.

Increasing shore control over the vessel may decrease the level of autonomy, but it doesn't eliminate it completely. Some level of autonomy on the part of the captain is the reality of the maritime transportation, as the captain remains the one who holds full responsibility on board. Thus, technologies that the captain can use to make efficient decisions are necessary besides vessel-to-shore ICT. One of these technologies would be vessel-to-vessel ICT, which enables captains of different ships to communicate with each other. Sharing data would help them make decisions about their speeds, which time to enter a port, and route changes. The complexity of the industry affects the design of vessel-to-vessel ICT. As there are many interrelated agents with unpredictable behaviors, real-time and accurate vessel-to-vessel ICT will prove critical in certain situations.

**Data integration/sharing**

Lastly, a distinction between the information systems in terms of their data integration should be taken into consideration. Data integration consists of gathering data from different sources, and providing a unified database. In our case, data integration is necessary within one unit of the industry. In other words, a company can integrate its data thanks the hierarchical structure – the upper level management having control over the employees. Similarly, data integration is possible as IMO has a hierarchical power over the other stakeholders. In sum, data integration is necessary for open ICT, sensor networks, SMIS, and environmental IT. The other information systems are designed to increase the collaboration between different stakeholders (e.g. companies), which requires data sharing instead of data integration. Data sharing is to share information with a relevant person, in terms of the characteristics of the person, and the location of him/her. There is no need to share all information an agent has. In addition, it is not realistic to force companies to integrate all of their data with other companies. Thus, GIS, vessel-to-vessel ICT, and ship-to-shore ICT should be designed to be data sharing systems.

# CHAPTER 5

## RESEARCH QUESTIONS FOR MARITIME INFORMATICS

After reviewing the academic literature, we conclude that prior studies have analyzed the problems of individual stakeholders and local solutions to them versus considering the maritime ecosystem as the unit of analysis. However, the large number of inter-related agencies, and the global nature of the industry means that local solutions are often suboptimal. A broader approach is needed to understand the ecosystem and develop more holistic solution. We now set forth a Maritime Informatics research agenda as a set of questions that address ecosystem problems (see Table 4).

**Table 4: Identified Research Questions for IS Community**

| | SAFETY | ENVIRONMENT | EFFICIENCY |
|---|---|---|---|
| **System Design** | RQ 1: What are the design principles of safety-related information systems for the commercial maritime ecosystem? | RQ 7: What are the design principles of environment-related information systems for the commercial maritime ecosystem? | RQ 13: What are the design principles of efficiency information systems for commercial maritime ecosystem? |
| **Policy** | RQ 2: What policies and regulations are needed to advance the use of information systems to achieve a safer working environment in the commercial maritime ecosystem? | RQ 8: What policies and regulations are needed to advance the use of information systems to achieve an ecologically sustainable commercial maritime ecosystem? | |

| | | | |
|---|---|---|---|
| **Information / data** | RQ 3: What data should be reported by each stakeholder in the commercial maritime ecosystem to inform IMO’s safety regulations enforcement and improvement? | RQ 9: What data should be reported by each stakeholder in the commercial maritime ecosystem to inform IMO’s environmental regulations enforcement and improvement? | RQ 14: What data at what granularity should be shared by stakeholders in the commercial maritime ecosystem to improve efficiency? |
| **Communication** | RQ 4: How can within and among stakeholder communication be changed to improve safety? | RQ 10: How can within and among stakeholder communication be changed to ecological sustainability? | RQ 15: How can within and among stakeholder communication be changed to improve efficiency? |
| **Behavior** | RQ 5: What factors affect the adoption and use of safety-related information systems in the maritime ecosystem? | RQ 11: What factors affect the adoption and use of environment-related information systems in the maritime ecosystem? | RQ 16: What factors affect the adoption and use of the information systems for efficiency in the maritime ecosystem? |
| **Economic/societal impact of the implementation** | RQ 6: What improvements in safety in the maritime ecosystem can be attributed to information systems? | RQ 12: What improvements in the ecological sustainability of the maritime ecosystem can be attributed to information systems? | RQ 17: What improvements in the efficiency of the maritime ecosystem can be attributed to information systems? |

**Safety**

For a safer maritime ecosystem, all stakeholders need to be not only engaged but committed. The IMO needs to monitor companies to ensure that its safety regulations are followed rigorously; subsequently, companies also need to track their ships or ports to make sure that all safety regulations are satisfied. To achieve their goals, each stakeholder can utilize an advanced information system to manage its safety initiatives. IS scholars need to determine the design principle of information systems that address the safety-related needs and purposes of the diverse stakeholders. To determine these systems, data to be reported by each stakeholder to inform IMO's safety regulations, characteristics and culture of the industry, and the technological restrictions should be taken into account. Moreover, the purpose of these systems should be to address the safety-related issues of the ecosystem, not just of one unit – an agent, a ship, or a port. Thus, they should enable data integration between all pertinent parties. For example, to avoid an accident, the information from one ship might not be enough. Information from all ships in the vicinity should be integrated. Furthermore, systems that address the safety-related issues more effectively and provide data integration need to be identified.

*RQ 1: What are the design principles of safety-related information systems for the commercial maritime ecosystem?*

One of the major concerns of IMO is safety at sea—a set of rules and regulations that the industry needs to uniformly follow. However, it is difficult to track all human related errors, or captains' attitudes at sea, given the lack of documentation, and autonomous nature of the maritime industry. This monitoring problem can be addressed by the use of advanced information systems. Safety-related data can be collected through sensor networks and shared with the regulators directly, or indirectly. In other words, the IMO can collect safety-related data and monitor commercial ships, or create policies to require companies to monitor their ships. For this decision, the autonomous nature of the shipping industry, and the working conditions need to be considered. Which monitoring policy to choose, what kind of data to collect, and how much data to share with the regulators are some of the questions which must be addressed by IS scholars.

*RQ 2: What policies and regulations are needed to advance the use of information systems to achieve a safer working environment in the commercial maritime ecosystem?*

*RQ 3: What data should be reported by each stakeholder in the commercial maritime ecosystem to inform IMO's safety regulations enforcement and improvement?*

Human error is the major cause of all accidents at seas (Berg, 2013; Goulielmos et al., 2013; Hetherington et al., 2006; Lutzhoft et al., 2011). These can be operative errors – related to the qualifications, or physical and mental conditions of personnel, or situational errors – related to work environment design, human-machine interaction, and management issues (Berg, 2013). As the maritime industry has a multicultural environment, one of the main reasons of human errors is poor communication between crew members due to the lack of linguistic skills in a common language as well as educational differences. To overcome these unique problems, a communication standard needs to be developed. The airline industry provides an excellent model for this practice, insofar as they have pre-identified commands which everybody needs to know and use in case of an emergency, even though those commands may not be in everyone's native language (Airbus, 2007). IS scholars need to determine which communication standard is more effective in maritime industry, and how IS can help implement it.

*RQ 4: How can within and among stakeholder communication be changed to improve safety?*

Safety-related initiatives can be successful only if all stakeholders in the industry make them of the upmost priority. Especially in the maritime industry, where all agents interact on a day to day basis, lack of participation by one agent in safety initiatives could affect the others. Therefore, developing the most appropriate information system will not guarantee a safer maritime ecosystem if even a few stakeholders do not implement it effectively. In the maritime ecosystem, various cultural factors are major barriers to the improvement of the safety management (Berg, 2013; Lappalainen, Vepsäläinen, & Tapaninen, 2010). Thus, all stakeholders need to share a common safety culture, which is defined as *"The assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance."* (IAEA, 2006). IS scholars need to identify the cultural factors affecting the adoption and the use of safety-related information systems.

*RQ 5: What factors affect the adoption and use of safety-related information systems in the maritime ecosystem?*

Information systems are effective tools to address safety concerns of an industry (National Research Council, 1999). However, a rigorous measurement of the impact of IS on safety is necessary. Currently, there are many different information systems in use. Understanding the impact of each of these systems in order to better compare them would be a useful standardization process. IS scholars need to analyze the impact of the use of IS systems on safety.

*RQ 6: What improvements in safety in the maritime ecosystem can be attributed to information systems?*

**Environment**

Various information systems could be used to monitor and manage environmental performance in the maritime industry. IS scholars need to identify the most appropriate design for these environment-related information systems. To do that, needs of various stakeholders should be more fully understood. For example, IMO's main goal is to track the environmental performance of the ships and ports; conversely, the ship operator's main goal is to satisfy the environmental regulations while being cost-efficient. Moreover, IS scholars need to analyze the standardization of the environment-related information system to be used for monitoring and documenting environmental performance.

*RQ 7: What are the design principles of environment-related information systems for the commercial maritime ecosystem?*

In terms of energy efficiency and pollution prevention, Maritime transportation is the most environmentally sound mode of mass transport. Its environmental performance could be improved even further and recognized in any policy, strategy, or action (IMO, 2013). The IMO is responsible for improving the environmental performance of the industry, so that it has rules and regulations to prevent pollution by ships (International

Maritime Organization, 2014a). As suggested by the International Maritime Organization (2013), advanced information systems should be implemented to address environmental concerns. In order to increase the effective use of these systems by different stakeholders, new policy and regulations need to be introduced. IS scholars need to identify these policies, considering the features, restrictions and uses of these information systems.

*RQ 8: What policies and regulations are needed to advance the use of information systems to achieve an ecologically sustainable commercial maritime ecosystem?*

For the effective operation of IMO policies, a comprehensive documentation system is necessary. The IMO can achieve this goal with use of advanced information systems—by collecting environment-related data and tracking the environmental activities of the ships and ports. As the IMO is the authority in the industry, it needs a system that supports data integration between it and all stakeholders. IS scholars need to identify what specific types of data to collect, and how much data to share with the regulators. In addition, a communication standard among all stakeholders needs to be developed for ecological sustainability. For example, when multiple ships plan to enter the same port, traffic will be inevitable and some of the ships would have to wait for long hours. Such a scenario would increase fuel consumption and subsequently, the pollution created by the ships. An appropriate communication may prevent these causes.

*RQ 9: What data should be reported by each stakeholder in the commercial maritime ecosystem to inform IMO's environmental regulations enforcement and improvement?*

*RQ 10: How can within and among stakeholder communication be changed to ecological sustainability?*

Sustainable maritime transportation system can be ensured if all stakeholders recognize environmental performance in their operations. Even if the first priority for commercial stakeholders is cost efficiency, their participation in environmental initiatives is critical. If they don't commit themselves to environmental improvement, their use of environment-related information systems will be limited. We need IS scholars to examine the motivational factors that affect the use of environment-related information systems. These factors may include, but are not limited to—financial, strategic, or cultural factors. The International Maritime Organization (2013) also emphasizes the importance of cultural factors by suggesting that  a culture of environmental stewardship is promoted among all stakeholders.

*RQ 11: What factors affect the adoption and use of environment-related information systems in the maritime ecosystem?*

Information systems are expected to be useful tools to address the environmental concerns of the industry (IMO, 2013). However, IS scholars need to provide a rigorous demonstration of the impact of IS on environmental improvements. In addition, IS scholars need to analyze different environment-related information systems and their various impacts.

*RQ 12: What improvements in the ecological sustainability of the maritime ecosystem can be attributed to information systems?*

**Efficiency**

The main focus of commercial operators is efficiency in their operations. Besides satisfying the safety and environmental regulations of the IMO, they need to meet their financial objectives. Maritime transportation is the most efficient form of transport, so that commercial stakeholders need to keep efficiency in their daily operations to meet competitive demands. In addition, the industry needs to continue improving efficiency by implementing new technologies and ship-to-shore interfacing (IMO, 2013). As the efficiency literature reveals, optimization algorithms are used to make smarter decisions. To build better algorithms and then test them, more information is needed from various resources. Information systems can help the commercial stakeholders with data gathering, decision making, and communication.

In our research agenda, we focus on the ecosystem-wide solutions to the efficiency problem. From our literature review, and ecosystem analysis, we see that various stakeholders – such as ship operators and port authorities – interact on a day-to-day basis. The efficiency of one stakeholder could be improved using relevant information gathered by other stakeholders. Thus, information systems that enable data sharing between inter-related stakeholders are necessary to create then maintain efficient daily operations. IS scholars need to identify the appropriate information systems. In addition, what kind of data, and how much data needs to be shared—and between which stakeholders—must be analyzed.

*RQ 13: What are the design principles of efficiency information systems for commercial maritime ecosystem?*

*RQ 14: What data at what granularity should be shared by stakeholders in the commercial maritime ecosystem to improve efficiency?*

Various commercial operators make up the industry including, but not limited to, the ship owners, port operators, and ship operators. Daily interaction between multiple commercial stakeholders is inevitable in a maritime ecosystem. For example, ship operators need to interact with port operators every day in order to be able to use the port facilities, as well as arrange port entrance and exit times. Therefore, the optimization strategies of a stakeholder are highly dependent on another stakeholders' situations, strategies, and daily operations. In this case, effective communication between the various stakeholders is critical. Due to the global nature of the industry, stakeholders who need to continuously interact will often be from different countries and cultures. Communication in a multinational environment requires standardization.  IS scholars need to identify the most effective communication standard for the maritime industry, and how IS can support this aim.

*RQ 15: How can within and among stakeholder communication be changed to improve efficiency?*

Information systems developed for efficiency purposes need to be used by all stakeholders to achieve their goals. If an agent needs information from another agent who is not using the system, there is less benefit in using the system. Therefore, there is a high need for behavioral studies that analyze the motivation for the use of information systems for efficiency purposes.

*RQ 16: What factors affect the adoption and use of the information systems for efficiency in the maritime ecosystem?*

Lastly, IS scholars need to provide a rigorous demonstration of the impact of IS on efficiency improvement at seas. In addition, IS scholars need to analyze different information systems and their subsequent effects on efficiency. In this way, better systems may be developed over time.

*RQ 17: What improvements in the efficiency of the maritime ecosystem can be attributed to information systems?*

# CHAPTER 6

# CONCLUSION

Maritime transportation forms the backbone of international trade. Its success remains crucial to our current global economy and its importance shows no signs of waning. Therefore, both industry and academia must commit themselves to solving prominent problems in the industry. As the most efficient and cost-effective mode of transport, improvements in the efficiency, safety, and ecological sustainability of the maritime industry will have considerable social benefits. In this respect, IMO suggests that digitization of the seas is a way to further improve operations of the industry.

Research in the maritime transportation domain has attracted scholars from different fields: operations research, economics, policy, international trade, cultural, and environmental studies. The ultimate purpose of the research has been mainly to improve efficiency, safety, or environmental performance. By reviewing the literature, we identified problems addressed by previous studies and their approach towards solving these problems. These studies have collectively contributed valuable analysis of (as well as insight *into*) the industry, as well as some useful solutions to the stakeholders' critical problems. However, we believe that the maritime industry is ultimately an ecosystem, which requires a broader approach to its problems versus a singular focus on one stakeholder. Even though a local approach might be useful for individual solutions, such an approach fails to address problems which persist across the industry.

An ecosystem approach should be adopted in future studies in order to achieve the efficiency, safety, and environmental goals of the industry. As all stakeholders are inter-related in such a complex ecosystem, and interact with each other on a day-to-day basis, local solutions are less effective. Improving the efficiency, safety, and environmental performance for one stakeholder highly depends on the other stakeholders. Therefore, future studies need to take the problems, needs, and characteristics of the ecosystem into consideration, and seek solutions for the ecosystem-wide problems.

Our work has some limitations. First, we reviewed the recent literature (since 2005) on maritime industry efficiency, safety, and environmental performance. We excluded policy, economics, and technological studies from our literature review, which may provide a different perspective for future studies. We cover only research questions related to the three main goals of the industry. Lastly, we don't analyze the technological restrictions in this study. In the implementation of the information systems, technical constraints will prove critical. For example, the expensive satellite systems will be a critical barrier for developing effective communication systems.

We believe that information systems plays a critical role in maritime ecosystem research. In the current work, we identified the characteristics and main problems of the maritime ecosystem and explained how information systems can serve the goals of the industry. We introduced maritime informatics as a new research stream that studies the application of information systems in order to increase the efficiency, safety, and ecological sustainability of the world's shipping industry. We also presented potential research questions which might be addressed by future studies, with the sincere hope that our current work helps facilitate more research in this new important field.

## REFERENCES


Agarwal, R., & Ergun, Ö. (2008). Ship Scheduling and Network Design for Cargo Routing in Liner Shipping. *Transportation Science*, *42*(2), 175–196. Retrieved from http://pubsonline.informs.org/doi/abs/10.1287/trsc.1070.0205

Airbus. (2007). *Flight Operations Briefing Notes - Cabin Operations - Planned Ground Evacuation*. Retrieved from http://www.airbus.com/fileadmin/media_gallery/files/safety_library_items/AirbusSafetyLib_-FLT_OPS-CAB_OPS-SEQ11.pdf

Alderton, T., Bloor, M., & Kahveci, E. (2004). *The Global Seafarer: Living and Working Conditions in a Globalized Industry* (p. 208). International Labour Organization. Retrieved from http://books.google.com/books?id=eSFSO-netPYC&pgis=1

Al-Khayyal, F., & Hwang, S.-J. (2007). Inventory constrained maritime routing and scheduling for multi-commodity liquid bulk, Part I: Applications and model. *European Journal of Operational Research*, *176*(1), 106–130. Retrieved from http://www.sciencedirect.com/science/article/pii/S0377221705005771

Axelsson, J., Akerstedt, T., Kecklund, G., & Lowden, A. (2004). Tolerance to shift work-how does it relate to sleep and wakefulness? *International Archives of Occupational and Environmental Health*, *77*(2), 121–9. Retrieved from http://www.researchgate.net/publication/9014333_Tolerance_to_shift_work-how_does_it_relate_to_sleep_and_wakefulness

Berg, H. P. (2013). Human Factors and Safety Culture in Maritime Safety (revised). *TransNav, International Journal on Marine Navigation and Safety Od Sea Transportation*, *7*(3). Retrieved from http://www.transnav.eu/Article_Human_Factors_and_Safety_Berg,27,443.html

Bilgen, B., & Ozkarahan, I. (2007). A mixed-integer linear programming model for bulk grain blending and shipping. *International Journal of Production Economics, 107*(2), 555–571. Retrieved from http://www.sciencedirect.com/science/article/pii/S0925527306002805

Brønmo, G., Christiansen, M., Fagerholt, K., & Nygreen, B. (2007). A multi-start local search heuristic for ship scheduling—a computational study. *Computers & Operations Research*, *34*(3), 900–917. Retrieved from http://www.sciencedirect.com/science/article/pii/S0305054805001644

Caschili, S., & Medda, F. R. (2012). A Review of the Maritime Container Shipping Industry as a Complex Adaptive System. *Interdisciplinary Description of Complex Systems - Scientific Journal*, *10*(1), 1–15. Retrieved from http://ideas.repec.org/a/zna/indecs/v10y2012i1p1-15.html

Celik, M. (2009). A hybrid design methodology for structuring an Integrated Environmental Management System (IEMS) for shipping business. *Journal of Environmental Management*, *90*(3), 1469–75. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=Refine&qid=10&SID=1AHOrnukuMk3B5OkFa3&page=1&doc=3

Celik, M., Cebi, S., Kahraman, C., & Er, I. D. (2009). Application of axiomatic design and TOPSIS methodologies under fuzzy environment for proposing competitive strategies on Turkish container ports in maritime transportation network. *Expert Systems with Applications*, *36*(3), 4541–4557. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=2&SID=2CYM8pElJ8sLzGkOJOA&page=1&doc=2

Celik, M., Lavasani, S. M., & Wang, J. (2010). A risk-based modelling approach to enhance shipping accident investigation. *Safety Science*, *48*(1), 18–27. Retrieved from http://www.sciencedirect.com/science/article/pii/S0925753509000952

Christiansen, M., & Fagerholt, K. (2006). Maritime transportation. *Transportation*. Retrieved from http://books.google.com/books?hl=en&lr=lang_en|lang_tr&id=DHM7U_d-E4gC&oi=fnd&pg=PA189&dq=maritime+transportation+christiansen&ots=7RlpDsdr4T&sig=YwXphrtPgpNfv-uRGgpxGZj3jhQ

Corbett, J. J., Wang, H., & Winebrake, J. J. (2009). The effectiveness and costs of speed reductions on emissions from international shipping. *Transportation Research Part D: Transport and Environment*, *14*(8), 593–598. Retrieved from http://www.sciencedirect.com/science/article/pii/S1361920909001072

Cumberland, B. C., Jessup, L. M., & Valacich, J. S. Examining an Information System to Support Maritime Traffic and Commerce: Research Opportunities for the IS Discipline, 9 Communications of the Association for Information Systems (2002). Retrieved from http://aisel.aisnet.org/cais/vol9/iss1/2

European Union. (2012). e-Maritime. Retrieved October 18, 2014, from http://ec.europa.eu/transport/modes/maritime/e-maritime_en.htm

Eyring, V., Isaksen, I. S. A., Berntsen, T., Collins, W. J., Corbett, J. J., Endresen, O., … Stevenson, D. S. (2010). Transport impacts on atmosphere and climate: Shipping.

*Atmospheric Environment*, *44*(37), 4735–4771. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231009003379

Face of Shipping. (2011). Face of Shipping - Exploring the contributions of the maritime industry. Retrieved from http://www.faceofshipping.com/gallery/by_speaker.php?speaker=Dimitrios+Theologitis

Fitzgerald, W. B., Howitt, O. J. A., Smith, I. J., & Hume, A. (2011). Energy use of integral refrigerated containers in maritime transportation. *Energy Policy*, *39*(4), 1885–1896. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=2&SID=3CIOQsPqOGvx8fjVmPx&page=1&doc=39

Gkonis, K. G., & Psaraftis, H. N. (2009). *Some key variables affecting liner shipping costs*. *Laboratory for Maritime Transport*. Retrieved from http://www.martrans.org/documents/2009/prt/TRB_paper 10_3188_Gkonis_Psaraftis_revised.pdf

Gordon, J. R. M., Lee, P.-M., & Lucas, H. C. (2005). A resource-based view of competitive advantage at the Port of Singapore. *The Journal of Strategic Information Systems*, *14*(1), 69–86. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=8&SID=1EJqruK37KbBpxhhVWu&page=1&doc=3

Goulielmos, A. M., & Gatzoli, A. (2012). The Role of a Ship's Master in Theory and Practice: Lessons From Marine Accidents. *Journal of Critical Incident Analysis*. Retrieved from http://jcia.aciajj.org/files/2012/12/Goulielmos-et-al.-4-Final.pdf

Goulielmos, A. M., Goulielmos, M. A., & Gatzoli, A. (2013). The accident of passenger-  car vessel Samina Express (2000), when 80 persons died. Retrieved from http://www.emeraldinsight.com/doi/abs/10.1108/09653560910965682

Grønhaug, R., Christiansen, M., Desaulniers, G., & Desrosiers, J. (2010). A Branch-and-Price Method for a Liquefied Natural Gas Inventory Routing Problem. *Transportation Science*, *44*(3), 400–415. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=2&SID=2Dfx8w4F7ZIPhUFnYli&page=1&doc=11

Henderson, J. C., & Venkatraman, N. (1993). Strategic alignment: leveraging information technology for transforming organizations. *IBM Systems Journal*, *32*(1), 4–16. Retrieved from http://dl.acm.org/citation.cfm?id=1663581.1663583

Hetherington, C., Flin, R., & Mearns, K. (2006). Safety in shipping: the human element. *Journal of Safety Research*, *37*(4), 401–11. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=2&SID=1AHOrnukuMk3B5OkFa3&page=1&doc=4

Hoff, A., Andersson, H., Christiansen, M., Hasle, G., & Løkketangen, A. (2010). Industrial aspects and literature survey: Fleet composition and routing. *Computers & Operations Research*, *37*(12), 2041–2061. Retrieved from http://www.sciencedirect.com/science/article/pii/S0305054810000699

Horck, J. (2005). Getting the best from multi-cultural manning. *BIMCO Bulletin*, *100*, 28–36.

IAEA. (2006). *IAEA Safety Standards for protecting people and the environment - The Management System for Facilities and Activities*. Retrieved from http://www-pub.iaea.org/MTCD/publications/PDF/Pub1252_web.pdf

IMO. (2013). A concept of sustainable maritime transportation system. Retrieved August 30, 2014, from http://www.imo.org/About/Events/WorldMaritimeDay/WMD2013/Documents/CONCEPT OF  SUSTAINABLE MARITIME TRANSPORT SYSTEM.pdf

IMO. (2014). IMO | Our Work. Retrieved October 17, 2014, from http://www.imo.org/OurWork/Pages/Home.aspx

International Chamber of Shipping. (2009). Shipping, World Trade and the Reduction of CO2 Emissions. Retrieved September 03, 2014, from http://www.ics-shipping.org/docs/default-source/resources/environmental-protection/shipping-world-trade-and-the-reduction-of-co2-emissions.pdf?sfvrsn=14

International Maritime Organization. (2014a). IMO | Marine Environment. Retrieved October 18, 2014, from http://www.imo.org/OurWork/Environment/Pages/Default.aspx

International Maritime Organization. (2014b). IMO | Maritime Safety. Retrieved October 18, 2014, from http://www.imo.org/OurWork/Safety/Pages/Default.aspx

Lappalainen, J., Vepsäläinen, A., & Tapaninen, U. (2010). Analysis of the International Safety Management Code, in: Efficiency of the ISM Code in Finnish Shipping Companies. Kouvola, Finland: Publications from the Centre for Maritime Studies, University of Turku.

Li, S., Meng, Q., & Qu, X. (2012). An overview of maritime waterway quantitative risk assessment models. *Risk Analysis : An Official Publication of the Society for Risk Analysis*, *32*(3), 496–512. Retrieved from http://apps.webofknowledge.com.prx.library.gatech.edu/full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=1BR6wwjYtRLtAqClB5t&page=5&doc=47

Lutzhoft, M., Grech, M. R., & Porathe, T. (2011). Information Environment, Fatigue, and Culture in the Maritime Domain. *Reviews of Human Factors and Ergonomics*, *7*(1), 280–322. Retrieved from http://rev.sagepub.com/content/7/1/280.abstract

Maritime Industry Foundation. (2013). Maritime Directory | Maritime Industry Knowlage Center. Retrieved October 17, 2014, from http://www.maritimeinfo.org/en/Maritime-Directory/

Merrick, J. R. W., Dorp, J. R. van, & Dinesh, V. (2005). Assessing Uncertainty in Simulation-Based Maritime Risk Assessment.: EBSCOhost. *Risk Analysis*, *25*(3). doi:10.1111/j.1539-6924.2005.00616.x

National Maritime Polytecnic. (2006). *Mixed nationality crews: The Filipino Seafarers' Experience*.

National Research Council. (1999). *Applying Advanced Information Systems to Ports and Waterways Management* (p. 54). National Academies Press. Retrieved from http://books.google.com/books?id=NjMUu8Mw3X4C&pgis=1

Norstad, I., Fagerholt, K., & Laporte, G. (2011). Tramp ship routing and scheduling with speed optimization. *Transportation Research Part C: Emerging Technologies*, *19*(5), 853–865. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=2&SID=3CIOQsPqOGvx8fjVmPx&page=1&doc=16

NPR. (2013). Shipping: The "Invisible Industry" That Clothes And Feeds You | WBUR & NPR. Retrieved September 03, 2014, from http://www.wbur.org/npr/211981786/shipping-the-invisible-industry-that-clothes-and-feeds-you?ft=3&f=211981786

Psaraftis, H. N., & Kontovas, C. A. (2010). Balancing the economic and environmental performance of maritime transportation. *Transportation Research Part D: Transport and Environment*, *15*(8), 458–462. Retrieved from http://www.sciencedirect.com/science/article/pii/S136192091000074X

Psaraftis, H. N., & Kontovas, C. A. (2013). Speed models for energy-efficient maritime transportation: A taxonomy and survey. *Transportation Research Part C: Emerging Technologies*, *26*, 331–351. Retrieved from http://www.sciencedirect.com/science/article/pii/S0968090X12001246

Rai, A., Pavlou, P. A., Im, G., & Du, S. (2012). Interfirm IT Capability Profiles And Communications For Cocreating Relational Value: Evidence From The Logistics

Industry. *MIS QUARTERLY*, *36*(1), 233–262. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=8&SID=1EJqruK37KbBpxhhVWu&page=1&doc=1

Ronza, A., Vílchez, J. A., & Casal, J. (2007). Using transportation accident databases to investigate ignition and explosion probabilities of flammable spills. *Journal of Hazardous Materials*, *146*(1-2), 106–23. Retrieved from http://apps.webofknowledge.com.prx.library.gatech.edu/full_record.do?product=WOS&search_mode=Refine&qid=28&SID=1BR6wwjYtRLtAqClB5t&page=1&doc=3

Samuels, F., Sultana, M. M., & Chakraborty, S. (2013). *Bangladeshi sailors - characteristics, working conditions, and HIV and AIDS-related vulnerabilities*. Retrieved from http://www.refworld.org/pdfid/523ab7814.pdf

Trucco, P., Cagno, E., Ruggeri, F., & Grande, O. (2008). A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation. *Reliability Engineering & System Safety*, *93*(6), 845–856. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=2&SID=2CYM8pElJ8sLzGkOJOA&page=1&doc=5

Ulusçu, O. S., Ozbaş, B., Altiok, T., & Or, I. (2009). Risk analysis of the vessel traffic in the strait of istanbul. *Risk Analysis : An Official Publication of the Society for Risk Analysis*, *29*(10), 1454–72. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=2&SID=3CIOQsPqOGvx8fjVmPx&page=1&doc=29

UNCTAD. (2013). Review of Maritime Transport 2013. Retrieved August 30, 2014, from http://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=753

van de Wiel, G., & van Dorp, J. R. (2009). An oil outflow model for tanker collisions and groundings. *Annals of Operations Research*, *187*(1), 279–304. Retrieved from http://link.springer.com/10.1007/s10479-009-0674-5

Wackett, M. (2014). Felixstowe's Loss Is Gateway's Gain as Congestion Grips North Europe's Ports - gCaptain Maritime & Offshore News. Retrieved September 07, 2014, from http://gcaptain.com/felixstowes-loss-gateways-gain-congestion-grips-north-europes-ports/

World Shipping Council. (2014a). Efficiency | World Shipping Council. Retrieved October 16, 2014, from http://www.worldshipping.org/benefits-of-liner-shipping/efficiency

World Shipping Council. (2014b). Global Economic Engine | World Shipping Council. Retrieved October 15, 2014, from http://www.worldshipping.org/benefits-of-liner-shipping/global-economic-engine

Yip, T. L. (2008). Port traffic risks – A study of accidents in Hong Kong waters. *Transportation Research Part E: Logistics and Transportation Review*, *44*(5), 921–931. Retrieved from http://apps.webofknowledge.com.proxy-remote.galib.uga.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=2&SID=3CIOQsPqOGvx8fjVmPx&page=1&doc=25

## APPENDIX: DETAILED LITERATURE REVIEW

**Table 5: List of selected publications in maritime transportation research since 2005, their field of study, methodology, findings, and future research suggestions**

| Selected publications | Field of study | Methodology | Findings | Future research suggestions |
|---|---|---|---|---|
| (Agarwal & Ergun, 2008) | Operations Research | Mathematical modelling and computational experiments | Developed a mathematical model for the simultaneous ship-scheduling and containerized cargo-routing problem for liner shipping, which allows for transshipping cargo from one ship to another | An extension of the model to allow for multiple ship types on a service route, and to account for weekly changes in demand |
| (Al-Khayyal & Hwang, 2007) | Operations Research | Mixed integer linear programming | Developed a mathematical model for efficient routes and loading/unloading schedules for a fleet of ships carrying liquid bulk products, considering the multiple compartments dedicated to different products. | A robust procedure that to solve larger problems |
| (Bilgen & Ozkarahan, 2007) | Operations Research | Mathematical modelling and computational experiments | Developed an integrated model for blending, loading and transportation decisions | An extension of the model to include land transportation from storage sites to loading ports, and to consider the limited number of vessels. |
| (Brønmo et al., 2007) | Operations Research | Multi-start local search heuristics, set partitioning, computational study with eight real test cases | Developed a multi-start local search heuristics for solving tramp ship scheduling problems. Supported their method by testing on real cases. | Richer models for the problem. New methods to solve larger cases |
| (Grønhaug et al., 2010) | Operations Research | Path-flow model and a branch-and-price method as a solution | Developed a model for the liquefied natural gas inventory routing problem and testing the branch-and-price solution method by real-world instances | Improving the running time of the algorithm. Developing valid inequalities |

| | | | | |
|---|---|---|---|---|
| (Hoff et al., 2010) | Operations Research | Literature survey | Provided an overview of the industrial aspects of combined routing and fleet composition problems in transportation | A larger perspective and risk and flexibility in the models. Testing the models with real-world data. |
| (Norstad et al., 2011) | Transportation Research | Multi-start local search heuristics, and computational experiment | Developed a model to solve tramp ship routing and scheduling problem, considering that the speed is not fixed. | N/A |
| (Celik et al., 2010) | Risk Analysis | Fuzzy extended fault tree analysis (FFTA), case study | Integrated FFTA into Shipping Accident Investigation (SAI) reports to ensure a consistent database, decision aid to accident analysis, and prevention efforts | The utilization of the outcomes from FFTA on SAI to establish an extended database. The integration of a risk-based decision analysis techniques into SAI reports |
| (Li et al., 2012) | Risk Analysis | Literature review | Provided a detailed review and assessment of various quantitative risk assessment models for maritime waterways | The effect of human errors should be quantified. Parameter uncertainties should be addressed. |
| (Merrick et al., 2005) | Risk Analysis | Bayesian simulation techniques, case study | Developed Bayesian simulation technique to model uncertainty in the assessment of maritime risk | Development of a Bayesian accident probability model, which incorporates historical accident data and expert judgments |
| (Trucco et al., 2008) | Reliability Engineering | Bayesian Belief Network (BBN) to model the maritime transportation system and case study to apply the proposed model | Proposed the use of BBN as a better risk analysis tool for a complex socio-technical systems | An extension of the proposed model on the side of economic analysis in order to help the stakeholders evaluate the cost of achieving safety |
| (Ulusçu et al., 2009) | Risk Analysis | Aggregate simulation/risk model | Observations about the risk in the Strait of Istanbul based on real data (e.g. scheduling changes, and waiting times increase risk, pilotage service is necessary, difference between daytime and night-time risks) | Analyzing what kind of modifications to be done in scheduling to accommodate a larger volume of nighttime traffic. An extension of the research to other areas. |

| | | | | |
|---|---|---|---|---|
| (van de Wiel & van Dorp, 2009) | Operations Research | Oil outflow model and simulation data analysis | Developed an oil outflow model for collision and grounding accidents of tankers | Use of methodology in different analysis such as comparisons of analysis scenarios across accident types, oil outflow categories, and various risk interventions |
| (Yip, 2008) | Transportation Research | Negative binomial regression model | Found a pattern in port traffic risks. Revealed that the collision accidents are the most popular incidents when port traffic is heavy, and that injuries during accidents is more likely in passenger-type vessels. | Comparison of port traffic risks across the world, and between traffic control philosophies. An extension to consider the evolution of the adoption of information technology in port traffic control and its effect on the traffic risks |
| (Celik, 2009) | Environmental Management | Hybrid design methodology, Fuzzy Axiomatic Design, and Analytic Hierarchy Process | Analyzed the degree of compliance between ISM Code clauses and ISO 14001:2004 requirements | An extension of the scope of the integrated system to cover other issues, such as occupational health, environmental management, safety, and quality. |
| (Corbett et al., 2009) | Transportation Research | Profit-maximizing equation | Analyzed the impacts of fuel tax policy and a speed reduction mandate on $CO_2$ emissions | N/A |
| (Eyring et al., 2010) | Environmental Studies | Top-down and bottom-up approaches to produce spatially resolved ship emissions inventories | Assessed the current knowledge on ship emissions and their impact on atmospheric composition, air quality, ecosystems and human health. Examined the effects of technological improvements and policy strategies on reducing emissions | A complete synthesis of the impact of shipping on atmospheric composition and climate, exploring the uncertainties in the ship emission inventories, using different methods, and creating global models using larger datasets |
| (Fitzgerald et al., 2011) | Energy Policy | Archival data | Revealed facts related to energy consumption and Co2 emissions in refrigerated maritime transport that carry food, plant, and animal (e.g. Refrigeration accounts for ~19% of a refrigerated container's energy use on a journey) | The scope of this study was exported and imported food products of New Zealand. Data from all over the World should be analyzed for more confident results. |

| | | | | |
|---|---|---|---|---|
| (Psaraftis & Kontovas, 2010) | Transportation Research | Literature review and scenario analysis | Examination of the previous models to show the trade-off between maritime logistics effects and environmental policies | N/A |
| (Psaraftis & Kontovas, 2013) | Transportation Research | Taxonomy, survey | Provided a taxonomy and survey of speed models in maritime transportation. | Issues that will shape future research are determined: reduced freight rates and fleet overcapacity, port congestion, adoption of Energy Efficiency Design Index, market based measures related to Co2 emissions, and possible policies on speed limit |
| (Ronza et al., 2007) | Ecological Studies | Probability estimation methods, archival data | Analyzed two major accident databases to determine ignition and explosion probability data, and compared the results with literature data | Further validation against reported data |