Jorge E. Hernández · Dong Li
José Elias Jimenez-Sanchez
Miguel Gaston Cedillo-Campos
Luo Wenping *Editors*

Collaborative Logistics and Intermodality

Integration in Supply Chain Network Models and Solutions for Global Environments

Springer

Collaborative Logistics and Intermodality

Jorge E. Hernández • Dong Li •
José Elias Jimenez-Sanchez •
Miguel Gaston Cedillo-Campos • Luo Wenping
Editors

Collaborative Logistics and Intermodality

Integration in Supply Chain Network Models and Solutions for Global Environments

Springer

Editors
Jorge E. Hernández
Management School
University of Liverpool
Liverpool, UK

Dong Li
Management School
University of Liverpool
Liverpool, UK

José Elias Jimenez-Sanchez
Mexican Institute of Transportation
Pedro Escobedo, Querétaro, Mexico

Miguel Gaston Cedillo-Campos
Mexican Logistics & Supply Chain Association
(AML)
Autonomous University of Nuevo Leon
San Luis Potosi, Mexico

Luo Wenping
School of Economics and Management
Shanghai Maritime University
Shanghai, China

ISBN 978-3-030-50956-9 ISBN 978-3-030-50958-3 (eBook)
https://doi.org/10.1007/978-3-030-50958-3

© Springer Nature Switzerland AG 2021
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This book is regarding the MASC-RISE-EU project EC-Asia Research Network on Integration of Global and Local Agri-Food Supply Chains Towards Sustainable Food Security (GOLF), which is focused on combining world-leading research, in cooperation with agri-food, logistics and retail stakeholders, to ensure and secure sustainable, resilient and healthy food supplies to society. This project is led by Dr. Dong Li, from the University of Liverpool Management School, UK, and considers partners from eleven institutions in six countries, who will evaluate food supply chains and look to understand the integration of global and local systems to facilitate bio-economic solutions, especially to enhance sustainability and widen the benefits of local supply chains from a broader, circular economy perspective in the agri-food context. Thus, key areas covered in this project are regarding integrated multi-level (geographically global and local) and multi-dimension (economic, environmental, resilient) measurement of agri-food supply systems and development of innovative methodologies for assessing, designing and planning place-based sustainable food supply chains.

In this regard, the knowledge gathered in this book is oriented to capture experts' view in the concept of collaboration in supply chains to support sustainable logistics since it is important to acknowledge that supply chains play a more important role in globalised economy nowadays. In fact, one of the major challenges to supply chain academics and practitioners is the increasing demand for sustainability in global supply chains, not only in economic but also in environmental and social aspects. With these challenges and impacts of transportation operations on the sustainability of supply chain operations, collaboration in logistics services and integrated management of different modes of transport are crucial to achieve the competiveness and sustainable performance of the globally distributed supply chains. Specifically, from the logistic point of view, as established by Karia (2020), the logistics industry is a key contributor to global economic growth for empowering human and goods movement. Karia (2020) also addresses that the growth of logistics industry is growing exponentially as the global economy increases. Indeed, it is strategically prominent for meeting customer demands globally fostering the right place at the right time with the right goods in the right quantity and the right package, at the right cost.

Therefore, and considering the study from Yuang et al. (2019), it acknowledged that collaborative and sustainable logistic key topic trends are focusing on greenness, information sharing and managerial functions, where it has become evident that greenness and the environment are the main challenges for regional and global sustainable development in logistics. Yaung et al. (2019) also addressed that most of the supply chain and logistic companies are very limited by their own capabilities; hence, they do not normally possess all the resources to generate innovation; thus, the main reason for collaboration is to obtain such resources, especially knowledge, from other supply chain stakeholders. In the light of this, innovative and collaborative solutions need to be developed to enable the transportation and logistics operations in order to provide sustainable and resilient services through seamlessly integrated supply chain processes and optimal use of transport capacity (infrastructure, transport and handling equipment, etc.) across global supply chains with balanced performance of sustainability. Therefore, it is necessary to consider several alternatives to transport products across the supply chain, in a way that transportation aspects, such as levels of accidents, emissions, noise from transport and passengers, are achieved optimally. This implies that intermodality will be the way to combining different modes of transport in a seamless travel experience. This will necessarily imply positive logistics and sustainable impacts, especially in terms of enhancing access to local services between a large variety of transport terminals and the neighbouring cities (e.g. via train, metro, bus or even boat), increment in complementary feeder services between the transport terminals and the various parts of the surrounding region, improvement of competing services between major city centres of neighbouring regions and enhancement of alternative services that will fully replace current feeder services that are a source of waste, inefficiencies and bottlenecks.

Therefore, and in order to enhance the understanding of contributions of collaborative logistics and intermodality to sustainable logistics services, this book collects a rich variety of research in the area of logistic and transport service innovation, with a view to offer more sustainable global supply chains. The book consists of nine double-blind reviewed chapters that address challenges and propose solutions from different perspectives: from greener supply chain processes to collaborative logistic operations; through multimodal transport services or optimal facility use; and targeting at solutions from enhanced sustainability to minimised waste of resources. In the twenty-first century, increased uncertainties in global supply chains have been clearly seen in various forms from climate change, epidemics and terrorism threats to increasing economic upheaval. The uncertainties create significant risks to international container supply chains (CSCs). First chapter presents a systematic review and foresight of research challenges facing the development of resilient and sustainable CSCs and, more specifically, to identify opportunities and future research agenda on development of resilient and sustainable CSCs. To achieve the resilience and sustainability of supply chains, extensive studies have been reported in the literature in strategies and modelling of logistics and transport services (Gunasekaran et al.

2015). However, as a major form of international transport services, CSCs are facing specific challenges with rising risk and uncertainties (Lee and Song 2017). Considering these current logistic challenges, the nine accepted chapters are described as follows.

In first chapter, Dr. Yang Zaili et al. present their work titled "*Challenges and Developments in Integrated Container Supply Chains—A Research Agenda for the Europe-China Research Network on Integrated Container Supply Chains (ENRICH) Project*". In this chapter, authors present a research agenda by incorporating resilience and sustainability concepts into a taxonomy of six key interactive domains. Further analysis in the research justified the research domains with several noteworthy tendencies in future studies. This finding provides an integrated research and practice framework for moving CSC management strategies from the efficiency and value-added orientation towards a resilience and sustainability-focused regime. The global supply chains involve operations across national borders and are governed by different administrative authorities. It is challenging for the global supply chain players to collaboratively and efficiently operate transport facilities and logistics services under different governance structure with different sustainability goals (Mentzer 2004).

In the next chapter, second chapter, Dr. Wenping Luo presents his work titled "*A Research Framework for Cross-National Comparative Logistics*", in which the logistics challenges are addressed in a comparative logistics viewpoint in the cross-national logistics context. It conceptualises a theoretical framework that facilitates pinpointing key variables in the logistics systems of different countries. The framework can help understand the main barriers of achieving efficient and collaborative logistics services in the global supply chain context. The research finding provides an effective path to tackle the challenges in global logistics operations and facilitate sustainable supply chains. Transport has been a major contributor of negative environment impacts in supply chains. It has been widely recognised that environmentally sustainable and economic efficient transport and logistics services can be achieved through employing optimally interconnected transport modes (Bask and Rajahonka 2017). In the complex international supply chains, it is still challenging how such optimal arrangement can be achieved with different supply chain configurations, and what are the main factors influencing mode selection, and what would be the strategic change of the different transport modes in more such sustainability-driven markets (Qaiser et al. 2017). In fact, chapters "Supply Chain Solutions to Upstream Buyer Consolidation with Green and Resilient Supply Chain Designs in the China-Europe Containerized Cargo Flows", "Impact Analysis of Slow Steaming on Inland River Container Freight Supply Chain", "Modelling Container Port Logistics and Intermodality from the Perspective of Environmental Sustainability" and "Random Forest Regression Model Application for Prediction of China's Railway Freight Volume" present good attempts at addressing such challenges, where chapters "Supply Chain Solutions to Upstream Buyer Consolidation with Green and Resilient Supply Chain Designs in the China-Europe Containerized Cargo Flows" and "Impact Analysis of Slow Steaming on Inland River Container Freight Supply Chain" present quantitative analysis of supply chain performance with sustainability-oriented transport and logistics services. The transport mode selection is affected by the market needs of cargo distributions.

After this, third chapter is written by Dr. Ning Lin and Dr. Harald M. Hjelle, and they present their work titled "*Supply Chain Solutions to Upstream Buyer Consolidation with Green and Resilient Supply Chain Designs in the China-Europe Containerized Cargo Flows*". In this work, authors present their findings on positive impacts of consolidation operations in upstream supply chains on adoption of the short-sea transport mode. This strategy on supply chain configuration for cargo distributions is believed to be able to promote greener transport operations. On the other hand, a green initiative of transport services can affect supply chain performance and strategy on the supply chain configuration. One of the frequently adopted initiatives in the maritime transport is slow steaming of shipping line operations for reduced cost and GHG emissions. This strategy, however, may increase uncertainty of liners' operation time and have impacts on the downstream supply chain costs, including the inventory control strategy.

Following the same impact in logistic concept, the following chapter, fourth chapter, is written by Dr. Wang Zhengguo et al. in which they present their work titled "*Impact Analysis of Slow Steaming on Inland River Container Freight Supply Chain*", which addresses main research on green initiative impacts. This is presented by addressing key findings of relationships between the shipping line speed and inventory control performance. In fact, the sustainability-driven supply chain development has led to changes in the transport service markets (Woodburn 2017), and there are various factors and mechanisms of driving the adoption of environmentally sustainable transport and logistics services. Thus, it is crucial to understand the role of the key factors and mechanisms in promoting sustainable supply chain operations to inform policymaking and perform effective strategies.

Then, under the modelling of logistics process, fifth chapter presented by Dr. Gang Dong is titled "*Modelling Container Port Logistics and Intermodality from the Perspective of Environmental Sustainability*", which addresses and identifies the business preferences for adopting a variety of transportation modes in a maritime port-hinterland logistics network under different environment-related costs. The research reveals interactive decision-making behaviour of businesses involved in the network and informs optimal strategies and environmental policies to encourage sustainable supply chain operations. The role of rail freight in improving environmental performance in inland transport systems has attracted more attention.

As a continuation from chapter "Modelling Container Port Logistics and Intermodality from the Perspective of Environmental Sustainability", sixth chapter is presented by Dr. Yang Wang and Dr. Lu Xiaochun. Their research is titled "*Random Forest Regression Model Application for Prediction of China's Railway Freight Volume*". In this contribution, an innovative approach to predict rail freight volume with major demands from key industrial sectors is proposed. This approach enhances understanding of changes in the rail freight volume with key economic factors and supports policymaking for more sustainable transport systems. The contribution of intermodal transport services to sustainable supply chains relies on resource-efficient, green and integrated operations of transport and logistics processes that connect the multiple stages and multiple modes of transport operations (Lam and Gu 2016; Colicchia et al. 2017).

Following this, chapters "An Optimization Approach for the Train Load Planning Problem in Seaport Container Terminals", "Utilizing Breakthrough Innovations: The Need for Information Sharing as a New Key Performance Indicator for Container Port Operations" and "Scheduling Periodical Deliveries from a Distribution Centre to Minimize the Fleet Size" present research on operational level solutions to improving efficiency and minimising waste to facilitate sustainability in supply chains. Maritime ports play an important role in facilitating efficient intermodal operations and sustainability of supply chains.

Therefore, in line with the operational logistic challenges, the next chapter, seventh chapter, is presented by Dr. Daniela Ambrosino et al. Their work is titled "*An Optimization Approach for the Train Load Planning Problem in Seaport Container Terminals*", in which a planning approach for improving efficiency of the train loading process to assign containers of different sizes to wagon slots of a train is proposed. The loading operations do not only affect performance at the rail terminal, but also in the stacking areas and internal traffic in the port. An integrated planning approach is crucial to maximise the volume loaded on the train and minimise unproductive movements, distance and time in the loading process. This will enhance both the economic and environmental sustainability of the seaport container terminal operations and the intermodal supply chain.

Following this, eighth chapter is presented by Dr. Bjorn Jager and Dr. Ning Linis. Their work is titled "*Utilizing Breakthrough Innovations: The Need for Information Sharing as a New Key Performance Indicator for Container Port Operations*". This chapter addresses a key challenge in the supply chain collaboration and information sharing. Through a case study with a maritime port, the impact of information sharing on the performance of the port and the entire supply chain is investigated and the measurement of the collaborative activity is defined. The contribution of collaboration through information sharing is recognised as significant particularly in the form of technology-driven innovation. Information sharing should be a new performance indicator integrated into the KPI framework of sustainable logistics operations, as proposed in the chapter.

Finally, in ninth chapter, Dr. Jiyin Liu and Dr. Aiying Rong present their work titled "*Scheduling Periodical Deliveries from a Distribution Centre to Minimize the Fleet Size*". In this chapter, key challenges in distribution of cargo to customers in downstream supply chains are presented. Distribution centres play an increasingly important role in fulfilling sustainable deliveries for customer services, particularly in the context of increasing use of online shopping. Optimally planned routing and timing of the services can reduce carbon emissions while maintaining economic efficiency. In addition, this chapter presents a planning approach to fulfil periodical deliveries with minimised fleet size and travel distance. The approach can practically support more sustainable delivery services.

The collection of the chapters provides in-depth insights into challenges that contemporary logistics and transport services are facing in the global supply chains.

The studies presented a full spectrum of research agenda, from strategies of innovation in global supply chains and logistics to operational approaches to performing sustainable logistics operations. We expect that this book edition will support both academics and practitioners in developing sustainable supply chain research and practice, considering both theory and practice

Liverpool, UK	Jorge E. Hernández
Liverpool, UK	Dong Li
Shanghai, China	Wenping Luo
Querétaro, Mexico	José Elias Jimenez-Sanchez
San Luis Potosi, Mexico	Miguel Gaston Cedillo-Campos

References

Bask, A., & Rajahonka, M. (2017). The role of environmental sustainability in the freight transport mode choice: A systematic literature review with focus on the EU. *International Journal of Physical Distribution & Logistics Management, 47* (7), 560–602.

Colicchia, C., Creazza, A., & Dallari, F. (2017). Lean and green supply chain management through intermodal transport: insights from the fast moving consumer goods industry. *Journal of Production Planning & Control, 28*(4), 321–334.

Gunasekaran, A., Subramanian, N., & Rahman, S. (2015). Green supply chain collaboration and incentives: Current trends and future directions. *Transportation Research Part E: Logistics and Transportation Review, 74*, 1–10.

Karia, N. (2020). Green logistics practices and sustainable business model. In *Handbook of research on the applications of international transportation and logistics for world trade*.

Lam, J. S. L., & Gu, Y. (2016). A market-oriented approach for intermodal network optimisation meeting cost, time and environmental requirements. *International Journal of Production Economics, 171*(2), 266–274.

Lee, C. Y., & Song, D. P. (2017). Ocean container transport in global supply chains: Overview and research opportunities. *Transportation Research Part B: Methodological, 95*, 442–474.

Mentzer, J. T., Myers, M. B., & Cheung, M. S. (2004). Global market segmentation for logistics services. *Industrial Marketing Management, 33*(1), 15–20.

Qaiser, F. H., Ahmed, K., Sykora, M., Choudhary, A., & Simpson, M. (2017). Decision support systems for sustainable logistics: a review and bibliometric analysis. *Industrial Management & Data Systems, 117*(7), 1376–1388.

Woodburn, A. (2017). An analysis of rail freight operational efficiency and mode share in the British port-hinterland container market. *Transportation Research Part D 51*, 190–202.

Yuan, C. H., Wu, Y. J., & Tsai, K. M. (2019). Supply chain innovation in scientific research collaboration. *Sustainability, 11*(3), 753.

Contents

Challenges and Developments in Integrated Container Supply Chains: A Research Agenda for the Europe-China Research Network on Integrated Container Supply Chains (ENRICH) Project

Z. Yang, Y. Wang, D. Li, H. Hjelle, X. Yan, X. Shi, K. Cullinane, D. Zhang, A. Huang, J. Wang, R. Riahi, D. Song, P. Drake, J. E. Hernandez, Z. Jin, L. Shen, Z. Qu, and N. Lin

Abstract Since the start of the current century the world has experienced uncertainties in the form of climate change, epidemics, terrorism threats and increasing economic upheaval. These uncertainties create risks for the proper functioning of logistics management and have stimulated research into the development of resilient and sustainable container supply chains (CSCs). The purpose of this study is to examine the research challenges facing the development of resilient and sustainable CSCs and, more specifically, to identify opportunities and provide recommendations for future studies into the operational research, safety, security and resilience, climate change, ICT and intermodal transportation aspects of CSCs. The work will highlight the most difficult research problems in the engineering, operations and

---

Z. Yang (✉) · J. Wang · R. Riahi · Z. Qu
Liverpool John Moores University, Liverpool, UK
e-mail: z.yang@ljmu.ac.uk

Y. Wang
Edinburgh Napier University, Edinburgh, UK

D. Li · D. Song · P. Drake · J. E. Hernandez
The University of Liverpool, Liverpool, UK

H. Hjelle · N. Lin
Molde University College, Molde, Norway

X. Yan · D. Zhang
Wuhan University of Technology, Wuhan, China

X. Shi · A. Huang
Beijing Jiaotong University, Beijing, China

K. Cullinane
University of Gothenburg, Gothenburg, Sweden

Z. Jin · L. Shen
Dalian Maritime University, Dalian, China

J. E. Hernández et al. (eds.), *Collaborative Logistics and Intermodality*,
https://doi.org/10.1007/978-3-030-50958-3_1

management of CSC systems. The proposed research will have a significant impact on our understanding of how the resilience and sustainability of CSC systems can be enhanced through the gathering and exchange of knowledge and expertise in different aspects of CSCs in a newly established consortium funded by the EU (i.e. ENRICH—*E*C-Chi*N*a *R*esearch Network on *I*ntegrated *C*ontainer Supply C*h*ains, 2013–2017). The success of the research project will provide vital information on how to improve the resilience of CSCs more effectively and how to enhance the sustainability of supply chains in an ever-changing environment where new technologies are developed and introduced. To achieve this objective, this work reviews the major research challenges for, and developments in, integrated CSCs and demonstrates the major uncertainties in CSC operations due to climate change, terrorist threats and increasing economic upheaval. It will also provide insights into the research directions and agenda necessary for tackling these uncertainties in a holistic way at the level of the entire chain, through the use of ICT and intermodal logistics management techniques.

Keywords Integrated Container Supply Chains · Europe-China Research Network · ENRICH Project · Maritime Transport

1 Introduction

Since the start of the current century the world has experienced uncertainties in the form of climate change, epidemics, terrorism threats and increasing economic upheaval. These uncertainties create risks for the proper functioning of logistics management and have stimulated research into the development of resilient and sustainable container supply chains (CSCs). CSC management strategies are therefore moving from a cost saving or a value added orientation towards a resilience and sustainability focused regime concerning carbon emissions and pollution, safe and secure transportation and integrated logistics process improvement. The need for systematic methodologies and analytical tools to address the above concerns is widely recognized among academics and practitioners in different segments of the air, road, rail, sea, inland waterways and port industries (in which the five transport modes are often deemed as the links while the port is considered as the node connecting the links in typical CSCs). Nevertheless, the incorporation and integration of mathematical techniques, engineering models and management methods from the different segments for improving the resilience and sustainability of CSCs as a whole, while maintaining their competitiveness in terms of cost effectiveness and operational efficiency, is still largely unexplored. The investigation of previous research in the relevant areas reveals that there are a number of challenges to be overcome before a valid and robust CSC integration framework can be applied to practical systems. These challenges are not well exploited within the current literature and cannot be easily resolved without exploring the expertise, and exchanging knowledge, from the different areas associated with CSCs.

The first challenge is to develop a holistic model which can effectively accommodate and integrate classical approaches such as traffic optimisation modelling in the individual segments of CSCs. For instance, traffic optimisation research to improve supply chain operation efficiency including trajectory, scheduling and dispatching has been widely conducted in rail, road, air, shipping and ports, respectively. However, to realise door-to-door service through CSCs, physically aggregating the local traffic optimal solutions from different segments may not ensure the delivery of a global optimal solution from an overall CSC management perspective, in which various objective functions are set on the basis of different resource constraints. Consequently, how to rationally synthesise the local optimal solutions and to tackle data sets from different sources (which may be incompatible) become the questions to be answered in this proposed research (i.e. ENRICH—*E*C-Chi*N*a *R*esearch Network on *I*ntegrated *C*ontainer Supply C*h*ains, 2013–2017). This probably requires simulation based and analytical models, as well as the exchange of expert domain knowledge between all the associated segments in particular chains.

Secondly, newly developed/developing subjects such as the impact of climate change on CSCs and CSC safety and security assessment need to be addressed through tackling technical difficulties. For instance, recent developments around the world have clearly pushed climate change to the forefront of the global political agenda, as a result of the potential threats it poses to human development and prosperity. The impact of climate change (e.g., global warming and extreme climate) can have disastrous implications for CSCs and, in consequence, international trade and the global economy. Indeed, the impact of climate change, as a general issue, has not been overlooked by researchers in the past decades, with no shortage of studies investigating the impacts of climate change on various issues, notably rising sea levels and the vulnerability of coastal areas and marine eco-systems. Recently, a few studies have been undertaken tackling the issue of climate change mitigation in transportation, largely focusing on 'de-carbonization' in cities and various transport sectors (Ng et al. 2013). While these studies present important steps in understanding and modelling the impacts of climate change on transport systems, a number of important areas remain unexplored. The transportation sector is still lacking 'organizational resilience' to climate change threats. Few prior studies (e.g. Yang et al. 2017) have actually focused on the adaptation plans and strategies for addressing climate change threats on transportation; even fewer on supply chains and CSCs.

A series of terrorist attacks on transport systems in the past decade, together with the recent rampant pirate activities in Somali waters, have raised the issue of CSC system vulnerability into sharp focus and have posed a new challenge to devise sound procedures for increasing system safety and security. The challenge is even more compelling, when the complexity that characterizes today's container transportation networks is taken into account. The close interrelationships and interdependencies among a large number of system elements measurably increase the exposure to potential intentional harm and the level of vulnerability. They also increase the difficulty of assessing the impact of losing some of the system components, as well as identifying the most effective protective measures. As a result, the development of advanced analytical tools for addressing the issues of CSC systems vulnerability, security investment and the design of resilient networks is urgently needed. This may be best achieved through the establishment of an international network of relevant expertise from engineering, economics, management and technology fields.

Solutions to the above challenges contribute to the enhancement of CSC resilience and sustainability from operational aspects. However, new problems arise as to how traditional cost benefit analysis modelling, information and communication technology (ICT) support and intermodal management in CSCs (or associated segments) can best be adapted and integrated from economic and technical perspectives. For instance, benefits from reduced risks and costs associated with the implementation of each safety/security measure need to be compared and synthesised from each CSC segment for the purposes of overall decision making. In addition, there are many uncertainties, especially when the value of human life and environmental damage are concerned. The evaluation of costs and benefits may be conducted using various uncertainty methods and techniques. Furthermore, the integration of CSCs requires the establishment of a research network in ICT (e.g. Radio Frequency Identification (RFID)) and its application and diffusion within CSCs. The network will explore a number of key challenges, including application of RFID to minimise empty running to reduce traffic congestion, better and enhanced data storage (and management) capability to deal with pollution and risk issues, as well as traceability and integrity, as they relate to the need for CSC security from deliberate tampering, contamination and terrorism.

In this setting, the aim of this study is to examine the research challenges of developing resilient and sustainable CSCs; more specifically to identify opportunities and provide recommendations for researchers to conduct studies associated with operational research, safety, security and resilience, climate change, cost benefit analysis, ICT and intermodal transportation in the context of CSCs. The findings will serve as a stepping stone for developing an integrated CSC resilience and sustainability enhancement methodology, aimed at addressing long-lasting changes in operational, environmental, economic, technical and managerial practices in different segments of the industry. It will be achieved by developing a physical and virtual grouping of academics and researchers designated to create an interdisciplinary think-tank and knowledge exchange platform through an EU-funded project ENRICH (*E*C-Chi*N*a *R*esearch Network on *I*ntegrated *C*ontainer Supply C*h*ains). The research challenges requiring to be addressed urgently are analysed and presented in the following six sections before it reaches the conclusion in Sect. 8.

2 CSC Integration and Performance

Nowadays, container transport related process and activities are no longer exclusively maritime in nature during the process of international shipment. Instead, more cargoes are transported in discrete units around the world through integrated supply chains (Christopher 1998) which are composed of containers, trucks, railway wagons, container vessels and container port/terminal facilities. As such, strengthening the integration and thereby improving the performance of CSCs, especially with respect to operational efficiency and capacity optimisation, emerges as the major concern when designing and structuring the supply chains which containers move along.

The concept of supply chain integration was first developed on the basis of the value chain model (Porter 1985) which explained how the optimisation of value added activities along the chain will improve the output performance of organisations. In other words, optimised integration across a supply chain maximises the capturing of the value generated along it (Frohlich and Westbrook 2001). Practically, identified attributes of an integrative supply chain strategy are generally based on two main tenets, namely (a) technological facilitation and (b) operational facilitation (Vickery et al. 2003). The former facilitates supply chain integration through computerised operations and integrated information systems, while the latter refers to those practices that strengthen the linkages between the partners occupying different positions in the supply chain (Panayides and Song 2008). Accordingly, integration within the context of CSC research will primarily involve two significant flow movements—the integrity of supply chain information flow and the related physical container cargo flow. *However, whether efficient servicing and superior performance of CSC operations can be achieved depends on not only the internal integrity of each flow, but more importantly how these concepts of integrity are interconnected.*

Empirical determination of variables for measuring the integration of CSCs could be rather complicated. However, the application of the network concept provides a great alternative where a multi-layer network represents the container trade, seamless information sharing, and actual cargo transportation from top to bottom respectively (Wang and Cullinane 2014). The business process of CSCs consisting of the links of suppliers, distributors, consumers, including active moves in all modes of transport (i.e. road, rail and sea) is simulated and visualised with the support of seamless movement of information flows (see Sect. 6). Existing and potential barriers affecting physical flow movement will then be identified by taking into account capacity constraints, service availability, intercontinental trade and transport patterns, as well as legal, institutional and regulatory concerns. Finally, an integrated traffic multi-objective network model capable of dealing with container shipments in an entire CSC could be developed and provide an optimal solution for time, cost and energy consumption efficiency.

CSCs present a container flow network. Network robustness denotes the capacity to resist the effects of a random or selected removal of nodes or edges in full or in part. The performance of CSC integration could be measured using two measures of network performance—global network efficiency and local efficiency clustering coefficient (Latora and Marchiori 2001). Latora and Marchiori (2001) have introduced the concept of efficiency of a network, which measures how efficiently the information is exchanged over the network. In general, the efficiency of network relates to the shortest distance of each pair of nodes, because information spreads rapidly along a network with a small shortest path length (Latora and Marchiori

2003; Wang et al., 2006). In the ENRICH project, nodes are separated from the network by two strategies—the removal and degradation strategies. The removal strategy separates nodes randomly, while the degradation strategy reduces the efficiency of the nodes by percentage. The clustering coefficient is an important concept which reflects transitivity at a local level. Watts and Strogatz (1998) proposed so-called clustering coefficient to measure local cohesiveness of the network in the neighbourhood of a particular node. The neighbours of a node refer to all nodes linking to the node directly. The clustering coefficient will also be applied to measure the performance of CSCs using the removal and degradation strategies.

3 Safety Analysis of CSCs

Risk is defined as a combination of the probability of occurrence of an undesired event and the degree of its possible consequences (Wang and Trbojevic 2006). For a supply chain system, risk estimation and failure prevention of a component is regularly performed to ensure that the system is in a good and safe condition. This is particularly important when new technologies within high value sub-systems and components are involved. However, when deciding which component needs to be investigated and which risk control measure needs to be employed, it is a very challenging task given the safety dependency among the components. In other words, the failure of one component may affect the safety of the others, which depend on it. The safety analysis of the interdependency among the components is often carried out by using a measure of "occurrence likelihood" and ignoring the importance of "consequence severity". Overlooking the consequence severity will result in inaccuracy of evaluation, particularly in the CSC context, in which many risks are often of low likelihood but high consequence. Consequently, the safety analysis of components relies on not only their high risk nature but also their safety impacts on other items and even the whole system. *How to rationally combine the two, the components' own (internal) risks and their (external) safety impacts on the system in order to best present their criticality in complex supply chain systems is an outstanding question to answer in the literature.* Furthermore, safety dependency also affects the development of cost effective risk control measures. The risk information will normally be treated confidentially at a local component level in CSCs. It leads to a lack of visibility in monitoring the safety performance of a whole CSC system. It is often the case that one member of a supply chain has no detailed knowledge of what goes on in other parts of the chain (e.g. adopting (or not) adequate risk mitigation/control measures for assuring the resilience and sustainability of the chain). Because there is no visibility of upstream and downstream flows and stocks, confidence declines and the risk of making ineffective safety decisions becomes an inevitable consequence. This requires a new way of developing optimal risk measures in safety decisions with new concerns over multiple attributes under uncertainties in a global dynamic environment. Given the safety interdependency in complex CSC systems, the major research challenges are: *(a) how to accurately estimate component risk and predict system safety in a dynamic environment; and (b) how to introduce control measures to ensure the system safety at an acceptable level in a cost-effective manner from a global perspective?* Attempts using Bayesian statistics and evidential reasoning seem promising in dealing with risk evaluation with no or little objective data in a dynamic environment, while the use of system dynamics in port security management (Yeo et al. 2013) has revealed its strengths in tackling risk economics from a systemic perspective and thus will be further researched.

4 Security Management of CSCs

A series of terrorist attacks associated with transport sectors in the past decade (e.g. the 9/11 attacks in New York in 2001, the attacks on Madrid's commuter trains in 2004 and the London underground and bus bombings in 2007) have raised the issue of CSC system vulnerability into sharp security focus and have posed a new challenge to devise sound procedures for increasing system resilience. A large number of security control measures associated with container transportation have been proposed via various regulations (USA 2002; IMO 2003; Canada 2003; European Parliament 2004) such as the International Ship and Port Facility Security Code (ISPS), the Container Security Initiative (CSI), the Customs Trade Partnership Against Terrorism (C-TPAT), Partners in Protection (PIP), and the EU Authorized Economic Operator (AEO). Although such measures have greatly enhanced CSC security performance, their effectiveness is still criticized and needs to be further justified. For instance, it is arguable that the ISPS Code does not prescribe a generally accepted methodology to carry out quantitative security assessment (Yang et al. 2014). *If security measures cannot be assessed quantitatively, the security management system may not motivate industrial companies/local authorities to take them seriously, possibly because their effects are not visible in a state-of-the-art risk assessment.*

With the nearly infinite number of attack scenarios and the persistent nature of the threats, the use of risk assessment, as the solution to managing security, faces a number of research challenges despite the efforts exerted at the highest level of public administration (Masse et al. 2007; Canada 2003; IMO 2003; European Parliament 2004) and by researchers from various backgrounds (Garrick 2002; Bier and von Winterfeldt 2007; Willis 2007). Previous research of using risk assessment in counter-terrorism security management mainly focused on critical system analysis. The motivation for identifying the critical systems is the need for prioritising activities and resources on security investments and risk reduction processes (Aven 2009). Currently, the methods of evaluating the criticality parameters mainly use subjective judgements based on crisp utility values and also simulation results (Patterson and Apostolakis 2007), probabilistic data in databases (Dillon et al. 2009) and linguistic description based on fuzzy sets (Yang et al. 2009, 2013). The methods, which enable the tackling of one kind of uncertainty, often ignore the others when being developed under a specified scenario where strong assumptions are present. Previous studies indicate that uncertainty treatment theories have been used to facilitate risk assessment, including simulation (Monte Carlo), fuzzy logic, analytical hierarchy process, artificial neural networks, evidential reasoning and Bayesian networks. *It will be necessary and beneficial to make use of advantages of the individual uncertainty treatment methods to develop a holistic and powerful risk-based security management tool that is capable of dealing with CSC terrorism security assessment under large uncertainties.*

5 Sustainable CSC Management

Natural resource depletion and climate change have become great challenges. Innovation in management and technology in the transportation industry to improve the sustainability of logistics operations and their resilience to climate change related interruptions has become, therefore, increasingly important (Finley and Schuchard 2011). Extensive studies have been reported on the development of innovative approaches to improving the sustainability of logistics operations (Lopez et al. 2009; Sadegheih et al. 2010; Janic 2011). In containerised transportation operations, sustainable CSC operations require enabling technologies, facilitating packaging solutions, maximizing the use of low carbon transport modes and minimum empty container movements, etc. to ensure both operational efficiency and environmental benefits. To achieve such objectives, the following main challenges need to be overcome.

The performance of CSCs is inherently and closely associated with the performance of different layers of transportation services, the packaging solutions of the cargo being transported in containers and the relevant cargo handling logistics systems in the chains (Moura and Oliveira 2009; Martin 2014). To achieve sustainable operations, the CSCs should therefore be managed through integrated sustainability planning of all the relevant service elements. Carbon emissions in CSCs could be reduced by optimised multimodal or intermodal transportation and reducing empty container transits (Sadegheih et al. 2010; Macharis and Bontekoning 2004). *However, choices of transportation modes are affected by the solutions to the question as to which container devanning location will be used and how it will reduce empty container movements.* For a sustainable solution, multi-dimensional performance needs to be assessed, taking into account both economic and environmental impacts, through the multi-layered measurement of the transportation services, the packaging of cargoes and associated logistics facilities as an integrated system. Possible solutions can be developed through the combination of the identification of a Key Performance Indicator (KPI) framework and the transformation of different impacts/dimensions onto the traditional performance measures in efficiency and effectiveness (Gunasekarana et al. 2004; Zhu et al. 2012). Classical multi-criteria decision making methods, including both multi-attribute decision making and multi-objective decision making models are often incorporated to conduct the assessment of sustainability development of transport systems (e.g. Yang et al. 2017).

Furthermore, due to the complexity of CSCs, it is crucial to understand the interactions between the multiple layers in a CSC and their impacts on sustainability performance. A container is a reusable article of transport equipment (Armstrong 1981). To study container transportation as the movement of cargoes within a packaging system, requires appropriate efforts in understanding the impact of the interactions among cargoes, packaging, containers and logistics operations on sustainability performance. Packaging logistics needs to be researched in terms of interactions between packaging and logistics services (Saghir 2004). *Packaging efficiency (mainly in terms of spatial utilisation) in CSCs cannot be simply represented by a single packaging or a single phase during the transportation. Instead it requires an investigation of cargo characteristics and how containers themselves are sustainably managed in their lifecycle for efficient value recovery and minimum environmental impact.*

Greener operations in CSCs do not always refer to economic benefits. Policies and legislations involving sustainable supply chain management play an important role in advancing green logistics practice (Nolanda and Lemb 2002; Newell 2012; Toloue 2014). Policies such as carbon tax, cap and trade schemes, motorway taxes, congestion charging and the availability of subsidies for energy efficient vehicles in a specific transport context are all producing significant impacts on CSC sustainable management. *What remains unclear is the extent to which the combined use of these policies impacts upon CSCs and which policies have an extended influence across the whole chain system.*

6 Information and Communication Technology (ICT)

Confronted with increasing competition, a container port has to compete with others by its advanced involvement in CSC integration, instead of being an individual unit. ICT plays an important role in enhancing the performance of CSCs. Substantial studies have identified it as a key success factor in supply chain integration (Císařová and Široký 2009; Rastrick and Corner 2010; Cepolina 2011; He and Cheng 2012; Comendador et al. 2012). It is notable that ICT brings to CSC management not only great opportunities, but also significant challenges. Consequently, there is an urgent need to make a systematic investigation of CSC systems with a focus on ICT. Specifically, some emerging issues on CSC integration using ICT are listed as follows.

(a) *In-depth understanding of the implications of ICT for CSC integration.* ICT has been imposing evolutionary impacts on all aspects of a CSC system. For instance, comprehensive skills in data management have been a vital factor in building the core competitiveness of CSC systems. Therefore, it is highly valuable to investigate how ICT changes traditional supply chain management from different perspectives, including strategy making, operational, managerial and governance aspects.

(b) *Identifying key differences between CSCs and traditional supply chains and recognizing the main benefits acquired by implementing ICT in a CSC system.* The functions of ICT in freight transport by road are classified into six categories, i.e., asset tracking, onboard status, load conditions and tampering attempts, gateway facilitation, freight status information, and network status information. However, CSC represents a system which is much wider than land transport, involving more actors and transport modes. The functions of ICT imposed on a CSC system are beyond the current literature, requiring a new analysis. *We lack critical understanding of which new services ICT will provide to exploit its maximum benefit to CSCs.*

(c) *Establishing suitable ICT-based platforms to facilitate effective CSC management.* A successful ICT-based platform involves at least three dimensions, including the user type, economic efficiency and management rules. The user type determines the main functions of the ICT-based platform. For example, governments focus on common functions serving the whole of society, while transport service providers are interested in convenient one-stop solutions. The concept of economic efficiency emphasizes the benefits of the platform against the cost. It implies that the most suitable ICT tools, instead of the most advanced or sophisticated ones, should be selected to compose the platform. In order to make sure of the continuous and smooth running of the ICT-based platform, management rules with strict logic should be established, in which information security rules need more attention.

(d) *Investigating approaches to improve CSC management with ICT.* The development of ICT has raised many new challenges in CSC management, such as the management of unexpected events, the integration of computer services, the combination of different types of logistic networks, the combination of different transport modes, the optimization of vehicle routing and the optimization of container yard scheduling, etc. Furthermore, evaluation methods for ICT-based CSCs should be exploited to test robustness and resilience and to identify bottlenecks in the CSC construction.

7 Intermodal Management in CSCs

Trying to integrate a green concept into the management of intermodal CSCs is a key challenge for improving the environmental performance of international trade flows (Macharis et al. 2010). An enhanced understanding about this would establish a platform for developing more effective policy incentives at both global and regional levels (Bouchery and Fransoo 2014a). To obtain this, a better understanding of how business partnerships actually work is necessary. Purchasing behaviour related to the environmental aspects of CSCs—and the trade-offs of such factors versus other traditional performance indicators is a highly interesting research area in need of more in-depth understanding (Lammgård and Andersson 2014). *Variability in time-use is a key performance indicator where maritime supply chains may have a bigger challenge than other modes of transport do. Understanding the relationships between time-related indicators of global ocean transportation networks and how shippers manage these challenges is also a significant research area (Harrison and Fichtinger* 2013*) that needs more work.*

Various environmental policy regimes affect the way these partnerships work collaboratively, and consequently the effectiveness of the policy options should be analysed in order to minimize the environmental footprint of these intercontinental CSCs. Central to modern CSCs is the characteristic hub-and-spoke type of networks, and the understanding of the concept and central functions of a logistics hub in such a setting is a key issue (Nam and Song 2011). In order to address the important dimensions for an integrated service, defining and understanding the service quality in maritime supply chains is important (Thai 2008). *The organization of container port hinterland transportation in CSCs often encompasses many different actors that may not be aligned to optimize the whole chain* (Acciaro and McKinnon 2013; Bouchery and Fransoo 2014b).

Along with the assessment of policy regimes, focus should be put on how these supply chains could be integrated further. Better integration would enhance efficiency from a business perspective, and at the same time often reduce emissions and other environmental impacts. Exploring the potential for improving information flows, e.g. through an enhanced utilization of modern auto-ID technologies like RFID, would be a central challenge in this respect (Jedermann et al. 2009; Daschkovska and Scholz-Reiter 2011; Arendt et al. 2012). *Understanding the need for organizational transformation necessitated from the introduction of such systems into the supply chain, seems to be an area where more research is required* (Wamba and Chatfield 2009).

Quantitative decision support tools have been developed to support the various decisions made by stakeholders in intermodal supply chains and they have the potential to enhance financial and environmental performance. Macharis and Bontekoning (2004) identified intermodal freight transport as a new research area for operations research (OR), focusing on strategic, tactical and operational problems that might be analysed by such tools. This is further developed by SteadieSeifi et al. (2014), dividing their focus into the pre-haul, long-haul and end-haul parts of the supply chain. A research agenda for the further development of such tools has recently been proposed by Caris et al. (2013), focusing on tools applied to policy support, terminal network design, intermodal service network design, intermodal routing, drayage operations and ICT innovations. Although substantial developments have been made in recent years in all these areas, further challenges are identified. *Better decision support tools may enhance the utilization of the transport capacity, e.g. in the form of reducing the volume, and transport distance carried, of empty containers* (Theofanis and Boile 2009; Braekers et al. 2011, 2013).

8 Conclusion

Rising risk and uncertainty stimulate innovative research for achieving long-term resilient and sustainable CSCs in the twenty-first century. This research work, along with an EU Marie Curie research exchange programme "ENRICH", provides insights into the research challenges around integrated CSCs by bringing together an international team of researchers with a wide variety of skills in operations research, safety and security studies, green logistics, economic modelling, ICT and intermodal management. The research challenges are addressed by incorporating resilience and sustainability concepts into a new research agenda to respond to the long-lasting changes in operational, environmental, economic, technical and managerial practices in different segments of the rail, road, air and sea transport industries from an overall supply chain perspective. In light of such developments, this work has presented an updated review and analysis of the major research challenges faced in the six different, but highly interactive, aspects of integration (performance efficiency), safety, security, sustainability (green logistics), ICT and intermodal management. The findings from this work reveal several noteworthy tendencies in future studies as follows:

(a) *Use of emerging techniques in green logistics to deal with the issues caused by climate change from both mitigation and adaptation aspects.*
(b) *Development of flexible risk quantification methods to enhance CSC resilience and sustainability against threats from terrorists, pirates and climate change.*
(c) *Incorporation of optimisation, simulation, ICT, cost and intermodal modelling to facilitate the advanced integration of CSC segments concerning carbon emissions and pollution, safe and secure transportation and integrated logistics process improvement.*
(d) *Opening of new research dimensions of an interdisciplinary nature in both container transportation and logistics management, requiring research in a collaborative academic environment.*

These tendencies together represent a stepping stone to facilitating the movement of CSC management strategies from a cost-saving or a value-added orientation towards a resilience and sustainability focused regime.

Acknowledgements This work is partially funded by the EU FP7 Marie Curie IRSES project "ENRICH" (612546).

References

Acciaro, M., & McKinnon, A. (2013). Efficient hinterland transport infrastructure and services for large container ports. In *International Transport Forum Discussion Paper*. http://www.internationaltransportforum.org/jtrc/RoundTables/2013-Container-Shipping/Acciaro-MackinnonHintgerlandNov2013.pdf. Accessed 30 Oct 2014.

Arendt, F., Meyer-Larsen, N., Muller, R., & Veenstra, A. W. (2012). Practical approaches towards enhanced security and visibility in international intermodal container supply chains. *International Journal of Shipping and Transport Logistics, 4*(2), 182–196.

Armstrong, T. J. (1981). Packaging trends and implications in the container revolution. *Journal of Maritime Law & Commerce, 12*, 427–465.

Aven, T. (2009). Identification of safety and security critical systems and activities. *Reliability Engineering & System Safety, 94*, 404–411.

Bier, V. M., & von Winterfeldt, D. (2007). Meeting the challenges of terrorism risk analysis. *Risk Analysis, 27*, 503–504.

Bouchery, Y., & Fransoo J. (2014a). Cost, carbon emissions and modal shift in intermodal network design decisions. *Internal Report, BETA publication: Working Papers, 452*, 33.

Bouchery, Y., & Fransoo J. (2014b). Intermodal hinterland network design with multiple actors. *Internal Report, BETA publication: Working Papers, 449*, 30.

Braekers, K., Janssens, G. K., & Caris, A. (2011). Challenges in managing empty container movements at multiple planning levels. *Transport Reviews, 31*(6), 681–708.

Braekers, K., Caris, A., & Janssens, G. K. (2013). Integrated planning of loaded and empty container movements. *OR Spectrum, 35*(2), 457–478.

Canada. (2003). *Security & emergency preparedness, marine transportation regulations*. Canada: Government of Canada.

Caris, A., Macharis, C., & Janssens, G. K. (2013). Decision support in intermodal transport: A new research agenda. *Computers in Industry, 64*(2), 105–112.

Cepolina, S. (2011). Fostering the garment industry competitiveness: The ICT contribution. *Global Journal of Enterprise Information System, 3*(2), 5–14.

Christopher, M. (1998). *Logistics and supply management*. London: Pitman.

Císařová, H., & Široký, J. (2009). Logistics technology and the city logistics. *Logistics in Materials, 4*(4), 28.

Comendador, J., López-Lambas, M. E., & Monzón, A. (2012). A GPS analysis for urban freight distribution. *Procedia—Social and Behavioral Sciences, 39*, 521–533.

Daschkovska, K., & Scholz-Reiter B. (2011). How can electronic seals contribute to the efficiency of global container system? In: *Dynamics in logistics* (pp. 457–467). Springer.

Dillon, R. L., Liebe, R. M., & Bestafka, T. (2009). Risk-based decision making for terrorism applications. *Risk Analysis, 29*, 321–335.

European Parliament. (2004). Regulation (EC) No. 725/2004 on enhancing ship and port facility security. *EU Official Journal, L129*, 0006–0091.

Finley, T., & Schuchard, R. (2011). Adapting to climate change: A guide for the transportation industry, *BSR Report*. http://www.bsr.org/en/our-insights/report-view/adapting-to-climate-change-a-guide-for-the-transportation-industry. Accessed 30 September 2014.

Frohlich, M. T., & Westbrook, R. (2001). Arcs of integration: an international study of supply chain strategies. *Journal of Operations Management, 19*, 185–200.

Garrick, B. J. (2002). Perspectives on the use of risk assessment to address terrorism. *Risk Analysis, 22*, 421–422.

Gunasekarana, A., Patelb, C., & McGaugheyc, R. E. (2004). A framework for supply chain performance measurement. *International Journal of Production Economics, 87*, 333–347.

Harrison, A., & Fichtinger, J. (2013). Managing variability in ocean shipping. *International Journal of Logistics Management, 24*(1), 7–21.

He, H., & Cheng, H. (2012). Analyzing key influence factors of city logistics development using the fuzzy decision making trial and evaluation laboratory (DEMATEL) method. *African Journal of Business Management, 6*, 11281–11293.

IMO. (2003). *International Ship and Port Facility Security (ISPS) Code*. International Maritime Organisation, UK.

Janic, M. (2011). Assessing some social and environmental effects of transforming an airport into a real multimodal transport node. *Transportation Research Part D: Transport and Environment, 16*, 137–149.

Jedermann, R., Ruiz-Garcia, L., & Lang, W. (2009). Spatial temperature profiling by semi-passive RFID loggers for perishable food transportation. *Computers and Electronics in Agriculture, 65* (2), 145–154.

Lammgård, C., & Andersson, D. (2014). Environmental considerations and trade-offs in purchasing of transportation services. *Research in Transportation Business & Management, 10*, 45–52.

Latora, V., & Marchiori, M. (2001). Efficient behavior of small-world networks. *Physical Review Letters, 87*(19), 198701.

Latora, V., & Marchiori, M. (2003). Economic small-world behavior in weighted networks. *The European Physical Journal B-Condensed Matter and Complex Systems, 32*(2), 249–263.

Lopez, I., Rodriguez, J., Buron, J. M., & Garcia, A. (2009). A methodology for evaluating environmental impacts of railway freight transportation policies. *Energy Policy, 37*, 5393–5398.

Macharis, C., & Bontekoning, Y. M. (2004). Opportunities for OR in intermodal freight transport research: A review. *European Journal of Operational Research, 153*, 400–416.

Macharis, C., Van Hoeck, E., Pekin, E., & van Lier, T. (2010). A decision analysis framework for intermodal transport: Comparing fuel price increases and the internalisation of external costs. *Transportation Research Part A: Policy and Practice, 44*(7), 550–561.

Martin, C. (2014). The packaging of efficiency in the development of the intermodal shipping container. *Mobilities, 9*, 432–451.

Masse T., O'Neil S., & Rollins J. (2007). The Department of Homeland security's risk assessment methodology: Evolution, issues, and options for congress. *Congressional Research Service Report No. RI33858, USA*.

Moura, A., & Oliveira, J. F. (2009). An integrated approach to the vehicle routing and container loading problems. *OR Spectrum, 31*(4), 775–800.

Nam, H. S., & Song, D. W. (2011). Defining maritime logistics hub and its implication for container port. *Maritime Policy & Management, 38*(3), 269–292.

Newell, P. (2012). The political economy of carbon markets: The CDM and other stories. *Climate Policy, 12*, 135–139.

Ng, A., Chen, S., Cahoon, S., Brooks, B., & Yang, Z. (2013). Climate change and the adaptation strategies of ports: The Australian experiences. *Research in Transportation Business & Management, 8*, 186–194.

Nolanda, R. B., & Lemb, L. L. (2002). A review of the evidence for induced travel and changes in transportation and environmental policy in the US and the UK. *Transportation Research Part D: Transport and Environment, 7*(1), 1–26.

Panayides, P. M., & Song, D. W. (2008). Evaluating the integration of seaport container terminal in supply chains. *International Journal of Physical Distribution & Logistics Management, 38*(7), 562–584.

Patterson, S. A., & Apostolakis, G. E. (2007). Identification of critical locations across multiple infrastructures for terrorist actions. *Reliability Engineering & System Safety, 92*, 1183–1203.

Porter, M. (1985). *Competitive advantage*. New York: Free Press.

Rastrick, K., & Corner, J. (2010). Understanding ICT based advantages: A technosavvy case study. *Interdisciplinary Journal of Information, Knowledge, and Management, 5*, 305–329.

Sadegheih, A., Li, D., Sribenjachot, S., & Drake, P. R. (2010). Applying mixed integer programming for green supply chain management. *South African Journal of Industrial Engineering, 21* (2), 13–24.

Saghir M. (2004, April 30–May 3). The concept of packaging logistics. In *The second world conference on POM and 15th annual POM conference, Cancun, Mexico*.

SteadieSeifi, M., Dellaert, N. P., Nuijten, W., Van Woensel, T., & Raoufi, R. (2014). Multimodal freight transportation planning: A literature review. *European Journal of Operational Research, 233*(1), 1–15.

Thai, V. V. (2008). Service quality in maritime transport: conceptual model and empirical evidence. *Asia Pacific Journal of Marketing and Logistics, 20*(4), 493–518.

Theofanis, S., & Boile, M. (2009). Empty marine container logistics: facts, issues and management strategies. *GeoJournal, 74*(1), 51–65.

Toloue, R. (2014, September 29). Carbon policies targeting road transport: Is there a safety consequence? In *Proceedings of European Transport Conference 2014. Frankfurt, Germany.*

USA. (2002). *Maritime Transportation Security Act.* http://www.tsa.gov/assets/pdf/MTSA.pdf. Accessed 8 May 2009.

Vickery, S. K., Jayaram, J., Droge, C., & Calantone, R. (2003). The effects of an integrative supply chain strategy on customer service and financial performance: an analysis of direct versus indirect relationship. *Journal of Operations Management, 21*, 523–539.

Wamba, S. F., & Chatfield, A. T. (2009). A contingency model for creating value from RFID supply chain network projects in logistics and manufacturing environments. *European Journal of Information Systems, 18*(6), 615–636.

Wang, Y. H., & Cullinane, K. P. B. (2014). Traffic consolidation in East Asian container ports: A network flow analysis. *Transportation Research A: Policy and Practice, 61C*, 152–163.

Wang, J., & Trbojevic, V. M. (2006). *Design for safety of large marine and offshore engineering products.* London, UK: Institute of Marine Engineering, Science and Technology (IMarEST).

Wang, B., Tang, H., Guo, C., Xiu, Z., & Zhou, T. (2006). Optimization of network structure to random failures. *Physica A: Statistical Mechanics and its Applications, 368*(2), 607–614.

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of ‘small-world’ networks. *Nature, 393* (6684), 440–442.

Willis, H. H. (2007). Guiding resource allocations based on terrorism risk. *Risk Analysis, 27*, 597–606.

Yang, Z. L., Bonsall, S., & Wang, J. (2009). Use of fuzzy evidential reasoning in maritime security assessment. *Risk Analysis, 29*, 95–120.

Yang, Z., Ng, A. K. Y., & Wang, J. (2013). Prioritizing security vulnerabilities in ports. *International Journal of Shipping and Transport Logistics, 5*, 622–636.

Yang, Z., Ng, A. K. Y., & Wang, J. (2014). Incorporating quantitative risk analysis in port facility security assessment. *Transportation Research Part A: Policy and Practice, 59*, 72–90.

Yang, Z., Ng, A., Lee, P. T. W., Wang, T., Qu, Z., Rodrigues, V. S., Pettit, S., Harris, I., Zhang, D., & Lau, Y. T. (2017). Risk and cost evaluation of port adaptation measures to climate change impacts. *Transportation Research Part D: Transport and Environment*. https://doi.org/10.1016/j.trd.2017.03.004

Yeo, G. T., Pak, J. Y., & Yang, Z. (2013). Analysis of dynamic effects on seaport adopting port security. *Transportation Research Part A: Policy and Practice, 49*, 285–301.

Zhu, Q., Sarkis, J., & Lai, K. (2012). Examining the effects of green supply chain management practices and their mediations on performance improvements. *International Journal of Production Research, 50*(5), 1377–1394.

A Research Framework for Cross-National Comparative Logistics

Wenping Luo

Abstract When companies expand internationally under various pressures or opportunities, they find “logistics barriers” in cross-national logistics. This chapter conceptualizes the field of Cross-National Comparative Logistics (CNCL). Firstly, the areas of logistics to compare is discussed which include the concepts, thoughts and practices. Secondly, the factors causing the difference in “logistics” are discussed, which include the development level, market maturation or economic system, and culture. The operationalization of the factors is further discussed.

Keywords Comparative logistics · Global logistics · Cross-cultural study

1 Introduction

In the face of globalization, the ability to effectively manage logistics in a cross-national context has become one of the crucial success factors in today’s business world. More and more academicians and practitioners have warned of the global or cross-national logistics problems and recognized the importance of tackling the field of cross-national logistics.

However, Luo et al. (2001) reviewed relevant literature in the field of cross-national (cultural) comparative logistics and found it is in its infancy. There have been a number of attempts to identify the difference in logistics mainly by the countries of original (COO) research in logistics. In general, these efforts have focused on the description of business environment, logistics infrastructure, states of logistics and problems and challenges with implicit comparison to logistics in western developed countries. The previous research has not attempted to identify the relationship empirically among the logistics and business environment factors.

W. Luo (✉)
School of Economics and Management, Shanghai Maritime University, Shanghai, PR China
e-mail: wluo@shmtu.edu.cn

J. E. Hernández et al. (eds.), *Collaborative Logistics and Intermodality*,
https://doi.org/10.1007/978-3-030-50958-3_2

2 Define the Field and Research Problems

Stock (1997) argued that logistics discipline has been developing by applying theories from other disciplines. CNCL research could also benefit from experiences of comparative research in general and comparative research in management and marketing in specific as logistics discipline deals with management and starts partly from marketing.

By referring to the definition of cross-national comparative research in other disciplines, for example, marketing (Boddewyn 1981), we can define the field of cross-national comparative logistics (CNCL):

Cross-national comparative logistics (CNCL) is the systematic detection, identification, classification, measurement, and interpretation of similarities and differences in logistics and its sub-areas among entire national systems or parts thereof.

3 What to Compare in Cross-National Comparative Logistics

There is a general agreement that comparison is about similarities and differences by definition. Disagreement is more about how far the analysis should go. As it is argued in comparative study in other disciplines, like marketing, comparative study should deal with type (A) and type (B) as well as type (E) in Fig. 1. As comparative study (marketing) "is not simply a description of either marketing or environmental

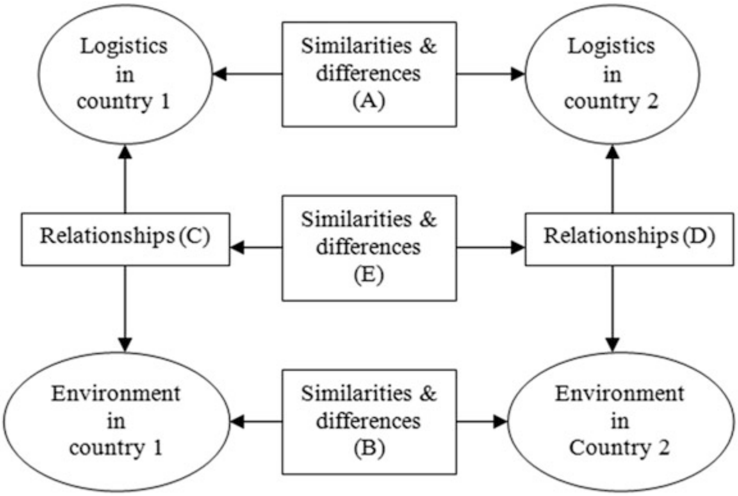


Fig. 1 Five facets in comparative logistics. Source: by author

differences but rather a comparison of relationships between marketing and its environment in two or more countries" (Boddewyn 1981).

Such a pragmatic approach was actually proposed and supported early by Verba (1967, 1971) when he studied comparative organization. Verba suggested a two-stage approach to obtain meaningful tests of complex phenomena: first looking for the relationship between dependent variables and independent variables within each single nation and then comparing this relationship between countries.

4 Dimension of Logistics to Compare

Mentzer and Kahn (1995) pointed out that the maturation of the logistics discipline would necessitate the adoption of a theory development approach to research.

In conceptualizing comparative logistics, we need first to determine what aspects of logistics to compare (type (A) is to compare aspects of logistics, see Fig. 1). Only after that, the models that might be able to explain the differences or similarities in aspects of logistics can be developed (type (C) or (D) research). This is similar in comparative study in other disciplines. For example, in discussing the comparative organization, Cheng (1989) recommended the initial selection of dependent variables followed by the selection of theory links independent variables.

The definition of logistics has evolved from a narrow approach concerning only physical distribution to a broader perspective of supply chain management. Simply to say, logistics is the planning, developing, organizing, coordination and controlling of the physical flows from material supplier to final customer. Compared to other disciplines, such as marketing and management, CNCL research tends to be more complicated with regard to the scope to compare as "few areas of business operations involve the complexity or span the geography typical of logistics" (Bowersox and Closs 1996).

4.1 Logistics Concepts and Thoughts

In the determination of the aspects or areas of logistics to compare between developed and developing countries, it is important first to examine the relevance of the logistics discipline developed in developed countries. Several authors in the logistics discipline have raised the concern of the relevance of logistics to developing countries. For example, Dazie (1990) argued:

> In spite of the continuous flow of management technology from the industrialized countries to the Third World, recent experience suggests that there is a lack of correspondence between many management discipline's organizing framework, orientation and emphasis, and the environment of Third World countries. This lack of correspondence raises several concerns about the applicability of most management disciplines, including logistics and how the discipline can most effectively be taught.

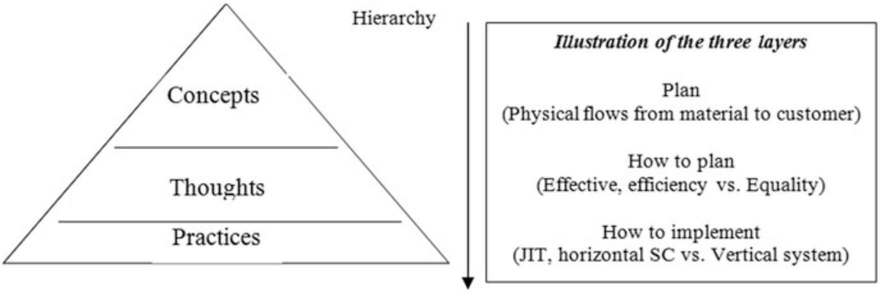


Fig. 2 Hierarchy of logistics to compare. Source: by author

In studying the supply challenges in Africa, Nollet et al. (1994) also argued:

> The key question is whether their challenges represent a professional responsibility that knows no national boundaries and should be shared with supply professionals anywhere in the world. The nature of the challenges is not unique to the less developed world, although the severity probably is. Might there be an opportunity to understand the supply challenges in the developed countries better and differently by trying to address those in the less developed parts of the world.

For the purpose of examine the relevance of the discipline developed in the environment of developed countries, it is appropriate to compare the very basic aspects of the discipline, i.e. the basic ideas underlying the logistics discipline or more specifically the basic concepts and thoughts in logistics.

To obtain further substantive knowledge in CNCL logistics research about the differences or similarities in logistics, the logistics practices should be compared.

Thus, a three-layer logistics phenomenon is suggested to compare between developed and developing countries. Figure 2 depicts the relationship among logistics concepts, thoughts and practices.

4.2 *Logistics Practices*

The further classification of the logistics practices as discussed above, needs to consider the substantive knowledge, equivalence and more practically, the difficulty and cost of access to the data. Two streams of CNCL practices can be identified. One is the comparison of the logistics best practice (LBP) by the Global Logistics Research Team in developed countries and the other is cross-national comparison (usually implicitly) in the general state of logistics or defined as logistics average practices (LAP).

The LBP comparisons are based on over a decade of learning from survey and interview research on how some of the world's best-managed firms actually use logistics to achieve competitive superiority. A model is developed that captures the capabilities and competencies of world class logistics (Council of Logistics

Table 1 World class capabilities

Logistics competency	World class capabilities
Positioning	Strategy, Supply Chain, Network, Organization
Integration	Supply Chain Unification, Information Technology, Information Sharing, Connectivity, Standardization, Simplification, Discipline
Agility	Relevancy, Accommodation, Flexibility
Measurement	Functional Assessment, Process Assessment, Benchmarking

Source: Council of Logistics Management (1995) *"World class logistics—the challenge of managing continuous change", Oak Brook, IL*

Management 1995). Overall, competency results from achieving high level performance related to 17 specific capabilities as showed in Table 1.

The LBP comparisons emphasize creating universality. The assumption as Adler (1994) argued it is possible for multinational and multicultural organizations to use a manager-created balance between specific and general approach. Adler added, synergistic research focuses on better understanding when both naturally occurring and created universal approaches are most effective and when maintaining culturally specific patterns is most effective. Best practice research, however, focuses on created rather than naturally occurring phenomena. The criticism to best practice research is often found. For example, Cavusgil and Gas (1997) argued comparative theory verification calls for more extensive inter-cultural sampling than research that has the objective of best practice comparisons.

The general state of logistics, or logistics average practice (LAP), using the normal sampling instead of the sampling of "best companies" to assess the state of logistics practice in a country is a traditional approach of investigation, which asks the question "what is" instead of "what could be". A number of articles in the literature deals with the LAP in a country with the label of "logistics (or sub-areas of logistics) in country X". Examples are given in Table 2.

The four articles are selected for the reason they represent relatively comprehensive scopes of the LAP in a country. Through careful evaluation of the articles in this area, the components of the LAP in a country can be grouped into following areas as shown in Fig. 3:

Importance of cost or service: assessing the state or the nature of a market (seller's market, competitive or very competitive). The more competitive the market, the more relevance of the logistics discipline.

Logistics organization: assessing the state of awareness and advance in the integration of logistics.

Technology adoption: assessing the state of technology advancement in logistics (e.g. information communication technology).

Skills in logistics management: assessing the mastering of the concepts and skills in logistics as logistics advancement to some extent is a function of concept and skill logisticians have. For example, whether the firm able to execute the performance measurement etc.

Table 2 Selected articles regarding to assessing the state of logistics in a country

Articles	Scope
Logistics in Canada (Chow and Heaver 1995)	Service priority; focus vs. differentiation; logistics organization (scope, formalization, concentration, and proximity); supply chain organization strategy; outsourcing, supply chain formalization
Physical distribution in New Zealand (Marr 1985)	Attitudes towards distribution; adoption of integrated distribution; position of distribution in the company hierarchy (management / organization profile, scope of distribution, the company role of the distribution executive)
Logistics in Korea (Kim 1996)	Status of logistics within organization; organizational characteristics; responsiveness; outsourcing and partnership; improvement action; customer service; technology adoption and use; cost effectiveness
Supply chain management practices in Asia Pacific today (McMullan 1996)	Management concerns (key issues, importance and costs of supply chain management); roles and responsibilities (department, report sub-process); competitive strategies (outsourcing, value-added services, technology enables, major concerns when selecting new system, type of software firms plan to implement, supply management); performance management (financial, customer, service, warehousing and transportation)

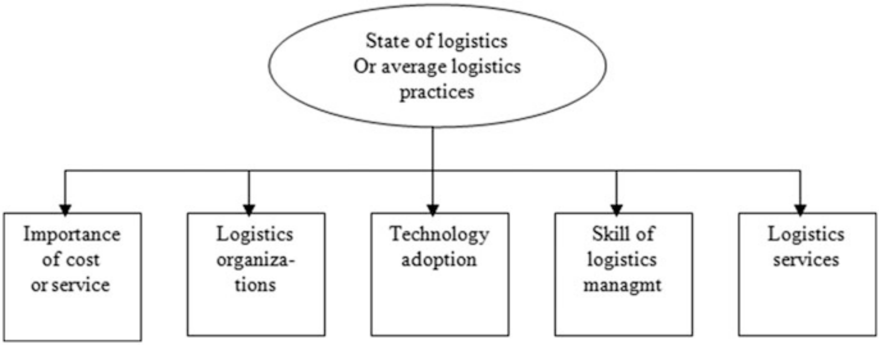


Fig. 3 Components of logistics average practice (LAP) in a country. Source: by author

State of logistics services sector: assessing the logistics services availability. For example, whether outsourcing or third party logistics (3PL) is used.

This classification is tentative and is still not very precise; it needs to be further discussed among the CNCL researchers internationally. However, an initial step should be started.

4.3 Sub-areas of Logistics to Compare

In literature study, Luo et al. (2001) revealed that 40% of the articles study the sub-areas of logistics in supply, distribution and transportation. Sub-areas of logistics are related to the logistics supply chain and have their own characteristics too. For example, the choice of distribution (marketing channel) goes with choice of logistics channel (Cooper et al. 1992). The transportation and warehousing infrastructure will facilitate or prevent the adoption of logistics practice for example, just in time (JIT).

5 Conceptualizing the Models

5.1 Development Level Model

Luo et al. (2001) found that in the CNCL research relating to developing countries, the problems and challenges in logistics practices are closely related to many factors which can be attributed to economic development level. These factors include logistics related infrastructure (which include soft and hard aspects of infrastructure); logistics concept and skill (education level related); and market conditions. It is obvious that economic development level is relevant to logistics differences between countries with different economic development level. See Fig. 4.

The propositions of the development level approach includes: The logistics differences among countries are related to the economic development level of those countries. The differences among logistics practices are dynamic, as the economic development level is dynamic.

5.2 Economic System Model

In the literature study of CNCL relating to developing countries, Luo et al. (2001) found that economic system is one of the perspectives that describe and explain

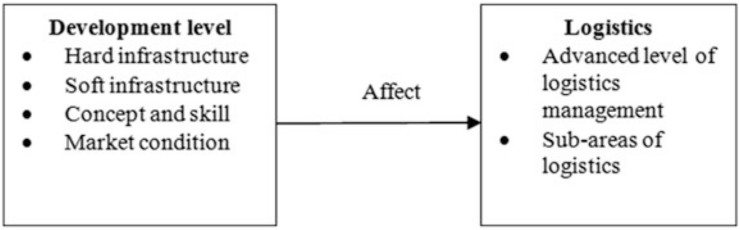


Fig. 4 Development model (economic development level approach). Source: by author

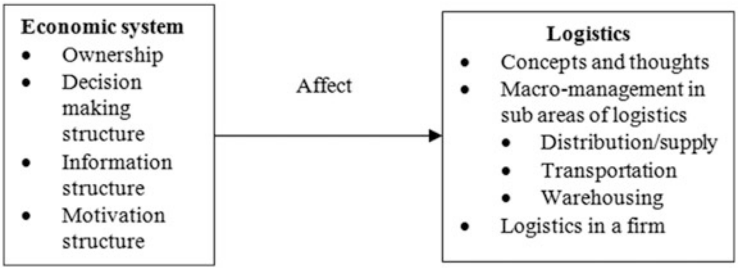


Fig. 5 Macro model (economic system approach). Source: by author

logistics in former planned economies. The observations in China also have clearly indicated that economic system is relevant to logistics at the theoretical (concepts and thoughts) and macro-management levels. The macro model using economic system as the explanatory variable is especially relevant to CNCL among countries with different economic system (refer to Fig. 5).

This model is basically a macro approach that considers that the economic system has external constraints to the macro-management of logistics on a country level. It concentrates on the economic system factors in the environment. The economic system differences could be expressed by decision-making structure (DM), information structure (IS), property rights or ownership structure (OS) and motivation structure (MS) as discussed above.

From this perspective, economic system is the variable to shape the logistics differences. The cross-national logistics differences (or similarities) in the areas indicated in Fig. 5 (especially countries with a former planned economic system) can be explained.

The propositions includes: Logistics is fundamentally different between countries with a centrally planned economy system and market oriented system. The differences are at theoretical level (concepts and thoughts) and macro-management, and practices level of a firm as well.

5.3 *Cultural Model*

The basic premise to this model is that managerial practices are related to cultural variables such as attitudes, beliefs, and value systems, need hierarchies, etc. (Fig. 6).

Cultural variable in the early stage studies was not well defined and leads to confusion. Hofstede (1994) filled an important vacuum and quantified the dimensions of culture and made it available for researchers to study the cultural influences in management and other areas. The dimensions of culture defined and quantified by Hofstede include Individualism, Power distance, Uncertainty avoidance, Masculinity and Confucian.

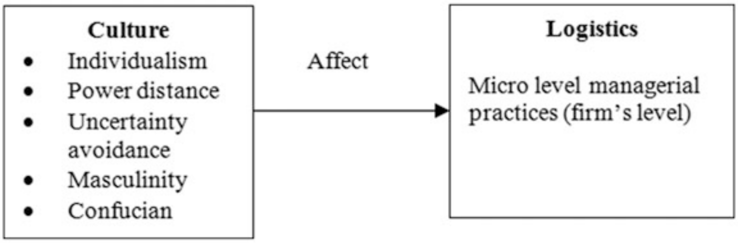


Fig. 6 Cultural approach (micro model). Source: by author

6 Conclusion

Compared with cross-national comparative study in other disciplines, such as management and marketing, comparative logistics in general and comparative logistics relating to developing countries in specific is still in its infancy.

The comparison of logistics across countries needs to compare logistics itself and the business environment as well. Furthermore, the relationship between logistics and business environment among countries should also be compared to understand the important variables across counties. Logistics is a complex phenomenon which has three layer in general, including concepts, thoughts and practices. The variables to explain the difference in logistics include development level, economic system and culture.

Further research in a pragmatic approach is suggested which need cooperation among research in different countries. After define the research problem, researchers need to ensure conceptual and functional equivalence when design the research. Construct the sampling need to be designed and instrumentation be developed. Then data collection, analysis and interpretation are followed.

References

Adler, N. (1994). A typology of management studies involving culture. *Journal of International Business Studies,* Fall, 29–47.

Boddewyn, J. (1981). Comparative marketing: the first twenty-five years. *Journal of International Business Studies,* Spring – Summer, 61–79.

Bowersox, D., & Closs, D. (1996). *Logistical management—The integrated supply chain process*. New York: McGraw-Hill.

Cavusgil, T., & Gas, A. (1997). Methodological issues in empirical cross-cultural research: a survey of the management literature and a framework. *Management International Review, 37*(1), 71–95.

Cheng, J. (1989). Towards a contextual approach to cross-national organisation research: A macro perspective. *Advances in International Comparative Management, 4*, 3–18.

Cooper, J., O'Laughlin, K., & Kresge, J. (1992). The challenge of change: Logistics in the New Europe. *The International Journal of Logistics Management, 3*(2), 1–16.

Council of Logistics Management. (1995). *World class logistics—the challenge of managing continuous change*. Oak Brook, IL.

Dadzie, K. (1990). Transfer of logistics knowledge to third world counties. *International Journal of Physical Distribution and Logistics Management, 20*(9), 10–16.

Hofstede, G. (1994). *Cultures and organisations: software of the mind: intercultural cooperation and its importance for survival.* London: McGraw-Hill.

Luo, W., Roos, H. B., & van Hoek, R. I. (2001). Cross-cultural logistics between developed and developing countries: literature review and propositions. *International Journal of Logistics Management-Research and Applications, 4*(1).

Mentzer, J., & Kahn, K. (1995). A framework of logistics research. *Journal of Business Logistics, 16*(1), 231–249.

Nollet, J., Leenders, M., & Diorio, M. (1994). Supply challenges in Africa. *International Journal of Purchasing and Materials Management,* Winter, 52–56.

Stock, J. (1997). Applying theories from other disciplines to logistics. *International Journal of Physical Distribution and Logistics Management, 27*(9/10), 515–539.

Verba, S. (1967). Some dilemma in comparative research. *World Politics,* 20, 111–127.

Verba, S. (1971). Cross-national survey research: the problem of credibility. In I. Valier (Ed.), *Comparative methods in sociology: Essays on trends and applications* (pp. 309–356). Berkeley, CA: University of California Press.

Supply Chain Solutions to Upstream Buyer Consolidation with Green and Resilient Supply Chain Designs in the China-Europe Containerized Cargo Flows

Ning Lin and Harald M. Hjelle

Abstract The Asia-Europe container trade is second only to the Transpacific trade in the world in terms of volumes transported. The typical structure of the supply chains associated with this trade is that containers are stuffed in China and the cargo is subsequently cross-docked at a major European logistics hub or closer to the customer for further shipment to the final retailing point. This may be one of the reasons why short sea container shipping has only a limited market share of intra-European cargo flows, since once the cargo is unloaded from containers, it is more likely to be forwarded by land-based modes of transport. Paving the way for a greater proportion of cargo to be cross-docked in China rather than in Europe, may prove to be more cost-efficient and less environmentally damaging than the typical solution. Based on interviews with central actors on the Chinese and European side of the supply chains, this chapter discusses the strengths and weaknesses of the typical solution and alternative solutions such as upstream buyer consolidation. Ultimately, a realization of the potentials related to a shift from the typical design of these supply chains to new alternatives, is dependent on an identification of key decision makers and their gains and losses related to the various solutions. The main decisions related to the design of the supply chains under the alternative solutions seem to be on the European side. Therefore, most shipments of consumer goods from China to Europe seem to be bought with FOB-type of terms. It also seems that European or global LSPs interact with buyers in the design of the supply chains, and that the disadvantages of Chinese LSPs in international logistics network and relations with potential European customers limit their role in this respect. Cost efficiency, lead times, agility and environmental performance of the alternative supply chain design is central to the choice of designs, as is an assessment of potential risks related to the China-Europe container trades. Recent disruptions related to carrier financial robustness has put the issue of building up a resilient supply chains a key issue, which is also relevant in this setting.

N. Lin (✉) · H. M. Hjelle
Molde University College, Molde, Norway
e-mail: ning.lin@himolde.no; harald.hjelle@himolde.no

J. E. Hernández et al. (eds.), *Collaborative Logistics and Intermodality*,
https://doi.org/10.1007/978-3-030-50958-3_3

Keywords Upstream buyer consolidation · Maritime feeder services · Asia-Europe container supply chains · Environmental impact · Resilient supply chains

1 Introduction

Worldwide containerized trade in 2015 was estimated to have increased by 2.4% from 2014, and reached 175 million TEUs. The Asia-Europe container trade is second only to the Transpacific trade in terms of volumes transported. More specifically, containerized trade volumes in 2015 were 21.7 million TEUs in the Asia–Europe container trade, accounting for 12.4% of total worldwide containerized trade (UNCTAD 2016). The pursuit of less expensive sources of supply by European importers is the main driving force that have kept the cargo volume in the Asia-Europe container trade at a high level for many years.

Sea containers coming from China to Europe are typically stuffed at the locations of the manufacturer in China. The consignments are thereafter transshipped in logistics hubs in Europe. Reconsolidation for onward movement to the final destinations is typically conducted in logistics hubs in North-West Europe or consolidation centers in destination countries. This is what we label as the “business-as-usual” (BAU) solution. The problem is that these reconsolidated shipments are most often moved by road transport to their final destinations, even if sea transport could provide a less costly and superior environmental solution. A potential solution is conducting upstream buyer consolidation in the Far East. Therefore, cargos can be delivered directly to local ports close to the final retailing points and bypass the distribution centers (DCs) in Europe to some extent. Many bonded areas and free trade zones are established in China during recent years, and these could facilitate upstream buyer consolidation services. In addition, Hong Kong is almost a free trade zone except for liquor, tobacco and a few other products. Multi-country consolidation (MCC) and multi-origin consolidation (MOC) services can be offered there. These policies in the Far East may facilitate more efficient supply chain designs.

The BAU solution, based on road transport on the European side, effectively contributes to more congested road networks and potentially higher logistics and environmental costs than if these cargoes were transported via maritime feeder links or railways.

Currently, only about 37% of cargo is transited among EU Member States in this way (Pastori 2015). Maritime feeder links can be an efficient and economic method for cargo owners to transport their cargo from logistics hubs in Europe to their destinations by sea. Figure 1 shows an example of such a maritime feeder solution for cargo with destinations in North European peripheral areas. An Iceland-based world leading cold-chain logistics service provider routinely services these markets. This itinerary starts at Rotterdam and ends in the port of Murmansk in Russia, serving 2 British ports, 28 Norwegian ports and 1 Russian port. On individual trips, some of the Norwegian ports will be omitted if there is no cargo.

Fig. 1 A case of a North European maritime feeder service serving British, Norwegian and Russian markets. Source: shortseaschedules.com

Except of the consideration of environmental issues, establishing a resilient supply chain is also crucial for European buyers. The supply chain connecting China to Europe typically crosses many countries. There are many potential disruptions at every leg and node of these supply chains. Creating resilient supply chains is key to European importers, a fact highlighted by the disruptions created by the financial problems of a global carrier active in this supply chain.

The purpose of this chapter is to analyze the design of these sea- and container-based supply chains, both the typical solution and alternative solutions, such as buyer consolidation. The strengths and weaknesses of these solutions, as well as the green and resilient issues of the new alternatives will also be discussed. Furthermore, the chapter also analyzes the capability of LSPs in China, impediments of shifting to the new alternatives from the typical solution and the key decision-makers in this system changing.

This chapter is structured as follows: Section 2 provides a review of the research literature relating to Asia-Europe sea container supply chains. In Sect. 3, the research design is described. Section 4 presents findings from our primary data collected through interviews. Based on Sects. 2, 3 and 4, we then analyze and discuss the BAU solution in comparison with new supply chain alternatives in Sect. 5. Resilient supply chain solutions are illustrated in Sect. 6. Finally, conclusions are presented in Sect. 7, along with an assessment of research limitations and suggestions for further research.

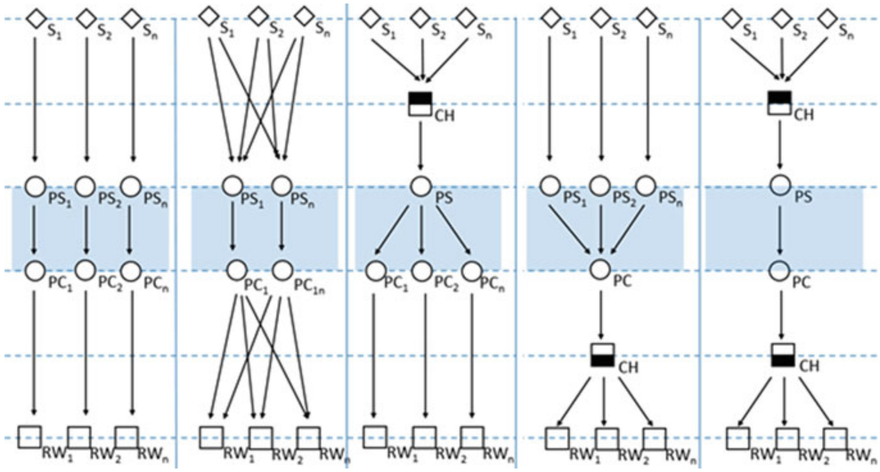
2 Literature Review

2.1 Asia-Europe Sea Container Supply Chain Configurations

In terms of global supply chain management, Cheong et al. (2007) considered a network design model by deciding the number and location of consolidation hubs to minimize the total logistics cost of international inbound logistics. Other researchers have proposed frameworks for supply chain strategy selection in relation to different aspects such as air-freight or sea-freight, centralized or decentralized inventory holding and lean and/or agile supply chains (Lovell et al. 2005; Martin et al. 2006).

On the basis of a literature review and interviews with LSPs, Creazza et al. (2010) mapped five containerized sea-based supply chain configurations from Asian factories to European retailers. The framework proposed for the supply chain design and setup process was based on characteristics of the business environment relating to a pure cost perspective. These five configurations are as follows: (1) direct deliveries with full container load (FCL) from individual suppliers to retailer's regional warehouses (RW); (2) direct deliveries with less than container load (LCL) from individual suppliers to retailer's RWs; (3) a one echelon supply chain with consolidation hub in the Far East; (4) a one echelon supply chain with consolidation hub in Europe; and (5) a two echelon supply chain with consolidation hubs in both the Far East and Europe—see Fig. 2. All these configurations differ in terms of complexity, lead-time, risk of delay and cost structure. Supply chain lead-times tend to increase with an increasing number of transit nodes. That is to say, direct deliveries with FCL from suppliers to RWs (Solution 1) generally lead to the least complexity, lowest risk of delay and shortest supply chain lead-times. However, it does not always imply the most cost-efficient supply chain solution (Zeng and Rossetti 2003). In addition, pursuing economies of scale in transportation by means of reducing shipment frequency will definitely lead to an increase of inventory cost. However, the research conducted by Creazza et al. (2010) only considered supply chains from suppliers to retailer RWs, with an important segment of these Asia-Europe container supply chains being ignored—the final leg from RWs to retail stores. In addition, because of the typical location of RWs in Europe, road haulage is usually used in the last segment of these supply chains, which is typically more environmentally damaging than maritime feeder services (Hjelle 2014).

Bygballe et al. (2012) discussed the pros and cons of different Asia-Europe container supply chains. They described four supply chain configurations within the context of containerized sea-based supply chains from Chinese suppliers to Norwegian retailers, based on their working experience and observations on a focal company. The benefits and drawbacks of each configuration were discussed from both a logistics cost and a customer service perspective. This focal Norwegian retailer adopts four supply chain configurations according to different cargoes: (1) deliveries between individual producers and retail stores; (2) consolidation in the customer country; (3) consolidation in the supplier country; and (4) consolidation in both countries, which are similar to solutions (1), (4), (3) and (5) respectively as



Solution (1) Solution (2) Solution (3) Solution (4) Solution (5)

Key:

S	Suppliers
CH	Consolidation Hub
PS	Ports in Suppliers' Countries
PC	Main Port in Customers' Countries
RW	Regional Warehouse
🟦	Sea Transport

Fig. 2 Five Asia-Europe container supply chain solutions (adapted from Creazza et al. 2010)

mentioned earlier. Compared with the research conducted by Creazza et al. (2010), Bygballe et al. (2012) also takes the customer service issue into account. However, this does not imply that the latter applied a more holistic perspective than the former, as the latter only considered four supply chain configurations. The differences in dimensions and configurations make the findings of these two papers different to some extent. For instance, solution (5) in Creazza et al. (2010) is not the most cost-efficient solution under any circumstances when compared with other solutions. While, Bygballe, et al. (2012) proposes that solution (4) is the most appropriate design for high-value products that are moved in lower volumes. Moreover, neither studies consider the possibility of adopting less environmentally damaging transport solutions after consignments arrive in Europe.

This research presented herein will explore new alternative supply chain solutions based on primary information collected from interviews with logistics service providers (LSPs) and cargo owners (COs) involved in the China-Europe trades. An important objective of the paper is to analyze the pros and cons of different alternative container supply chain solutions.

2.2 The Potential of Shortsea/Rail Based Intermodal Transport

To different degrees, the alternative supply chain configurations discussed above may facilitate short sea or rail based intermodal logistic services for the European part of the supply chain. Since around 70% of industrial production in Europe is located within 150–200 km of the sea, it has been argued that the geography of Europe should favor maritime feeder services (Suárez-Alemán et al. 2013). In addition, short sea feedering is broadly regarded as a less environmentally damaging (Hjelle 2014; Vanherle 2008; Hjelle and Fridell 2012) and economically competitive (Delhaye et al. 2010) mode of transport, at least compared with road haulage. The main comparative drawbacks of maritime feeder services are typically that it has low frequency, weaker reliability and longer door-to-door transit time (EU-Commission 2002; Medda and Trujillo 2010). These problems may not be insurmountable, however, and many researchers have proposed possible solutions to tackle these drawbacks (Vanherle 2008; Button and Drexler 2005; Notteboom 2006; Vernimmen et al. 2007).

Rail transport is also an environmentally friendly mode of transportation, typically emitting less than CO_{2-} equivalents per tonne-km than short sea vessels if electrified (EEA 2015). Rail based intermodal transport may also significantly reduce logistics costs compared with road transportation (Patterson et al. 2007; Bergqvist and Behrends 2011; Ye et al. 2014).

2.3 Risk and Resilient Supply Chains

Many organizations have adopted the lean philosophy when designing their supply chains. One of the main purposes of this thinking is to reduce costs, because all kind of non-value added activities are regarded as wastes from the perspective of lean (Harrison and van Hoek 2014). The low cost solutions create a high margin and make the supply chain leaner, but may also make the supply chains more vulnerable, and less able to handle disturbances (Azevedo et al. 2008). In addition, to reduce purchasing cost, there are increasing number of European retailers sourcing abroad, especially from Asia. The lengthening of supply chains and the crossing of many country borders generally increases risks and reduces resilience. Christopher and Peck (2004) defined three levels of risks: (1) internal to the firm, (2) external to the firm but internal to the supply chain network, and (3) external to the network. These risks lead to disruptions that cause negative influences on all partners in the same supply chain.

Resilience is the ability of certain supply chains that can overcome unpredictable business risks. We adopt the definition given by Christopher and Peck (2004) in this chapter: “the ability of a system to return to its original state or move to a new, more desirable state after being disturbed.” Practices of agile supply chains and resilient supply chains have much in common, at least including: keeping necessary inventory, excess buffer capacity and supply chain visibility (Vonderembse et al. 2006; Carvalho and Cruz-Machado 2011). Therefore, agility can be seen as an essential capability for building resilient supply chains (Christopher and Peck 2004). Up until now, much focus has been put on risks related to single sourcing strategies and disruptions in the transport chains related to "physical" incidents like bad weather or port closures. Recently we have seen that the financial robustness of the main deep sea carrier may also represent a risk factor.

2.4 Logistics Industry in China Under the Context of International Trade

Upstream buyer consolidation requires high quality logistics services in China to serve European buyers. Therefore, a brief review of logistics service providers in China is necessary. China's transportation and logistics industry grows in line with economic growth. The annual increase rate of total logistics value are 10.7%, 9.5%, 7.9%, 6.8% and 6.1% respectively during the last 5 years from 2012 to 2016 (NDRC et al. 2012, 2013, 2014, 2015, 2016). Meanwhile, the GDP growth rate of China has dropped to 6.7% in 2016 from 7.9% in 2012 (NBS 2015, 2016).

Cargo owners, including European retailers and Chinese suppliers, seem to have an increasingly positive attitude regarding the development of the Chinese logistics industry. The Logistics Performance Index (LPI) score of China, according to The World Bank (2014, 2016), was ranked 27th out of 160 in 2016, and, 30th in 2007. That is to say, China's performance in logistics is evaluated to be better than around 80% countries in the world. In addition, China is in second place in the upper middle-income performers group. However, there is still a large gap between China and developed countries. The LPI score of China in 2016 was 3.66 which is 86.5% of the top score belonging to Germany. All G7 countries rank higher than China (Word Bank 2016; Arvis et al. 2016).

However, most of China's logistics service providers are still in the early stage of their development. There is a great number of small-sized truck service providers in China, most of them having only a tiny market share. Although no official data provides the specific number of logistics enterprises operating in China, Wang (2012) stated that the number is over 800,000 in 2012. According to China's Ministry of Commerce (MOFCOM) Department of Circulation Industry Development (MOFCOM-DCID 2013), the top 20 road transport companies in China account for less than 2% of market share. Nearly 40% of the market share is accounted for by self-employed LSPs, with each of them having only one vehicle. In contrast, in USA, the top five road transport companies have a 60% market share (MOFCOM-DCID 2013). The fragmented logistics services in China give rise to low efficiency and high logistics cost. Chinese LSPs typically lack international logistics networks and good relationships with potential foreign customers. This means that the upstream buyer consolidation services focused in this chapter seem to be mainly offered by Foreign LSPs. Only a few Chinese LSPs offering such services can be identified.

3 Methodology

In order to investigate the new alternatives to the BAU solution in terms of containerized sea-based supply chains from Chinese suppliers to European retailers, a series of 17 interviews with COs and LSPs were conducted in the UK, Netherlands, Norway, Sweden and China. All respondents are at management level and involved in the cargo flows from Asia to Europe. All interviews were conducted according to a semi-structured interview guide based on the literature review and the main research questions. This guide was developed in English. However, interviews were conducted in the native language of the respondents (English, Dutch, Norwegian, Swedish and Chinese). After each interview, the interviewer took the responsibility of transcribing and later translating the transcripts into English. For reasons of commercial confidentiality, the names of the respondents and focal companies have been anonymized. However, the roles and background of respondents and the relevant business of these focal companies are described in the final transcripts. All interviews have been conducted in the following manner:

- All interviews are made with audio recording, and conducted according to a common interview guide
- Interviews were made in the native language of the respondent
- Transcripts of the interviews were made based on the audio recordings
- All transcripts were e-mailed to the respondents for verification and corrections
- After the final version of the transcript is agreed upon by the interviewer and the respondent, the audio-file was deleted
- The quality-checked transcribed interview was then translated into English
- All interviews were made face-to-face or via telephone/video-link
- The duration of the interviews ranged from 20 to 50 min
- Interviews were conducted between November 2015 and August 2016

4 Presenting Data

Based on these exploratory interviews, the authors identify five different Asia-Europe containerized sea-based supply chain designs currently in use, including one BAU solution and four alternative supply chain solutions that serve to illustrate the principle of upstream consolidation. The Concept BAU and Concept C are similar to solution (4) and solution (5) in Fig. 2 respectively, although previous literature did not clearly mention which transport mode(s) (sea, rail or road) is/are adopted within the European leg. Other solutions (Concepts A1, A2 and B) are to be considered new concepts, based on the findings to emerge.

4.1 Concept BAU: Consolidation in Customer Country (Fig. 3a)

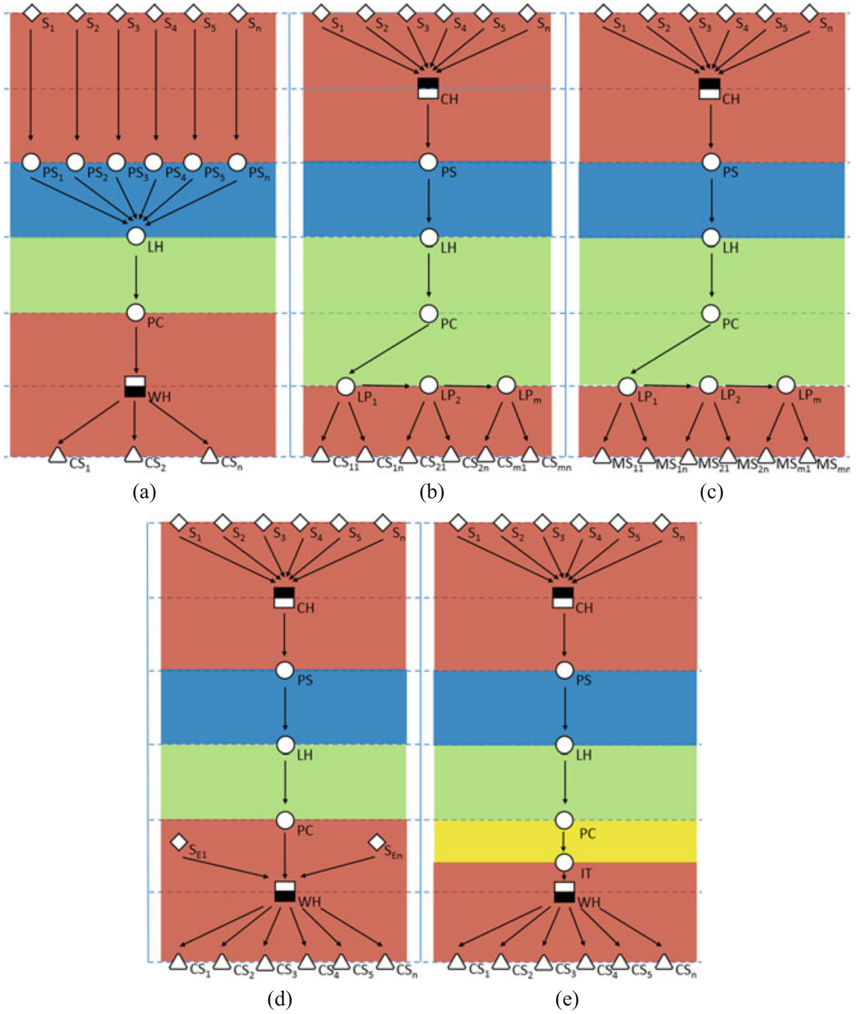
Company A is a Norwegian textile retail chain offering a large variety of curtains, bed sets and other useful interior products for the home. It has more than 130 wholly-owned stores across the country. They typically ask LSPs to transport FCL shipments (40 feet containers) from China to Norway which have not been opened in other places in Europe. After containers arrive at their main warehouse in Norway, they are cross-docked for final shipments. Cargos are distributed by a Norwegian LSP via road transport during this final leg.

4.2 Concept A1: Upstream Consolidation for One Buyer (Fig. 3b)

Company B is a Norwegian no-frills supermarket with cut-price articles sold in more than 200 shops located all over Norway. Products from different producers in mainland China are consolidated close to the major ports of Shanghai and Ningbo. Load carrying units from China to Norway are 40-foot containers loaded with palletized products for the shops. Each loaded container is dedicated for one or a few shops. Without having been split elsewhere in Europe, after arriving at the Port of Borg in Norway, containers are transported by a Norwegian feeder ship company along the coast to the nearest port for each store. Therefore, this solution dramatically decreases road travel distance to the shops compared with the BAU solution. This respondent also mentioned that there are certain LSPs that have been offering upstream buyer consolidation in China for many years in Shenzhen, Shanghai and Hong Kong. Moreover, this business enables them to obtain increasing volumes and establish new offices in the Far East for offering these services.

4.3 Concept A2: Upstream Consolidation for a Group of Buyers (Fig. 3c)

Company C is an LSP headquartered in Norway and have their own warehouses, distribution centers, and trailers in Norway and Sweden. They also have buyer consolidation service in China. After arriving at Rotterdam via the international deep-sea leg, containers are transshipped at Hogezoom onto short sea ships operated



(a) (b) (c)

(d) (e)

KEY

S	Suppliers	LP	Local Ports
SE	European Suppliers	CS	Stores Belonging to The Same Chain
CH	Consolidation Hub	MS	Different Stores in One Shopping Mall
PS	Ports in Suppliers' Countries	🟥	Road Transport
LH	Logistics Hub in Europe	🟦	Intercontinental Deep Sea Transport
PC	Main Port in Customers' Countries	🟩	Short Sea Transport
IT	Intermodal Terminal	🟨	Rail Transport
WH	Buyers' Warehouse		

Fig. 3 Asian-Europe sea container supply chain solutions. (**a**) Concept BAU. (**b**) Concept A1. (**c**) Concept A2. (**d**) Concept B. (**e**) Concept C

either by a feeder ship company or themselves for final destinations in Norway. These short sea ships either go directly via a milk run route to three or four customers where the goods are delivered, or it goes to their warehouse in the Oslo area, from where they distribute all over Norway. In addition, one shopping mall contains a large number of stores. Company C can arrange all deliveries for a shopping mall under one contract. After containers arrive at a mall, their employees can unpack and label products in this mall and place them in stores.

4.4 Concept B: Upstream and Downstream Buyer Consolidation (Fig. 3d)

This supply chain solution also includes consolidation with European suppliers. Before being transported to Norway, the products are consolidated in China. At the warehouse in Norway the products from China will be consolidated with other products from Europe or Norway before being distributed to shops.

4.5 Concept C: Upstream and Downstream Buyer Consolidation with Intermodal Transport Solution in Europe (Fig. 3e)

Company D offers all kinds of professional and DIY products in Norway, Sweden and Poland at competitive prices. A world's leading LSP has been a long-term partner of this focal company since the beginning of the 1990s and helps them to consolidate in China according to buyer requirements. In the European leg of this supply chain, the Port of Gothenburg is the container unloading port. Company D has one central warehouse / DC which is located in Skara, Sweden that serves all markets, including Norway, Sweden and Poland. From the Port of Gothenburg the company uses a daily rail-based intermodal solution to a dry port located in Falköping, about 25 km from the central warehouse. The rail-based intermodal solution enables cost-efficient and less environmentally damaging transport and higher service quality through the use of the dry port in Falköping as a buffer for full containers and as a depot for empty containers (Monios and Bergqvist 2015; Ye et al. 2014). The final distribution from the central warehouse to the company's stores is made by road. However, the company is currently investigating the possibility of using rail-based intermodal solutions for stores in northern Sweden and Norway.

5 Discussion

Based on the sea container supply chain configurations proposed by Creazza et al. (2010) and Bygballe et al. (2012), and the outcomes from exploratory interviews illustrated in Sect. 5, alternative solutions that are characterized by upstream buyer consolidation and downstream intermodal logistics services can be reviewed. In this section, the pros and cons of these solutions are discussed, the key potential decision-makers behind a shift from the BAU solution to new alternatives will be identified and the impediments that could challenge such a shift of supply chain design and setup will be explored.

5.1 Strengths and Weaknesses of the Identified Supply Chain Designs

Most of the respondents confirm that the BAU solution is the prevailing supply chain organization in the market. One of the respondents, however, reports that there is already a substantial amount of cargo that is consolidated in China, based on customer preferences, and afterwards shipped to Rotterdam for distribution. This respondent perceives that there are many competitors offering the Concept A1 solution to his customers in the Netherlands. Concept A2 is the least frequently used one among these five supply chain solutions identified during our interview, for the reason that stores are not willing to share sensitive information with external parties, especially other stores located in the same shopping mall, who might be their competitors. In addition, the potentially higher risk of disturbances relating to the cargoes of other stores and the fact that stores need to decide on orders much earlier are also impediments of the implementation of Concept A2. Therefore, only a handful of companies agree to consolidate together. The seemingly widespread use of the BAU solution indicates that it probably has advantages in some settings. In what follows, the comparative advantages of Concept BAU are assessed vis a vis upstream buyer consolidation combined with intermodal transportation on the European side.

Responsiveness Sending cargoes from local distribution centers in Europe can reduce lead-times compared with sending cargoes from the Far East every time (taking at least 4–5 weeks from China to Norway). Accordingly, higher responsiveness and agility is achieved by the BAU solution, because of its ability to meet changes in customer demand.

Lead-Time Road transportation is normally faster than maritime feeder services when distances are similar. One of our respondents points out that if ships leave Rotterdam on a Friday, they will arrive in the south of Norway on Sunday. Cargo can then be delivered on Monday for customers located in the south of Norway, within 2–3 days for the middle and western part of Norway (Bergen and Ålesund) and within 4–5 days for customers in the far north. At the same time, the lead-time for maritime feeder services is around 6–7 days for the far north of Norway, though waterborne transport may be only 50% of the cost of road transport.

Punctuality Ship delivery times are not as precise as those of trucks. One respondent suggested that some clients are very strict in terms of time constraints. They request products to be delivered at shops by 10:00 am. For this reason, his company has taken the decision to use road transport.

Simplicity Trucks can easily deliver a door-to-door service. Road-based transportation has better hinterland access than its seaborne and rail-based counterparts. If LSPs shift from the BAU solution to any intermodal solutions, they still need trucks to deliver cargo from a local port or train station to the final destinations (stores). In addition, more connection nodes means greater possibilities for delay.

Reduced Risk of Defective Products An increasing number of European retailers purchase from China or other Asian countries for cost-saving reason. If there is any problem about the products, it is easier to replenish under the BAU solution compared with the new alternatives where cargos have to be delivered from a warehouse located in the Far East every time. Just the transportation typically takes at least 4–5 weeks. If defective products are identified at the point of retailing, the problem may be limited to this specific product. However, a defective or not sufficiently documented product is identified by the customs, the whole container will be denied access to the country. This container may also contain other products. One of our respondents reported on such an experience related to a shipment of toys from Hong Kong to the USA. The container carried toys from different suppliers. Problems were detected with a Barbie doll (one type of toy in that container) by the US customs. The reason was that the painting of that Barbie doll might have negative influence on the health of children. Consequently, they had to ship the whole container back, remove the Barbie dolls and re-ship the container with the remaining toys to the USA.

Lower Requirement of Products Characterized by Stable Demand A precondition of conducting upstream buyer consolidation is that retailers should know the demand of each store when cargos are in the origin country. Therefore, the new solution suits products that has stable demand, which enables retailers to make the forecast in advance. However, the BAU solution do not have such a requirement.

Reduced Requirement of Low Supplier Dispersion The alternative solutions require an actor in the Far East to conduct buyer consolidation. If a European buyer sources from three suppliers located in e.g. Changdu (an inland city in China), Qingdao (a city in the northern China) and Shenzhen (a city in the southern China) respectively, there is no suitable place in China for consolidation activities. There suppliers are more than one thousand kilometers away from each other. In this situation, consolidating in a DC in Europe (the BAU solution) should be a feasible solution for this European buyer. The alternative solution does not suit them.

By contrast, alternative solutions also have certain comparative advantages. The following are the advantages associated with combining upstream buyer consolidation and downstream intermodal transportation.

Logistics Cost Due to the consolidation of freight in Asia, the transportation of the cargo from the consolidation center in Asia to the final destinations has huge potential for economies of scale (Bygballe et al. 2012) and possibly enhanced load unit (container) utilization. In addition, transporting containers in Europe by short-sea (Delhaye et al. 2010) / rail based (Ye et al. 2014) intermodal transport services is cheaper than trucks under many occasions.

Inventory Cost Inventory cost can be considerably lower in the Far East, mainly because of the lower costs of labor and warehousing. By arranging consolidation in Asia, COs and LSPs can position the most intensive logistics work where the labor cost is the cheapest.

Environment Making a shift from road to short sea feedering in Europe is a major characteristic of Concept A1 and A2. Many researchers have made comparisons between maritime feeder services and road transport in terms of CO_2e emissions per metric ton-kilometer. Generally speaking, the former performs better (Hjelle 2014; Hjelle and Fridell 2012). The emissions of maritime feeder services causes less local impact than road transportation unless inland waterways and ports are located in the middle of cities or fairways lie close to the coast (Hjelle 2014). In addition, the new legislation, SECA Directive 2012/33/EU (EU-Commission 2012), was published in 17 November 2012, amending Council Directive 1999/32/EC about the sulphur content of marine fuels. That is to say, the performance of maritime feeder services in terms of sulphur emissions have improved significantly since 1 January 2015 in the North Sea, the Baltic Sea and the English Channel (cf. Cullinane and Bergqvist 2014), which are relevant areas for the supply chains treated in this chapter.

Respondents describe several cases where their customers focus on the environmental aspect when designing their supply chains. A paper manufacturer is one of them. All their transport from Hogezoom and Hayen (Netherlands) to Norway and Sweden were originally by road. They reorganized their production to fit their pallets to containers. The investments for these changes have soon been won back as this “greener” transport is also cheaper. The use of maritime transport has thus created a “win-win” situation, both for the operator and for the environment. In addition, a Japanese leading automotive company also considers environmental performance in their distribution chains. Spare parts for the Norwegian market are supplied from Brussels. Earlier they utilized 12–15 trailers every week, driving 1500 km one way to Norway. Now these cargoes are shipped by sea in 45-foot containers. The same goes for a Swedish furniture retailer who also focuses on environmental performance, as they prefer to send their cargoes for the Norwegian market by sea, directly from Baltic producers to their Norwegian warehouses.

Weight Verification Time The regulation by IMO (2014) about weight verification has taken effect from 1 July 2016. Given that weights need to be verified at or near the point of departure, consolidation in Europe means weight verification should be conducted again in Europe, as it could become a combined activity or service of consolidation. Therefore, upstream buyer consolidation may have advantages in both cost and time saving in this aspect.

Upstream buyer consolidation and downstream intermodal transport are two main characteristics of the alternative solutions. On the one hand, maritime feeder services may have an advantage in terms of environmental sustainability and cost saving. The slightly increased transit time associated with the leg from logistics hub in Europe to the final destination could be compensated by more advanced planning systems, and may also be offset by less need for warehousing and re-consolidation on the European side. Making a shift from road to sea is feasible and can lead to a "win-win" situation, both for cargo owners and for the environment. This has been confirmed by some of the early movers in this market.

On the other hand, upstream buyer consolidation also brings other benefits. As discussed above, to shift consolidation center from Europe to China may reduce logistics cost and inventory cost. If there is no inventory kept in Europe under this scenario, however, such a shift may have a negative impact on customer service level and responsiveness to changes in market needs.

Therefore, cargo owners will have to balance the tradeoff between cost savings and customer service levels. This balance will be very different for different consumer products. For instance, supply chains for electronics or fashion shoes will have much stronger preferences for agility and high responsiveness than those for garden furniture or low end manual tools. There is no universally superior supply chain design. In some cases one could find a hybrid solution, or keep a limited safety stock at DCs in Europe. We believe the alternative solutions characterized by upstream buyer consolidation and downstream maritime feeder services suit products with the following characteristics: (1) stable demand and easy to forecast, (2) high overall annual demand, (2) low annual average demand between a supplier and a store, (3) low value products with high handling cost, (4) low supplier dispersion, and (5) high labor cost differential between the supplier country and the customer country.

5.2 Who Are the Decision-Makers?

Based on the discussion above, new alternative solutions with upstream buyer consolidation and downstream intermodal transportation may have many advantages, including cost efficiency and lower environmental impact. A potential redesign of supply chains could therefore be desirable. Identifying the key decision-makers in the design of such supply chains is therefore of interest. According to our findings, European buyers are typically the decision makers.

More specifically, cargo owners, as customers of logistics services, have the right to make the strategic decision whether they shift from BAU solutions to the alternative solutions. In this situation, LSPs, as service providers, typically propose operational solutions to meet the requirements of their customers. These potential solutions will be evaluated by the cargo owners before being implemented. That is to say, the cargo owner makes the decision at both the strategic and the operational level, while the LSPs' role seems to be to provide feasible plans and be responsible for implementation.

The cargo ownership will change at some stage of the supply chain, and the timing of this change may be significant when mapping critical decision-makers in our setting. The question is whether European buyers or Chinese suppliers are decision makers. Based on the information provided by our respondents, it is quite clear that the European buyers make the final decision about the design of the supply chains, rather than the Chinese suppliers. It seems that most deals are made subject to INCOTERMS like "free on board" (FOB), which leaves the control of the supply chain design mainly on the buyer side. Additionally, regarding upstream buyer consolidation solutions, a Chinese supplier could not coordinate with all other suppliers to shift to the alternative solutions and consolidate their products somewhere in China. For example, a European buyer may source from 50 suppliers in China. One Chinese supplier most likely have no idea about who the other 49 suppliers are. Alternatively, this supplier only know a small part of the whole picture. Adding to this picture is the aforementioned dominance of global or European LSPs in this trade, which further strengthens the European role as decision-makers.

5.3 Impediments to Upstream Buyer Consolidation

According to the experience of the respondents, the process of making a shift from the BAU solution to these new alternative supply chain solutions may face several impediments. The most prominent reported impediments are:

Increased Risks Due to Unproven Solutions The supply chain configuration would change a lot during a shift from the BAU solution to the alternative solutions. Prior to the change, no one can guarantee that the new solution suits their business better than their current solution does. The decision-maker therefore faces a substantial risk related to the unproven new design. The potential benefits of the new solution include relieving the pressure of buyers' DCs in Europe, cost savings, decreased risk of delay and less environmental impact. These benefits may have to be demonstrated in peak seasons where the potential benefits are expected to be most prominent. But, since a major part of the revenues are earned during peak seasons the potential losses are also substantial. Conducting more limited trials may also limit the risks, but does not necessarily prove the superiority of the concept.

Lack of Trust in the Initial Stage of Cooperation Because there are many uncertainties in this stage and this European buyer may finally do not use the LSP who helps them to do the trial, European buyers are reluctant to share information about their current solution with this LSP. In addition, without the necessary information, it is very difficult for this LSP representing the new solution and earning the trust from this buyer. This vicious circle very likely leads to a watered-down trial result.

Unwillingness of Sharing Data Between Retailers In terms of Concept A2, the biggest challenge is that stores need to share information with external parties. Revealing traded quantities, especially with direct competitors within the same shopping center may prove an impediment to the realization of such a concept.

Added Risks Related to Individual Suppliers' Delay Unlike the situation in the BAU solution where cargo is shipped directly from every supplier to the buyer's DC in Europe, cargos from different suppliers, under the alternative solutions, should be consolidated in the Far East. If there is a delay caused by a single supplier, cargos from other suppliers will also have to wait for the delayed cargo, which leads to more delays. Alternatively the late shipment will have to be shipped separately, which causes higher logistics costs.

Vested Interests Some powerful vested interests might impede the change from the BAU solution to these alternatives. They may be in the form of European consolidation hubs / distribution centers or large road transport companies. More specifically, if consolidation hubs are relocated to China, and local distribution shifts from road to sea, the profitability of these European companies may be undermined by these alternative supply chain solutions.

Another situation is that certain European buyers have established their own warehouses in Europe and hired employees working there. Although they may understand the potential savings of new alternatives, it may still be difficult to make the system changing decision. Not only because it may be controversial to lay off local employees, but also because the same facilities may be shared with other supply chains which still may need the facilities and the services offered. Some may choose to only use the alternative solutions as a supplement to their current solutions during peak seasons for these reasons.

Lack of Awareness LSPs offering innovative solutions may struggle to get the attention of potential customers. Especially the big companies may have very segregated departments which makes it hard to offer services where the main point is to offer well integrated services where the benefits are to be found in the integration itself. Typically, a big trading company may have a transport purchasing department that is only interested in negotiating ocean freight rates. The potential gains from upstream buyer consolidation may not be visible to that department, and for a LSP achieving focus on the total solution seems to be hard in many cases. In addition, potential customers may not only be reluctant to share information about the full costs of the whole supply chain, they may actually lack this overview in their own organization.

Longstanding Working Habits Some European retailers want to do the local distribution themselves, because they think it is better for them to have more control over the consolidation center. They are used to having the consolidation center in

Europe instead of at the other side of the world, where they may have more limited control.

6 Practices to a Resilient Supply Chain

6.1 Risks in the Supply Chain

Modern supply chains may be subjected to greater risks than before due to the longer and more complex supply chains. The supply chain connecting Chinese suppliers and European retailers typically crosses many countries. Potential disruptions may appear at any legs and nodes of a supply chain, and may bring severe loss to all organizations playing in this chain. That is to say, making supply chains more resilient is a crucial challenge for European retailers. Potential risks in this China-Europe containerized cargo supply chain are identified by our respondents along the following three dimensions:

Internal to the Retailer The main possible pinch point inside European retailers is the capacity shortage of their DCs during peak seasons (Risk 1). DC's capacity is typically not designed based on the potential highest cargo volume. This is because the cargo volume will decrease dramatically after the peak season. Enough working capacity in the peak season implies many idle workers in the off-season, which is not a cost efficient way to handle cargos for retailers. However, if a DC only work well in off seasons, it will be the bottleneck of the supply chain in the peak season. Take company B as an example, they have more than 200 stores and 40,000 square meter warehouse space in Norway. The amount of cargos coming from different countries booms during marketing campaigns, such as the outdoors campaign, Christmas campaign and Halloween campaign. All cargo should be consolidated and transported to stores in time. If they route all cargo through their DC and thereafter distribute them to stores during peak seasons, their DC does not have enough capacity to handle all cargo, which leads to many delays and potentially lost sales.

External to the Retailer but Internal to the Supply Chain Network Problems caused by the suppliers on the Asian side of the supply chains, mainly include delays and defective products (Risk 2). The expectation is that all products are delivered on time in the right condition. Significant delays in the production makes it hard to deliver in time to retailing points within an acceptable cost. Defective products identified at the point of retailing, as discussed above, may influence the sales revenue of this product. Moreover, if a defective product is identified by the customs, the whole container will be denied access to the country. As a consequence, the sales of all products in this container are influenced.

Risks imposed by the LSPs is another category of supply chain risks (Risk 3). The container shipping freight rate on Asia-Europe trade hit US$205 per TEU in mid 2016 and it was even lower in 2015 (Knowler 2016). This creates a challenging business environment for most of the carriers engaged in this trade. COSCO and

China Shipping have agreed to merge to battle the downturn. Unfortunately, Hanjin, the Korean based and world's seventh-largest container shipper, faces the threat of bankruptcy due to the imbalance of supply and demand in this industry. As a result, US$14 billion worth of cargos are floating on the ocean. Because terminal operators fear that Hanjin will not have the ability to pay them, Hanjin's ships are not allowed to moor and unload their containers (Young 2016). This kind of situation represents a major disruption in the supply chains relevant to our setting, and means an added risk to European retailers.

External to the Network External uncertainties could be the fourth main risk. There are many potential external uncertainties in this China-Europe supply chain. To illustrate how such risks may materialize in a relevant supply chain setting, take a Norwegian retailer as an example. If they have a marketing campaign starting in week 10, their LSP should receive cargo from their suppliers in week 1 latest. This is because all cargo should be delivered to stores in week 9. 38 days are spent at sea (5 weeks). That is to say, their LSP should palletize and ship cargo out in the week 3, and receive cargo from suppliers in the first 2 weeks. In this schedule, week 3 is crucial. What should they do if week 3 is in the rainy season and no ship departures due to a typhoon? What should they do if week 3 is in the Spring Festival and everybody in China in their vacation? Week 8 is also important. What should they do if ships arrive at Norway during Easter, or when the local freight forwarder is on strike? What should they do if week 8 is in winter and stormy weather conditions delay transports in northern Norway? In addition, Somali pirates and natural disasters like earthquakes and tsunamis are also potential risks to this vulnerable supply chain.

6.2 Potential Risk-Mitigating Strategies

Upstream buyer consolidation could be one possible solution to the Risk 1. Company B could outsource some activities of their local DC to one or a few Chinese warehousing supplier(s). These Chinese suppliers could consolidate their cargo based on the demand of each retailing point in China. Besides the cost and environment advantages discussed above, this outsourcing can relieve the pressure for the local DC of this Norwegian retailer during peak seasons. Therefore, company B can have enough working capacity and warehouse space during peak seasons and do not need to concern about the problem of idle workers in off seasons. Their DC in Europe can only focus on store replenishment and distributing products coming from East Europe. In addition, buyer consolidation could also save transit time. Consolidated shipments can be delivered to Norway's west coast cities directly (like Bodø, Stavanger and Bergen), and do not need to go to the Oslo area to consolidate.

It is worth noting that, generally, more nodes would increase the probability of delays. However, conducting buyer consolidation does *not* mean that one more node is added in the supply chain. Small-sized shipments are typically consolidated by commercial consolidation services before leaving the country of origin in order to increase container utilization. Compared with the traditional commercial consolidation service (LCL/LCL service), the buyer consolidation service (LCL/FCL service) will convert LCL shipments to FCL shipments, thereby avoiding deconsolidation and sorting activities in the destination country. These two activities must be conducted in the traditional solution because every container contains cargo of more than one consignees after commercial consolidation. In addition, buyer consolidation service may enhance the possibility of utilizing rail or sea transport in the last part of the supply chain. Without the need of de-/re-consolidation in the destination countries, cargos transported by the new alternative solution can be transshipped directly from coming container ships to trains or short-sea feeder vessels for onward movement. By contrast, cargos transported by the traditional solution need to be reconsolidated in a warehouse according to the demand of the final retailing points. The extra pre-haulage from the warehouse to a terminal and the container handling activity in the terminal will dramatically decrease the cost competitiveness of intermodal solutions. That is to say, upstream buyer consolidation may reduce the carbon emission of a supply chain because rail or short-sea based intermodal transport is typically greener than their road based counterpart (Hjelle 2010; Ye et al. 2014).

Keeping a safety stock could be a possible solution used cooperatively with upstream buyer consolidation to tackle the Risk 1. Conventionally, in the “lean” era, all kinds of inventory are regarded as “waste” and should be eliminated. Inventory is regarded as an indication of the fact that the product flow is disrupted, and leads to delays because longer time is taken to move products through the process. Delays causes extra inventory that has to be held to compensate for the delay (Harrison and van Hoek 2014). This is a vicious circle. However, the China-Europe supply chain in our case is too long to replenish from the Far East every time there is a shortage. The European retailers may need to reevaluate the definition of waste in the supply chain, focusing on the total performance of the chain and not only on inventory costs. They may need to keep necessary stock at certain strategic locations, like the DC of the company B. They could use this inventory to serve their more than 200 stores in Norway and avoid the loss of sales.

In addition, vendor management is typically an integrated service of upstream buyer consolidation. To consolidate cargos, LSPs have to work proactively to communicate with manufacturers and negotiate the cargo delivery date, rather than wait for the arrival of cargos, which will lead to the inefficient usage of warehouse space. That is to say, LSPs typically help their customers to manage suppliers and control the cargo delivery date, thereby reducing the possibility of delay. However, it is nearly impossible to avoid disruptions from suppliers 100%, like delayed delivery and defective products (Risk 2), especially during peak seasons. For instance, one supplier may need to deliver Christmas trees to many customers within similar periods. Delay may easily happen in this case. During our interviews, we found that some practitioners choose to build up safety stock in the consolidation centers in the Far East to tackle this problem: they place orders 2 weeks earlier than their competitors do. By doing this, they can avoid the risk of delay and receive cargo earlier. In addition, suppliers are also happy with this solution because it balances suppliers' capacity. As a result, suppliers may give them better prices sometimes. By contrast, the extra cost for these buyers to build up safety stock is only the inventory cost for 2 more weeks in China.

Shifting supply base strategy from lean to flexible sourcing is another possible solution to the Risk 2. Traditionally, to improve quality and reduce cost and inventory, buyers and suppliers should work together as partners. JIT and lean thinking advocate single suppliers for each product to help develop a long-term relationship of loyalty and trust. However, this has to be balanced against the risk related to single sourcing strategies to reduce potential losses of sales due to problems caused by one supplier and thereby create a more resilient supply chain. If there is a problem with one supplier, they still have other suppliers. Their sales will not be influenced significantly. However, the drawback of this solution is that the purchasing cost will be increased.

Flexible Transportation To reduce the influence caused by the delays due to suppliers (Risk 2), the uncertainties of LSPs (Risk 3) and the external uncertainties (Risk 4), during our interview, we found all of our respondents mentioned that their companies have flexible transportation solutions. Global 3PL providers may have contracts with more than 10 ship companies and also have alternative air and rail based solutions to reduce lead-time when emergencies occur.

Take company C as an example, one of their Norwegian customers have supermarkets in Bodø, a city located north of Arctic Circle. The Port of Bodø could be frozen and there would be snowstorms during winter time. However, the Christmas campaign should always be started on time. Therefore, this LSP typically prepare a truck fleet near the Port of Stavanger during winter. If necessary, they can unload containers at Stavanger and go on road during the final leg to guarantee all products can be delivered to the north part of Norway in time.

Risk Management Culture Fostering a risk management culture within a business (such as European retailers) or even extend this culture to their product suppliers and logistics service providers can reduce the influences from external uncertainties (Risk 4) to a large extent. Risk should be a concern of everyone in this supply chain. The LSP of that Norwegian retailer mentioned that in response to Risk 4 type of problems, one may apply 2 more buffer weeks and prepare all shipments 12 weeks in advance rather than 10 weeks to reduce the influence from any uncertainties on their supply chain. Even with 2 extra bugger weeks, there will be many remaining uncertainties. Therefore, they still need to prepare a "plan B" in advance to solve potential problems. During our interview, we noticed that some LSPs have a list of potential disruptions and established work-arounds for each type of incident.

Resilient supply chains will generally not be the lowest-cost solutions. On the one hand, outsourcing warehousing activities could reduce inventory and transportation costs, and also have a positive influences on the environment. On the other hand, there must be certain investments to establish a resilient supply chain, including extra HR cost, inventory cost, purchasing cost and transportation cost. Supply chain risks is a most serious threat to the continuity of a business (Christopher and Peck

2004). Establishing resilient supply chains may enhance the competitiveness of a company, enable them to cope with the uncertainties in their business and facilitate stable profits. Although enhancing the continuity of a company is very important to all company owners, especially for those in the business environment with many uncertainties, the return on the investment in establishing resilient supply chains may be very difficult to quantify ex ante.

7 Concluding Remarks and Implications

7.1 Conclusions

In this chapter, the authors firstly introduce the current situation of logistics industry in China, including local actors and foreign LSPs, because the China-Europe supply chain relies on the support of these LSPs to a large extent. Although there are certain challenges faced by local players, their development prospects are promising, because of the robust economic environment, practitioner confidence and the support from the government. Many international LSPs are also operating in China, which currently seem to have advantages in technology, European customer base and international logistics networks. They may be the main actors to serve the system changing at this stage.

We have mapped the most typical Asia-Europe containerized sea-based supply chain solutions (the BAU solution) against identified alternative solutions based on a literature review and interviews with mid- and high-level managers in COs and LSPs involved in the cargo flows from Asia to Europe. Based on this mapping, certain main comparative advantages of these solutions are discussed. We conclude that new alternative solutions are worthy of further investigation, mainly due to the potential for gains in cost-efficiency and lower environmental impacts. The added complexity may be addressed by the support of more sophisticated information systems. The shift from the BAU solution needs to be initiated and driven by key decision makers. These potential change-makers are typically located in the headquarters of European buyers. A number of impediments have also been identified that need to be overcome in order to facilitate such a shift towards upstream consolidation solutions. Finally, major risks in this supply chain and the possible solutions identified in our research are also illustrated in the Sect. 7, which is crucial for establishing a resilient supply chain and facilitating the continuity of a business.

7.2 Limitations and Scope for Further Research

The main limitation of this research lies in the limited number of respondents, which may or may not be representative of the Asia-Europe container trades at large, although we believe that expert sampling, combined with snowballing have directed us towards central actors in this trade. All findings in this chapter are based on knowledge obtained from previous research and the working experience of practitioners as obtained from interviews. Some of the preliminary findings of this exploratory study need to be corroborated and examined in greater detail. In particular, the assumption that certain concepts may prove more cost-efficient or less environmentally damaging needs to be analyzed and substantiated through further research, digging deeper into specific solutions. Also, the identification of key decision-makers, and the issue about the cost and benefit tradeoffs in establishing resilient supply chains is worthy of further investigation. The preliminary identification of conceptual solutions might still not cover all existing configurations, and should probably be augmented through further investigation. A potential redesign of supply chains would inevitably mean that the roles, power and profits of supply chain actors may be affected. This raises a need for further knowledge about how different actors are affected by the different alternative configurations. Potential incentive problems in supply chain collaboration may result in sub-optimizing behavior and therefore also constitutes an important area for further research.

Acknowledgments The research presented in this chapter is partly based on the SeaConAZ-project, which is funded by the Norwegian Research Council under the Transport 2025 program, and partly on the ENRICH project, funded under the EC FP7 Grant No. PIRSES-GA-2013-612546.

References

Arvis, J. -F., Saslavsky, D., Ojala, L., Shepherd, B., Busch, C., Raj, A., et al. (2016). *Connecting to compete 2016—Trade logistics in the global economy: The logistics performance index and its indicators* (pp. 76). The World Bank.

Azevedo, S., Machado, V., Barroso, A., & Cruz-Machado, V. (2008). Supply chain vulnerability: environment changes and dependencies. *International journal of logistics and transport, 2*(1), 41–55.

Bergqvist, R., & Behrends, S. (2011). Assessing the effects of longer vehicles: the case of pre-and post-haulage in intermodal transport chains. *Transport Reviews, 31*(5), 591–602.

Button, K., & Drexler, J. (2005). Recovering costs by increasing market share: an empirical critique of the S-curve. *Journal of Transport Economics and Policy, 39*(3), 391–404.

Bygballe, L. E., Bø, E., & Grønland, S. E. (2012). Managing international supply: The balance between total costs and customer service. *Industrial Marketing Management, 41*(3), 394–401. https://doi.org/10.1016/j.indmarman.2011.06.013.

Carvalho, H., & Cruz-Machado, V. (2011). *Integrating lean, agile, resilience and green paradigms in supply chain management (LARG_SCM)*. INTECH Open Access.

Cheong, M. L., Bhatnagar, R., & Graves, S. C. (2007). Logistics network design with supplier consolidation hubs and multiple shipment options. *Journal of Industrial and Management Optimization, 3*(1).

Christopher, M., & Peck, H. (2004). Building the resilient supply chain. *The International Journal of Logistics Management, 15*(2), 1–14.

Creazza, A., Dallari, F., & Melacini, M. (2010). Evaluating logistics network configurations for a global supply chain. *Supply Chain Management, 15*(2), 154–164. https://doi.org/10.1108/13598541011028750.

Cullinane, K., & Bergqvist, R. (2014). Emission control areas and their impact on maritime transport. *Transportation Research Part D: Transport and Environment, 28*, 1–5.

Delhaye, E., Breemersch, T., Vanherle, K., Kehoe, J., Liddane, M., & Riordan, K. (2010). *The COMPetitiveness of EuropeAn Short-sea freight Shipping compared with road and rail transport* (pp. 136). European Commission DG Environment.

EU-Commission. (2002). *Short sea shipping: a transport success story*. Brussels: Commission of the European Communities, Energy and Transport DG.

EU-Commission. (2012). Directive 2012/33/EU of the European Parliament and of the Council of 21 November 2012 amending Council Directive 1999/32/EC as regards the sulphur content of marine fuels. *Official Journal of the European Union*.

Harrison, A., & van Hoek, R. I. (2014). *Logistics management and strategy* (5th ed.). Upper Saddle River, NJ: Pearson.

Hjelle, H. M. (2010). Short sea shipping's green label at risk. *Transport Reviews, 30*(5), 617–640.

Hjelle, H. M. (2014). Atmospheric emissions of short sea shipping compared to road transport through the peaks and troughs of short-term market cycles. *Transport Reviews, 34*(3), 379–395.

Hjelle, H. M., & Fridell, E. (2012). *When is short sea shipping environmentally competitive?* INTECH Open Access.

IMO. (2014). *Safety of life at sea (SOLAS) convention*. In IMO (Ed.).

Knowler, G. (2016). Forwarders report zero freight on wretched Asia-Europe trade. http://www.joc.com/maritime-news/trade-lanes/asia-europe/forwarders-report-zero-freight-wretched-asia-europe-trade_20160318.html. Accessed 1.10.2016.

Lovell, A., Saw, R., & Stimson, J. (2005). Product value-density: managing diversity through supply chain segmentation. *International Journal of Logistics Management, 16*(1), 142–158. https://doi.org/10.1108/09574090510617394.

Martin, C., Peck, H., & Towill, D. (2006). A taxonomy for selecting global supply chain strategies. *International Journal of Logistics Management, 17*(2), 277–287. https://doi.org/10.1108/09574090610689998.

Medda, F., & Trujillo, L. (2010). Short-sea shipping: an analysis of its determinants. *Maritime Policy & Management, 37*(3), 285–303. https://doi.org/10.1080/03088831003700678.

MOFCOM-DCID. (2013). Problems and suggestions on reducing logistics costs in China. *Market Modernization, 32*, 3.

Monios, J., & Bergqvist, R. (2015). Using a "virtual joint venture" to facilitate the adoption of intermodal transport. *Supply Chain Management: An International Journal, 20*(5), 534–548.

NBS. (2015). *2015 China statistical yearbook*. Beijing: China Statistics Press.

NBS. (2016). *2016 China statistical yearbook*. Beijing: China Statistics Press.

NDRC, NBS, & CFLP. (2012). *Briefing on China logistics operation 2012*. Beijing.

NDRC, NBS, & CFLP. (2013). *Briefing on China logistics operation 2013*. Beijing.

NDRC, NBS, & CFLP. (2014). *Briefing on China logistics operation 2014*. Beijing.

NDRC, NBS, & CFLP. (2015). *Briefing on China logistics operation 2015*. Beijing.

NDRC, NBS, & CFLP. (2016). *Briefing on China logistics operation 2016*. Beijing.

Notteboom, T. E. (2006). The time factor in liner shipping services. *Maritime Economics & Logistics, 8*(1), 19–39. https://doi.org/10.1057/palgrave.mel.9100148.

Pastori, E. (2015). Modal share of freight transport to and from EU port.

Patterson, Z., Ewing, G., & Haider, M. (2007). Shipper preferences suggest strong mistrust of rail: results from stated preference carrier choice survey for Quebec City—Windsor Corridor in Canada. *Transportation Research Record: Journal of the Transportation Research Board*, 67–74.

Specific CO2 emissions per tonne-km and per mode of transport in Europe, 1995-2011. (2015). European Environment Agency. https://www.eea.europa.eu/data-and-maps/figures/specific-co2-emissions-per-tonne-2. Accessed 07 May 2017.

Suárez-Alemán, A., Campos, J., & Jiménez, J. L. (2013). Short sea shipping competitiveness and the European maritime policy a case study. In *Paper presented at the 13th world conference on transport research, Rio de Janeiro*.

UNCTAD. (2016). *Review of maritime transport 2016*. United Nations.

Vanherle, K. (2008). The road vs. shortsea "race": Comparing both transport modes within an intermodal concept. http://www.shortsea.be/html_en/publicaties/documents/finaal rapport race-EN-101008.pdf . Accessed 01.02.2016.

Vernimmen, B., Dullaert, W., & Engelen, S. (2007). Schedule unreliability in liner shipping: Origins and consequences for the hinterland supply chain. *Maritime Economics & Logistics, 9*(3), 193–213. https://doi.org/10.1057/palgrave.mel.9100182.

Vonderembse, M. A., Uppal, M., Huang, S. H., & Dismukes, J. P. (2006). Designing supply chains: Towards theory development. *International Journal of Production Economics, 100*(2), 223–238. https://doi.org/10.1016/j.ijpe.2004.11.014.

Wang, Y. (2012). The ability of medical logistics in China needs to be enhanced. *Modern Logistics News*, A3.

Word Bank. (2014). Country Score Card: China 2014—Line. http://lpi.worldbank.org/international/scorecard/line/254/C/CHN/2014#chartarea.

Word Bank. (2016). Country Score Card: China 2016. http://lpi.worldbank.org/international/scorecard/radar/254/C/CHN/2016#chartarea.

Ye, Y., Shen, J., & Bergqvist, R. (2014). High capacity transport associated with pre- and post-haulage in intermodal road-rail transport. *Journal of Transportation Technologies, 4*(3), 13.

Young, A. (2016). That sinking feeling: Why the bankruptcy of shipping giant Hanjin has so many companies worried. http://www.salon.com/2016/09/12/that-sinking-feeling-why-the-bankruptcy-of-shipping-giant-hanjin-has-so-many-companies-worried/. Accessed 01.10.2016.

Zeng, A. Z., & Rossetti, C. (2003). Developing a framework for evaluating the logistics costs in global sourcing processes: An implementation and insights. *International Journal of Physical Distribution & Logistics Management, 33*(9/10), 785–803.

Impact Analysis of Slow Steaming on Inland River Container Freight Supply Chain

Wang Zhengguo, Jiang Hui, and Xiong Yifan

Abstract Based on the literature research and the related concept of inland river container freight supply chain, this chapter analyzes the influence of inland river container freight supply chain under the reduced vessel speeds. Firstly, this chapter describes the research problems and makes assumptions, then establishes a two-echelon inventory management model based on controllable lead time and stable demand, analyzes the impact of slow steaming on inland river container freight supply chain from a quantitative perspective, and finally studies the impact of slow steaming on the inventory cost and inventory strategy of the shipper and consignee in the container freight supply chain, gives some feasibility suggestions.

Keywords Slow steaming · Inland river · Container · Supply chain · Inventory analysis

1 Problem Description

1.1 Basic Problem Description

In recent years, because of the impact of economic crisis on the global trade market, an additional strategy for shipping companies is to slow down vessels compared to sailing at full speed. In this chapter, considering the effect of slow steaming (Htut 2014; Meyer et al. 2012; Qi and Song 2012) on the lead time in inland water, it is proposed to establish a simple two-stage inventory system based on demand determination and controllable lead time in the container freight supply chain. The system contains a shipper and a consignee, and does not consider container transport from downstream to upstream.

W. Zhengguo (✉) · J. Hui · X. Yifan
School of Logistics Engineering, Wuhan University of Technology, Wuhan, China
e-mail: zgwang@whut.edu.cn

J. E. Hernández et al. (eds.), *Collaborative Logistics and Intermodality*,
https://doi.org/10.1007/978-3-030-50958-3_4

In the basic inventory control strategy, assume that both the consignee and the shipper choose (t, R) strategy to manage inventory (Shi-hua and Yong 2002; Mingjun and Zhihong 2011; Axsater 1990; Bookbinder et al. 2000), and determine the optimal inventory control strategy in the environment of reduced vessel speeds, and determine the decision variables in the corresponding inventory model. First, the inventory control strategy is determined by the lowest cost of the consignee, then considering the interaction between two nodes in the secondary inventory system, the shipper's inventory control strategy is determined.

1.2 Model Symbol

S, S^*: Target inventory level of the consignee and shipper, the decision variables;
T, T^*: Order cycle of consignee and shipper, the decision variables;
L, L^*: Lead time of consignee and shipper;
L_1, L_2, L_3: L_1 Shipping time of the shipper to the consignee, L_2 the order waiting time due to stockout caused by the shipper, L_3 the order processing time of the shipper;
t: The time interval between the first order and the second order from the consignee;
Q: shipper's order quantity;
SS: consignee's safety stock;
D: average demand of consignee per unit time;
σ: demand standard deviation of consignee per unit time;
C, C^*: Consignee and shipper's unit order cost;
h, h^*: Consignee and shipper's cost per unit of holding an inventory;
β: The proportion of delivery delay of the consignee, $1 - \beta$ is the proportion of sales loss;
$1 - \alpha$: Consignee service level indicating that the existing inventory can meet the percentage of customer needs;
k: safety factor;
π_1: Cost of delay in delivery of unit goods;
π_2: Marginal profit of unit goods;
F: The total cost of the shipper's unit time;
F_b: Basic freight of shipper;
F_{s1}: Shipper's goods depreciation surcharge;
F_s: Other surcharge of the shipper;
f: Rate of single container;
m: Number of transported containers;
RC, RC^*: Fixed order cost of consignee and shipper;
ETC, ETC^*: the expected total cost in unit time of the consignee and shipper;
EOC, EOC^*: The expected order cost in unit time of the consignee and the shipper;
EHC, EHC^*: The expected inventory carrying cost in unit time of the consignee and the shipper;
ESC, ESC^*: the expected shortage cost in unit time of the consignee and the shipper;

1.3 Model Hypothesis

Assume 1: The second level inventory system runs indefinitely, each node decide independently to manage its own inventory.

Assume 2: The secondary inventory system contains and contains only one item, which does not cause loss in supply chain transfer. Skip-level order and equal-level order within supply chain are not permitted.

Assume 3: In the secondary inventory management system, the shipper and the consignee adopt the regular order strategy to manage inventory.

Assume 4: In the secondary inventory system, the shipper's restocking batch must be an integer multiple of the consignee's replenishment batch.

Assume 5: In the secondary inventory system, we use the ideal model, the shipper's order cycle is an integer multiple of the consignee.

Assume 6: Consignee: the demand from the downstream enterprise X in the order cycle is normal distribution, mean is μT, the standard deviation is $\sigma\sqrt{T}$; Shipper: the demand is replenishment requirement from the consignee.

Assume 7: Without considering the shipper's lead time, namely the lead time of the shipper is 0, the lead time of consignee is composed of three parts(time of carriage of shipper to consignee, order waiting time due to the out of stock of the shipper and shipper's order processing time);assuming that the shipment time of the manufacturer to the seller is related to the speed, the shipper can respond quickly to the order of the consignee, that is, the order processing time of the shipper is 0.

Assume 8: The shipper system is not allowed to be out of stock; but the consignee's system is allowed to be out of stock, partly delayed delivery, part of the sales loss, and defines the consignee's service level as 1, which shows the ratio of shortage quantity and order quantity in a period.

Assume 9: The shipper conducts transactions with the consignee on the basis of CFR, but the goods do not have any accidents on the way.

1.4 Model Definition

The model of this chapter is to consider the impact of deceleration on the transportation time, so as to affect the lead time of the consignee, and to provide some suggestions on the inventory control strategy of the consignee, and to develop the shipper inventory control strategy according to the mutual influence between two nodes.

1. Calculation of transport time

According to the relationship between speed and time in kinematics, the transportation time = distance / speed.

2. Effect of deceleration on lead time

By $L = L_1 + L_2 + L_3$, show that the lower the speed, the longer the transportation time and the longer lead time.

The order cycle $T = L + t$, the lower the corresponding speed, the longer the order cycle is.

2 Model Construction of Container Freight Supply Chain Control System

In the previous hypothesis, in the secondary inventory system, the shipper and the consignee adopt (t ,S) order strategy, that is, inventory check point time is t, with different batches, to keep inventory at optimal inventory level. Also ensure that within a single order cycle T, and only one order. Before the model is built, some important variables are determined here:

(a) Average demand in order period T:

$$D_T = T \times D \tag{1}$$

(b) The demand standard deviation in order period T:

$$\sigma_L = \sqrt{T} \times \sigma \tag{2}$$

(c) Safety stock

$$SS = \mathrm{k} \times \sqrt{T} \times \sigma \tag{3}$$

(d) Target stock level

$$S = \mathrm{D} \times \mathrm{T} + \mathrm{SS} = \mathrm{D} \times \mathrm{T} + \mathrm{k} \times \sqrt{T} \times \sigma \tag{4}$$

2.1 Consignee Model

This model from the perspective of the consignee, considering the impact of different lead time on the consignee, and identify the order cycle, optimal inventory level and safety inventory of different lead time, the expected total cost of the consignee includes order cost, inventory control cost and shortage cost.

$$ETC = EOC + EHC + ESC \tag{5}$$

1. The consignee unit time to expect the order cost

$$EOC = \frac{RC}{T} + \mathrm{C} \times \mathrm{D} \tag{6}$$

2. Consignee unit time expected inventory holding cost

The demand X in the order cycle is normal distribution, mean is μT, the standard deviation is $\sigma\sqrt{T}$. Assume that the implementation of the demand in T is *x*, B denote the expected value at the end of each cycle, then

$$\begin{aligned} \mathrm{B} &= \int_R^\infty (x - R) f(x)\, \mathrm{dx} \\ &= \int_{\mu T + k\sigma\sqrt{T}}^\infty \left(x - \mu T - k\sigma\sqrt{T}\right) \cdot \frac{1}{\sqrt{2\pi} \cdot \sigma\sqrt{T}} \mathrm{e}^{\left[-\frac{1}{2}\left(\frac{x-\mu T}{\sigma\sqrt{T}}\right)^2\right]} \mathrm{dx} \end{aligned} \tag{7}$$

Let $\mathrm{a} = \frac{x-\mu T}{\sigma\sqrt{T}}$, then $\mathrm{B} = \sigma\sqrt{T}\varphi(k) - k\sigma\sqrt{T}\,[1 - \Phi(k)]$.

Among them, $\varphi(k)$ and $\Phi(k)$ respectively denote the probability density function and distribution function of the standard normal distribution. Let $\Psi(\mathrm{k}) = \varphi(k) - k[1 - \Phi(\mathrm{k})]$, then $\mathrm{B(R)} = \sigma\sqrt{T}\Psi(\mathrm{k})$. The expected net stock at the end of each cycle is $\mathrm{S} - D \times T + (1 - \beta)\mathrm{B}$, and the net stock level of goods after arrival is $\mathrm{S} + (1 - \beta)\mathrm{B}$. The inventory level is reduced approximately evenly to $\mathrm{S} - D \times T + (1 - \beta)\mathrm{B}$, so the average inventory level is $\mathrm{S} + (1 - \beta)\mathrm{B} - \frac{D \times T}{2}$, the expected inventory holding cost within the unit time:

$$\mathrm{EHC} = \mathrm{h} \times \left[\mathrm{S} + (1 - \beta) \times \mathrm{B} - \frac{D \times T}{2}\right] \tag{8}$$

3. Expected Out—Out Cost Per Unit Time of Consignee

The expected delay in delivery of each cycle is B, and when the delivery occurs, compensation shall be provided to the customer. For the goods of postponed delivery, the profit loss of the unit commodity is π_1, the expected profit loss within each cycle is $\pi_1\beta\mathrm{B}$. For the goods sold loss, the marginal profit π_2 of the consignee is all loss, the expected sales loss within each cycle is $(1 - \beta)\pi_2\mathrm{B}$.

Therefore, the consignee unit time expected shortage cost:

$$\mathrm{ESC} = \frac{[\pi_1 \beta + \pi_2 (1 - \beta)] \times \mathrm{B}}{T} \tag{9}$$

In summary, the expected total cost function of the consignee's unit time:

$$\mathrm{ETC} = \frac{RC}{T} + \mathrm{C} \times \mathrm{D} + \mathrm{h} \times \left[\mathrm{S} + (1 - \beta) \times \mathrm{B} - \frac{D \times T}{2}\right] + \frac{[\pi_1 \beta + \pi_2 (1 - \beta)] \times \mathrm{B}}{T} \tag{10}$$

And satisfy constraints $\frac{B}{S} \leq \alpha$.

4. Model analysis

Since we already know that $\mathrm{S} = \mathrm{D} \times \mathrm{T} + \mathrm{k} \times \sqrt{T} \times \sigma$, T instead of S, put T in the ETC equation to have:

$$\mathrm{ETC} = \frac{RC}{T} + \mathrm{C} \times \mathrm{D} + \mathrm{h} \times \left[\mathrm{D} \times \mathrm{T} + \mathrm{k} \times \sqrt{T} \times \sigma + (1 - \beta) \times \mathrm{B} - \frac{D \times T}{2}\right] + \frac{[\pi_1 \beta + \pi_2 (1 - \beta)] \times \mathrm{B}}{T} \tag{11}$$

Get a partial derivative of T:

$$\frac{\partial ETC}{\partial T} = \frac{-RC}{T^2} + \frac{D \times h}{2} + \frac{h \times \sigma(\mathrm{k} + (1 - \beta) \times \Psi(\mathrm{k}))}{2} T^{-\frac{1}{2}} - \frac{\sigma}{2} \times [\pi_1 \beta + \pi_2 (1 - \beta)] \times \Psi\left(\mathrm{k} \times T^{-\frac{3}{2}}\right) \tag{12}$$

Differentiate the partial derivative of T:

$$\frac{\partial^2 ETC}{\partial T^2} = \frac{2RC}{T^3} - \frac{h \times \sigma}{4} (k + (1 - \beta) \times \Psi(\mathrm{k})) \times T^{-\frac{3}{2}} + \frac{3\sigma}{4} \times [\pi_1 \beta + \pi_2 (1 - \beta)] \times \Psi(\mathrm{k}) \times T^{-\frac{5}{2}} \tag{13}$$

From above, we can know that the second derivative of T is greater than zero, that is, the total cost function is about the convex function T, so the minimum value is obtained when the first derivative equals Zero, namely: $\frac{\partial ETC}{\partial T} = 0$.

So, we get an identity of T:

$$\frac{D \times h}{2} + \frac{h \times \sigma \times (\mathrm{k} + (1 - \upbeta) \times \Psi(\mathrm{k}))}{2} T^{-\frac{1}{2}} \\ = \frac{RC}{T^2} + \frac{\sigma}{2}[\pi_1 \upbeta + \pi_2(1 - \upbeta)] \times \Psi(\mathrm{k}) \times T^{-\frac{3}{2}} \tag{14}$$

So according to $\mathrm{S} = \mathrm{D} \times \mathrm{T} + \mathrm{SS} = \mathrm{D} \times \mathrm{T} + \mathrm{k} \times \sqrt{T} \times \upsigma$, the optimal order period T can be obtained, then the optimal inventory level can be determined.

2.2 Shipper Model

For shippers, the demand for each order cycle is from the order of the consignee, the demand is a discrete batch demand, but when the operating time of the system is indefinite, we can see the quantity of the shipper reduced as a smooth linear change.

From the previous hypothesis, we can know:

1. Ordering cycle:

$$T^* = \mathrm{n} \times \mathrm{T} \tag{15}$$

2. Order quantity in order period:

$$\mathrm{Q} = \mathrm{D} \times n \times T \tag{16}$$

3. Shipper unit time to expect order cost:

$$EOC^* = \frac{RC^* + C^* \times Q}{T^*} \tag{17}$$

4. Shipper unit time expected inventory holding cost:

$$EHC^* = \frac{h^*}{T^*}\left[\frac{n \times (n - 1) \times T^2 \times D}{2}\right] \tag{18}$$

5. Expected cost of shipper unit time:

Because the shipper is not allowed to be Out of stock under the assumption, and when the shipper delivers the goods to the container in the ship, the Out of stock cost of the shipper can be regarded as zero, that is, $ESC^* = 0$.

6. Expected freight of shipper unit time:

$$\mathrm{F} = F_b + F_S + F_{S1} = 600 \times 0.012 \times V^{3.12} \times \frac{L}{T} + \mathrm{m} \times \mathrm{f} \times (\mathrm{s} + s_1)/T^* \tag{19}$$

7. Expected total cost of shipper unit time:

$$\begin{aligned} ETC^* &= EOC^* + EHC^* + ESC^* + \mathrm{F} \\ &= \frac{RC^* + C^* \times Q}{T^*} + \frac{h^*}{T^*}\left[\frac{n \times (n-1) \times T^2 \times D}{2}\right] + 600 \\ &\times 0.012 \times V^{3.12} \times \frac{L}{T} + \mathrm{m} \times \mathrm{f} \times (\mathrm{s} + s_1)/T^* \end{aligned} \tag{20}$$

8. Model analysis

In order to determine the optimal order quantity and order period of the shipper, the minimum positive number n is obtained with the lowest value of the above formula, so it can be expressed as:

$$\mathrm{C(n)} = \frac{RC^* + C^* \times Q}{T^*} + \frac{h^*}{T^*}\left[\frac{n \times (n-1) \times T^2 \times D}{2}\right] \tag{21}$$

Derivation of n:

$$\frac{dC(n)}{dn} = -\frac{RC^*}{n^2 T} + \frac{1}{2} \times \mathrm{T} \times \mathrm{D} \times h^* \tag{22}$$

Let above expression be zero, the optimal n will be obtained (because n is an integer, so round up at the later value).

$$\mathrm{n} = \frac{1}{T} \times \sqrt{\frac{2RC^*}{D \times h^*}} \tag{23}$$

From above formula, it can be seen that the order of the consignee will greatly affect the shippers order cycle.

3 Model Validation

For the demand of a product is normal distribution, the average of the unit time demand is D = 400 units, the standard deviation is $\sigma = 90$ units / weeks, the fixed order cost of the consignee RC = 200 yuan / week, the unit order cost C = 25 yuan / unit, the inventory cost in the unit time = 0.05 yuan / unit; The fixed order cost of the shipper is 800 yuan, the unit order cost = 20 yuan / unit, the inventory cost within the unit product unit time = 0.01 yuan /unit. The profit loss of the delay delivery of the unit goods = 10 yuan, the marginal profit of the unit goods = 20 yuan.

This product uses container liner shipping from Wuhan port to Tianjin port, according to the data, Wuhan port to Tianjin port is 620 nautical miles, a container can hold 200 units, transportation cost f = 5000 yuan, cargo stowage is 10%, other surcharge is 5%.

3.1 Transportation Time at Five Speeds

According to the characteristics of large inland river transport volume and low speed, the transportation speed of ships is between 9 and 13, so the main research is the following speed: 7, 9, 11, 13 and 15. The transportation time of each speed on this route is shown in Table 1.

3.2 The Optimal Solution and Suggestion of Consignee Inventory Model

1. When the delay delivery ratio $\beta = 0.8$, the solution results of the optimal order cycle and optimal inventory level of the consignee when the security factor is 0, 0.25, 0.5, 0.75, 1, are shown in Table 2 (Fig. 1).

From Table 2, the optimal order cycle and the optimal inventory level and the inventory cost of the consignee decrease with the improvement of the safety factor, and the optimal safety stock of the consignee increases with the improvement of the

Table 1 Transport time at each speed

Vessel speed (knot)	Transportation time (day)	Consignee's Lead time L (day)	Shipper's order cycle (day)
7	3.7	3.7	$3.7 + t$
9	2.9	2.9	$2.9 + t$
11	2.3	2.3	$2.3 + t$
13	1.9	1.9	$1.9 + t$
15	1.7	1.7	$1.7 + t$

Table 2 Solution results of consignee's optimal order cycle and optimal inventory level under different safety factors

K	Optimal T	Optimal SS	Optimal S	Optimal ETC
0	9.24	0	3696.75	10,256.88
0.25	7.96	63.48	3247.12	10,218.24
0.5	6.90	118.21	2878.44	10,185.69
0.75	6.07	166.33	2595.25	10,159.75
1	5.46	210.28	2393.96	10,140.43

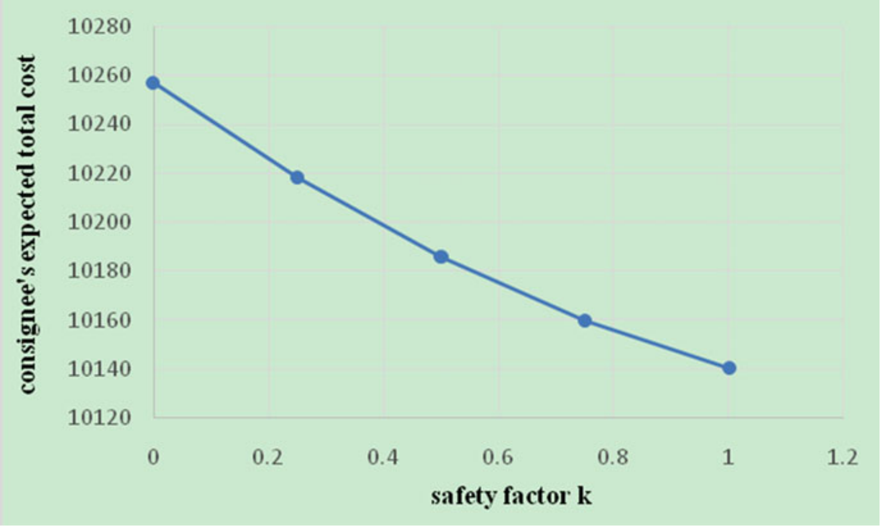


Fig. 1 The consignee's optimal ETC with different safety factor

safety factor. In this model, the Out of stock cost of the consignee is far higher than the inventory cost, so the consignee must set a higher safety factor, that is frequent ordering, and maintain a high safety stock in order to reduce the cost.

2. When t = 5 days, under different safety factors, the consignee's expected total cost varies with vessel speed, which is showed in Fig. 2.

In order to verify the reliability of result data, the value of t is 8, 11, 14, the data trend figure is given in Figs. 3, 4, and 5.

From the consistency of the above data, we can find that when the speed is unchanged, the higher the safety factor set, the lower inventory cost of the consignee, the reason may be that the cost of goods is far greater than the inventory cost; When the safety factor does not change, the lower the speed, the higher the inventory cost. This means that when the speed is lowered, to keep the security factor, the consignee costs more costs.

3. Relevant recommendations of consignee's inventory management

Combined with Tables 2 and 3, we can find that the transportation time is longer, especially after the slow steaming, the transportation time is longer, the order lead time is longer, the order period is lengthened, and the inventory cost increases. In the reduced vessel speeds, the following recommendations are made to the inventory management of the consignee.

1. For goods with high value, large cost, increase order number or shorten order period;
2. For goods with strong market demand, increase their safety stock and avoid sales loss;

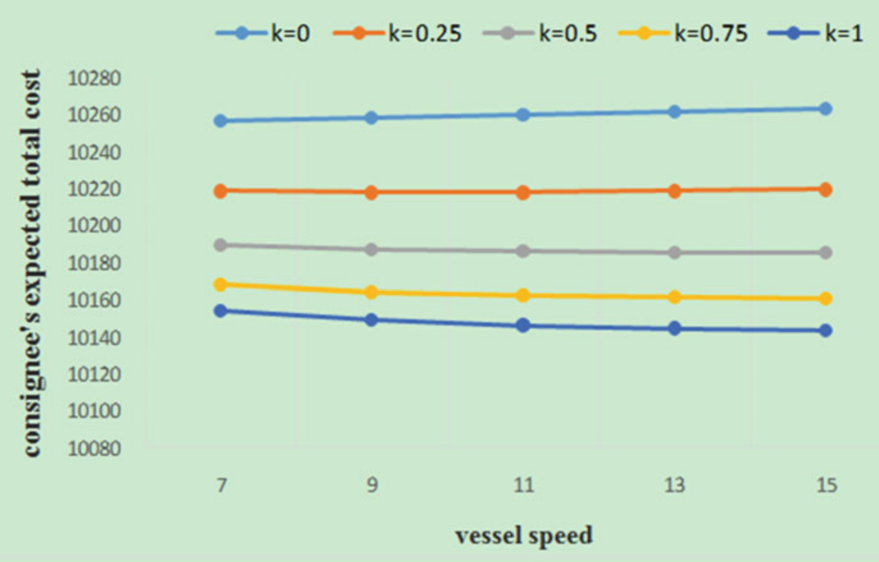


Fig. 2 Relationship between speed and total expected cost of consignee at different k value at $t = 5$

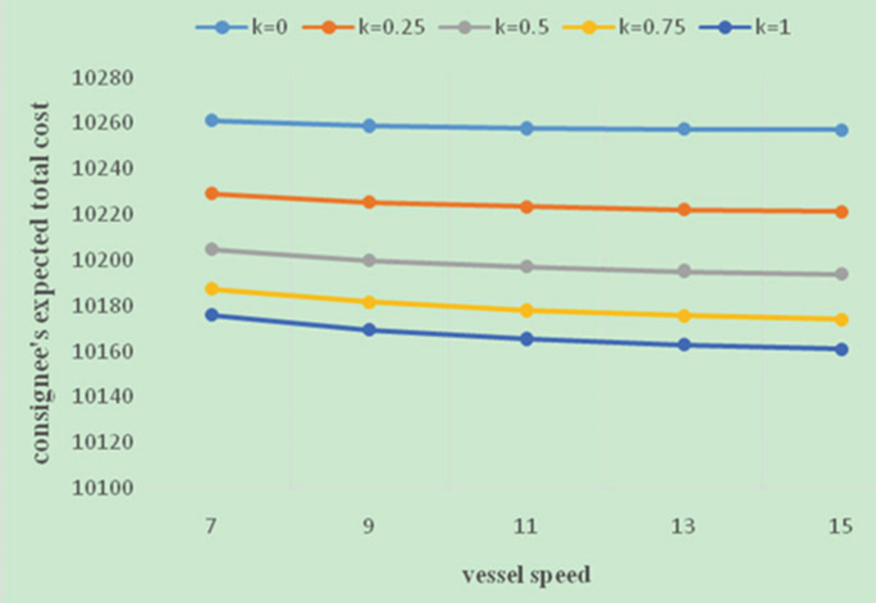


Fig. 3 Relationship between speed and total expected cost of consignee at different k at $t = 8$

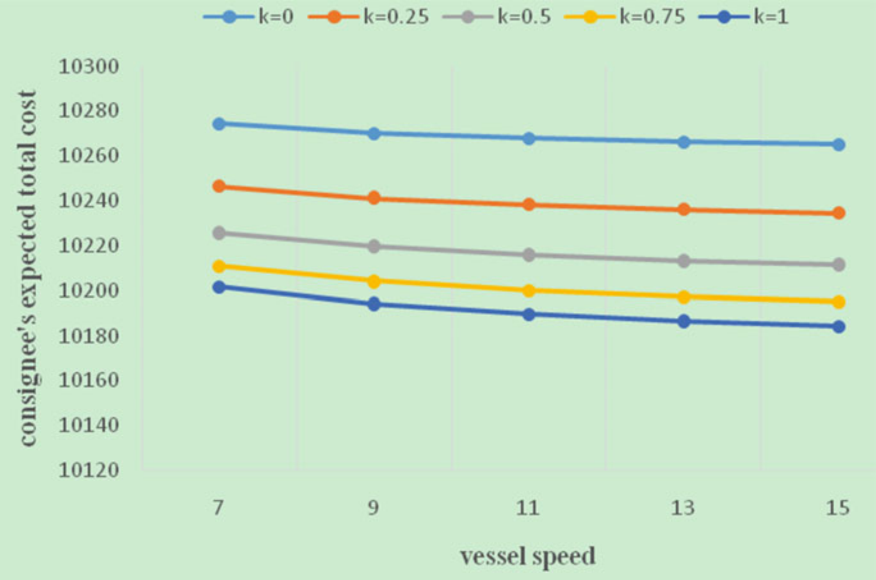


Fig. 4 Relationship between speed and total expected cost of consignee under different k value at $t = 11$

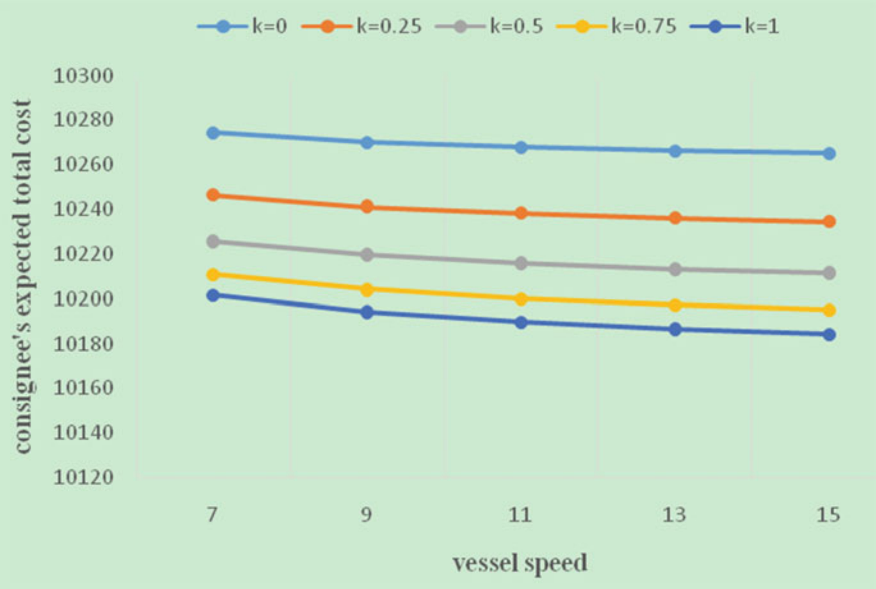


Fig. 5 Relationship between speed and total expected cost of consignee at different k at $t = 14$

Table 3 Consignee's expected total cost under different speed at $t=5$

V	k = 0	k = 0.25	k = 0.5	k = 0.75	k = 1
7	10,257.13	10,218.90	10,189.54	10,168.27	10,153.93
9	10,258.7	10,218.23	10,187.07	10,164.41	10,149.02
11	10,260.62	10,218.53	10,186.09	10,162.43	10,146.30
13	10,262.44	10,219.14	10,185.73	10,161.32	10,144.63
15	10,264.08	10,219.84	10,185.66	10,160.67	10,143.54

Table 4 Results of n at different speeds

V	n	T^*	Q	ETC^*
7	2	18	7200	10,948.74
9	3	24	9600	12,127.46
11	3	21	8400	13,217.08
13	3	21	8400	15,714.57
15	3	21	8400	19,174.90

3. For general cargo, adjust the order period to the optimal order cycle as far as possible to minimize the cost.

3.3 The Optimal Solution and Suggestion of the Shipper Inventory Model

1. Solution of n at different speeds

From Figs. 6–9, the trend of shipper's expected total cost versus speed is the same, the cost increases with higher speed, but the cost will decrease with higher t. Table 4 result of shipper's expected n, T*,Q and ETC* at different speeds.

2. Relevant recommendations of shipper's inventory management

Combined with the above data analysis, in the deceleration environment, the following recommendations for the inventory management of shippers:

In the range of 7–15, the order cycle can be appropriately increased to apportion the high fixed order cost and transportation cost.

4 Conclusion

In this chapter, a two-echelon inventory management model based on controllable demand stable demand is established, considering the effect of speed on supply chain lead, the influence of speed on shippers and consignee costs. After considering these effects, the consignee and shipper rebuild the inventory strategy.

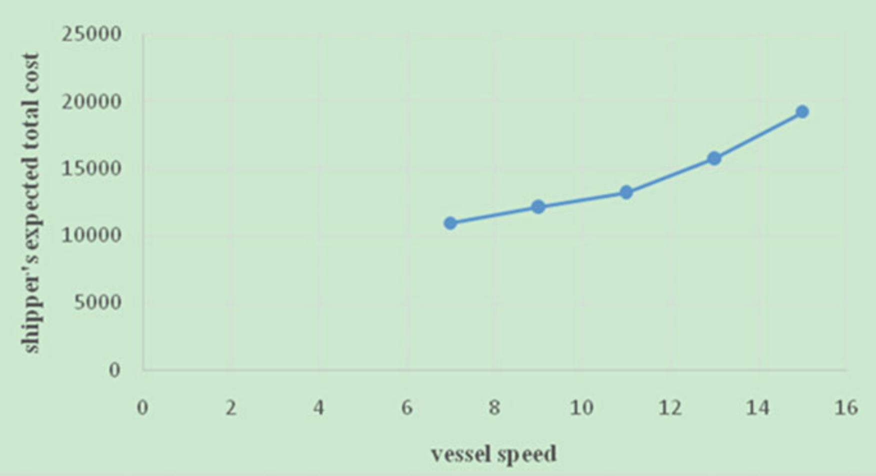


Fig. 6 Relationship between different speed and expected total cost of shipper at $t = 5$

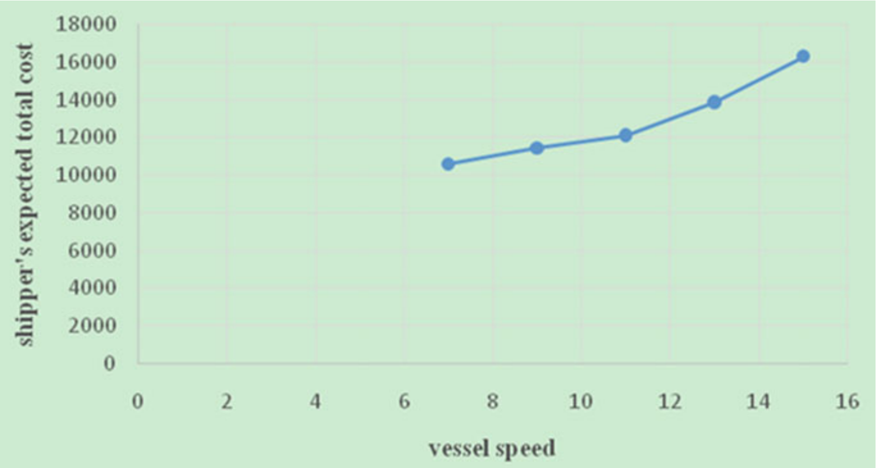


Fig. 7 Relationship between different speed and expected total cost of shipper at $t = 8$

Using the specific data validation model, we find that the cost of the consignee is a linear relationship with the speed. The lower the speed, the higher, the cost. The shipper's cost and speed is not a simple linear relationship, but vary with speed fluctuations. In addition, the inventory strategy adopted by services for different types of goods in response to the slowdown should also be different.

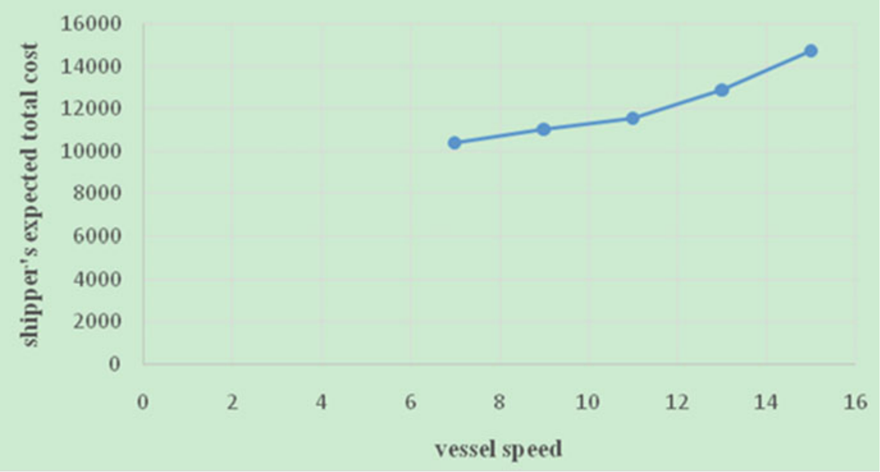


Fig. 8 Relationship between different speed and expected total cost of shipper at $t = 11$

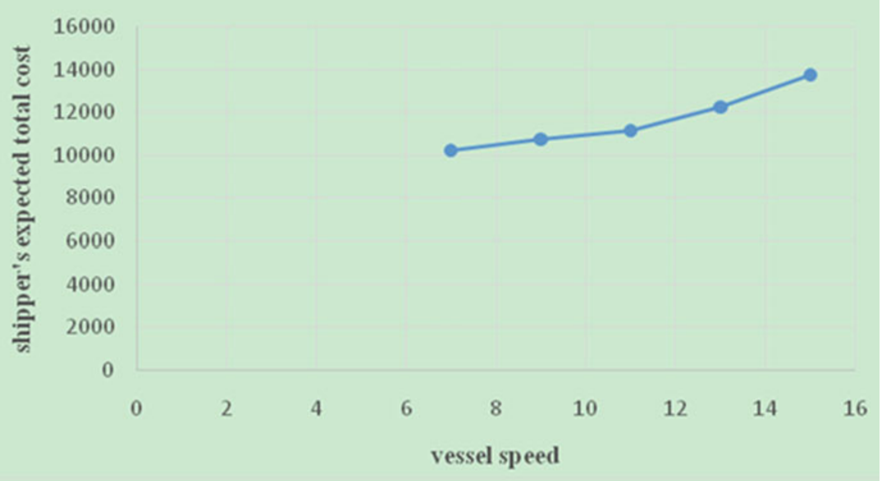


Fig. 9 Relationship between different speed and expected total cost of shipper at $t = 14$

References

Axsater, S. (1990). Simple solution procedures for a class of two-echelon inventory problems. *Operation Research, 38*(1), 64–69.

Bookbinder, J. H., Cakanyildirim, M., Bookbinder, J. H., & Gerchak, Y. (2000). Continuous review inventory models where random lead time depends on lot size and reserved capacity. *International Journal of Production Economics, 68*, 217–228.

Htut, T. W. L. (2014). *Impact of slow steaming on shipper's inventory*. Rotterdam: Erasmus University.

Meyer, J., Stahlbock, R., & Vo, S. (2012). Slow steaming in container shipping. In *45th Hawaii international conference on system sciences*.

Mingjun, J. I., & Zhihong, J. I. N. (2011). Inventory optimization model with controllable lead time. *Journal of Dalian Maritime University, 37*(1), 87–90.

Qi, X., & Song, D.-P. (2012). Minimizing fuel emissions by optimizing vessel schedules in liner shipping with uncertain port times. *Transportation Research Part E, 48*, 863–880.

Shi-hua, M. A., & Yong, L. N. (2002). A (Q,r) Inventory model based on stochastic lead time. *Computer Integrated Manufacturing Systems, 05*, 396–398.

Modelling Container Port Logistics and Intermodality from the Perspective of Environmental Sustainability

Gang Dong

Abstract With the protection and restoration of ecological environment becoming the first priority, the chapter constructs Logit model of container port logistics and intermodality from the perspective of environmental sustainability. Then a two-stage game that involves three major container port logistics and intermodality between Port of Shanghai and its hinterland of Yangtze River Economic Belt is analyzed. The Nash equilibria of container port logistics and intermodality are solved taking noise pollution and harmful gas emission into account respectively and simultaneously, which can be decision-making support of regulations promulgated and operation optimized in order to realize environmental sustainability of container port logistics and intermodality.

Keywords Port logistics · Intermodality · Logit model · Two-stage game · Environmental sustainability

1 Introduction

As a node in the global supply chain, a port connects its hinterland to the rest of the world by an intermodal transport network; it is the intermodal chains rather than individual ports that compete. The cost of moving goods between the hinterland and ports is largely determined by the transportation infrastructure around the ports as well as the transportation system in the inland, it is argued that hinterland accessibility has been one of the most influential factors of seaport competition. Consequently, container port logistics and intermodality, such as road capacity, rail system and dedicated cargo corridors, are critical for major seaports as well as inland regions where shippers and consignees locate. The key factors for container port competitiveness have shifted away from hardware and labor towards software and

---

G. Dong (✉)
School of Economics and Management, Shanghai Maritime University, Shanghai, PR China
e-mail: gangdong@shmtu.edu.cn

J. E. Hernández et al. (eds.), *Collaborative Logistics and Intermodality*,
https://doi.org/10.1007/978-3-030-50958-3_5

technology, implying that the most competitive ports rely on efficient hinterland logistics systems.

The environmental consequences of increasing international trade and transport have become important as a result of the current climate challenge. Products are increasingly being manufactured in one part of the world, transported to another country and then redistributed to their final country of consumption. Since 1990, growth in world trade, of which more than 80% is carried by seagoing vessels (measured by weight), has been higher than ever before and transport volumes have nearly doubled. CO_2 emissions from maritime transport rose from 562 million tons (all tons are metric) in 1990–1046 million tons in 2007 (Second IMO GHG study 2009), which is an 86% increase. This is a high rate of growth, compared to the total global growth in CO_2 emissions from 20,941 million tons in 1990 to 28,846 million tons in 2007, which is a 38% increase. Moreover, The Third IMO GHG Study 2014 estimates that international shipping emitted 796 million tons of CO_2 in 2012, this represented 2.2% of the global emissions of CO_2 in 2012. However, the "business as usual" scenarios continue to indicate that those emissions are likely to grow by between 50 and 250% in the period to 2050, depending on future economic and energy developments.

Although the responsiveness of international trade to GDP growth may have moderated over recent years, demand for maritime transport services and seaborne trade volumes continue to be shaped by global economic growth and merchandise trade development. The volumes of seaborne trade expanded from 7.9 billion tons in 2009 to 10.05 billion tons in 2015, taking the average increased rate of 4.6% annually. Even though containerized commercial services dated from the 1950s, the last decades have witnessed a radical transformation of the shipping market with the emergence of the container as increasingly important transportation equipment, the containerization started to seriously affect global trade patterns and manufacturing strategies in the 1990s. The number of full containers transported by shipping mainlane in 2015 was increased by 2.4% to 175 million TEUs, which accounts for more than half the value of all international seaborne trade and around one sixth of its volume. As the most important gateways for international trade, the container port is becoming a key determinant of countries' competitiveness. In 2015, the overall port industry, including the container sector, experienced significant declines in growth, with growth rates for the largest ports only just remaining positive. The 20 leading ports by volume experienced an 85% decline in growth, from 6.3% in 2014 to 0.9% in 2015. Of the seven largest ports to have recorded declines in throughput, Singapore was the only one not located in China. Nonetheless, with 14 of the top 20 ports located in China, some ports posted impressive growth, and Suzhou container port even grew by double digits, run up to 12.50%. The top 20 container ports, which usually account for about half of the world's container port throughput and provide a straightforward overview of the industry in any year, showed a 95% decline in growth, from 5.6 per cent in 2014 to 0.5% in 2015.

China's container throughput has been maintaining the first of world for twelve consecutive years more, forming five regionalization, scale-up and modernization port clusters involving Southwest Coast, Pearl River Delta, Southeast Coast, Yangtze River Delta and Bohai Sea. To capture a larger share of global shipping, many coastal ports of China are investing heavily in container terminals to expand the capacity to serve as a hub port, usually the joint ventures terminals are established to obtain a large capital investment required. Therefore, more and more capacity and region imbalances are emerging, such as excess capacity, underutilized berth, rising costs and many other issues, resulting fierce price competition among port cluster, even in one port area. The container terminal operator usually negotiates with Liner Company in the September or October every year and eventually signs the lump-sum rates of port charges for the next year. In this process of price negotiation, the priority considerations of liner company are the economic hinterland, capacity and efficiency of the container terminal, but not sensitive to port charges, which holding small proportion of liner company's total costs, so the terminal operator is often in a relatively strong position compared to liner company and has a greater pricing strategy possibility to improve its business performance.

Meanwhile, the growing throughput of container port and the consequent freight logistics have been causing serious environment impact on its city and economic hinterland. Although vessels spend a substantial portion of their time in ports and their greenhouse gas (GHG) emissions have a greater effect on coastal residents than on the open sea, few studies have examined how vessels produce GHG emissions in port and inland areas. According to Shanghai Municipal Environmental Monitoring Center, the ships emit mainly sulfur dioxide and nitrogen oxides, the proportions of which are 12.4 and 11.6% among total amount pollutants of Shanghai City in 2015. Moreover, $PM_{2.5}$, or so called fine particles, are receiving increasing attention as an indicator of air quality due to their role in health risks and since they mainly can be attributed to anthropogenic emissions, the port area emission of which reaches 5.6% contribution to the total amount of pollutants of Shanghai City in 2015.

Furthermore, since Yangtze River Economic Belt officially rose to national strategy on September 25, 2014, the protection and restoration of the Yangtze River ecological environment has been given the first priority. Yangtze River Economic Belt covers 11 provinces, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan and Guizhou, with the area of 2.05 million square kilometers, the population and GDP of more than 40% of the country. According to the guidance, the four strategic positions of Yangtze River Economic Belt are defined: firstly, the inland river economic belt with global influence; secondly, the coordinated development belt with interactive three regions; thirdly, the internal and external opening belt with comprehensive promotion; fourthly, the pilot belt with ecological civilization construction. Under this background, it is essential to accelerate the convergence of existing modes including waterway, roadway and railway connecting with Shanghai and its economic hinterland, realizing environmental sustainability of container port logistics and intermodality through reasonable internalized mechanism.

2 Related Literature

As the logistics activities of firms are becoming increasingly dynamic and global in nature, private and public decision makers focus on the development of port freight flows and intermodal transportation. Tavasszy et al. (2006) describe characteristics of the DSS called SMILE (Strategic Model for Integrated Logistic Evaluations) produces forecasts of freight flows related to the Netherlands for a large number of products and modes of transport. Comtois and Dong (2007) study competition between the ports of Ningbo and Shanghai by measuring the overlapping hinterland of container distribution for Zhejiang province, analyzing the strategies pursued by international carriers and terminal operators to secure success in this increasingly competitive environment. Yeo et al. (2008) identify the components influencing port competitiveness and presents a structure for evaluating them, a regional survey of shipping companies and owners employed factor analysis to reveal that port service, hinterland condition, availability, convenience, logistics cost, regional centre and connectivity are the determining factors. Charles (2008) considers the absence of transshipment raises the issue of the competition/complementarity between sea–river shipping and a transport chain associating inland and maritime transport. Notteboom and Rodrigue (2009) study a series of issues can either further accelerate the adoption of containerization worldwide, future containerization will be largely determined by interactions within and between four domains ranging from a functional to a spatial perspective. Saeed and Larsen (2010) discuss a two-stage game that involves three container terminals located in Karachi Port in Pakistan, the resulting payoffs (profits) of these coalitions are analysed on the basis of “core”, the real winner is the outsider (the terminal at the second port) which earns a better payoff without joining the coalition, and hence will play the role of the “orthogonal free-rider”. Franc and Horst (2010) analyze why and how shipping lines and terminal operating companies enlarge their scope in intermodal transport and in inland terminals, discussing a number of cases from the Hamburg–Le Havre range. Wilmsmeier et al. (2011) examine the spatial development of freight infrastructure, developing a conceptual model that draws attention to the directional development of intermodal corridors in relation to inland terminals. Lehtinen and Bask (2012) focus on a potential, sustainable, intermodal transport option in the EU connecting two geographical areas: the Nordic and Southeast European countries, showing that in this type of business model the operators (rail, shipping and trucking companies) will increasingly focus on their basic function, transport. Regmia and Hanaoka (2012) assess infrastructure and operational status of two important intermodal transport corridors linking North-East and Central Asia namely: Korea–China–Central Asia; and Korea–China–Mongolia–Russian Federation. Meisel et al. (2013) present a model and solution approach for combining production and intermodal transportation planning in a supply network, the model includes relevant decisions regarding production setups and output volumes of plants, cargo consolidation at intermodal terminals, and capacity bookings for road and rail transports. Song et al. (2016) consider the competition between two ports involving both hinterland shipments and transshipments, taking a transport chain perspective including deep-sea, port, feeder and inland transportation, presenting a static cost model to examine ports' relative competitiveness and justify the development of game models.

Researches related to the low-carbon port logistics and green corridor are as follows. Li et al. (2011) use qualitative methodology and some quantitative methods to analyze the urgency, necessity and feasibility of developing low-carbon ports in China. Iannone (2012) explores the nexus between sustainability and port hinterland container logistics. In particular, the methodology and results of an empirical analysis based on applications of a network programming tool called the "interport model" are presented and discussed. Psaraftis and Panagakos (2012) present the SuperGreen project and the results achieved so far, aiming at developing integrated, efficient and environmentally friendly transportation of freight between major hubs and by relative long distances. Jiang et al. (2012) use the carbon dioxide emission calculation model published by IPCC to measure carbon dioxide emissions and fuel inputs of the three types of multimodal transport (road-sea, railway-sea, and river-sea) in ports of China, the results show that increasing the proportion of railway-sea transportation and river-sea transportation to a reasonable level will achieve great energy saving, emission reduction, and economic benefits. Nieuwenhuisa et al. (2012) study the trade-off between shipping from domestic plants and investing in transplant facilities for Asian manufacturers, an established transport cost model is adapted to track CO_2 emissions along the built-up vehicle supply chain from the final assembly plant to a local distribution location. Vierth and Karlsson (2014) study the effects of enabling the use of longer road vehicle combinations and/or longer trains in an intermodal freight corridor that extends from central Sweden to the Ruhr area in Germany, the freight flows, modal split, logistics costs and CO_2 emissions are studied and rough socioeconomic analyses are carried out. Rodrigues et al. (2015) use five scenarios in the context of UK import trade to assess total CO_2 emissions and costs of import re-routing containers, the overall objective is to assess possible carbon mitigation strategies for UK supply chains by using a combination of alternative ports and revised multimodal strategies, the model adopted includes three elements: port expansion, container handling and freight transport, the alternative scenarios explore different settings modal shift and short sea shipping. Alemán et al. (2016) examine the evolution and drivers of productivity and efficiency changes across developing regions, indicating that improvements in liner connectivity and the existence of multimodal links increase the level of port efficiency.

Moreover, logit models have been used to analyze advance purchase behavior based on revealed preferences data for the airline industry (Chiou and Liu 2016; Escobari 2014; Vulcano et al. 2010), hotel (Newman et al. 2014) and railway industry (Hetrakul and Cirillo 2014). Within the airline industry, Vulcano et al. (2010) proposed a choice-based RM model with readily available airline data such as data for flight schedules, revenue accounting, seat availability and screen scrape (sample information about alternatives and fares offered by competitors at different points in time during the booking horizon). To exploit passenger preferences, a single-segment MNL model was constructed. Their simulation result showed significant improvements (1–5%) in average revenue in the tested markets. Escobari (2014) empirically estimated advance purchase behaviors of air tickets with discrete choice random utility model. Their preference dataset included detailed data for contemporaneous prices and for characteristics of both chosen and non-chosen flights. The estimated results shown that quantity demanded is more responsive to prices for departures in the morning and evening when compared to departures in the afternoon. Chiou and Liu (2016) empirically investigated advance purchase behaviors based on the air ticket transaction data by using a continuous logit model. The estimation results show that advance purchase behaviors are significantly affected by price, price uncertainty, time of day (morning, afternoon and evening flight), days of week (flight on Friday), months of year (peak or off-peak seasons), and consecutive holiday. Accordingly, different pricing strategies should be used for different flights to maximize revenue.

Furthermore, many countries, regions and international organizations have adopted more stringent regulations to address air-polluting gases from ships. In principle, these measures focus on the emission activities of vessels at sea. Winnes and Fridell (2010) present results from emission measurements for the main engines onboard two ships and characterizes quantities and potential impacts of emissions from manoeuvring, the observed nitrogen oxides levels vary throughout the manoeuvring period but at lower levels than at cruising speed. There are also peak concentrations of particles, at both the start-up and the shut-down of the engines, the increase is big enough to suspect a notable impact on air quality in port cities over the short period that manoeuvring at reduced speeds takes place. Lindstad et al. (2012) investigate the effects of economies of scale on the direct emissions and costs of maritime transport, the results showing that emissions can be reduced by up to 30% at a negative abatement cost per ton of CO_2 by replacing the existing fleet with larger vessels. Chang et al. (2013) take a bottom-up approach based on individual vessels' characteristics and using data on vessels processed by the port in 2012 estimate emissions, indicating that the level of emissions is five times higher than that estimated through the top-down approach, among various types of vessels, international car ferries are the heaviest emitters, followed by full container vessels and car carriers. Chang et al. (2014) measure the emissions of noxious gases (NG), such as SO_2, NO_X and PM, from vessel operations in a potential Emission Control Area in the Port of Incheon, Korea, providing a detailed estimation of NG emissions based on the type of vessel and the movement of the vessel from the moment of its arrival (anchoring and maneuvering to approach a berth) to its docking, cargo handling, and departure. Lee and Song (2017) survey the extant research in the field of ocean container transport, a wide range of issues is discussed including strategic planning, tactical planning and operations management issues, which are categorized into six research areas, such as competition and cooperation between carriers, ports, and terminals; network design and routing, ship scheduling and slow steaming; empty container repositioning, safety and disruption management. Sheng et al. (2017) develop an integrated model to investigate the economic and environmental effects of a unilateral maritime emission regulation vis-à-vis a uniform maritime emission regulation, showing cautions against unilateral regulations, and emphasizes the importance to take into account the effects of alternative emission policies on the operations of shipping companies and ports.

Our research is different from the previously mentioned research done in the same field in the following aspects. First up, the chapter uses the multinomial logit model to model container port logistics and intermodality by solving a numerical example with the help of real data. Secondly, most researchers discussed inter-port competition as well as intra-port competition, but we focus on intermodality logistics connected container port and its hinterland. Thirdly, we take the costs of noise pollution and harmful gas emission into account, analyzing the effects on container port logistics and intermodality system. Finally, in this chapter we try to consider both cooperative and non-cooperative aspects, discussing the dynamic equlibria of container port logistics and intermodality system from the view of internalization of external costs, supporting decision-making of regulations promulgated and operation optimized to realize environmental sustainability of container port logistics and intermodality.

3 Modeling Approach

As the attributes of port competitiveness identified included port service, hinterland condition, availability, convenience, logistics cost, regional center and connectivity. Therefore, from the perspective of shipper or freight forwarder in the hinterland, the user utility of selecting logistics and intermodality i connected the gateway port and its hinterland can be written:

$$U_i = a_i - \beta(p_i + t_i) - \delta(np_i + hg_i) \tag{1}$$

Where U_i is the “utility” of shipper or freight forwarder in the hinterland selecting logistics and intermodality i to the gateway port, a_i is the alternative specific constant for the logistics and intermodality i between the gateway port and the hinterland, p_i and t_i are respectively the charge and time cost per TEU from the hinterland to the gateway port by the logistics and intermodality i. Especially, the environmental sustainability of the logistics and intermodality mainly include noise pollution and harmful gas emission, denoting as np_i and hg_i. Moreover, β and δ are the coefficient of three kinds of logistics and intermodality costs.

The individual demand of the logistics and intermodality i between the gateway port and the hinterland are given by the total aggregate demand through Logit expression:

$$\mathrm{Q_i} = \mathrm{A}e^{\theta \ln\left(\sum e^{U_i}\right)} \frac{e^{U_i}}{\sum e^{U_i}} \tag{2}$$

Where A is the coefficient of total aggregate demand in the hinterland, reflecting the demand for container transportation and supplementary service, derived from regional economic growth, industrial production and international trade. θ denotes the changes in charge, time cost and environmental costs of one logistics and intermodality will not only shift the container traffic to it from others logistics and intermodality corridors, but also affect the total aggregate demand in the hinterland.

Therefore, the profit function of the logistics and intermodality operator may be given:

$$\mathrm{R_i} = [(1 - \mathrm{r_i})\mathrm{p_i} - \mathrm{c_i}] * \mathrm{Q_i} \tag{3}$$

Where $\mathrm{r_i}$ and $\mathrm{c_i}$ are respectively the average operating profit margin and the operation cost per TEU of the logistics and intermodality i between the gateway port and the hinterland.

We differentiate the profit function with respect to its charge and set the derivative equal to zero. Thus, the Nash equilibrium is characterized by the first-order condition:

$$\begin{aligned}\frac{\mathrm{dR_i}}{\mathrm{dp_i}} &= (1 - \mathrm{r_i}) \times \mathrm{A}e^{\theta \ln\left(\sum e^{U_i}\right)} \frac{e^{U_i}}{\sum e^{U_i}} + [(1 - \mathrm{r_i})\mathrm{p_i} - \mathrm{c_i}] \\ &\times \mathrm{A}\left[e^{\theta \ln\left(\sum e^{U_i}\right)}(-\theta\beta)\left(\frac{e^{U_i}}{\sum e^{U_i}}\right)^2 + e^{\theta \ln\left(\sum e^{U_i}\right)}(-\beta)\frac{e^{U_i}}{\sum e^{U_i}}\left(1 - \frac{e^{U_i}}{\sum e^{U_i}}\right)\right]\end{aligned} \tag{4}$$

By taking the derivative of Eq. (4) and setting it equal to zero we get the equilibrium charge of the logistics and intermodality i:

$$p_i^* = \frac{\mathrm{c_i}}{1 - \mathrm{r_i}} + \frac{1}{\beta\left[1 - (1 - \theta)\frac{e^{U_i}}{\sum e^{U_i}}\right]} \tag{5}$$

Moreover, if all the operators of logistics and intermodality connected the gateway port and the hinterland make decision as a unified multimodal transport operator based on environmental sustainability, or can reach a binding agreement under the support of government's guidance, all parties select the cooperation strategy to realize the overall profit maximization of the logistics and intermodality. Therefore, we also consider unifying the individual logistics and intermodality operator into a whole entity, the overall profit of the logistics and intermodality connected the gateway port and the hinterland is taken as:

$$R = [(1 - r_i)p_i - c_i] * Q_i + [(1 - r_{-i})p_{-i} - c_{-i}] * Q_{-i} \tag{6}$$

Where p_{-i} , Q_{-i}, r_{-i} and c_{-i} are respectively the charge, individual demand, average operating profit margin and the operation cost per TEU of the other logistics and intermodality between the gateway port and the hinterland.

According to the overall profit function of the logistics and intermodality system, the Nash equilibrium is characterized by taking the derivative and setting it equal to zero:

$$\begin{aligned}
p_i^* = \Bigg[& 1 + \beta c_i - \beta c_i \frac{e^{U_{-i}}}{\sum e^{U_i}} - \beta c_i \frac{e^{U_i}}{\sum e^{U_i}} - r_{-i} \frac{e^{U_{-i}}}{\sum e^{U_i}} - r_i + r_i \frac{e^{U_{-i}}}{\sum e^{U_i}} \\
& + \theta \frac{e^{U_{-i}}}{\sum e^{U_i}} + \beta\theta c_i \frac{e^{U_{-i}}}{\sum e^{U_i}} + \beta\theta c_i \frac{e^{U_i}}{\sum e^{U_i}} - 2\beta\theta c_i \frac{e^{U_i}}{\sum e^{U_i}} \frac{e^{U_{-i}}}{\sum e^{U_i}} - \theta r_i \frac{e^{U_{-i}}}{\sum e^{U_i}} \\
& + \beta\theta^2 c_i \frac{e^{U_i}}{\sum e^{U_i}} \frac{e^{U_{-i}}}{\sum e^{U_i}} \Bigg] \Bigg/ \Bigg[\beta(1 - r_i) \Bigg(1 - \frac{e^{U_{-i}}}{\sum e^{U_i}} - \frac{e^{U_i}}{\sum e^{U_i}} + \theta \frac{e^{U_{-i}}}{\sum e^{U_i}} + \theta \frac{e^{U_i}}{\sum e^{U_i}} \\
& - 2\theta \frac{e^{U_i}}{\sum e^{U_i}} \frac{e^{U_{-i}}}{\sum e^{U_i}} + \theta^2 \frac{e^{U_i}}{\sum e^{U_i}} \frac{e^{U_{-i}}}{\sum e^{U_i}} \Bigg) \Bigg]
\end{aligned} \tag{7}$$

$$\begin{aligned}
p_{-i}^* = \Bigg[& 1 + \beta c_{-i} - \beta c_{-i} \frac{e^{U_{-i}}}{\sum e^{U_i}} - \beta c_{-i} \frac{e^{U_i}}{\sum e^{U_i}} - r_i \frac{e^{U_i}}{\sum e^{U_i}} - r_{-i} + r_{-i} \frac{e^{U_i}}{\sum e^{U_i}} + \theta \frac{e^{U_i}}{\sum e^{U_i}} \\
& + \beta\theta c_{-i} \frac{e^{U_{-i}}}{\sum e^{U_i}} + \beta\theta c_{-i} \frac{e^{U_i}}{\sum e^{U_i}} - 2\beta\theta c_{-i} \frac{e^{U_i}}{\sum e^{U_i}} \frac{e^{U_{-i}}}{\sum e^{U_i}} \\
& - \theta r_{-i} \frac{e^{U_i}}{\sum e^{U_i}} + \beta\theta^2 c_{-i} \frac{e^{U_i}}{\sum e^{U_i}} \frac{e^{U_{-i}}}{\sum e^{U_i}} \Bigg] \Bigg/ \Bigg[\beta(1 - r_{-i}) \Bigg(1 - \frac{e^{U_{-i}}}{\sum e^{U_i}} - \frac{e^{U_i}}{\sum e^{U_i}} + \theta \frac{e^{U_{-i}}}{\sum e^{U_i}} \\
& + \theta \frac{e^{U_i}}{\sum e^{U_i}} - 2\theta \frac{e^{U_i}}{\sum e^{U_i}} \frac{e^{U_{-i}}}{\sum e^{U_i}} + \theta^2 \frac{e^{U_i}}{\sum e^{U_i}} \frac{e^{U_{-i}}}{\sum e^{U_i}} \Bigg) \Bigg]
\end{aligned} \tag{8}$$

4 Background Information About the Case Study

4.1 Container Port and Its Hinterland

4.1.1 Port of Shanghai

Port of Shanghai is situated at the middle of the 18,000 km-long Chinese coastline, where the Yangtze River, known as "the Golden Waterway", flows into the sea. It is the leading port in the T-shaped waterway network composed by the Yangtze River and the coastline, and is also China's largest comprehensive port and one of the country's most important gateways for foreign trade, the annual import and export trade through Shanghai, in terms of value, accounts for a quarter of China's total foreign trade. As China's largest container port, also the world's largest container port, the geographical location of Shanghai Port is shown in Fig. 1.

The container throughput of Shanghai Port has been maintaining the first of world for six consecutive years, which increased up 3.5–36.53 million TEUs in 2015. Since the 1990s, Shanghai Port's container throughput continued to grow rapidly. However, there were lots of issues including inadequate water depth, water resources lacking, as well as a greater gap in container terminal handling capacity. In recent years, neighboring countries and regions are stepping up the construction of container terminal 15 m water depth, source of international competition for me increasingly fierce competition in the situation.

To enhance the international competitiveness of Shanghai, Yangshan Deepwater Port Project was started in April 2002, the first phase was completed for opening on December 10, 2005. According to the plan, Yangshan Deepwater Port will have 30 container berths along 10 km deepwater shoreline with the throughput capacity of 15.6 million TEUs in 2020, mainly undertaking handling operation of large ocean shipping vessel around the clock. Therefore, there are two major container port areas in Shanghai. One is Waigaoqiao Container Port Area, including Waigaoqiao container terminals of Phase 1, Phase 2 & 3, Phase 4, Phase 5 as well as Phase 6. The other is Yangshan Deepwater Port Area, including container terminals of Phase 1 & 2, Phase 3 and Phase 4. With its favorable geographical location and unique strategic positioning, two major container port areas has been playing a vital part in building Shanghai into an international shipping center and contributing towards the flourishing economy in Shanghai and Yangtze River Delta through concerted efforts, promoting Shanghai Port to be one of the busiest ports in the world.

4.1.2 Yangtze River Economic Belt

China's longest river is also one of the busiest inland rivers for freight traffic worldwide. Rising in southwest China's Yunnan and emptying into the sea at Shanghai, the Yangtze River economic belt involves nine provinces and two municipalities. It covers an area of 2.05 million square kilometers and accounts for more

Fig. 1 Location of Waigaoqiao Port area and Yangshan Deepwater Port area in Shanghai

than 40% of the country's population and economic aggregate, which is shown in Fig. 2.

Yangtze River economic belt seeks to enhance the traffic capacity of the river and its tributaries. An integrated transport system will connect roads, railways and air routes by 2020. The service industry, green energy and modern agriculture feature prominently in plans for the belt, with coordinated urbanization along the river, including the Chengdu-Chongqing city cluster and Guizhou and Yunnan provinces. The belt will be a new growth engine for the country, help access regions along the upper and middle reaches of the Yangtze and boost growth in inland regions,

Fig. 2 Yangtze River and Yangtze River economic belt

reducing the development gap between east, central and western regions. Water resources will be protected through strict control over pollution along the river.

4.2 Port Logistics and Intermodality

4.2.1 Roadway

There is well-established road network of Yangtze River Economic Belt, such as G2 (Beijing-Shanghai), G15 (Shenyang-Haikou), G40 (Shanghai-Xian), G42 (Shanghai-Chengdu), G50 (Shanghai-Chongqing) as well as G60 (Shanghai-Kunming). In addition, Shanghai also has many provincial highways, such as S1 (Shanghai downtown to Pudong Airport), S2 (Shanghai downtown to Luchaogang), S4 (Shanghai downtown-Jinshan), S5 (Shanghai downtown-Jiading), S19 (Xinnong-Jinshanwei), S26 (Shanghai-Changzhou), S32 (Shanghai-Jiaxing-Huzhou), S36 (Tinglin-Fengjing) and so on. Meanwhile, as located at the end of Shanghai mainland area in geographic space, there are only S2 and G1501 directly connecting the land region of Yangshan deepwater port area with Shanghai downtown and Yangtze River Economic Belt, which is shown in Fig. 3.

Especially, Donghai Bridge is the only roadway corridor between the land region and Yangshan deepwater port area, which is the first long-distance cross-sea bridge in China with the line of 32.5 km and the design speed of 80 km, opening by the end of 2005 with the designed period of 100 years, as well as the annual capacity of more

Fig. 3 Roadway logistics corridor between Port of Shanghai and Yangtze River economic belt

than 500 million TEUs. In fact, the actual container traffics are over 700 million TEUs in recent years, the limited capacity severely restricted the container throughput and hinterland range of Yangshan Deepwater Port.

4.2.2 Railway

Although the container transported by railway has been grew rapidly, the share of which is still small, even less than 1% (Fig. 4).

Because Yangshan Deepwater Port and Luchaogang Railway Container Central Station are in separately operation, the railway has not yet been directly connected with Yangshan Deepwater Port. Therefore, the container of from Luchaogang Railway Container Central Station to Yangshan Deepwater Port must pass through the Donghai Bridge, largely increasing transit time and transport cost to the shipper of Yangtze River Economic Belt. Therefore, as one of 18 railway central stations, Luchaogang Railway Container Central Station is connecting the national railway network through Pudong Railway, the main destinations are Hefei of Anhui province, Nanchang of Jiangxi province, Suzhou of Jiangsu province. The designed capacity of Luchaogang Railway Container Central Station reaches 1.8 million TEUs, but the actual container throughput was only 5000 TEUs in the first operational year of 2006, accounting for 0.15% of Yangshan Deepwater Port. With the

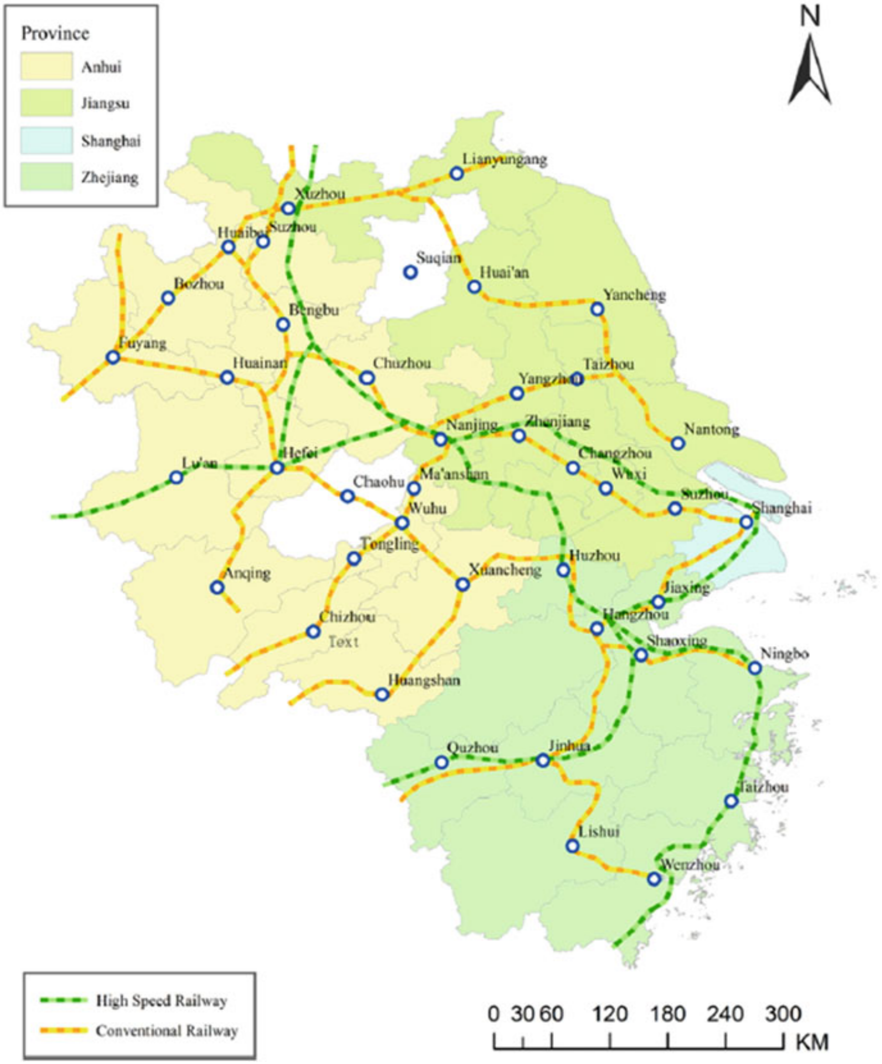


Fig. 4 Railway logistics corridor between Port of Shanghai and Yangtze River economic belt

further developing of Dayangshan port area, Shanghai needs to realize the railway directly arriving Yangshan Island besides increasing the coverage scope and operation frequency of existing railway, as well as broadening the type and aspect of goods containerization. According to the "The deeper plan of backbone road network in Shanghai" approved by Shanghai Municipal Government, the second Donghai Bridge was been planned in January, 2014, which is designed for two functions of rail and road simultaneously, connecting the Shanghai land area and

Dayangshan Island, promoting the modernization and striding development of sea-rail container transport in Yangshan Deepwater Port.

4.2.3 Waterway

Among the inland waterways of Yangtze River Economic Belt, Yangtze River originates in Tanggula of Qinghai-Tibet Plateau, flowing through Qinghai, Tibet, Yunnan, Sichuan, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, Shanghai, etc., 11 provinces, municipalities and autonomous regions, injecting the East Sea at Shanghai with total length of 6300 km, ranking third in the world river with the basin area of over 180 square kilometers, accounting for about one-fifth of the country's total area, which is shown in Fig. 5.

Moreover, Yangtze River has been known as the "golden waterway" reputation with plenty of water, ice-free all year round and excellent condition waterway, among which the length of route waterway are 2838 km, from Shuifu of Yunnan down to the mouth of the Yangtze. According to river hydrology and geographical feature, Yangtze River is divided into three sections: the upstream section is above Yichang of Hubei province, the midstream section is from Yichang to Hukou of Jiangxi province, the downstream section is below Hukou. To enhance the development of Shanghai Port and Yangtze River Economic Belt, the national project of Yangtze River—12.5 Meters Deepwater Channel from Nanjing was held on August 28 in 2012. The first-stage project from Taicang to Nantong of Jiangsu province was on test run on July 9, 2014, with the length of 56 km and investment of 5.17 billion yuan. After the whole project being completed, the 50,000 tons ocean-going vessel

Fig. 5 Roadway logistics corridor between Port of Shanghai and Yangtze River economic belt

will reach to Nanjing directly, remarkably improve the transportation capacity of Yangtze River.

5 Numerical Analysis

5.1 Assumptions About the Parameters of the Model

First up, the port logistics line lengths of Shanghai in main years are given in Tables 1 and 2.

Secondly, the port logistics turnover volumes of Shanghai in main years are introduced.

Thirdly, the details about the logistics and intermodality between container port of Shanghai and its hinterland (Chengdu of Yangtze River economic belt) at present are given in Table 3.

In general terms, *a* is the alternative specific constant for the logistics and intermodality between the gateway port and the hinterland, the scale of which depends on charge and time, operation efficiency, geological location and value-added service, such as on-time delivery, frequency, tracking, vehicle monitoring, compensation commitment as well as extending financial service. Therefore, based on the background information about the logistics and intermodality between Shanghai Port and Yangtze River Economic Belt, Chengdu city, Sichuan province, the values of which are calculated to be $a_1 = 3340$, $a_2 = 605$, $a_3 = 750$.

According the operational data of the logistics and intermodality and the findings of related research, the average charges of the logistics and intermodality between Shanghai Port and Chengdu city are $p_1 = 20,000, p_2 = 7000, p_3 = 5000$ RMB/TEU, the average times of the logistics and intermodality are $t_1 = 183.05$, $t_2 = 274.58$, $t_3 = 411.87$ RMB/TEU, the noise pollution costs of the logistics and intermodality are $np_1 = 245.55$, $np_2 = 130.68$, $np_3 = 487.91$ RMB/TEU, and the harmful gas emission costs of the logistics and intermodality are $hg_1 = 37, 118.25$, $hg_2 = 2626.38$, $hg_3 = 4420.77$ RMB/TEU. Moreover, the gross weight of one

Table 1 The port logistics lines lengths of Shanghai in main years.

Indicators/year	2000	2010	2014	2015
Highway				
Operation Mileage (km)	5970	11,974	12,945	13,195
# High Speed Highways	98	775	825	825
Railway				
Operation Mileage (km)	257	414	456	456
Mainline Railway Length Extended (km)	397	697	825	825
Navigable Inland Waterways				
Length of Navigable Inland Waterways (km)	2100	2110	2073	2058

Table 2 The port logistics turnover volumes of Shanghai in main years (100 million tons· km)

Year	Turnover volume	Highway	Railway	Waterway
1990	3359	11	111	3236
1995	4187	9	143	4030
2000	6620	56	122	6430
2001	6992	60	113	6808
2002	7472	65	100	7295
2003	8587	69	118	8385
2004	10,036	71	42	9899
2005	12,132	73	47	11,986
2006	13,837	80	55	13,683
2007	15,949	85	35	15,789
2008	16,031	253	29	15,712
2009	14,436	244	25	14,118
2010	16,173	266	26	15,818
2011	20,367	284	21	20,005
2012	20,427	288	18	20,067
2013	17,868	299	14	17,497
2014	18,691	301	12	18,320
2015	19,553	290	11	19,196

Table 3 Logistics and intermodality between container port of Shanghai and its hinterland

Logistics	Intermodality	Charge	Time	Reliability	Environmental sustainability
Chengdu Factory (Hinterland) - Yangshan Deepwater Port (Shanghai)	Road-Sea	20,000 RMB/TEU	4 days	High	Low
Chengdu Factory (Hinterland) - Chengdu Railway Container Central Station - Luchaogang Railway Container Central Station - Yangshan Deepwater Port (Shanghai)	Road-Rail-Road-Sea	7000 RMB/TEU	6 days	Medium	Medium
Chengdu Factory (Hinterland) - Luzhou port - Yangshan Deepwater Port (Shanghai)	Road-Waterway -Sea	5000 RMB/TEU	9 days	Low	High

TEU should be within 27 tons complied with the regulations of the Container Branch of China Ports Association.

As the direct cost coefficient of the logistics and intermodality, its value has been estimated by researchers in many similar ways, based on these values we assume that the values in our model are $\beta = \delta = 0.006$. Moreover, the changes in charge, time and environmental costs of the logistics and intermodality will not only shift the

Table 4 Nash equilibrium of container port logistics and intermodality market share under different scenarios

Intermodality	Regardless of environmental sustainability (%)	Taking noise pollution into account (%)	Taking harmful gas emission into account (%)	Taking noise pollution and harmful gas emission into account (%)
Road-Sea	77.37	78.33	37.04	28.23
Road-Rail-Road-Sea	6.37	6.19	17.73	21.94
Road-Waterway-Sea	16.26	15.48	45.23	49.83

container traffic to the logistics and intermodality from other logistics and intermodality, but also affect the total aggregate demand. Therefore, the value are assumed to be A = 1.5, $\theta = 0.006$. Referring to the annual report in 2015 of the representative operator, such as Shanghai Jiao Yun Co., Ltd., China Railway Tielong Container Logistics Co. , Ltd. as well as Sinotrans & CSC Holdings Co., Ltd., the average operating profit margins of the logistics and intermodality are respectively are $r_1 = 20.19\ \%$, $r_2 = 24.35\ \%$, $r_3 = 10.81\%$. The operation cost per TEU of the logistics and intermodality between the gateway port and the hinterland are $c_1 = 14, 241$, $c_2 = 5238$, $c_3 = 4230$ RMB/TEU.

5.2 Equilibrium Results

As a reference, we just take the charge and time cost into the competitive game of the logistics and intermodality connected Shanghai Port and its hinterland, such as Chengdu City of Yangtze River Economic Belt, regardless of noise pollution and harmful gas emission. The Nash equilibrium is resolved respectively through Mathmatica 9.0 by inputting the parameters used in the model (Table 4).

6 Conclusions and Policy Implications

Under the background of protecting and restorating of the port logistics and intermodality environment has been given the first priority, port logistics and intermodality along Yangtze River Economic Belt is sorely in need to accelerate the convergence of existing modes including waterway, roadway and railway. In order to realize the optimization of port logistics and intermodality along Yangtze River Economic Belt based on the existing hardware reserves of rail, super highway, the Yangtze waterway and inland fairway etc., multinomial logit model is used to model container port logistics and intermodality from the perspective of environmental sustainability, combining with the operating conditions of Chengdu-Yangshan logistics and intermodality system, solved the Nash equilibrium through the parameter values: the transport charges, container volumes and percentages are close to the actual operational data under scenario of taking no account of environmental costs. When we only consider the environmental cost of noise pollution, the market shares of three logistics and intermodality remain essentially unchanged. However, under scenario of taking harmful gas emission environmental cost into account, the market shares of three logistics and intermodality change dramatically, more specifically, the market shares of Road-Rail-Road-Sea and Road-Waterway-Sea are both in a substantial increase. If environmental costs of noise pollution and harmful gas emission are considered simultaneously, the market share of Road-Sea has slumped, more positively, the market shares of Road-Rail-Road-Sea and Road-Waterway-Sea go a step further, approximately reaching 20% and 50% respectively. These research findings can support decision-making of regulations promulgated and operation optimized of container port logistics and intermodality, realizing environmental sustainability through reasonable internalized mechanism.

Acknowledgements The authors are grateful to anonymous reviewers for their valuable and constructive comments. The research was supported by National Natural Science Foundation of China (Grant No. 71774109).

References

Alemán, A. S., Sarriera, J. M., Serebrisky, T., & Trujillo, L. (2016). When it comes to container port efficiency, are all developing regions equal. *Transportation Research Part A: Policy and Practice, 86*, 56–77.

Chang, Y. T., Song, Y., & Roh, Y. (2013). Assessing greenhouse gas emissions from port vessel operations at the Port of Incheon. *Transportation Research Part D : Transport and Environment, 25*, 1–4.

Chang, Y. T., Roh, Y., & Park, H. (2014). Assessing noxious gases of vessel operations in a potential Emission Control Area. *Transportation Research Part D : Transport and Environment, 28*, 91–97.

Charles, L. (2008). Sea–river shipping competitiveness and its geographical market area for the Rhône–Saône corridor. *Journal of Transport Geography, 16*(2), 100–116.

Chiou, Y. C., & Liu, C. H. (2016). Advance purchase behaviors of air passengers: A continuous logit model. *Transportation Research Part E: Logistics and Transportation Review, 93*, 474–484.

Comtois, C., & Dong, J. (2007). Port competition in the Yangtze River Delta. *Asia Pacific Viewpoint, 48*(3), 299–311.

Escobari, D. (2014). Estimating dynamic demand for airlines. *Economics Letters, 124*(1), 26–29.

Franc, P., & Horst, M. V. (2010). Understanding hinterland service integration by shipping lines and terminal operators: a theoretical and empirical analysis. *Journal of Transport Geography, 18*(4), 557–566.

Hetrakul, P., & Cirillo, C. (2014). A latent class choice based model system for railway optimal pricing and seat allocation. *Transportation Research Part E: Logistics and Transportation Review, 61*, 68–83.

Iannone, F. (2012). The private and social cost efficiency of port hinterland container distribution through a regional logistics system. *Transportation Research Part A: Policy and Practice, 46* (9), 424–1448.

Jiang, B., Li, J., & Mao, X. Y. (2012). Container ports multimodal transport in China from the view of low carbon. *The Asian Journal of Shipping and Logistics, 28*(3), 321–343.

Lee, C. Y., & Song, D. P. (2017). Ocean container transport in global supply chains: Overview and research opportunities. *Transportation Research Part B: Methodological, 95*, 442–474.

Lehtinen, J., & Bask, A. H. (2012). Analysis of business models for potential 3Mode transport corridor. *Journal of Transport Geography, 22*, 96–108.

Li, J., Liu, X., & Jiang, B. (2011). An exploratory study on low-carbon ports development strategy in China. *The Asian Journal of Shipping and Logistics, 27*(1), 91–111.

Lindstad, H., Asbjørnslett, B. E., & Strømman, A. H. (2012). The importance of economies of scale for reductions in greenhouse gas emissions from shipping. *Energy Policy, 46*, 386–398.

Meisel, F., Kirschstein, T., & Bierwirth, C. (2013). Integrated production and intermodal transportation planning in large scale production distribution networks. *Transportation Research Part E: Logistics and Transportation Review, 60*, 62–78.

Newman, J. P., Ferguson, M. E., Garrow, L. A., & Jacobs, T. L. (2014). Estimation of choice-based models using sales data from a single firm. *Manufacturing & Service Operations Management, 16*(2), 184–197.

Nieuwenhuisa, P., Beresfordb, A., & Choic, A. K. Y. (2012). Shipping or local production? CO2 impact of a strategic decision: An automotive industry case study. *International Journal of Production Economics, 140*(1), 138–148.

Notteboom, T., & Rodrigue, J. P. (2009). The future of containerization: perspectives from maritime and inland freight distribution. *Geojournal, 74*(1), 7–22.

Psaraftis, H. N., & Panagakos, G. (2012). Green corridors in European surface freight logistics and the SuperGreen Project. *Procedia - Social and Behavioral Sciences, 48*, 1723–1732.

Regmia, M. B., & Hanaoka, S. (2012). Assessment of intermodal transport corridors: Cases from North-East and Central Asia. *Research in Transportation Business & Management, 5*, 27–37.

Rodrigues, V. S., Pettit, S., Harris, I., Beresford, A., Piecyk, M., Yang, Z., & Ng, A. (2015). UK supply chain carbon mitigation strategies using alternative ports and multimodal freight transport operations. *Transportation Research Part E: Logistics and Transportation Review, 78*, 40–56.

Saeed, N., & Larsen, O. I. (2010). An application of cooperative game among container terminals of one port. *European Journal of Operational Research, 203*, 393–403.

Second IMO GHG study 2009. (2009, April). London, UK: International Maritime Organization (IMO).

Sheng, D., Li, Z. C., Fu, X. W., & Gillen, D. (2017). Modeling the effects of unilateral and uniform emission regulations under shipping company and port competition. *Transportation Research Part E: Logistics and Transportation Review, 101*, 99–114.

Song, D. P., Lyons, A., Li, D., & Sharifi, H. (2016). Modeling port competition from a transport chain perspective. *Transportation Research Part E: Logistics and Transportation Review, 87*, 75–96.

Tavasszy, L. A., Smeenk, B., & Ruijgrok, C. J. (2006). A DSS for modelling logistic chains in freight transport policy analysis. *International Transactions in Operational Research*, *5*(6), 447–459.

Third IMO GHG Study 2014. (2014, October). London, UK: International Maritime Organization (IMO).

Vierth, I., & Karlsson, R. (2014). Effects of longer lorries and freight trains in an international corridor between Sweden and Germany. *Transportation Research Procedia, 1*(1), 188–196.

Vulcano, G., van Ryzin, G., & Chaar, W. (2010). Choice-based revenue management: an empirical study of estimation and optimization. *Manufacturing & Service Operations Management, 12*(3), 371–392.

Wilmsmeier, G., Monios, J., & Lambert, B. (2011). The directional development of intermodal freight corridors in relation to inland terminals. *Journal of Transport Geography, 19*(6), 1379–1386.

Winnes, H., & Fridell, E. (2010). Emissions of NO_x and particles from manoeuvring ships. *Transportation Research Part D, 15*, 204–211.

Yeo, G. T., Roe, M., & Dinwoodie, J. (2008). Evaluating the competitiveness of container ports in Korea and China. *Transportation Research Part A: Policy and Practice, 42*(3), 910–921.

Random Forest Regression Model Application for Prediction of China's Railway Freight Volume

Yang Wang and Xiaochun Lu

Abstract **Purpose:** The China Railway has an important impact on the transport of domestic energy products. The Chinese Prime Minister sees railway freight as a barometer of the Chinese economy; therefore, the study of China's Railway freight is meaningful. During the past 5 years, from 2012 to 2016, China Railway freight volume continually declined, leading to a very serious situation. It is important to predict the volume of rail freight because it indicates the development of the Chinese economy. The prediction of China's railway freight by a traditional regression model is not very effective because it is too sensitive to changes in statistical data. In particular, economic changes in China are now too large, resulting in significant changes in railway freight volume. In this chapter, we aim to use an machine learning model to predict China's railway freight volume and attempt to determine whether the random forest regression model is more effective than the conventional forecasting method.

Design/methodology/approach: In this chapter, random forest regression is applied to quantitatively predict railway freight volume. Six independent variables were collected from Jan 2001 to Dec 2016 in relation to China's railway freight. After data analysis, a random forest regression model of China's railway freight volume was built using the R language. To obtain the most suitable regression model, the random forest regression error is contrasted with the multiple linear regression model. The result shows that random forest regression model performed better than linear regression.

Findings: The results in this study indicate the following: (1) the random forest regression model is able to predict railway freight volume using the selected variables. (2) By comparison of the variance and the normalized mean square error (NMSE) of different models, the best random forest regression model is obtained, and this model performs accurate prediction. (3) Compared with the multiple linear regression model, the random forest regression model exhibits superiority in

---

Y. Wang · X. Lu (✉)
School of Economics and Management, Beijing Jiaotong University, Beijing, China
e-mail: 16120588@bjtu.edu.cn; xclu@bjtu.edu.cn

J. E. Hernández et al. (eds.), *Collaborative Logistics and Intermodality*,
https://doi.org/10.1007/978-3-030-50958-3_6

prediction accuracy, robustness and fitness. (4) Although coal makes up the largest proportion of railway freight, refined oil production also has a large impact.

Keywords Railway freight volume · Prediction model · Random forest regression

1 Introduction

China has been undergoing rapid development that has slowed in recent years. Correspondingly, the China Railway freight also showed a downward trend, and the Chinese Prime Minister has utilized railway freight as an indicator of the China's economy.

Therefore, it is worthwhile to study China's rail freight. As an important part of modern comprehensive transportation systems, railways provide high efficiency in transcontinental transportation at a cheaper cost than airfreight and a faster speed than shipping by sea. Railway transportation is a main logistics channel for crude oil, coal, steel and other bulk materials in China. The railway has important positions and functions in places other than China as well. With the development of the "One Belt and One Road" in China, railway freight is also a difficult substitute in the domestic trade as well as the Sino-EU Trade. This chapter focuses on the Chinese railway freight and expands the vision to China's logistical development and the Sino-EU railway transportation.

With increasingly fierce competition in the Chinese domestic freight market and the decrease of coal prices, the railway freight situation is not optimistic. A comparison of the 2013 with 2014 data shows that total freight volume and total turnover volume decreases by 4.3% and 6.1%, respectively from January to November 2014. Additionally, data shows that income from railway freight accounts for 61.48% of total revenue in 2013 for the China Railway Corporation. As an important link in railway freight and the Chinese economy, accurate forecasting of railway freight volume is helpful to assess the development of China's logistics industry and national economy.

2 Literature Review

In the past, scholars have studied different methods to improve accuracy and applicability of prediction modelling, especially for railway freight. The railway freight forecast methods mainly focus on time series (Chi et al. 2013) and regression analysis (Yandong and Congzhou 2015) in the early stage. However, exogenous variables, which have a great influence on railway freight, show fuzziness and uncertainty. Therefore, prediction precision is affected to some extent. In recent years, scholars have researched those problems by using the neural network and the fuzzy mathematics method. For example, Huawen and Fuzhang (2014) introduced the maximum Lyapunov exponent method and a back propagation (BP) neural network to forecast growth amount and the growth rate of railway freight traffic. The results showed that the predictive accuracy of a maximum Lyapunov exponent method is better than a BP neural network. Tao and Jinlong (2014) proposed a generalized regression neural network (GRNN) to estimate railway freight volume. Rui and Yan (2014) established a hybrid radial basis function (RBF) neural network model to estimate railway freight. Yan et al. (2014) designed a particle swarm optimization-generalized regression neural network (PSO-GRNN) model to predict railway freight volume. The particle swarm optimization (PSO) algorithm with time linear decreasing inertia weight and time varying acceleration coefficients are applied to optimize a basic GRNN model by searching for the optimal smoothing parameter. Other researchers (Yang et al. 2010; Yue and Bin 2012) forecasted China's railway freight or passenger volume using a grey model and a Markov-chain grey model.

All the above methods have made excellent progress but have also created some baffling problems. For example, a BP neural network is largely dependent on training samples that conclude less robustness of the prediction model obtained from the training data.

Random forest (RF), introduced by Breiman (2001), is a popular machine-learning algorithm that is primarily used for prediction (Vitorino et al. 2014), clustering similar observations (Shengnan et al. 2015), and selecting feature variables that are important for prediction (Silke et al. 2015). This algorithm has the advantages of high prediction accuracy and good generalization ability, fast convergence speed and less adjustable parameters. Therefore, it has been widely applied in medicine (Liang et al. 2012), management (Chengde and Guolan 2007), economics (Kuangnan et al. 2010) and many other fields. For example, Cui Dongwen (2014) introduced a random forest regression (RFR) method to predict wastewater discharge. Rodriguez-Galiano et al. (2015) introduced a series of machine learning algorithms, namely, artificial neural networks, regression trees, random forest and support vector machines to prospectively estimate minerals and compare the performance of these algorithms. Zhenzi et al. (2014) studied RFR and its application in the relationship of metabolic regulation. Considering that the RFR method has not been applied in China's railway freight prediction, this chapter proposes research on the prediction of China railway freight volume by random forest regression. The purpose is to overcome the shortcomings of neural networks and linear regression.

3 Random Forest Regression Prediction of Chinese Railway Freight Volume

In this section, a random forest regression algorithm is introduced and tested, and a RFR model is built to predict Chinese railway freight volume.

3.1 Random Forest Regression Introduction

Random forest regression, an important application for the random forest algorithm, is a combination model consisting of many decision tree models $\{h(X, \Theta_k), k = 1, \cdots\}$, in which parameters are set and $\{\Theta_k\}$ is proved as an independent and identically distributed random vector. Given an independent variable x, the average prediction value is $h(X, \Theta_k)$. Decision tree models determine the final prediction value for each k. The principle of random forest regression (RFR) is shown in Fig. 1 (Svetnik et al. 2003).

3.2 Random Forest Regression Testing

In traditional statistical methods, it is necessary to make various assumptions for the distribution of variables and the formation of models. Then, the function is defined under these assumptions, and various kinds of discrimination guidelines are obtained, including varying kinds of test standards and critical statically values. However, the assumptions cannot be ignored if they fail, so these discrimination guidelines will not make any sense.

Without assumptions, such as traditional statistical models, the quality of random forest regression algorithm models is easily judged by a cross-validation method.

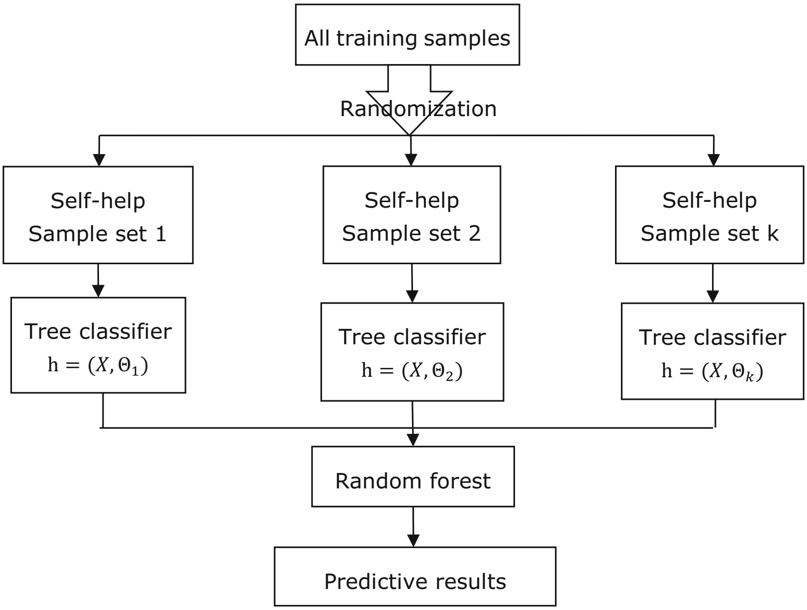


Fig. 1 Random forest regression principle

A random forest for regression is a predictor formed by growing trees depending on random vectors. All trees are independent identically distribution and are sampled from forest randomly. As the tree predictor is taking the average over a number of the trees, the generalization error of random forest regression depends on the strength of the individual trees in the forest and the correlation between them. Because of the Law of Large Numbers, random forest does not over fit in regression (Breiman 2001). Compared with traditional statistical models, this algorithm model has great advantages and convenience.

In this chapter, the mean absolute error (MAE), the mean relative error (MRE) and the normalized mean square error (NMSE) are used to calculate the model error. The normalized mean square error (NMSE) is defined as follows:

$$NMSE = \frac{\sum (\widehat{y}_i - y_i)^2}{\sum (\overline{y}_i - y_i)^2} \tag{1}$$

In this equation, y_i represents the actual value of the dependent variables of the test set, $\overline{y}_i$ represents the mean of the dependent variable, and $\widehat{y}_i$ represents its predicted value. For regression models, a smaller NMSE is better (NMSE ≥ 0).

3.3 Feature Variable Selection

From the statistical data provided by the China Railway Corporation, the railway freight category includes 28 kinds of goods, of which 14 kinds of goods accounted for 93.87% of the goods, as listed in Table 1. Coal, steel and crude oil transport accounted for 51.15%, 7.12% and 4.15%, respectively.

Table 1 Chinese railway freight of 14 kinds of goods

Category of Railway Freight	%
Coal	51.15
Steel	7.12
Mine construction	3.84
Coke	3.07
Non-metallic minerals	2.74
Crude oil	4.15
Fertilizer and pesticide	2.71
Phosphate rock	0.48
Salt	0.48
Grain	3.27
Metal ore	12.15
Container	2.67
Electrical	0.03
Less than truckload cargo	0.01
Total	93.87

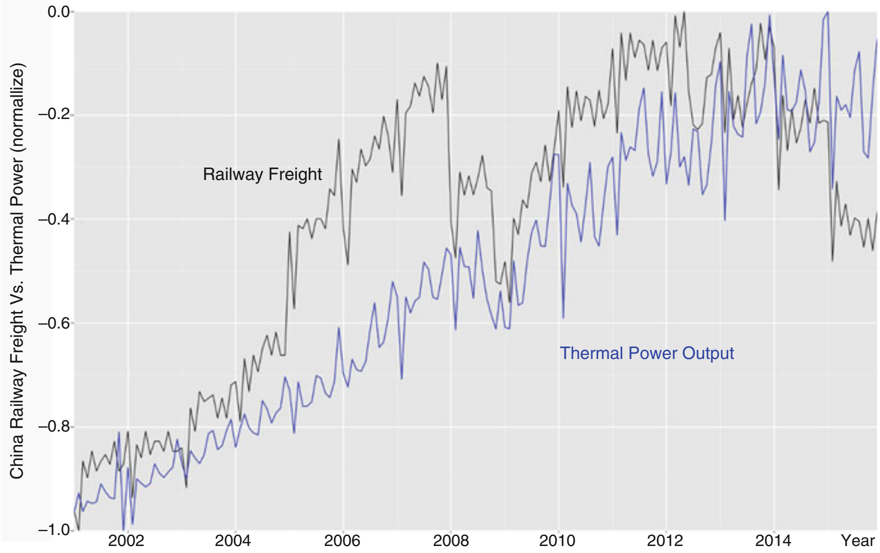


Fig. 2 Normalization time plot of railway freight and thermal power output

From the industry chain theory, coal, steel and crude oil production affect railway freight. Therefore, the output of steel products is shown as variable x1, raw coal production as variable x2, refined oil production as variable x3 in the proposed model.

Chinese thermal power output and coal transport are directly related. Figure 2 is a normalization curve of railway freight and thermal power output. As shown in Fig. 2, the trend of railway freight is similar with thermal power output. It is unknown which variable is more significant, so thermal power output is added as variable x4 in the model.

The railway freight traffic will be subject to the number of railway trucks, which is directly affected by the railway fixed assets investment. Therefore, the fixed assets investment (x5) is also added as one of factors. Finally, macro-economic development will inevitably influence railway freight transport. Therefore, the growth rate of industrial added value (x6) is selected as the last factor.

With data on China's railway freight volume and six variables from January 2001 to December 2015, a scatter matrix was plotted in Fig. 3. From Fig. 3, it is clear that correlation existed between railway freight volume and 5 variables except x6 (growth rate of industrial added value). Even though x6 has low correlation with railway freight volume, it is still selected as one of independent variables.

Six independent variables are selected in the initial RFR model to fully represent the influencing factors of railway freight. The model includes the following variables: steel products output (x1), raw coal output (x2), refined oil volume (x3), thermal power output (x4), fixed assets investment (x5), and growth rate of industrial added value (x6). The dependent variable chosen is the railway freight volume (y).

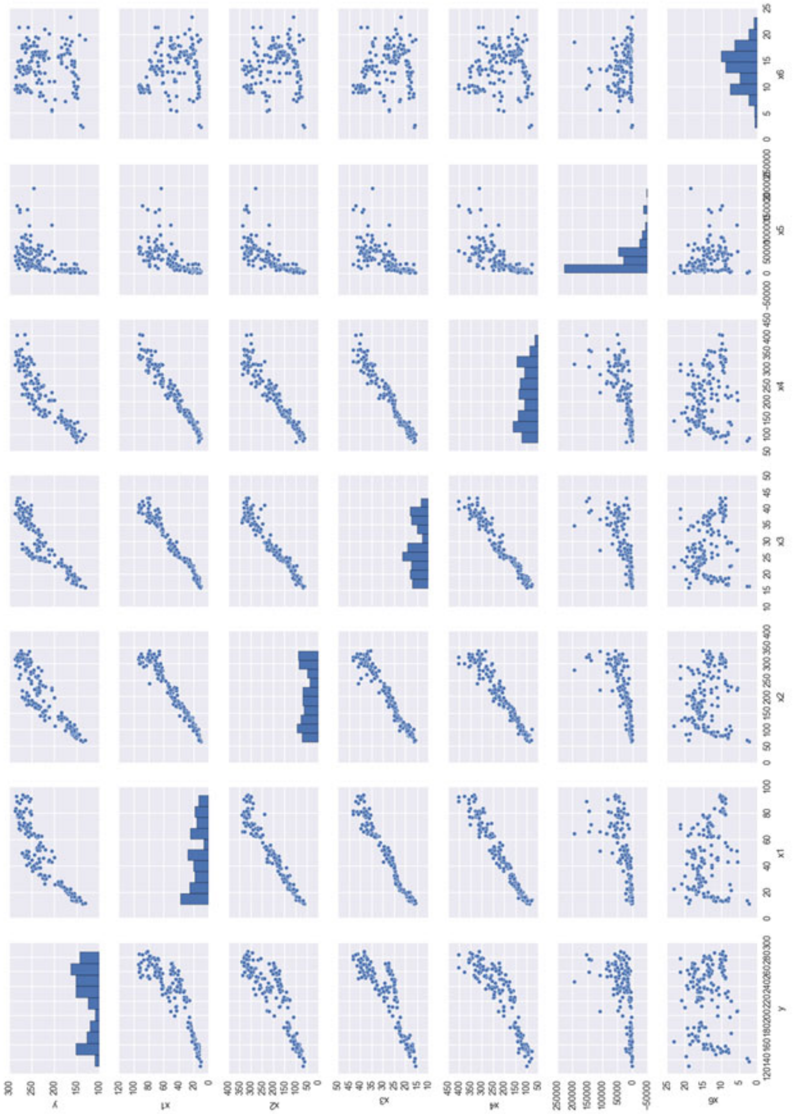


Fig. 3 Scatter matrix of independent variables and dependent variable

The initial model is determined as follows:

$$y = f(x1, x2, x3, x4, x5, x6) \tag{2}$$

3.4 Data Collecting and Checking

Data from China's railway freight volume was collected from January 2001 to December 2015 and were provided by the Statistics Center of the Chinese Railway Corporation. The original data were collected, checked and processed; however, various problems were found.

First, the raw coal data from Nov and Dec 2013, and Dec 2014 were not released. Therefore, the missing data were replaced with data from Oct 2013 and Nov 2014 (marked data in Appendix Table). Then, the raw coal time scatter plot is drawn to find outliers, as shown in Fig. 4. All points in Fig. 4 are in reasonable scope.

The data on railway fixed assets investment were found between 2001 and 2005 are annual data. However, monthly data is required in the proposed model. The fixed assets investment cumulative ratio every year is regular. For example, investment in

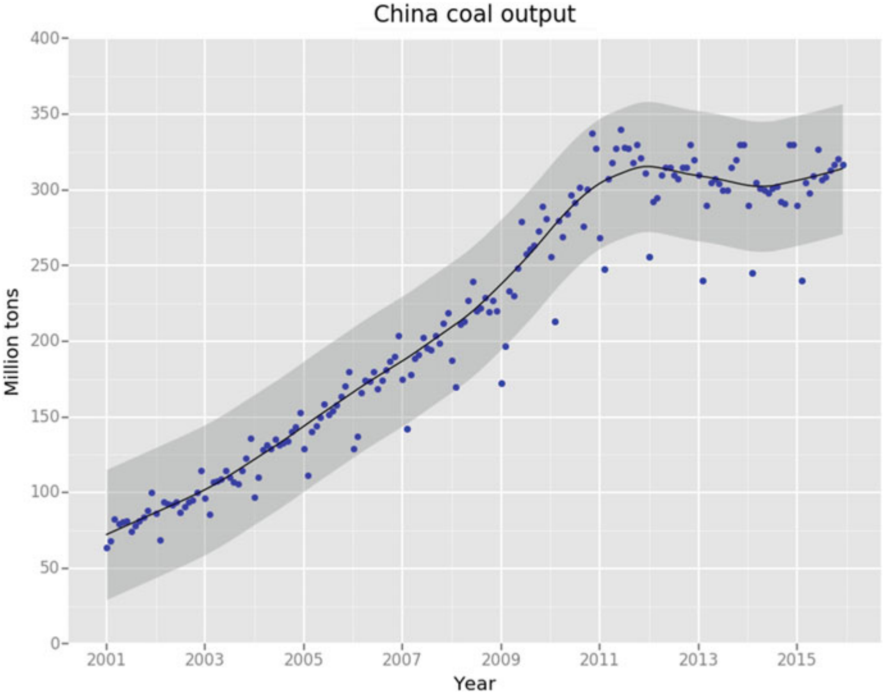


Fig. 4 Chinese coal output scatter plot

Table 2 Chinese railway fixed assets investment ratio in 2006

Month	Fixed assets investment (Million yuan)	%
Jan-2006	6571.17	3
Feb-2006	12,522.12	6
Mar-2006	26,664.24	13
Apr-2006	38,970.13	19
May-2006	58,468.71	28
Jun-2006	76,293.16	37
Jul-2006	89,994.22	44
Aug-2006	107,126.68	52
Sep-2006	124,187.21	60
Oct-2006	142,258.85	69
Nov-2006	164,885.71	80
Dec-2006	205,357.48	100

Table 3 Chinese railway fixed assets investment ratios

	Year								
Month	2006 (%)	2007 (%)	2008 (%)	2009 (%)	2010 (%)	2011 (%)	2012 (%)	2013 (%)	Mean (%)
Jan	3	3	2	6	4	6	2	3	4
Feb	6	6	4	6	6	11	5	6	6
Mar	13	11	8	11	11	19	9	10	11
Mar	19	16	12	17	17	27	14	17	17
May	28	23	19	24	24	35	20	24	25
Jun	37	31	25	33	33	44	27	32	33
Jul	44	39	32	40	39	51	35	39	40
Aug	52	45	41	47	49	57	42	47	47
Sep	60	55	51	55	59	63	53	56	56
Oct	69	63	62	63	70	68	65	64	66
Nov	80	73	74	72	83	78	78	77	77
Dec	100	100	100	100	100	100	100	100	100

January 2006 is 3% (shown as Table 2). The investment ratio in January of every year is similar, from 2 to 6%, (shown as Table 3). Therefore, according to the ratio in Table 3, the fixed assets investments from 2001 to 2005 can be interpolated.

The fixed assets investment time plot was drawn after interpolation and is shown in Fig. 5; it is evident that there are several peaks, especially after 2008. These data reflect the climax of Chinese railway development.

Finally, complete data on the six impact factors were found. Samples are shown in Table 4. However, the data are not sensitive for the random forest method for data quantities and units, so it is unnecessary to standardize the data.

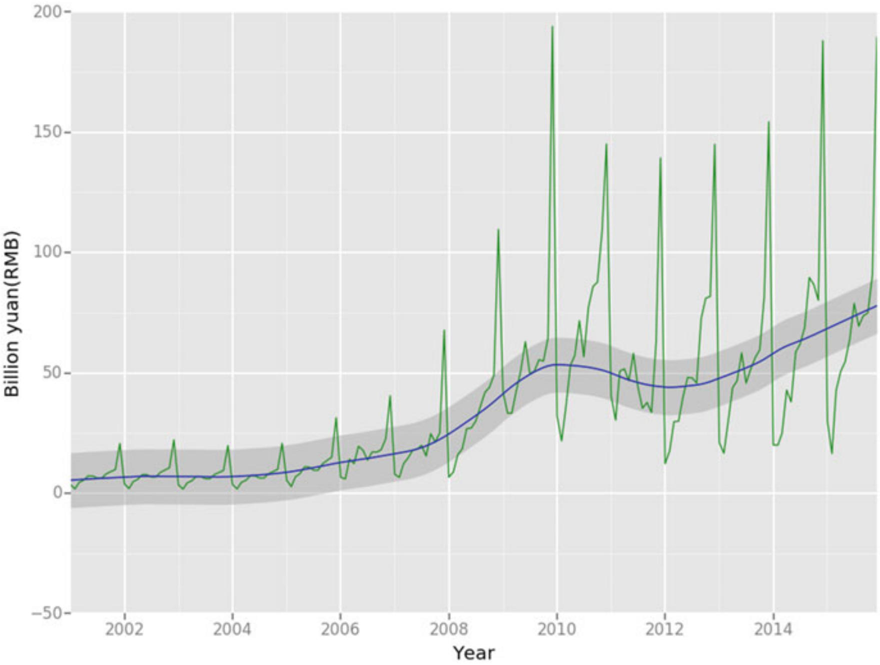


Fig. 5 Chinese railway fixed assets investment time plot

Table 4 Variable list of the regression model

Variables	Meaning
y	China railway freight volume
x1	Steel products output
x2	Coal output
x3	Refined oil output
x4	Thermal power output
x5	Railway fixed assets investment
x6	Growth rate of industrial added value

3.5 Model and Solution

In this chapter, an open source package, the randomForest package of the R language, is applied to solve this freight regression model. According to 3.3, the initial model is $y=f(x1, x2, x3, x4, x5, x6)$. Theoretically, the data should be independent. In Table 4, several variables are non-independent. The random forest regression is used to select the best feature variables. For example, x2 and x4 have strong correlation, and one should be removed from model. It is important to determine which of the two variables should be kept and which discarded. With the help of random forest regression, the decision can be made to select the best variables. When determining the final model, all variables will be independent.

Table 5 Importance of each variable

Variables	Increase in MSE (IncMSE)
x1	9,020,548
x2	4,926,904
x3	10,547,853
x4	5,794,482
x5	468,918
x6	230,126

To obtain a good prediction of the random forest regression model, a more complex method was used, which is called cross-validation. Cross-validation of the regression model code (with R language) is as follows:

```
dim (database)
n<-dim(database) [1]
m=sample(1:n, ceiling(n/2))
n<-100
NMSE<-rep(0,n)
NMSE0<-NMSE
set.seed(100)
for(i in 1:n){
    B=randomForest(y~.,data= database[-m,],ntree=i);
    y0=predict(B, database[-m,]);
    y1=predict(B, database[m,]);
NMSE0[i]<-mean((database$y[-m]-y0)^2)/mean((database$y[-m]-mean
(database$y[-m]))^2);
NMSE[i]<-mean((database$y[m]-y1)^2)/mean((database$y[m]-mean
(database$y[m]))^2)
}
```

After running this RFR model, the following result is obtained:

Call:

randomForest(formula = y ~., data = database[-m,], ntree = i, importance = TRUE, proximity = T)

Type of random forest: regression
Number of trees: 100

Number of variables tried at each split: 2

Mean of squared residuals: 1218032
% Var explained: 97.21

For this model, the detected trees number is 100. The variance of the initial regression model is 97.21%. NMSE0 is normalized mean square error of the training set and is 0.02108. NMSE is the normalized mean square error of the test set, which is 0.08222.

To improve the regression model, the mean square error (MSE) of 6 variables is analysed for ranking. Normally, the larger the increase in MSE (IncMSE), the more important the variable. The increase in MSE (IncMSE) of 6 variables is shown in Table 5 and Fig. 6. The importance of each variable can be determined.

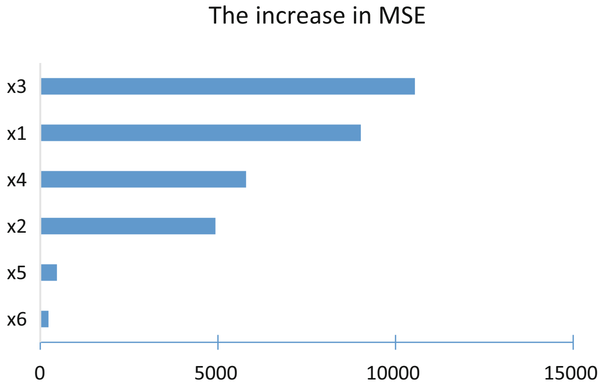


Fig. 6 Variables ranked by IncMSE

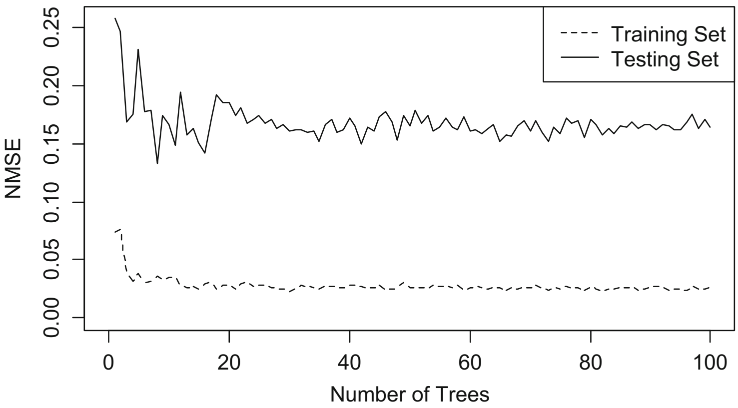


Fig. 7 NMSE curve of the RFR model

As shown in Table 5, the growth rate of the industrial added value (x6) is found, and the railway fixed assets investment (x5) have little effect on this model. Therefore, variable x6, x5 is removed, and the following improved RFR model is improved:

$$y = f(x1, x2, x3, x4)$$

For this new model, its variance explained as 92.11%. NMSE0 of the training set is 0.02024, and NMSE of the testing set is 0.12117. All of these numbers indicate that it has a little effect on model accuracy to remove variable x6, x5. Figure 7 is the NMSE changing curve. The decreased speed of NMSE is rapid in the early stage, and the NMSE0 and NMSE curves are relatively stable in the later stage with no ups and downs, which shows this model does not present over fitting.

Table 6 RFR model comparisons (number of trees=100)

ID	RFR model	Training set NMSE0	Testing set NMSE	Variance explained (%)
1	y = f(x1,x2,x3,x4,x5, x6)	0.02108	0.08222	93.38
2	y = f(x1,x2,x3,x4,x5)	0.02340	0.08990	92.60
3	y = f(x1,x2,x3,x4)	0.02024	0.12117	92.11
4	y = f(x1,x3,x4)	0.02968	0.15549	88.94
5	y = f(x2,x3,x4)	0.02617	0.18363	87.80
6	y = f(x1,x3)	0.02991	0.18081	86.72
7	y = f(x1,x4)	0.03360	0.15355	87.14
8	y = f(x3,x4)	0.03049	0.16410	87.75
9	y = f(x2,x3)	0.05246	0.09541	86.81

Choosing different influencing factors as the model input will achieve different RFR results. These results have been listed in Table 6.

Considering the independence of variables and the NMSE testing set, it appears that the ninth model is the best option in Table 6. In Model 9, coal output (x2) and refined oil output (x3) are independent. The testing set NMSE is 0.09541, not much higher than the training set NMSE0. Its variance proportion of the model is 86.71%, which is high enough to explain model. Therefore, the ninth model is chosen as the final RFR model. In this model, variable x6 does not exist, which means the growth rate of the industrial added value or industrial economic development does not have an obvious or direct influence on railway freight volume.

Using the ninth model, the prediction result shown in Fig. 8 is obtained. In this figure, dots indicate the predicted value, and the continuous curve is the historical data. As shown in Fig. 8, the forecast is consistent with the historical value.

3.6 *Evaluation of Random Forest Regression and Linear Regression*

To evaluate the prediction error of the final model, three testing indicators of the RFR model referred to in Sect. 3.5 have been calculated, and the results are shown in Table 6. To contrast and analyse the prediction performance of different machine learning algorithms, the linear regression model and BP neural network regression model were also evaluated using the same data.

For the multiple linear regression model, the x2, x3 variables in the initial model are considered as follows:

$$y = \mathrm{b} + \beta_1 x_2 + \beta_2 x_3$$

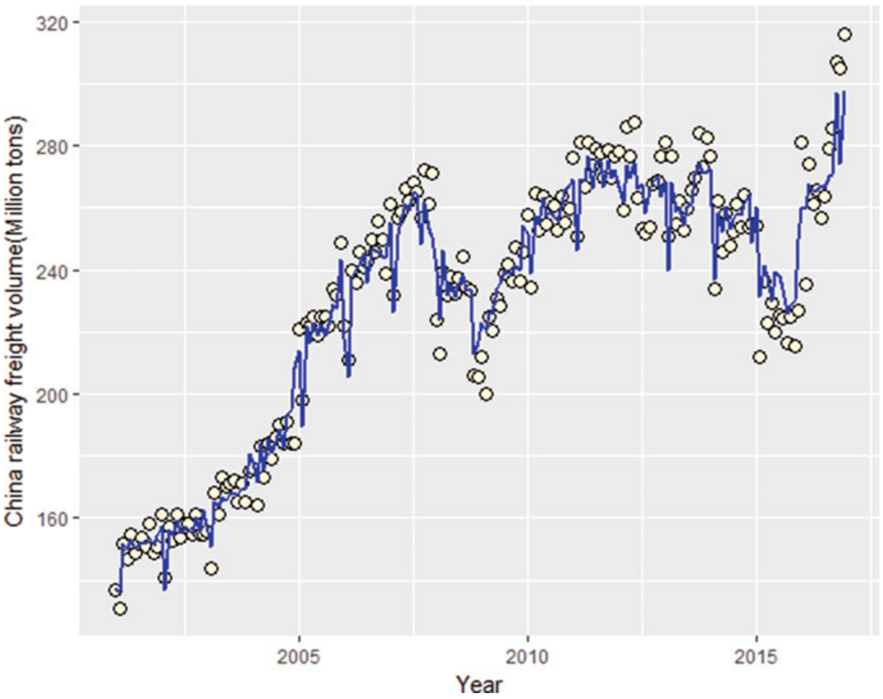


Fig. 8 Railway freight volume prediction from 2001 to 2016 with the random forest regression model

The regression result is as follows:

Residuals:

Min	1Q	Median	3Q	Max
–62.958	–19.998	1.592	18.139	56.197

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.114e+02	6.817e+00	16.337	<2e-16 ***
x2	8.425e-04	8.670e-04	0.972	0.332
x3	3.775e+00	2.125e-01	17.767	<2e-16 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 26.34 on 189 degrees of freedom

Multiple R-squared: 0.6372,

Adjusted R-squared: 0.6334

F-statistic: 166 on 2 and 189 DF, p-value: < 2.2e-16

This multiple linear regression model does not pass the significance test. After repeated comparison and adjustments, intercept x2 is removed and (x3)^2 is added to the linear regression model. The new linear regression is supposed as follows:

$$y = \beta_1 x_3 + \beta_2 (x_3)^2$$

Finally, the regression result is as follows:

Residuals:

Min	1Q	Median	3Q	Max
–49.97	–16.10	–2.31	14.20	51.57

Coefficients:

	Estimate	Std. Error	t value	Pr(>ltl)
x3	11.850246	0.220672	53.70	<2e-16 ***
I(x3^2)	–0.132266	0.005987	–22.09	<2e-16 ***

\-\-\-

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 21.62 on 190 degrees of freedom
Multiple R-squared: 0.9915,
Adjusted R-squared: 0.9914
F-statistic: 1.105e+04 on 2 and 190 DF, p-value: < 2.2e-16

The linear regression diagnostics are shown in Fig. 9. The normality assumption (Normal Q-Q in Fig. 9) and heteroscedasticity (Scale-Location in Fig. 9) meet the requirements of linear regression assumptions. The residuals and fitted value are nearly linear. By using the gvlma() function of R language, the linear regression comprehensive diagnosis result can be obtained as follows:

```
ASSESSMENT OF THE LINEAR MODEL ASSUMPTIONS
USING THE GLOBAL TEST ON 4 DEGREES-OF-FREEDOM:
Level of Significance =  0.05
Call:
 gvlma(x = mlrg)
                       Value   p-value          Decision
Global Stat           1.4454   0.83626    Assumptions acceptable.
Skewness              0.0171   0.89597    Assumptions acceptable.
Kurtosis              3.0525   0.08061    Assumptions acceptable.
Link Function        -1.9446   1.00000    Assumptions acceptable.
Heteroscedasticity 0.3204    0.57138    Assumptions acceptable.
```

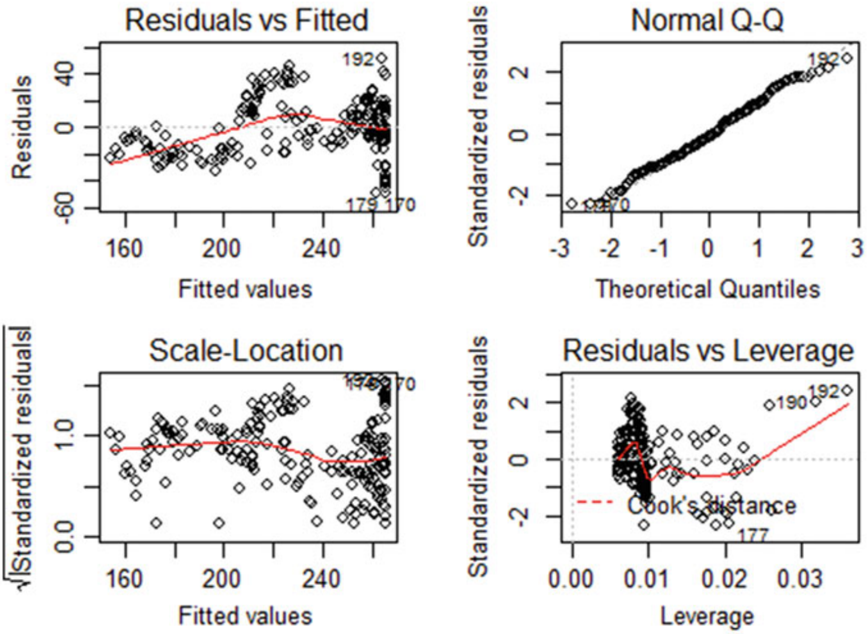


Fig. 9 Chinese railway freight volume linear regression diagnostics

The final linear regression model is obtained as follows:

$$y = 11.850246 \cdot x_3 - 0.132266 \cdot {x_3}^2$$

The linear regression model predicts the Chinese railway freight volume, as shown in Fig. 10.

Figure 10 illustrates that the linear regression effect is not as good as the random forest regression effect.

The mean absolute error (MAE), mean relative error (MRE), and normalized mean square error (NMSE) are evaluated to analyse the performance of the two different models. The evaluation result is listed in Table 7. All the indicators of the RFR model are at a minimum. RFR is more suitable for prediction of China's railway freight volume. Comparing the two regression models, the RFR predicted value has the following advantages: minor forecasting error and anti-disturbance ability.

3.7 *Chinese Freight Volume Prediction for 2017*

To verify the generalization performance of the RFR, the Chinese railway freight volume is predicted for 2017. Data from January to April 2017 are listed in Table 8.

After inputting the 2017 data into the RFR model, the prediction result shown in Table 9 and Fig. 11 was obtained.

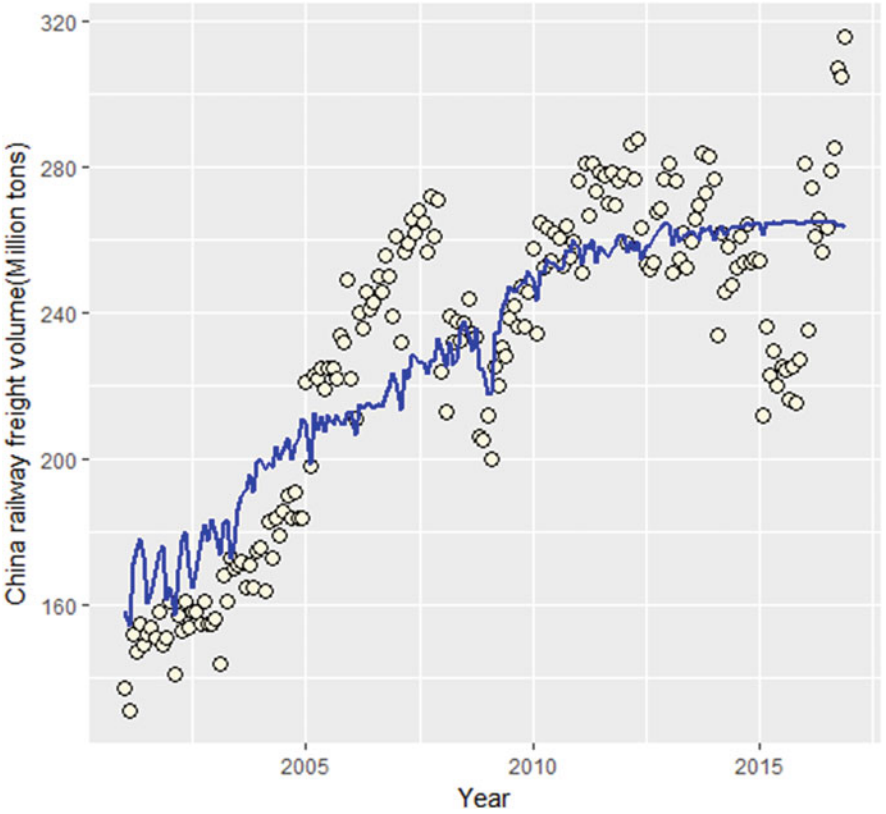


Fig. 10 Railway freight volume prediction with the linear regression model

Table 7 Prediction error comparison of three different models

Regression model	MAE (million tons)	MRE (%)	NMSE
Random Forest Regression	4.9892	2.20	0.0951
Linear Regression	17.575	8.48	0.2912

The predicted value was then compared with real data. The prediction max error is in April when the railway freight volume was 301.33 million tons, and the prediction value is 269.25; the forecast is not bad.

However, we also found that the random forest model is more dependent on historical data. If the input data exceed the peak value of the historical data, the random forest model cannot obtain a good prediction.

Table 8 Chinese railway freight volume and other data of 2016

Month	Freight volume (Million tons) y	Steel products output (Million tons) x1	Coal output (Million tons) x2	Refined oil output (Million tons) x3	Thermal power output (Billion kwh) x4	Fixed assets investment (Billion yuan) x5
Jan-2017	310.58	83.2765	29,976.3	47.505	363.995	21.68
Feb-2017	281.21	83.2765	29,976.3	47.505	363.995	20.01
Mar-2017	321.85	96.764	29,976.3	47.505	396.08	54.9
Apr-2017	301.33	94.898	29,453	44.452	352.18	57.84

Table 9 Prediction of Chinese railway freight volume in 2017

Date	Railway freight volume (Million tons)	Predicted value (Million tons)
Jan-2017	310.58	297.51
Feb-2017	281.21	297.51
Mar-2017	321.85	297.51
Apr-2017	301.33	269.25

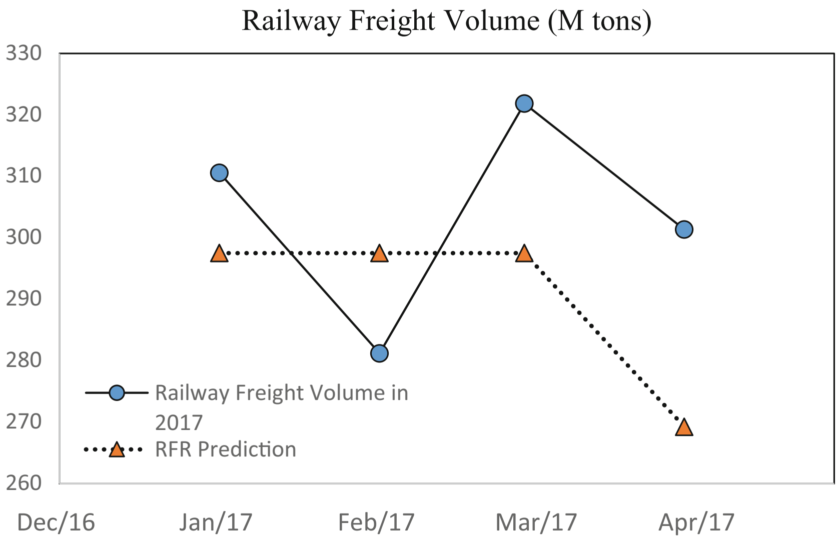


Fig. 11 Comparison of predicted values and real data for 2017

3.8 Comparison of the Two Models

From the regression process of the two models, it is clear that the robustness of the linear regression model offers lower results than random forest regression model. For multiple linear regression, the variables are x3 (refined oil output) and x4 (thermal power output). However, for the random forest regression model, the variables are x2 (coal output), x3. The linear regression model is sensitive to data changes and requires significant testing. The variable x2 (coal output) was removed because the variable did not pass the significance test in the linear regression model.

It was also found that the variables of the multiple linear regression model are inconsistent with those of the random forest model. Variables in the random forest regression model and the linear regression model cannot be substituted for each other.

Variable x3 is more important than other variables in both the random forest regression model and the multiple linear regression model. For the random forest regression model, the increase of MSE for x3 is 10,547,853, the largest in all variables. For the multiple linear regression model, the coefficient of x3 is 7.32621, which is greater than x4. Therefore, despite the fact that coal (variable x2) in the Chinese railway freight accounted for more than 50% of the total freight, it is not the most important variable in the regression model.

4 Conclusions

The random forest regression model shows that it is adequate for use in railway freight prediction. Compared with the multiple linear regression model, RFR has superiority in its high forecasting accuracy, fast training speed, satisfied robustness and fitness and strong anti-noise ability. However, this kind of regression is good at predicting historical data. Therefore, this regression method is better used in combination with the linear regression method.

By ranking the independent variables, it is clear that the refined oil output has a greater influence on Chinese railway freight than does coal output.

Acknowledgements This chapter is funded by the National Natural Science Foundation (Grant No. 71390334), the EC-China Research Network on Integrated Container Supply Chain Project (No. 612546), and the Beijing Logistics Informatics Research Base.

Appendix Table. Chinese Railway Freight and Other Industry Data

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Jan-2001	137.00	10.91	63.45	16.27	88.022	3.5930	2.3
Feb-2001	131.00	11.31	67.97	15.76	100.431	1.7965	19
Mar-2001	152.00	13.23	82.49	18.12	88.722	4.4913	12.1
Apr-2001	147.00	12.85	79.42	18.65	95.111	5.3895	11.5
May-2001	155.00	13.28	80.63	19.03	93.663	7.1860	10.2
Jun-2001	149.00	13.61	80.94	18.33	94.658	7.1860	10.1
Jul-2001	152.00	12.96	74.14	16.6	106.032	6.2878	8.1
Aug-2001	154.00	13.41	78.1	16.91	100.992	6.2878	8.1
Sep-2001	151.00	13.17	81.18	17.79	97.313	8.0843	9.5
Oct-2001	158.00	13.54	83.89	18.51	96.623	8.9825	8.8
Nov-2001	149.00	15.34	88.06	18.76	138.632	9.8808	7.9
Dec-2001	151.00	13.86	100.19	16.71	76.552	20.6598	8.7
Jan-2002	161.00	14.01	86.33	17.17	116.264	3.8509	18.6
Feb-2002	141.00	13.27	68.49	16.12	80.532	1.9255	2.7
Mar-2002	157.00	16.02	93.78	17.79	109.261	4.8137	10.9
Apr-2002	153.00	16.11	92.81	18.99	106.414	5.7764	12.1
May-2002	161.00	15.89	91.61	19.33	104.102	7.7018	12.9
Jun-2002	154.00	16.63	93.63	17.95	106.328	7.7018	12.4
Jul-2002	158.00	15.67	87.16	17.16	118.668	6.7391	12.8
Aug-2002	158.00	16.52	90.9	17.73	112.877	6.7391	12.7

(continued)

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Sep-2002	155.00	16.60	93.51	18.99	110.027	8.6646	13.8
Oct-2002	161.00	16.55	94.88	19.6	113.483	9.6273	14.2
Nov-2002	155.00	16.27	100.35	18.99	116.555	10.5900	14.5
Dec-2002	155.00	18.64	114.63	19.83	134.253	22.1428	14.9
Jan-2003	156.00	16.48	96.31	19.31	119.035	3.4397	14.8
Feb-2003	144.00	15.82	85.39	18.45	109.467	1.7198	19.8
Mar-2003	168.00	18.26	106.87	19.66	126.905	4.2996	16.9
Apr-2003	161.00	18.71	107.33	19.81	122.338	5.1595	14.9
May-2003	173.00	19.98	109.11	18.32	118.852	6.8794	13.7
Jun-2003	170.00	19.71	114.44	18.81	124.23	6.8794	16.9
Jul-2003	171.00	19.80	109.93	20.3	137.808	6.0194	16.5
Aug-2003	172.00	21.10	107.19	20.82	139.595	6.0194	17.1
Sep-2003	165.00	20.43	105.61	21.19	127.588	7.7393	16.3
Oct-2003	171.00	21.59	114.71	21.75	130.042	8.5992	17.2
Nov-2003	165.00	21.88	122.38	21	139.692	9.4591	17.9
Dec-2003	175.00	22.06	135.97	22.32	146.574	19.7782	18.1
Jan-2004	176.00	21.18	96.95	22.52	128.997	3.6055	7.2
Feb-2004	164.00	22.25	110.02	22.03	140.763	1.8028	23.2
Mar-2004	183.00	23.83	128.13	22.31	150.094	4.5069	19.4
Apr-2004	173.00	22.18	131.29	22.07	141.276	5.4083	19.1
May-2004	184.00	24.01	128.72	23.09	138.066	7.2110	17.5

(continued)

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Jun-2004	179.00	23.76	135.41	22.51	136.882	7.2110	16.2
Jul-2004	186.00	24.57	131.5	22.92	158.449	6.3097	15.5
Aug-2004	190.00	25.48	132.55	23.48	153.315	6.3097	15.9
Sep-2004	184.00	26.65	134.06	22.51	144.397	8.1124	16.1
Oct-2004	191.00	27.59	140.18	23.17	150.663	9.0138	15.7
Nov-2004	184.00	28.12	143.7	23.54	153.755	9.9152	14.8
Dec-2004	184.00	27.76	152.7	24.47	173.514	20.7317	14.4
Jan-2005	221.00	26.11	128.79	24.26	165.049	5.4572	20.9
Feb-2005	198.00	25.78	111.38	22.28	137.827	2.7286	7.6
Mar-2005	223.00	30.65	140.02	24.68	170.209	6.8216	15.1
Apr-2005	222.00	29.50	143.87	23.94	154.817	8.1859	16
May-2005	225.00	30.79	149.89	24.56	155.01	10.9145	16.6
Jun-2005	219.00	30.30	158.6	23.8	157.722	10.9145	16.8
Jul-2005	225.00	30.55	151.76	24.62	174.186	9.5502	16.1
Aug-2005	225.00	32.54	153.96	24.23	172.639	9.5502	16
Sep-2005	222.00	32.61	157.64	24.62	163.134	12.2788	16.5
Oct-2005	234.00	33.10	163.55	24.25	160.383	13.6431	16.1
Nov-2005	232.00	33.33	170.43	24.21	170.241	15.0074	16.6
Dec-2005	249.00	35.92	180.02	24.68	204.506	31.3791	16.5
Jan-2006	222.00	32.47	129.23	24.82	175.483	6.5712	12.6
Feb-2006	211.00	31.82	136.97	23.66	166.949	5.9510	20.1

(continued)

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Mar-2006	240.00	37.74	166.22	25.2	184.531	14.1421	17.8
Apr-2006	236.00	38.28	174.12	25.02	177.99	12.3059	16.6
May-2006	246.00	40.29	173.28	25.21	176.842	19.4986	17.9
Jun-2006	241.00	41.35	179.67	25.22	182.893	17.8245	19.5
Jul-2006	243.00	37.94	168.42	25	202.797	13.7011	16.7
Aug-2006	250.00	39.06	174.37	25.14	220.153	17.1325	15.7
Sep-2006	246.00	40.08	181.28	25.05	191.91	17.0605	16.1
Oct-2006	256.00	41.58	186.55	25.65	195.287	18.0716	14.7
Nov-2006	250.00	44.32	189.67	26.1	210.564	22.6269	14.9
Dec-2006	239.00	41.92	203.89	26.95	233.479	40.4718	14.7
Jan-2007	261.00	40.44	174.79	26.44	223.904	7.8542	12.6
Feb-2007	232.00	38.57	142.03	24.94	171.976	6.5746	12.6
Mar-2007	257.00	47.34	177.76	27.11	223.65	12.2157	17.6
Apr-2007	259.00	45.86	188.47	26.66	213.56	14.6766	17.4
May-2007	266.00	46.89	191.15	27.96	221.12	17.7775	18.1
Jun-2007	262.00	51.15	202.4	27.97	223.52	18.3120	19.4
Jul-2007	268.00	48.44	195.61	27.51	245.32	19.8683	18
Aug-2007	265.00	48.28	193.97	27.51	240.81	15.4582	17.5
Sep-2007	257.00	50.57	203.55	26.95	223.51	24.7323	18.9
Oct-2007	272.00	49.03	198.77	27.62	222.28	21.1956	17.9
Nov-2007	261.00	48.23	211.92	27.67	237.49	25.1356	17.3

(continued)

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Dec-2007	271.00	49.81	218.5	29.06	254.12	67.7690	17.4
Jan-2008	224.01	45.92	187.36	28.44	249.743	6.6502	15.4
Feb-2008	213.11	43.13	170.01	27.37	202.987	8.8449	15.4
Mar-2008	239.10	51.89	211.29	28.89	254.61	15.9165	17.8
Apr-2008	232.13	51.41	213.34	27.38	242.47	18.4833	15.7
May-2008	237.91	53.69	227	27.78	242.25	26.8180	16
Jun-2008	232.28	53.93	239.36	29.61	222.923	27.1270	16
Jul-2008	237.18	51.83	220.29	30.31	265.051	29.9385	14.7
Aug-2008	244.14	48.03	222.14	29.19	240.126	36.0258	12.8
Sep-2008	234.35	45.33	228.7	28.25	222.43	41.9183	11.4
Oct-2008	233.41	42.76	219.28	29.79	212.16	43.9156	8.2
Nov-2008	206.24	42.84	226.97	27.27	203.506	49.1718	5.4
Dec-2008	205.46	51.02	219.94	27.17	227.484	109.6393	5.7
Jan-2009	212.01	44.22	172.34	25.77	204.6	42.1759	11
Feb-2009	199.93	46.13	196.56	25.8	203.661	33.2695	11
Mar-2009	225.16	54.38	233.43	29.37	246.185	33.2695	8.3
Apr-2009	220.21	52.25	229.8	29.43	218.44	42.5924	7.3
May-2009	230.72	57.36	248.41	31.19	220.014	50.9313	8.9
Jun-2009	228.23	62.14	279.09	31.92	246.316	62.9944	10.7
Jul-2009	238.74	61.36	257.82	33.11	263.955	49.7445	10.8
Aug-2009	242.01	62.24	260.75	32.56	271.687	50.7265	12.3

(continued)

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Sep-2009	236.24	61.72	263.16	32.83	255.387	55.4840	13.9
Oct-2009	247.24	63.60	273.07	33.29	255.14	54.9122	16.1
Nov-2009	236.25	62.93	288.94	33.36	282.943	64.4570	19.2
Dec-2009	246.01	64.11	280.62	34.6	313.094	194.0332	18.5
Jan-2010	257.68	61.77	256.1	33.7	312.8	32.1840	12.8
Feb-2010	234.50	55.59	212.98	31.91	210.29	21.7840	12.8
Mar-2010	264.87	68.39	279.81	34.56	294.77	35.3916	18.1
Apr-2010	252.61	68.68	269.29	34.41	280.98	53.0815	17.8
May-2010	263.56	71.86	283.86	35.79	275.78	57.2350	16.5
Jun-2010	254.61	72.40	296.92	35.35	257.97	71.6981	13.7
Jul-2010	261.96	67.19	291.91	35.28	280.51	56.7347	13.4
Aug-2010	260.80	69.71	301.38	34.73	308.03	77.2319	13.9
Sep-2010	252.87	64.26	276.02	34.91	261.24	85.9048	13.3
Oct-2010	263.80	64.44	300.66	37.04	255.3	87.7507	13.1
Nov-2010	255.24	66.01	337.58	36.66	282.08	108.7950	13.3
Dec-2010	259.60	65.98	327.57	38.72	305.59	145.1310	13.5
Jan-2011	276.30	67.33	268.26	37.19	311.33	40.4357	14.9
Feb-2011	250.88	63.53	247.49	35.21	262.39	30.3833	14.9
Mar-2011	281.10	77.17	307.36	37.66	326.93	50.7976	14.8
Apr-2011	266.76	72.63	318.08	37.19	309.3	51.6567	13.4
May-2011	281.07	77.99	327.3	38.47	317.83	46.7197	13.3

(continued)

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Jun-2011	273.68	78.75	340.2	35.56	315.47	58.1232	15.1
Jul-2011	278.91	76.60	327.83	37.49	342.07	44.3029	14
Aug-2011	277.60	77.19	327.4	36.79	354.82	35.3043	13.5
Sep-2011	269.90	76.09	318	36.1	313.08	37.7091	13.8
Oct-2011	278.88	72.88	330	37.11	299.31	33.5598	13.2
Nov-2011	269.71	69.97	321	37.87	308.67	62.6549	12.4
Dec-2011	276.56	71.17	311	39.23	352.53	139.3327	12.8
Jan-2012	278.31	68.02	256	39.68	294.31	12.2822	21.3
Feb-2012	259.08	71.27	292	36.86	314.57	17.6494	21.3
Mar-2012	286.28	83.17	295	38.37	351.91	29.7075	11.9
Apr-2012	276.83	79.98	310	36.95	305.15	29.9584	9.3
May-2012	287.59	81.56	315	38.33	311.69	40.0564	9.6
Jun-2012	263.37	83.44	315	35.98	293.61	48.0970	9.5
Jul-2012	253.33	81.52	310	37.6	329.11	47.9632	9.2
Aug-2012	251.95	78.74	307	37.74	327.4	45.7842	8.9
Sep-2012	253.77	80.58	315	38.76	287.65	72.6580	9.2
Oct-2012	267.68	81.17	315	39.91	293.9	81.0127	9.6
Nov-2012	268.56	80.96	329.8	41.61	320.44	81.8002	10.1
Dec-2012	276.72	81.45	319.8	43.12	356.96	145.0460	10.3
Jan-2013	281.18	81.60	310	42.89	371.46	20.9936	8.9
Feb-2013	250.98	76.67	240	37.76	271.52	16.6321	8.9

(continued)

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Mar-2013	276.51	89.61	290	40.83	352.7	29.3815	8.9
Apr-2013	254.96	87.61	305	38.32	330.76	43.8956	9.3
May-2013	262.20	91.19	307	39.06	325.64	46.7074	9.2
Jun-2013	252.65	90.83	304	39.6	324.009	58.3211	8.9
Jul-2013	259.72	90.75	300	40.3	375.095	45.8139	9.7
Aug-2013	265.93	91.94	300	39.74	395.108	51.5394	10.4
Sep-2013	269.87	93.55	315	38.65	332.389	56.4273	10.2
Oct-2013	284.04	92.81	320	41.08	339.731	59.5572	10.3
Nov-2013	273.06	90.32	320[a]	40.17	358.533	82.1137	10
Dec-2013	282.81	90.41	320[a]	42.02	400.846	154.3621	9.7
Jan-2014	276.61	87.08	290	38.61	361.393	20.0205	9
Feb-2014	233.74	78.65	245	40.17	322.516	20.0205	8.6
Mar-2014	262.20	95.07	305	41.92	375.48	24.9900	8.7
Apr-2014	245.63	92.50	301	39.58	341.19	42.8600	8.7
May-2014	258.23	96.82	300	40.33	340.27	37.9710	8.7
Jun-2014	247.86	98.04	298	41.83	346.06	58.6730	9.2
Jul-2014	252.46	94.76	301	41.08	366.4	62.0220	9
Aug-2014	261.05	94.98	302	41.39	352.8	68.9660	6.9
Sep-2014	253.87	95.75	292	42.02	314.646	89.6480	8
Oct-2014	264.37	95.25	291	43.51	320.6	86.7260	7.7
Nov-2014	253.85	92.05	330	42.25	345.5	80.1580	7.2

(continued)

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Dec-2014	254.71	98.22	330[b]	44.58	398	188.0780	7.9
Jan-2015	254.17	88.31	290	42.94	403.05	30.1200	6.8
Feb-2015	212.13	79.76	240	39.7	291.43	16.4760	6.8
Mar-2015	236.34	97.56	305	44.69	349.72	42.6590	5.6
Apr-2015	222.74	96.41	298.02	43.13	340.9	50.6390	5.9
May-2015	229.46	98.48	309.39	43.92	344.38	54.6410	6.1
Jun-2015	220.03	98.43	326.72	43.35	336.35	63.9650	6.8
Jul-2015	225.23	92.30	306.66	43.54	365.77	78.8580	6
Aug-2015	224.22	94.50	308.63	44.34	377.79	69.4280	6.1
Sep-2015	216.40	94.69	312.68	44.43	314.59	73.7710	5.7
Oct-2015	225.12	94.27	316.95	44.25	310.72	74.8830	5.6
Nov-2015	215.36	93.96	320.23	43.92	353.18	90.6180	6.2
Dec-2015	227.04	95.38	316.59	45.83	385.59	189.4740	5.9
Jan-2016	281.26	81.14	256.73	43.54	157.18	20.67	5.9
Feb-2016	235.47	81.14	256.73	43.54	157.18	19.23	6.8
Mar-2016	274.33	99.23	293.80	44.91	364.19	42.70	6.8
Apr-2016	261.00	96.68	268.03	44.75	328.94	61.90	6
May-2016	265.75	99.46	263.75	44.23	330.00	73.00	6
Jun-2016	257.00	100.72	277.54	45.08	345.67	86.50	6.2
Jul-2016	263.49	95.94	270.01	45.32	388.85	65.73	6
Aug-2016	279.31	97.91	278.09	44.28	413.77	63.60	6.3

(continued)

Month	Railway freight (Mt)	Steel output (Mt)	Coal output (Mt)	Refined oil output (Mt)	Thermal power output (billion KW/h)	Fixed asset investment (billion yuan)	Growth rate of industrial added value (%)
Sep-2016	285.60	98.09	276.96	43.80	361.23	109.01	6.1
Oct-2016	307.21	97.68	281.85	47.05	355.53	81.06	6.1
Nov-2016	304.93	95.40	308.01	45.77	379.7	76.51	6.2
Dec-2016	315.79	95.711	31097.7	47.822	423.58	101.591	6

[a] Coal outputs from Nov and Dec 2013 were not published, and the missing data are replaced with data from Oct 2013

[b] Coal output from Dec 2014 was not published, and the missing data are replaced with data from Nov 2014

References

Breiman, L. (2001). Random forests. *Machine Learning, 45*, 5–32.

Chengde, L., & Guolan, P. (2007). Application of random forest on selecting evaluation index system for enterprise credit assessment. *Journal of Xiamen University (Natural Science), 2*, 199–203.

Chi, Z., Lei, H., & Zhichao, Z. (2013). Research on combination forecast of port cargo throughput based on time series and causality analysis. *Journal of Industrial Engineering and Management, 6*(1), 124–134.

Dongwen, C. (2014). Application of random forest regression model for wastewater discharge forecasting. *Water Technology, 8*, 31–36.

Huawen, W., & Fuzhang, W. (2014). Research on railway freight traffic prediction based on maximum Lyapunov exponent. *Journal of the China Railway Society, 4*, 7–13.

Kuangnan, F., Jianping, Z., & Bangchang, X. (2010). A research into the forecasting if fund return rate direction and trading strategies based on the random forest method. *Economic Survey, 2*, 61–65.

Liang, Z., Qiong, H., Ao, L., & Minghui, W. (2012). A genome-wide association study of Alzheimer's disease using random forests and enrichment analysis. *Scientia Sinica (Vitae), 8*, 639–647.

Rodriguez-Galiano, V., Sanchez-Castillo, M., Chica-Olmo, M., & Chica-Rivas, M. (2015). Machine learning predictive models for mineral prospectivity: An evaluation of neural networks, random forest, regression trees and support vector machines. *Ore Geology Reviews, 71*, 804–818.

Rui, S., & Yan, S. (2014). Mixed radial basis function neural network in freight volume forecasting. *Journal of Wuhan University of Technology (Transportation Science & Engineering), 6*, 1247–1250.

Shengnan, Y., Yuanfang, C., Qin, H., You, K., Ranran, H. & Shenghua, G. (2015). Using the random forest method for classification and regression in hydrology. In *Proceedings of the 2nd annual congress on advanced engineering and technology, CAET 2015* (pp. 213–218).

Silke, J., Gerhard, T., & Anne-Laure, B. (2015). Random forest for ordinal responses: Prediction and variable selection. *Computational Statistics and Data Analysis, 96*, 57–73.

Svetnik, V., Liaw, A., Tong, C., Culberson, J. C., Sheridan, R. P., & Feuston, B. P. (2003). Random forest: A classification and regression tool for compound classification and QSAR modeling. *Journal of Chemical Information and Computer Sciences, 43*, 1947–1958.

Tao, Z., & Jinlong, Z. (2014). Study on the forecast of freight volume based on GRNN. *Logistics Sci-Tech, 10*, 138–141.

Vitorino, D., Coelho, S. T., Santos, P., Sheets, S., Jurkovac, B., & Amado, C. (2014). A random forest algorithm applied to condition-based wastewater deterioration modeling and forecasting. *Procedia Engineering, 89*, 401–410.

Yan, S., Maoxiang, L., Danzhu, W., & Linyun, L. (2014). A PSO-GRNN model for railway freight volume prediction: Empirical study from China. *Journal of Industrial Engineering and Management, 7*(2), 413–433.

Yandong, Y., & Congzhou, Y. (2015). Prediction models based on multivariate statistical methods and their applications for predicting railway freight volume. *Neurocomputing, 158*, 210–215.

Yang, Y., Wen, D., & Lin, W. (2010). Freight volume prediction of coal transportation from Xinjiang based on Grey-Markov chain method. In *Proceedings of the 2010 international conference of logistics engineering and management*, Vol. 387, pp. 502–508.

Yue, Z., & Bin, S. (2012). Railway freight volume forecast in northeast region based on the improved gray model. *Journal of Railway Science and Engineering, 5*, 125–128.

Zhenzi, L., Tao, Z., Xiaoyan, W., & Kang, L. (2014). Methodology of regression by random forest and its application on metabolomics. *China Journal of Health Statistics, 2*, 158–160.

An Optimization Approach for the Train Load Planning Problem in Seaport Container Terminals

Daniela Ambrosino, Davide Anghinolfi, Massimo Paolucci, and Silvia Siri

Abstract In this work an optimization approach for defining loading plans for trains in seaport container terminals is presented. The problem consists in defining the assignment of containers of different length, weight and value to wagon slots of a train, in order to maximize the total value loaded on the train and to minimize unproductive movements, both in the stacking area and of the crane during the loading process. Due to the difficulty in solving this problem for real scenarios, a MIP heuristic solution approach based on a randomized matheuristics is proposed. Computational results are presented and discussed, showing the effectiveness of the proposed heuristic solution method.

Keywords Train Loading Problem · MIP heuristics

1 Introduction

The landside transport planning represents a crucial process in seaport container terminals for its impact on congestion and pollution and for the stronger rules imposed to terminals regarding the time spent by import and export containers in the stacking areas. Container terminals have to reach automation and efficiency in their whole organization. Optimization methods have been applied to the decision problems arising in many processes in container terminals, as shown in the surveys by Steenken et al. (2004) and Stahlbock and Voss (2008). This chapter presents an optimization approach for defining loading plans for trains.

D. Ambrosino
Department of Economics and Business Studies (DIEC), University of Genoa, Genova, Italy
e-mail: ambrosin@economia.unige.it

D. Anghinolfi · M. Paolucci (✉) · S. Siri
Department of Informatics, Bioengineering, Robotics, and Systems Engineering (DIBRIS), University of Genoa, Genova, Italy
e-mail: davide.anghinolfi@unige.it; massimo.paolucci@unige.it; silvia.siri@unige.it

J. E. Hernández et al. (eds.), *Collaborative Logistics and Intermodality*,
https://doi.org/10.1007/978-3-030-50958-3_7

Some research studies focus on train load planning problems in landside intermodal terminals. Bostel and Dejax (1998) propose some models and heuristics for container allocation problems on trains arising in rail-rail terminals with rapid transfer yards. Corry and Kozan (2006, 2008) face the problem of assigning containers to train slots considering, in their second work, different types of containers and loading patterns and minimizing the weighted sum of number of wagons and equipment working time. They propose metaheuristics, such as local search and simulated annealing, to solve the problem in practical applications. Only in a more recent work Bruns and Knust (2012) consider real weight constraints for wagons.

Studies on the Train Load Planning Problem (TLPP) arising in seaports started with Ambrosino et al. (2011) that, inspired by Bruns and Knust (2012), extended their models for a sequential train load by including the reshuffles in the stacking area, a crucial aspect in maritime container terminals. A more general train loading model, not imposing sequential loading but allowing also unproductive movements of the crane, is presented in Ambrosino et al. (2013) and in Ambrosino and Siri (2014). In the first work this general model is used for comparing different train loading policies and stacking strategies. In the second work different models are analyzed to identify the most suitable one for solving real problems in maritime container terminals (i.e., providing good and applicable solutions in an acceptable CPU time). Due to the difficulty in solving the model presented in Ambrosino and Siri (2014) for real scenarios, this chapter proposes a Mixed Integer Programming (MIP) heuristic approach consisting in a Randomized Neighborhood Search (RANS) algorithm firstly introduced by Anghinolfi and Paolucci (2011) and successfully applied to different logistic problems by Ambrosino et al. (2011) and by Anghinolfi and Paolucci (2014).

The chapter is organized as follows. Section 2 introduces the problem and its mathematical formulation. Section 3 describes the MIP heuristic approach, Sect. 4 reports the experimental results and conclusions are drawn in Sect. 5.

2 Problem Definition and Mathematical Formulation

The considered problem is inspired by a real case of an Italian port. The TLPP considers only one train at a time and, assuming shuttle trains directed to an inland port, neglects the destination of containers. Containers are characterized by length, weight and a priority value reflecting their importance. Containers that must be loaded on trains are stored in stacks of different heights in a specific stacking area close to the railway yard. From there, they are moved near the tracks with trailers and finally loaded on a train by a crane. Each train is composed of a set of wagons of different types, i.e., with different length and weight capacity, different possible configurations in terms of number and length of slots and weight capacity of each slot (more details are given in Ambrosino and Siri (2014)). The assignment of containers to wagon slots accounts for length and weight constraints.

The crane usually starts loading the train from the first wagon and goes on along the train without changing direction. Consequently, reshuffles may occur when the crane needs to load on the currently served wagon a container that is located below other containers in a stack. Another possibility, which allows to reduce reshuffles in the yard, is that the crane proceeds to the next wagon leaving a slot free, and it moves back later if a suitable container for such slot becomes available on the top of a stack; this latter movement represents an unproductive operation of the crane.

Unproductive operations, i.e., reshuffles in the stacking area and unproductive moves of the crane, represent a cost for the terminal and slow down the loading operations. For this reason, when dealing with the TLPP, they must be minimized. Moreover, the load plan should be realized in order to maximize the train utilization; in this chapter this goal is achieved by maximizing the total value of loaded containers.

The MIP formulation proposed in Ambrosino and Siri (2014) for solving the TLPP described above is here briefly reported. First of all, let us introduce the notation used in the multi-objective MIP model.

Let C denote the number of containers in the stacking area, W the number of wagons of the train and S the number of train slots. For each container $i = 1,\ldots,C$, w_i is the weight (expressed in tons), λ_i the length (i.e., $20'$ or $40'$), π_i the value. As for the length, containers are stored in homogeneous stacks of $20'$ or $40'$. The relative position of containers in the stacks is given by $\gamma_{i,j}$, $i, j \in \{1,\ldots,C\}$, where $\gamma_{i,j} = 1$ if container i is over container j in a stack, and $\gamma_{i,j} = 0$ otherwise. Let Q represent the height of the stacks (i.e., the maximum number of tiers). For each wagon $\omega = 1,\ldots,$ W, S_ω is the subset of slots, B_ω the subset of weight configurations, and ϖ_ω the weight capacity. Moreover, $B_{s,\omega}$ is the subset of weight configurations for slot s of wagon ω, μ_s the length of slot s (i.e., $20'$ or $40'$), ρ_s the position of slot s in the train (expressed in TEUs) with respect to the first slot of the first wagon, $\delta_{b,s}$ the weight capacity of slot s in the weight configuration b, and $\overline{\Omega}$ the weight capacity of the train. When loading the train, the maximum number of loading operations (T) is equal to the TEU capacity of the train, which corresponds to loading only $20'$ containers. The actual number of operations executed depends on the cargo composition (number of $20'$ and $40'$ containers loaded) and it is equal to the number of containers loaded on the train, that is not greater than T.

Finally, α and β are, respectively, the unitary reshuffling and crane movement costs.

The decisions are related to:

- The choice of a configuration b for each wagon ω (variables $f_{\omega,b} \in \{0,1\}$, $\omega = 1,\ldots,W$, $b \in B_\omega$);
- The assignment of a container i to a slot s at operation t (variables $x_{i,s,t} \in \{0,1\}$, $i = 1,\ldots, C$, $s = 1,\ldots, S$, $t = 1,\ldots,T$); obviously, container i can be assigned to slot s only if $\lambda_i = \mu_s$.

The number of reshuffles is accounted by means of variables $y_{i,j} \in \{0,1\}$ defined for $i, j \in \{1,\ldots,C\}$ such that $\gamma_{i,j} = 1$ then, $y_{i,j} = 1$ if container i is reshuffled to load container j. Variables $z_t \geq 0$, $t = 2,\ldots,T$ model the unproductive distance traveled by the crane due to operation t; assuming the crane initially positioned over the first wagon (e.g., on the left end of the train), z_t equals the distance in TEUs covered backward by the crane (e.g., from right to left) between operation $t-1$ and t. Finally, technical variables $u_t \geq 0$, $t = 2,\ldots,T$ are introduced for not computing the return of the crane to its starting position after the last loading operation as an unproductive movement. The adopted MIP formulation is the following:

$$\min \alpha \cdot \sum_{\substack{i,j\in\{1,\dots C\}:\\ \gamma_{i,j}=1}} y_{i,j} + \beta \cdot \sum_{t=2}^{T} z_t - \sum_{i=1}^{C} \pi_i \cdot \sum_{s=1}^{S} \sum_{t=1}^{T} x_{i,s,t} \tag{1}$$

$$\text{s.t.} \quad \sum_{s=1}^{S} \sum_{t=1}^{T} x_{i,s,t} \le 1 \quad i = 1, \dots, C \tag{2}$$

$$\sum_{i=1}^{C} \sum_{s=1}^{S} x_{i,s,t} \le 1 \quad t = 1, \dots, T \tag{3}$$

$$\sum_{i=1}^{C} \sum_{t=1}^{T} x_{i,s,t} \le 1 \quad s = 1, \dots, S \tag{4}$$

$$\sum_{b\in B_\omega} f_{w,b} = 1 \quad \omega = 1, \dots, W \tag{5}$$

$$\sum_{i=1}^{C} \sum_{t=1}^{T} w_i \cdot x_{i,s,t} \le \sum_{b\in B_{s,\omega}} \delta_{b,s} \cdot f_{\omega,b} \quad \omega = 1, \dots, W \quad s \in S_\omega \tag{6}$$

$$\sum_{i=1}^{C} \sum_{s\in S_\omega} \sum_{t=1}^{T} w_i \cdot x_{i,s,t} \le \varpi_\omega \quad \omega = 1, \dots W \tag{7}$$

$$\sum_{i=1}^{C} \sum_{s=1}^{S} \sum_{t=1}^{T} w_i \cdot x_{i,s,t} \le \overline{\Omega} \tag{8}$$

$$\sum_{s=1}^{S} \sum_{t=1}^{T} t \cdot x_{i,s,t} - \sum_{s=1}^{S} \sum_{t=1}^{T} t \cdot x_{j,s,t} \le T \cdot y_{i,j} + T\left(\sum_{s=1}^{S} \sum_{t=1}^{T} x_{i,s,t} - \sum_{s=1}^{S} \sum_{t=1}^{T} x_{j,s,t}\right) \quad i,j \in \{1, \dots C\} : \gamma_{i,j} = 1 \tag{9}$$

$$z_t \ge \sum_{i=1}^{C} \sum_{s=1}^{S} \rho_s \cdot x_{i,s,t-1} - \sum_{i=1}^{C} \sum_{s=1}^{S} \rho_s \cdot x_{i,s,t} - u_t \quad t = 2, \dots T \tag{10}$$

$$u_t \le T\left(\sum_{i=1}^{C} \sum_{s=1}^{S} x_{i,s,t-1} - \sum_{i=1}^{C} \sum_{s=1}^{S} x_{i,s,t}\right) \quad t = 2, \dots T \tag{11}$$

The objective function (1) minimizes a weighted sum of costs corresponding to reshuffles in the stacking area and unproductive crane movements, and maximizes the total value of the loaded containers. Constraints (2)–(4) regard the assignment of containers to train slots. Thanks to (2), each container can be assigned at most to one slot; constraints (3) require that at most one container-slot assignment is done for each operation, and (4) guarantee that at most one container can be loaded in each slot. Constraints (5)–(8) impose weight restrictions. In particular, for each wagon, a given weight configuration must be chosen, as imposed by (5), and constraints (6), (7) and (8) represent the weight capacity constraints for each slot, each wagon and for the whole train, respectively. Constraints (9)–(11) ensure that the reshuffling variables $y_{i,j}$ and the variables z_t and u_t related to the crane movement are correctly computed. It is important to remember that container i is re-handled if, when operation t is executed, a container j, located in the stacking area under i, is loaded on the train while container i has not yet been loaded. Thus, in constraints (9), if, for a pair of containers i and j such that $\gamma_{i,j} = 1$, j is loaded before i, the left hand side assumes a positive value, forcing variable $y_{i,j}$ to be positive; note that the second term in the right hand side of (9) is used for not considering the loading of i as a cause of reshuffling if container j is not loaded on the train.

2.1 A Simple Initialization Heuristics

Since in some test cases it has been observed that the MIP solver hardly finds a first feasible solution different from the trivial one (which corresponds to load nothing on the train), a simple procedure to generate a non trivial starting solution has been designed. Such a procedure assigns one container per wagon so that unproductive movements of the crane, as well as reshuffles in the storage area, do not occur. The procedure considers the wagons in sequence and iteratively scans the top of the stacks of containers in the stacking area searching for a container compatible (i.e., for length and weight) with the available slots on the current wagon. Whenever such a container is found, it is removed from the stack and assigned to the relevant wagon slot and the next wagon is considered. If a container compatible with the current wagon is not found, the wagon remains empty and the procedure goes on to consider the next wagon. Then, the initial solution loads a number of containers equal to the number of wagons in the best case, while it loads nothing (trivial feasible solution) in the worst case. Anyway, in the experimental tests, the worst case never occurs when applying the initialization heuristics.

3 The MIP Heuristic Solution Approach

Constraints (2)–(4) and (7) of the TLPP model are typical constraints of the Generalized Assignment Problem, which is a classical combinatorial optimization problem known to be NP-hard. Thus also the TLPP is NP-hard. Due to the difficulty in solving this model, the solution approach based on the RANS heuristics introduced by Anghinolfi and Paolucci (2011) is here described and applied to the TLPP.

The RANS heuristics is a simple iterative search algorithm that starts from a first feasible incumbent solution x^c for the original MIP problem and iterates the following three steps until the maximum time limit is reached:

1. Variables fixing by random choices. A partially fixed MIP sub-problem is defined by fixing the values of a subset of k randomly selected binary and integer variables equal to the ones in x^c. The parameter k is initialized equal to the 10% of total number of binary and integer variables.
2. Local search. The sub-problem is solved by a MIP solver fixing t_{mip} as maximum allowed time. The t_{mip} parameter is set equal to $\max\{T_{\min}, 2 \cdot t_{rel}\}$, where $T_{min} = 30$ s and t_{rel} is the time needed to solve the linear relaxation of the original problem. If a new best solution is found, the incumbent x^c is updated.
3. Parameter adjustment. If a new best solution is found in at most $t_{mip}/2$, then k is increased as $k = k{\cdot}1.1$; otherwise k is reduced as $k = k{\cdot}0.9$ and a new iteration starts.

RANS operates at the higher level as an iterated local search: steps 1 and 3 define the area in the solution space that is explored in step 2 by a local search. The solution neighbourhood used by RANS is randomly defined by hard fixing a subset of incumbent variable values. The dimension of such neighbourhood is controlled by k that is adjusted depending on the experienced difficulty in solving sub-problems (if the condition in step 3 is verified, the sub-problem is considered easily solved). In this way the exploration is terminated in a reasonable short time and the choice of the initial value of k becomes not critical. The self-tuning mechanism used for k makes also the choice of the T_{min} value not critical, since it allows reducing the neighbourhood size so that the sub-problems can be easily solved. This kind of self-tuning used for k is similar to the adaptation of the fraction of variables to be hard fixed in the mutation phase of the polishing MIP heuristics (Rothberg 2007).

4 Experimental Analysis

The proposed approach has been evaluated by considering 30 instances, randomly generated with reference to a real Italian case study. These instances are divided in six groups (A,. . .,F) that differ for the number of containers stored in the yard (30-40-50) and for the height of the stacks in the yard ($Q = 4$ or 6). In each instance, 60% of containers are 20′ long. 20′ containers have a π value equal to 10, 15 or 20, randomly assigned with equal probabilities, whereas these values are doubled for 40′ containers. 20′ container weights, expressed in tons, are uniformly distributed in $U[6, 24]$, whereas 40′ container ones in $U[10, 30]$. Containers are stored in stacks in accordance with their length. The train is composed of 15 wagons and its maximum load is 900 tons. The wagon composition of the train is randomly generated assuming three types of wagons with different maximum weight, available slots and number of alternative configurations. The train capacity (T) ranges from 33 to 42 TEUs. In the computational tests α and β are fixed to 5 in order to better represent the real operative scenario, in which the cost of these unproductive movements is almost equivalent. It is important to note that these weights have to be defined having in mind that the main aim is to load the train; some preliminary tests for tuning these weights have been executed.

RANS has been implemented in C++ on a 2.4GHz Intel Core 2 Duo E6600, 4GB RAM notebook, and Cplex 12.5 is the MIP solver used.

Table 1 shows the dimensions of the instances in terms of number of variables and constraints of the proposed model and the values of the objective function obtained by the MIP solver for different CPU time limits, i.e., 600 s, 1200 s, 1800 s, 3600 s and 14,400 s.

From Table 1 it is apparent that the objective (1) cannot assume values strictly greater than zero, as these are dominated by the trivial zero-cost solutions corresponding to not loading any container on the train. For shorter computational times the MIP solver was not able to find a solution different from the trivial one for several instances and even after 4 h of computation only the zero-cost solution was found for instance 26.

Figure 1 shows the behaviour in time of the three components of the objective function produced by the MIP solver together with the trend of the optimality gap for the six groups of instances.

The trend of the most relevant objective, i.e., the value of the loaded containers, is non-decreasing, whereas a non-monotonic trend can be observed for the cost of reshuffling and of unproductive movements of the crane. This is due to the fact that a possible increase in such components may lead to an improvement of the overall objective. This is also confirmed by the behaviour of the optimality gap that is monotonically decreasing in time. However, the considered instances appear difficult to solve since the gap for most of the instance groups is quite high even after 4 h of computation.

Table 2 compares the average results obtained by RANS over 5 runs with the ones of the MIP solver, fixing for both methods a maximum computation time which ranges from 600 to 3600 s.

Table 2 provides the percentage deviations of the results of RANS (computed as $100 \cdot (RANS\_obj - MIPsolver\_obj)/|MIPsolver\_obj|$) aggregated for the six groups of instances and, in the last row, shows the average percentage deviations over all the set of instances. Table 2 clearly shows the effectiveness of RANS, which was able to find better solutions even with a short computation time. Then, Table 3 summarizes the percentage deviations of the RANS results after 10 min with respect to the MIP solver ones for all the different available computation times. Here the values in boldface denote a prevalence in the average of RANS over the MIP solver, and it is easy to note that only for three instance groups and after 4 h of computation the MIP solver provided better results.

Further tests investigated the quality of the solution generated by the initialization heuristics and the possible benefits of this initialization for the MIP solver. Table 4 shows the percentage deviations of the MIP solver and RANS results with respect to

Table 1 The MIP solver results

Instances	Variables	Constraints	600 s	1200 s	1800 s	3600 s	14,400 s
1	53,154	373	–100	–370	–415	– 477.5	–517.5
2	36,059	362	–295	–600	–627.5	–665	–642.5
3	25,807	318	–470	–515	–515	–555	–555
4	38,969	351	–237.5	–270	–280	–407.5	–597.5
5	33,190	340	–300	–397.5	–502.5	–520	–510
6	30,772	372	–232.5	–140	–140	–505	–505
7	62,400	438	0	–190	–110	–150	–470
8	36,092	394	–120	–195	–390	–467.5	–530
9	33,386	383	–497.5	–502.5	–550	–565	–565
10	55,185	394	–77.5	–80	–315	–307.5	–375
11	29,125	356	–552.5	–605	–605	–605	–605
12	47,991	389	–280	–505	–510	–552.5	–552.5
13	40,909	367	–330	–450	–515	–405	–405
14	31,108	367	–550	–610	–610	–610	–610
15	55,617	378	0	–125	–142.5	–402.5	–457.5
16	55,651	414	–100	–100	–110	–337.5	–557.5
17	48,026	425	–130	–130	–130	–192.5	–540
18	48,294	403	0	–60	–65	–225	–535
19	55,644	403	0	–97.5	–115	–377.5	–430
20	51,762	436	–85	–205	–210	–210	–407.5
21	48,210	368	–50	–180	–302.5	–530	–530
22	59,534	379	–262.5	–300	–362.5	–415	–585
23	83,495	401	0	–200	–260	–277.5	–492.5
24	69,455	401	0	0	–285	–370	–297.5
25	100,716	467	–40	–40	–40	–150	–447.5
26	65,817	438	0	0	0	0	0
27	63,887	449	0	–70	–400	–440	–422.5
28	59,968	460	–80	–80	–302.5	–412.5	–375
29	64,633	471	–100	–100	–247.5	–367.5	–520
30	51,120	438	–225	–225	–267.5	–557.5	–562.5

the initial solution, pointing out that, although quite simple, the initialization heuristics produced average results better than the ones of the MIP solver after half an hour of computation for groups B and F, and even after an hour for groups D and E.

Table 5 provides an overall comparison of the RANS results after 600 s with the ones produced after 1 h by the MIP solver with and without the heuristics starting solution initialization. The columns of Table 5 show the average values for the six groups of instances for the loaded value (L), the number of reshuffles (R), the number of unproductive crane movements (U) and the percentage TEU occupancy on the train (O). In addition, Table 5 shows, for the initialized MIP and the RANS, the percentage deviation of the objective values from the MIP solver ones (D). The heuristics initialization produced an overall benefit in the objective function results obtained by the MIP solver, even if there is a worsening both in the overall

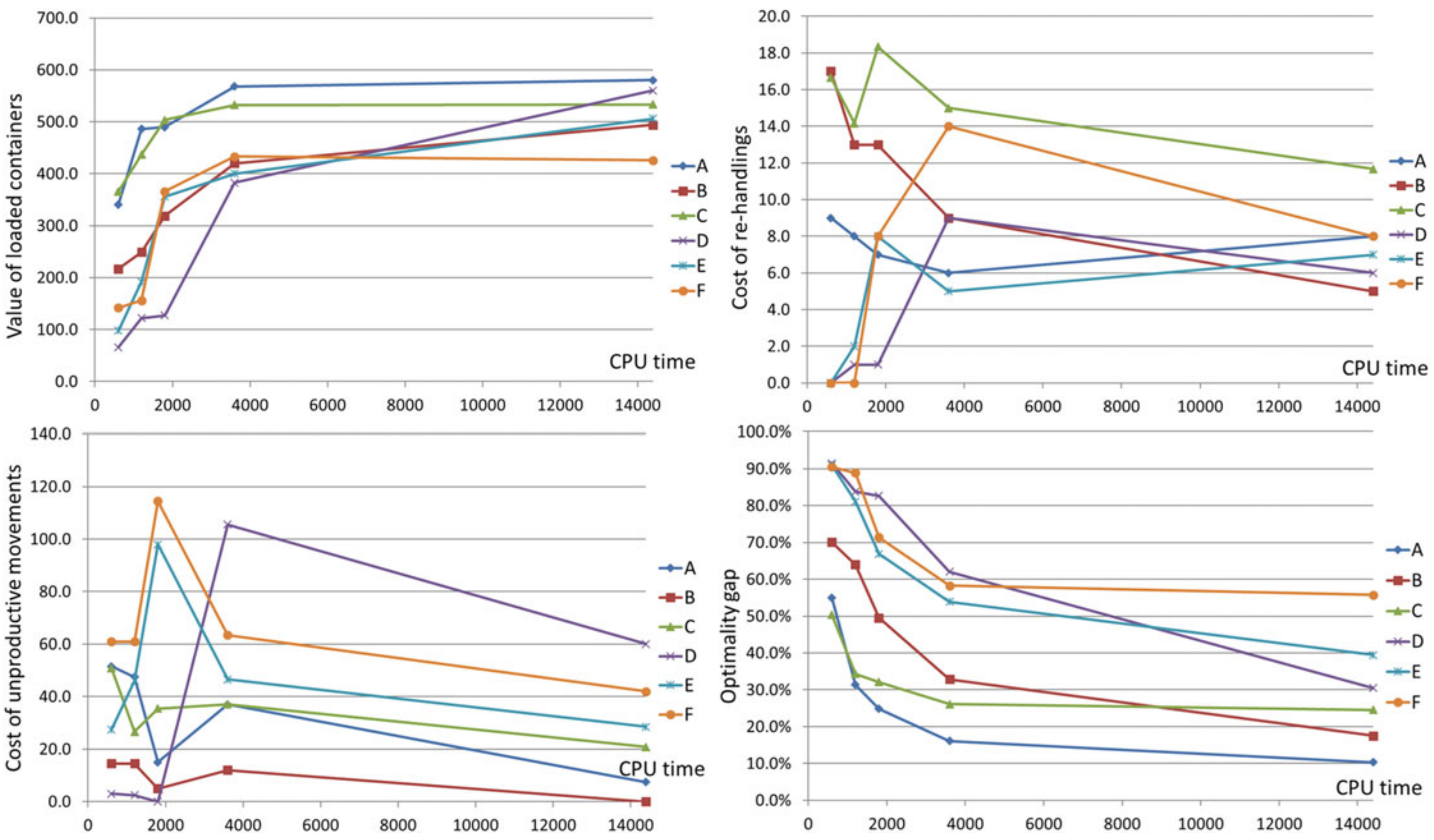


Fig. 1 The trends of the three objectives and the optimality gap obtained by the MIP solver

Table 2 Percentage deviations between RANS and MIP solver results

Groups	600 s	1200 s	1800 s	3600 s
A	–137.40	–33.80	–24.24	–6.36
B	–175.09	–175.19	–116.62	–46.76
C	–40.33	–69.34	–56.65	–15.63
D	–360.29	–370.59	–346.60	–113.16
E	–814.71	–446.06	–340.59	–97.51
F	–400.86	–459.51	–92.18	–35.51
Averages	–285.28	–245.25	–165.25	–53.07

Table 3 Percentage deviations of the RANS results after 600s w.r.t. the MIP solver results

Groups	600 s	1200 s	1800 s	3600 s	14,400 s
A	**–137.40**	**–30.55**	**–20.32**	**–1.55**	7.91
B	**–175.09**	**–153.31**	**–94.21**	**–28.09**	14.35
C	**–40.33**	**–60.66**	**–47.65**	**–7.55**	**–4.62**
D	**–360.29**	**–349.76**	**–315.58**	**–86.61**	5.06
E	**–814.71**	**–459.69**	**–345.90**	**–89.69**	**–19.48**
F	**–400.86**	**–463.37**	**–85.75**	**–25.97**	**–19.45**
Averages	**–285.28**	**–237.98**	**–153.84**	**–40.39**	**–2.13**

Table 4 Percentage deviations of the initialization heuristic solutions w.r.t. the MIP solver and RANS results

	MIP Solver				RANS
Groups	600 s	1200 s	1800 s	3600 s	600 s
A	–44.97	17.78	24.14	35.55	35.82
B	–100.65	–87.40	–49.89	2.51	24.57
C	9.68	10.62	17.36	34.61	38.93
D	–190.41	–177.10	–156.76	–20.52	37.34
E	–428.49	–202.15	–134.66	–3.38	42.86
F	–227.92	–260.22	–19.62	19.29	36.44
Averages	–142.23	–108.21	–54.40	11.07	35.99

loaded value and in the percentage occupancy of the train. On the other hand, the average RANS results are the best for the overall objective, the loaded value and train occupancy, paying this with a worse value for the two less important objectives. Finally, note that the 5% confidence interval for the average percentage deviations of RANS results in 600 s from MIP solver results in 1 h is [–66.49%, –14.29%], whereas from the initialized MIP solver is [–36.85%, –20.33%], thus denoting that in both cases RANS produced, on average, statistically significant better results.

Although the dimensions assumed for the yard in the previous experimental analysis are representative of the real case study used as reference, two final tests were performed in order to evaluate the ability of the proposed method to scale for larger yards. Therefore, two additional scenarios, denoted by *Medium* (M) and *Large* (L), respectively characterized by 100 and 500 containers in the yard, were randomly generated. The MIP model for scenario M includes 167,395 variables and 635 constraints, whereas the one for scenario L presents 675,887 variables and 2046 constraints. Table 6, analogously to Table 5, shows the comparisons between the

Table 5 The overall comparison of the MIP solver results with the RANS ones

	MIP solver (3600 s)				Initialized MIP solver (3600 s)					RANS (600 s)				
Grp	L	R	U	O (%)	L	R	U	O (%)	D (%)	L	R	U	O (%)	D (%)
A	518	1.4	1.9	87.31	448	0	0.4	75.38	13.41	537	8	7.5	90.55	–1.55
B	431	3	4.6	75.26	483	1.6	0.3	68.43	–14.66	532	22	96	93.24	–28.09
C	577	3.8	6.3	92.68	502	1.4	0.8	70.79	14.74	552	16	35.5	90.52	–7.55
D	396	1.6	14.7	68.03	405	3.8	1.8	70.18	–54.64	502	10	15	84.62	–86.61
E	438	2	6.7	68.22	365	0.6	1.5	60.87	–18.79	573	8	20.5	92.50	–89.69

Table 6 The comparison between MIP solver and RANS results for the larger yard scenarios

	MIP solver (3600 s)				Initialized MIP solver (3600 s)					RANS (600 s)				
Scenario	L	R	U	O (%)	L	R	U	O (%)	D (%)	L	R	U	O (%)	D (%)
M	30	0	0	8.11	280	0	0	54.05	–833.33	640	10	70	100.00	–1766.67
L	120	0	0	15.79	407	0	0	63.16	–239.17	760	0	55	100.00	–487.50

results obtained for the two new scenarios by the MIP solver (with and without initialization) in 3600 s and RANS in 600 s. The greater difficulty in finding good solutions for these new scenarios is highlighted by the low train occupancy levels obtained by the MIP solver. Better results are produced when the solver started from the solutions generated by the initialization heuristics, even if the final levels of occupancy of the train capacity are still quite unsatisfying. Note that the improvement obtained in 1 h by the MIP solver with respect to the starting solutions are only 3.70% for scenario M and 33.44% for scenario L. On the other hand, even for these larger cases, RANS shows its ability to find high quality results in an acceptable short time, in particular being able to exploit all the available train load capacity.

5 Conclusions

This chapter discusses a solution approach based on a MIP heuristics to the MIP model proposed for the train load planning problem at seaport terminals. Such heuristics performs a randomized iterative local search exploring a sequence of solution neighbourhoods by defining and solving MIP sub-problems. Experimental tests performed on a set of random instances, generated with reference to a real terminal context, showed the difficulty in solving the presented MIP model and the effectiveness of the proposed heuristic method to find good solutions in an acceptable computation time.

References

Ambrosino, D., & Siri, S. (2014) Models for train load planning problems in a container terminal. In J. Freire de Sousa & R. Rossi (Eds.), *Computer-based modelling and optimization in transportation*, Advances in intelligent systems and computing. Cham: Springer.

Ambrosino, D., Bramardi, A., Pucciano, M., Sacone, S., & Siri, S. (2011). Modeling and solving the train load planning problem in seaport container terminals. In *Proceedings of the 7th IEEE conference on automation science and engineering* (pp. 208–213).

Ambrosino, D., Caballini, C., & Siri, S. (2013). A mathematical model to evaluate different train loading and stacking policies in a container terminal. *Maritime Economics & Logistics, 15*, 292–308.

Anghinolfi, D. & Paolucci, M. (2011, May 4–6). A new MIP heuristic based on randomized neighborhood search. In *Proceedings of the VII ALIO–EURO—Workshop on applied combinatorial optimization, Porto, Portugal* (pp.84–87).

Anghinolfi, D., & Paolucci, M. (2014). A general purpose Lagrangian heuristic applied to the train loading problem. *Procedia—Social and Behavioral Sciences, 108C*, 37–46. Elsevier.

Anghinolfi, D., Paolucci, M., Sacone, S., & Siri, S. (2011). Freight transportation in railway networks with automated terminals: a mathematical model and MIP heuristic approaches. *European Journal of Operational Research, 214*(3), 588–594.

Bostel, N., & Dejax, P. (1998). Models and algorithms for container allocation problems on trains in a rapid transshipment shunting yard. *Transportation Science, 32*, 370–379.

Bruns, F., & Knust, S. (2012). Optimized load planning of trains in intermodal transportation. *OR Spectrum, 34*(3), 511–533.

Corry, P., & Kozan, E. (2006). An assignment model for dynamic load planning of intermodal trains. *Computers & Operations Research, 33*, 1–17.

Corry, P., & Kozan, E. (2008). Optimised loading patterns for intermodal trains. *OR Spectrum, 30*, 721–750.

Rothberg, E. (2007). An evolutionary algorithm for polishing mixed integer programming solutions. *INFORMS Journal on Computing, 19*, 534–541.

Stahlbock, R., & Voss, S. (2008). Operations research at container terminals: A literature update. *OR Spectrum, 30*, 1–52.

Steenken, D., Voss, S., & Stahlbock, R. (2004). Container terminal operation and operations research—A classification and literature review. *OR Spectrum, 26*, 3–49.

Utilizing Breakthrough Innovations: The Need for Information Sharing as a New Key Performance Indicator for Container Port Operations

Bjorn Jager and Ning Lin

Abstract As a response to higher customer demand and increased competition, innovations in port operations is of concern for port customers and port operators. The growth in world trade is doubling every 5–7 years with a corresponding increase in cargo container movements, most of which are handled by seaports. Moving more traffic through the limited area of a seaport can only be achieved by an increase in port performance. Shipowners, terminal operators and forwarding agents each have optimized their performance guided by values collected on key performance indicators. The purpose of this chapter is to contribute to the understanding of the use of key performance indicators as a mean to drive port innovations. We argue that the use of standard key performance indicators leaves ports in the region of incremental innovations with a diminishing rate of return of investments, missing out on the potential efficiency growth by breakthrough innovations. Our results from a case study at Oslo port shows that operations suffer from a lack of information sharing resulting in an unused potential, not captured by the current performance indicators. We propose a new Information Sharing Indicator to motivate and guide ports in adopting breakthrough innovations for information sharing.

Keywords Port Logistics · Key Performance Indicators · Metrics · Information Sharing · Innovations

---

B. Jager (✉)
Molde University College, Molde, Norway
e-mail: bjorn.jager@himolde.no

N. Lin
Centre for High North Logistics, Nord University, Bodø, Norway
e-mail: ning.lin@nord.no

J. E. Hernández et al. (eds.), *Collaborative Logistics and Intermodality*,
https://doi.org/10.1007/978-3-030-50958-3_8

1 Introduction

Generally, performance measurements are crucial for all types of organizations, including privately owned corporations, state-owned corporations and non-profits organizations because they illustrate the extent to which these organizations have achieved their targets. Port actors experience the ongoing digitalization of society. Assets within a port, like cargo containers, trucks, cranes, and employees, are increasingly being attached to digital devices that connect the asset with management systems over the Internet through wireless technologies (Wi-Fi, RFID) and associated management software. Examples are the Electronic Product Code Information System (EPCIS) and various dashboard management systems. The goals are to improve resource management, traffic flow, and management of infrastructure and environment, using real-time data and analytics (SmartPort 2014). This digitalization contributes to the transformation of port management from managing physical assets only, towards an increased need to manage the information used to plan and operate the port. In parallel with the digitalization, the growth of cities, as well as the growth of world trade, lead to an increasing amount of goods being handled by ports (Duranton and Turner 2012). Since ports and cities are naturally co-located, its land area is of premium value with few or no possibility for growth. Thus, an increasing amount of goods must be handled using the same or less land area. This challenge can only be met by improving the performance of ports. However, many ports struggle to improve their performance (Lin 2013). We postulate that a specific reason for this is the lack of performance metric that captures the ongoing digitalization, and thus can guide their efforts for improvements. The industry-wide port performance frameworks used consists of a set of key performance indicators (KPIs). Generally, the performance of a port is characterized by its ability to handle the movement of goods between the sea-side transporters and the land-side transporters. The most important measure for this service is the volume of goods handled per unit of time expressed as Container Throughput since the cargo container is the predominant transportation unit (SmartPort 2014; Cullinane and Wang 2010). Improving port performance by increasing the Container Throughput is a common goal of ports since it in turn gives lower ship-turnaround-time, as well as lower truck-turnaround-time of port customers. A previous study generalized the resources needed for port operations as land, labour and capital (SmartPort 2014). Capital includes port assets like cranes, ship-shore container gantry, straddle carriers and various container-handling trucks. These resources constitute the indicators in the KPIs. We show in this chapter that the KPIs used include performance indicators for physical capital, but they lack an indicator capturing the performance of the digitalization process. We identify information sharing between port actors and terminal operators as an important Key Performance Indicator (KPI). Information sharing is often discussed in conjunction with visibility. In this chapter, information sharing refer to an activity that leads to visibility of relevant events, objects and plans across company borders to support performance-related decisions. We motivate the need for an Information Sharing Indicator by conducting a case study of the main container terminal in Norway, the Oslo port. Oslo port handles most of Norway's import and export of merchandises. We describe the Information Sharing Indicator and propose how to incorporate it within the contemporary frameworks used by the industry for port performance measurements. The remaining of this chapter consist of a review of related literature in Sect. 2, a case study of the performance of Oslo port in Sect. 3, our proposal for Information Sharing as a new performance indicator in Sect. 4 followed by conclusions in Sect. 5.

2 Related Literature

A number of research papers show that information sharing is important for improving supply chain performance in general (Koçoğlu et al. 2011; Prajogo and Olhager 2012; Ye and Wang 2013), and in particular to counter the bullwhip effect, i.e. the demand variability amplification along a supply chain. It has proven to provide significant inventory reduction and cost savings (Lee et al. 2000). However, when it comes to performance measurement frameworks used by ports, information sharing is not included, and consequently not used. Some papers recognize the importance of information sharing on port performance. Olesen et al. describe the importance of how to enable information sharing in complex environments such as ports (Olesen et al. 2012, 2014). We find that several indicators like crane efficiency and area efficiency in previous frameworks are directly positively affected by information sharing, although it is not stated in an explicit manner. We investigate previous research on KPIs for port performance by focusing on the indicators identified by listing their input and output variables. Technology and automation have the potential to enhance port efficiency radically. Thus, we look at the theory of innovations to separate incremental innovations from breakthrough and disruptive innovations.

2.1 Input and Output Selection Using Data Envelopment Analysis

Commonly, Data Envelopment Analysis (DEA) is being used to benchmark the port performance of various ports. In our research, we do not use DEA since it requires more input data than what is currently available. However, since previous studies involving DEA give valuable insights regarding the input and output variables used. We identify KPI variables used by earlier researchers in Table 1.

As can be seen from Table 1, all of these papers use input and output variables related to physical aspects.

Table 1 Input and output variables by previous researches

Paper	Inputs	Outputs
Schøyen and Odeck (2013)	Berth length, terminal areas, yard gantry cranes, straddle carriers and container handling trucks	Container throughput
Kasypi and Shah (2013)	Terminal area, max draft, berth length, quay crane index, yard stacking index, number of vehicles, number of gate lanes	Container throughput
Yuen et al. (2013)	Number of berths, total length, port land-area, quay crane, yard gantries	Container throughput
Barros (2012)	Quay length, number of cranes, number of workers	Number of containers, dry bulk in tons, liquid bulk in tons
Barros et al. (2012)	Quay length, port area, labour	Number of containers, dry bulk in tons, liquid bulk in tons, delays in handing ship cargo
Cullinane and Wang (2010)	Terminal length, terminal areas, quayside gantry, yard gantry, straddle carrier	Container throughput
Hung et al. (2010)	Terminal area, ship-shore container gantry, number of container berth, terminal length	Container throughput
Wu and Goh (2010)	Terminal area, total quay length, pieces of equipment	Number of containers
Al-Eraqi et al. (2008)	Berth length, storage area, handling equipment	Ship calls, Container throughput
Cullinane et al. (2004)	Terminal length, terminal area, quayside gantry, yard gantry, straddle carriers	Number of containers

2.2 The Smart Port Project

The smart-port project is a comprehensive study of key factors for competitiveness for Mediterranean ports. The project has taken into account previous EU initiatives to compile all relevant information for making a holistic definition of the smart-port concept (SmartPort 2014). The scope of the project covers different categories of port competitiveness, including operational, energy, and environmental aspects resulting in 68 KPIs in total for the three categories. Our focus is on the operational issues; thus, we consider this part of the Smart Port project. The nine groups of KPIs for the operational category are:

- Berth productivity: Annual throughput (Twenty-foot Equivalent Unit (TEU)/ meter of container quay).
- Infrastructure productivity: Annual TEUs/Total terminal area, Annual TEUs/ Total storage or yard area, Annual TEUs/(Total storage or yard area + Total hinterland storage areas), Annual TEUs/ Number of containers terminals, Annual TEUs reefers/Total number of electrical outlets for reefers (static capacity).
- Capacity for receiving large vessels: Length of quay with +14 m depth (m)/ Total quay length (meters) – only container quay.

- Size and use of the maximum capacity: Annual TEUs/capacity of the containers terminals (static capacity), Average annual number of hours (containers terminals are working), Annual TEUs/Average annual number of hours (containers terminals are working).
- Technologic level: Number of Information and Communication Technologies (ICTs) that the port and terminals operators offer to the port community: Wireless communications (Private Mobile Radio for voice, Wi-Fi for data, etc.), Wireline communications (Private Automated Branch Exchange, Fiber Optical network, etc.), Radio-frequency identification (container identification, container security, entrance system, etc.), Optical Character Recognition, Closed-Circuit Television (Container/Truck identification, security, etc.), Global Navigation Satellite System, Differential Global Navigation Satellite System (Crain guidance, container/truck positioning, etc.), Technology Operations Services (Command and control integration, logistic support), Port Community System, Logistics Collaborative Systems, Business-to-Business systems.
- Level of automation: Annual throughput in TEU per number of quayside cranes, Percentage of automatized quayside cranes, Annual throughput in TEU per number of yard gantries, Percentage of automatized yard gantries, Annual throughput in TEU per number of equipment for internal movements (trucks, shuttle, etc.), Percentage of automatized equipment for internal movements (trucks, shuttle, etc.), Total percentage of automatized quayside cranes, yard gantries and equipment for internal movements.
- Level of Intermodality: Magnitude of the rail infrastructure (Total sidings in port area (Km)/Total terminal area), Use of the intermodality-railway option (Total TEUs transported by rail/Total TEUs), Use of the intermodality-road option (Total TEUs transported by road/Total TEUs).
- Lines calling at the port: Total number of TEUs/Number of carriers (only carriers of maritime transport), Number of main lines (large intercontinental and inter-oceanic lines with large ships and tonnage arriving in port and with a large volume of goods) /Total number of lines, Total TEUs per number of vessels that stops in the port.
- Quality, safety and security: Number of safety and security arrangements and certificates, Number of quality certificates or arrangements according any standard that can contribute to improve or ensure the operations' efficiency, Scope of the quality certificates or arrangements (Port activities covered by quality management systems), Scope of the safety and security arrangements and certificates (Port activities covered by the safety and security management systems).

Group 1–4 covers berth area, container throughput, capacity for large vessels, while group 5 focus on the technology available in terms of hardware and software. In group 6, the level of automation is expressed as container throughput per automated equipment. The Level of Intermodality in group 7, followed by the number of throughput per Lines calling at the port in group 8 and Quality and safety KPIs in group 9. This set of operational KPIs covers physical assets as well as software and security and quality. We note that the vital aspect of information sharing is not covered.

2.3 Woo, Pettit and Beresford (2011)

In respect to seaport performance, the most recent framework presented by Woo et al. (2011) is one of the most comprehensive frameworks in use. It is created based on the interests of all stakeholders of a port and it represents the latest development in this field. Woo et al. created this framework in 2008 and modified it in 2011. Woo et al. believe different interest groups in ports have their own preference on performance indicators and their preference may differ from one to another. Therefore, they selected four groups to conduct a survey, including port-operating companies, shipping companies, public sector organizations (i.e., government and port authority) and academics. Although academics are not stakeholders of a port, they believe academics have knowledge on logistics and port industry and may have a broader perspective of future issues. One hundred questionnaires were sent by email during their survey and 72 responses were received (Woo et al. 2008). They generated an initial port performance measurement framework based on the 72 responses in the survey resulting in 7 indicator categories with a total of 16 performance indicators. Three years later, they published a follow up of their study. Their new framework was validated by 100 questionnaires sent to the same four groups, namely, port operating companies, shipping companies, public sector organizations and Academics. Most importantly for our case, they identified the importance of cooperation among stakeholders from the survey responds, and they acknowledged this by including the category “Port cooperation and networking”. However, as can be seen in Fig. 1, they were not able to identify any performance indicators for this category. In addition, the port cooperation and networking category were identified by reference to the development of strategic relationships with overseas ports, between neighbouring ports and at inland ports. Previously, others like e.g. Notteboom and Winkelmans (2001) had suggested that even simple forms of coordination could help to counterbalance carrier power, especially when container flows towards the shared local hinterland of the neighbouring ports are involved. Thus, including the port cooperation and networking category was appropriate even if how to operationalize it in terms of performance indicators was not done. Since indicators for information sharing are missing (Fig. 1), we suggest adding it both for the Oslo port authority based on our case study and to the general framework (Fig. 5).

2.4 Incremental Versus Breakthrough Innovations

The etymology of innovation is from the Latin “innovare” that means to renew or change. We use the term innovation to address change from two perspectives; incremental and breakthrough innovations. Incremental innovations describe modest changes to existing products or services. These improvements keep a business competitive, by e.g. adding new product features and service enhancements. The

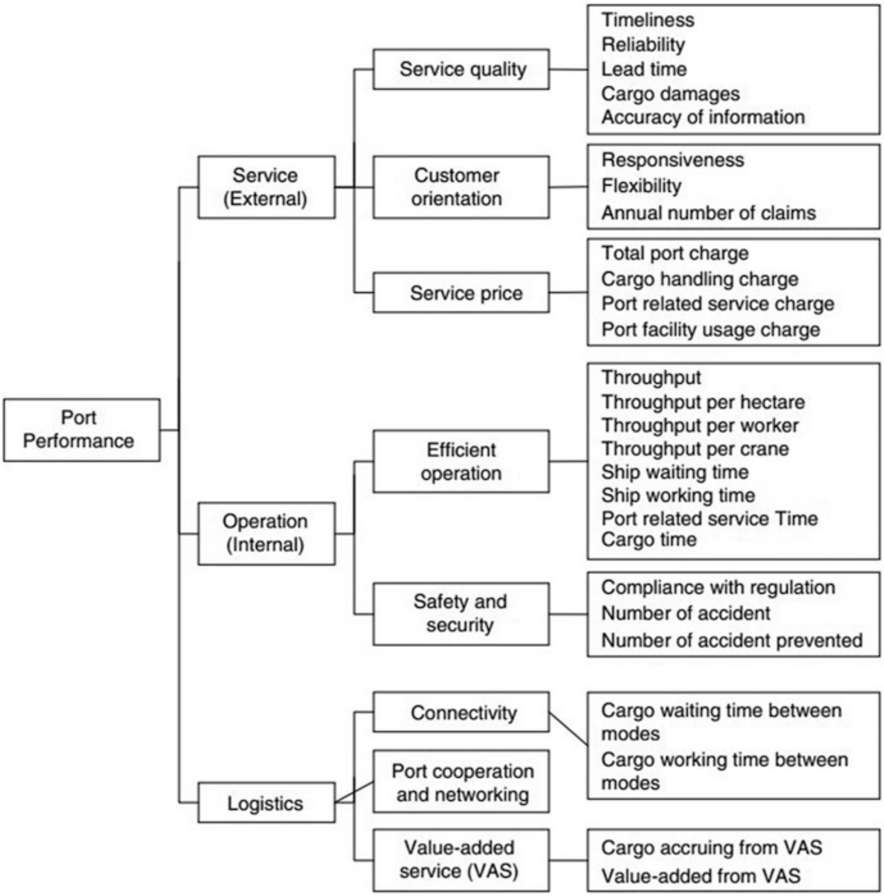


Fig. 1 Multi-dimensional port performance measurement framework (Woo et al. 2011)

incremental development of technologies is commonly characterized by a logistic function, denoted the S-curve since it follows an *S*-shaped growth path (Andersen 1999). It has an initial growth, followed by exponential growth, then a period in which the growth slows and then levels off, approaching—but never attaining—a maximum upper limit. The inflection point separating the S-curve into two equal regions of opposite concavity is called the point of diminishing performance (returns). For technologies, this means that, at some point, further investments in existing technologies will only give marginally increased performance. This is illustrated by the S-curve at the left in (Fig. 2). A breakthrough innovation refer to large technological improvements that propel an existing product or service ahead of competitors. Breakthrough innovations promise significant gains in performance compared with current products (Kalbach 2015; To 2006). A breakthrough

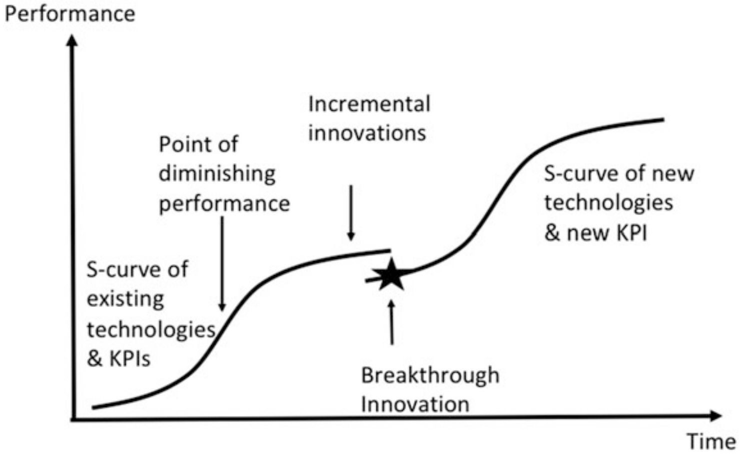


Fig. 2 The transition from one S-curve to a new S-curve need a new KPI capturing the performance of the breakthrough innovation. In our case: the new Information Sharing KPI

innovation implies entering the incubation region of a new S-curve, possibly at a lower level, intersecting the first curve at some point in time as illustrated in Fig. 2.

We argue that a new S-curve requires new performance indicators representing the driving element of the innovation. In our case, information sharing. The new "Information Sharing" KPI guide ports towards utilizing intelligent port systems enabling them to adapt to the breakthrough innovation. Without a new indicator, the indicators of the previous S-curve will guide companies, slowing down a move towards utilizing new technology of the next S-curve. We note that a breakthrough innovation differs from a disruptive innovation as defined by Clayton Christensen et al. (2015). Disruptive innovations result in worse product performance in the near term by bringing to market a very different value proposition of lower initial performance than had been available previously.

In summary, there is a gap in the existing literature on KPIs. The current literature mostly focuses on indicators related to the old S-curve; the physical movement or storage of goods. To enter the new S-curve one need to focus on information sharing to coordinate activities among actors in modern smart ports. This chapter aims at reducing this gap by introducing Information Sharing as a new KPI for container port operations.

3 Case Study: Performance of Oslo Port

In this section, we introduce the performance indicators currently used by Oslo port authority and we identify enablers for improving overall performance including a suggested performance indicator for information sharing.

3.1 Oslo Port

The port of Oslo is the major Norwegian port designated to passengers and freight. As is common for public ports, Oslo port is a municipally-owned company, non-profit / self-financing organization, reporting to the City of Oslo's department for transport and environment. Oslo port handles passengers and all kinds of commodities, including dry bulk, wet bulk, containers, Ro-Ro and parcels. In terms of this research, the performance of container terminals is our focus. There are two container terminals at the Oslo port: Oslo Container Terminal is the operator at Ormsundkaia, while Sjursøya Container Terminal works at Søndre Sjursøykai (Lin 2013). In container terminals in, or close to, city centres, the limited area is one of the main challenges as is also the case for Oslo port (Lin 2013). Oslo port has already lost certain customers and market share due to its limited storage area. To address this problem, the Oslo port authority wants to convert its container terminals into the most area-efficient terminals in Europe. They have made two efforts to improve area productivity during the last 10 years. Firstly, they purchased four Rubber Tired Gantry (RTG) cranes to replace reach stacker (RS) vehicles. RTGs are more efficient than reach stackers because the former requires less space for operation and they allow greater density in the stacking area than the RSs. Also, it is commonly known that RTGs have a higher automation potential (Kalmar Container Handling Systems 2015). Secondly, the Oslo port authority improved their terminal operating system (TOS) that also can contribute to increase the area efficiency by bettering housekeeping. Remarshaling is one of the main reasons for conducting housekeeping. The remarshaling operation is a way in Oslo port (it is also a common practice in a normal port) to speed up loading operation of export containers onto a ship. Because export containers normally are scattered around a block, containers on the storage area should be rearranged to mirror their final positions on the container ship. An advanced information system can provide a feasible working plan to convert the current layout of the storage area into the desired layout with the minimum number of container moves and travel distance. Since each movement of container requiring space, a better terminal operating system can improve the container flow, thereby increasing area efficiency.

3.2 Performance Measurement by Oslo Port Authority

The four performance indicators used by Oslo port authority to measure the performance of Oslo Container Terminal and Sjursøya Container Terminal were Container Throughput, Area Efficiency, Crane Efficiency and Gate-to-Gate time. These performance indicators are included in the framework created by Woo et al. (2011) who use other terms to interpret these indicators. We show the mapping in Table 2.

These performance indicators are the most frequently used ones by not only port authorities but also their stakeholders, including terminal operators, forwarding

Table 2 The relationship between the performances indicators used in Oslo port and the framework created by Woo et al. (2011)

Indicators adopted by Oslo port	Indicators in the framework created by Woo et al. (2011)
Container Throughput	Throughput
Area Efficiency	Throughput per Hectare
Crane Efficiency	Throughput per Crane
Gate-to-Gate Time	Included in indicator of "Timeliness"

agents, shipping lines, etc. More specifically, terminal operators use them to assess their own performance; port authorities need to measure their services providers' performance and port users (i.e., forwarding agents, shipping lines, etc.) use these indicators (especially, crane efficiency and gate-to-gate time) to compare service quality between different ports.

3.2.1 Container Throughput

Container throughput of Oslo port is 208,799 and 202,790 in terms of Twenty-foot Equivalent Unit (TEU) and 1346 and 1278 in terms of thousand tons in 2011 and 2012 respectively (Lin 2013). For more information, please see Tables 3 and 4. It is the most frequently used indicator and should be adopted by all container terminals worldwide.

In Oslo container terminal, throughput is constrained by the size of stacking storage area to a large extent, since both import and export containers need to stay at the terminal waiting for vehicles or container ships coming and collecting them.

Table 3 Container throughput (Number of TEUs) from 2003 to 2012

Year	Number of TEUs	Year	Number of TEUs
2003	162,385	2008	190,307
2004	177,019	2009	178,943
2005	170,505	2010	201,893
2006	172,065	2011	208,799
2007	196,252	2012	202,790

All information of this table is found from Oslo port's annual reports (Lin 2013)

Table 4 Container throughput (amount of tons) from 2003 to 2012

Year	Throughput (ton)	Year	Throughput (ton)
2003	1,166,000	2008	1,247,319
2004	1,226,822	2009	1,171,608
2005	1,088,840	2010	1,302,555
2006	1,042,842	2011	1,346,906
2007	1,149,482	2012	1,278,000

All information of this table is found from Oslo port's annual statistic reports (Lin 2013)

Table 5 Container throughput (amount of tons) from 2003 to 2012

Year	Container Throughput (1000 tons)	Terminal area (square meters)	Area efficiency (tons per square meter)
2011	1358	150,000	9.1
2012	1278	167,000	7.7

All information of this table is found from Oslo port's annual statistic reports (Lin 2013)

Export containers through Oslo port are given 7 days free time of storage. Containers can be delivered to the terminal and stay there for 7 days without cost for the shipper. In terms of import containers, there are 2 days free time. If a container stays at terminal longer than these limitations, the owner of this container will be charged a demurrage, which is costly. Hence, storing containers in a terminal beyond the days included is not an attractive option. Oslo port has already lost certain customers and market share due to its limited storage area (no more area to store unloaded containers of new customers). It happened when they shortened the free storage period for import container to 2 days. 5–7 days are more common in Norwegian ports (Berg 2013).

3.2.2 Area Efficiency

Oslo port authority wants to convert its container terminals into the most area efficient terminals in Europe. Therefore, area efficiency is adopted as a performance metric by Oslo port authority. It is calculated by the ratio of container throughput and terminal area. It is also worth to mention that the port authority regards container throughput in tons as output factor rather than number of TEU. Table 5 illustrates area efficiency in 2011 and 2012 provided by Oslo port authority.

3.2.3 Crane Efficiency

Currently, the gross crane efficiency is 20 lifts per crane hour and net one is 27 lifts per crane hour in Oslo container terminals (Hatteland 2013). The target of gross crane efficiency is 20 lifts per crane hour currently, thus Oslo Port has already met the target. Therefore, the port plans to increase this target to 27 lifts per crane hour. This new target is determined based on the analyses of terminal layout and certain simulations of crane efficiency, which testify this new target is technically achievable. An important measure in this regard will be to coordinate the stevedore's breaks with the remaining port actors. Since crane efficiency is the key determinant of ship working time and ship turnaround time, it has been a target for automation. We illustrate this trend by referring to the automation at Sydney's Patrick terminal (Saulwick 2015). Alistair Field, the managing director of Patrick Terminals and Logistics, commenting on the level of automation into its stevedoring operation: "This is fully automated, there are no human beings, literally from the moment this truck driver stepped out of his cabin from then onwards this AutoStrad will take it right through the quay line without any humans interfacing at all". They estimate that in total, the new system allows the stevedoring operation to take place with staff about half the previous size while also generating other advantages like safer operations, 24/7 operation without the need for expensive overhead lighting since the automated system navigate without the need for light, they use 20% less fuel, they incur lower maintenance costs, and when there is a rush the information system redirects workers from other tasks to focus on the most pressing job (Saulwick 2015). In the port of Oslo, the stevedores' break is one of the main obstacles of improving crane efficiency. If there is no stevedores' break, the ship turnaround time can be decreased by 25% (Hatteland 2013). One way to achieve this is by using four stevedores a team instead of three stevedores a team. The trade-off would be made between decreasing ship turnaround time by 25% and increasing manpower cost by 33%. However, in practice, most of shipping lines are not willing to pay for this service (Hatteland 2013), leading to further pressure for automation.

Ship design is another important external factor influencing crane productivity. Normally, after a container is moved to the quay side by port chassis, Ship-to-Shore Gantry (SSG) cranes attach to the container and lift it at waist-high. At this time, stevedores take proper container fittings and attach them to the container corners before the crane moves the container to the correct position on the ship with hatch covers. Fully automatic twist locks (which can automatically lock and unlock) can make the loading/unloading process more efficient then semi-automatic twist locks (which can automatically lock and should be manually unlocked) (Hatteland 2013).

In terms of a container ship with no hatch covers, the containers can be loaded directly into the cell guides and no fitting is called for. Loading and unloading process for a container ship like this is faster and more cost-efficient because cell guides in this ship are fixed structures that can keep containers without any other equipment, such as twist locks mentioned above. This type of container ship can dramatically reduce labour cost and fitting installing time (Pacificmarine 2013). Such measures depend upon coordinated operations and information exchange between the stakeholders.

3.2.4 Gate-to-Gate Time

Gate-to-gate time means the total time used by a vehicle from getting in to getting out of a container terminal. This indicator includes measures of issue like the traffic congestions in the terminal and time used to identify the right container. This indicator has high variability in practice. Generally speaking, if there is no traffic congestion in the terminal, 15 min should be taken from getting in to getting out (Hatteland 2013). However, when there is much traffic combined with internal and external vehicles, productivity will slow down dramatically. For instance, when the terminal is handling a container ship, at the same time, there is a big pressure on collecting containers from external actors (landside service) (Hatteland 2013). The Oslo port authority set a target for this indicator for 15 min. That is to say; if there is no high pressure on internal traffic, the port can meet this target. Oslo port set this target according to the capacity of the terminal and their experience (Hatteland 2013).

3.3 *Potential to Improve the Overall Performance*

In the storage area of Oslo container port, containers are unloaded from port chassis and stacked (or unstacked and loaded to port chassis) by RTGs and reach stackers. More specifically, arriving containers (imported) will be unloaded by SSGs from vessels, placed on port chassis, hauled to stacking area and stacked by RTGs. Normally, 2 days later, external trucks will come in and drive under the RTG crane to collect these containers. By contrast, exported containers are unstacked from the storage area, placed on port chassis, hauled to port's apron and loaded to ships by SSGs (see Fig. 3).

3.3.1 Traffic Congestion

According to the primary information obtained from interviews with informants, internal traffic congestion is the main obstacle of improving the performance on gate-to-gate time. Internal traffic congestion is mainly generated when handling ships and trucks at the same time. Making a balance between internal vehicles and external vehicles can improve the performance of gate-to-gate time. More specifically, after an external vehicle comes in and drives under the RTG crane, the RTG crane needs to lift a maximum of four containers normally to get the right container which should be loaded onto the truck. If at the same time, an internal vehicle comes

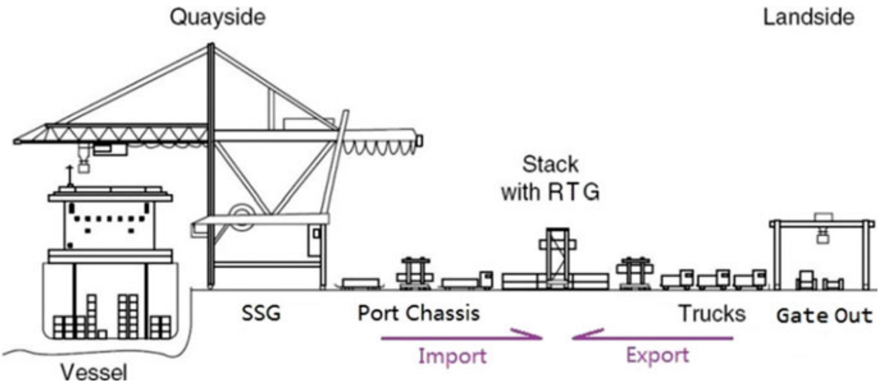


Fig. 3 Schematic representation of container flow in Oslo port

from the ship, it should wait in a queue behind the external truck. That is to say, the internal vehicle will fail to go back with container on time and the SSG must wait. The consequence is that not only the crane efficiency of SSG is decreased, but also the gate-to-gate time and ship turnaround time are increased (Madland 2013). Although the containers that come from ships may very well be collected before one that is already in stack and the internal vehicle should be given higher priority than external vehicles, the problem is that terminal does not know when a truck will come to collect an import container. When internal vehicles are driving between SSG and RTG with import containers, external vehicles may arrive and mix the traffic, hence causing queuing and waiting times. Consequently, the lack of information sharing among the stakeholders gives rise to the internal traffic congestion (Madland 2013).

The terminal operator does not have information on when, and in what sequence the containers are collected by external actors such as, forwarding agents. Therefore, the port operator fails to prepare in advance (Hatteland 2013). More specifically, when trucks come, truck drivers might ask for their container that could be positioned in the bottom of a stack, which generates many extra unnecessary lifts in order to get these containers (Madland 2013). Since each move of a container requires space, better information sharing between terminal operators and terminal users can reduce the number of lifts thereby improving the container flow and area efficiency. If the terminal operator had known this information in advance, it would be easier to move the containers what the truck drivers wanted to the top of the stack before they arrive, thereby dramatically reducing the gate-to-gate time. This situation of missing information gives rise to the main obstacle of improving gate-to-gate time. Currently, forwarding agents send orders to truck drivers asking them to pick up containers at terminal. When they arrive at the port and ask for their containers, the information goes to the crane driver. The truck driver has a booking reference that is connected to a container number. The container number is connected to an area reference and position in the stack. The booking is also connected to a ship operator. The terminal operator usually put different ship operators' containers in different stacks. For instance, Maersk's containers are put in Maersk Stack, etc. It is the Forman that has control on where each container is mainly by routine with no written records. Even if they are good at memorizing, as pointed out in the interview with Madland (2013), an information system promoting the sharing of information among stakeholders and a joint planning system will improve operational efficiency.

3.3.2 Container Sequence

It is possible for the terminal to get more or less full overview of information regarding ship handling by exchanging information with the ship owners. By contrast, the terminal knows nothing about in which sequence containers are collected by trucks until truck drivers come. Although loading information is available for ship handling in advance, in Oslo Container Terminal, there is no buffer area in front of the berth that can be used to temporarily store containers to be loaded onto a

Fig. 4 An effect diagram of information sharing on the performance

ship. This makes remarshaling in front of a berth impossible. As a consequence, terminal tractors move containers between ship and stacking area back and forth. SSG should wait for terminal tractors to load and unload containers to and from the ship. In Sjursøya Container Terminal, there is a very limited area for storage when using straddle carrier (2–3 containers per crane). This limited area also enables SSGs to put containers on the ground under crane without the need of waiting for internal vehicles' to come back. Hence, it makes flexibility but it is also impossible for operations of remarshaling in front of a berth, which hinder the improvement of performance (Madland 2013).

3.3.3 Discussion

To sum up, information missing (the lack of information sharing between terminal operators and forwarding agents) is the cause hindering the improvements of overall performance in container terminals of Oslo port, including area efficiency, crane efficiency, throughput and gate-to-gate time. See Fig. 4.

Information can improve the container flow, thereby increasing area efficiency. Because the size of the stacking storage area is the constraint of container throughput in Oslo container terminals, increased area efficiency leads to increased container throughput. In addition, the information provided by forwarding agents enables terminal operator to prepare containers before trucks come, which can dramatically reduce gate-to-gate time. Reduced gate-to-gate time leads to shorter queue in the stacking area which increases the possibility that port chassis coming from a ship can go back on time, thereby increasing SSG crane efficiency. However, since information sharing is not measured in any way by current performance metrics, the port and the related actors focus on the traditional metrics. Sharing of information is not measured, and thus, not managed well. A metric capturing the level of information sharing would make the importance of information sharing clear to all parties.

3.3.4 Further Evidence of the Importance of Information Sharing

The Port-Ship Coordinated Planning (PoShCoP) Project

Enhancing information sharing of port planning information across actors is also important for projects like The Port-Ship Coordinated Planning Project (PoShCoP 2015) where the central issue is the coordinated planning of ship-owners plans with the plans of ports. The planning of port movements of ships, and their associated approaching and departing phases, are often found to be poorly coordinated. A typical reason is that a plan might be good at an early stage, but as times passes, external events may happen that invalidates the plan, or makes it difficult to fulfil. This might be the delay of a ship due to bad weather, causing later congestion in the harbour, or the early arrival of a ship at a port when the ship could have slow-steamed instead, if it had known its slot time at the port. Slow steaming refers to the practice of operating container ships at significantly less than their maximum speed to save fuel and to smooth operations in ports. The PoShCoP project develops a cooperating operational planning system for combined port and ship planning from various levels. The simplest is that one actor is granted access to relevant plans of another actor during planning and re-planning, while the most advanced is to let the solvers (planning software) of each actor cooperate in order to find a solution that would benefit all actors involved. The methods developed in the PoShCoP project are within discrete optimization focusing on the core issues of route planning (and related planning problems like area utilization in the port). However, to be able to solve the planning problems by discrete optimization methods, the information must first be shared between ship-owners and port operators.

Workload Variance

The characteristic of the workload distribution of a typical day and a typical week was studied for Oslo port. Based on communication with the management at Oslo Port and the Sitma Port Consultancy (Lin 2013), two trends regarding the workload distribution of both the landside service and the quayside service were found. Typically, over a week, Monday, Tuesday and Thursday are the busiest days. Ships normally depart from ports located in central Europe on Friday, arriving at Oslo in the morning on Monday. Over a day, the workloads typically peak between 0900 and 1200 (Lin 2013). Although the ship owners' plans can be hardly changed by the Oslo port authority, port operators can make certain preparations before port users arrives. For example, lift the to-be-collected containers to the highest tier to reduce the workload when forwarding agents arrive. Certain preparations in advance can make the workload curve more smoothly and reduce the possibility that workload exceeds their capacity leading to congestion. Also, as for the PoShCoP project, delays of ships due to external factors like bad weather can cause congestion in the harbor which could be avoided by re-planning or by slow-steaming saving costs for all actors. Information sharing between port users and port operators are called for to make the worklist for preparation.

3.3.5 Relations Between Supply Chain Actors and Information Sharing

As discussed above, the information sharing between all actors is of importance for the efficiency of a port. However, information sharing among all actors may not be easy to achieve. A strong major actor and/or concerted efforts among all actors are typically needed.

Port operator as a strong actor A strong actor, to some extent, can control all activities in a port and set the "rules of the game". This strong actor may have the ability to require all other actors to share information. The port operator seems the one who very likely has the potential to be in such a controlling position in a port and ask for data sharing to increase their efficiency.

Government as a strong actor If even the port operator does not have the governance power to facilitate the information-sharing activities, it will be very difficult to see that any other individual LSPs playing in a port could be in a position to make data-sharing activities mandatory for all actors. In this situation, the government may trigger information sharing by making laws and regulations due to security or financial control reasons.

Port operator as an information buyer Under the situation where the strong actor is absent, the port operator may also take such a responsibility to facilitate the information sharing among actors. More specifically, they can buy information from other actors, like buying other services, thereby enhancing their efficiency, but unless the benefits for the port operator outweigh their costs.

Concerted efforts among actors Certain actors may see their benefits if a port can enhance efficiency. As discussed above, forwarding agents may benefit from the increased efficiency in the back yard of a port. Information provided by forwarding agents enables the terminal operator to prepare containers before trucks come. Reduced gate-to-gate time can also reduce the cost of forwarding agents. To this end, forwarding agents and other actors may be willing to share their information to increase the efficiency of a port and reduce their costs. However, the port operator cannot force those who are reluctant to share information and can accept the current port efficiency.

To sum up, information sharing can be achieved by a strong major actor and/or concerted efforts among all actors. A KPI of information sharing let actors to see the absence of information sharing and the related inefficiency in port operation and motivate port actors to share their information.

4 Information Sharing as a New Performance Indicator

Due to the importance of information sharing, it should be considered as a new performance indicator. Such an indicator will expose information sharing issues in an explicit manner, helping the actors to give information sharing a higher priority to improve performance. We argue for this first by an example for the port of Oslo, then we suggest generalizing it by including it in the performance measurement framework by Woo et al. (2011).

The following metrics are referred to as the "Information Sharing Indicator". It represents a novel approach to measuring the port operational performance in terms of information. The indicator is composed of two primary metrics. The first metric of the Information Sharing Indicator is "shared". This metric is a sum of zero/one variables showing whether information between two actors is shared (1) or not (0).

The type of information to be shared is information related to the operations of the port, which in this case is scheduling information made by ship owners, port operators and freight forwarders. We define the second part of the Information Sharing Indicator to be a "level" metric reflecting what extent scheduling information is exchanged. Schedules might change, so the freshness of the schedules have higher value the more recent they are. As a first approach to quantify the level of the information exchanged we define three classes (which can easily be extended with more classes). Short term is within a week, and long term is above 1 week. The information at the next level comes in addition to the information shared at the previous levels. The levels are:

1. Sharing of long term schedules and plans
2. Sharing of short term schedules and plans
3. Real-time sharing of deviations

The Information Sharing Indicator (ISI) is defined as the ratio of the actual value to the maximum value of the shared and level metrics:

$$\mathrm{ISI} = \frac{\sum_{i=1}^{N} S_i + \sum_{i=1}^{N} (S_i \times L_i)}{N + N \times L_{max}}$$

Where N is the total number of interactions between ship owners, port operators and freight forwarders on the landside. If each actor needs to communicate with all other actors the total number of interactions will be n(n − 1)/2 (assuming bidirectional information exchange). The complexity involved in multi-party networks for container handling is further described in (Jager and Hjelle 2015). S_i is one if information is exchanged and zero otherwise. L_i is the value of information exchanged. L_{max} is 3 in our case with 3 as the highest-level metric.

4.1 Example of Usage in Oslo Port

The three actors having the greatest effect on the performance are ship owners, port operators and freight forwarders. In the port of Oslo there is one port authority, an estimated 20 ship owners and an estimated 20 forwarding agents resulting in $n = 41$ actors. The total number of interactions, N, is $n(n - 1)/2 = 41(41 - 1)/2 = 820$. Fortunately, for the Oslo Port case the number of interactions is much lower. The port operator can be seen to act as a hub with which all ship owners communicate, and also the freight forwarders communicate with the port operator. In the general most advanced case one could envision that all actors cooperate in order to find a solution that would benefit all actors involved. For now we focus on starting sharing information among the central actors via a hub in which the number of interactions is proportional to n (Jager and Hjelle 2015). If the port operator shares information with each of the ship owners and each of the forwarding agents we get a maximum of $N = 40$ interactions. The Oslo port shares long-term schedules with most ship owners, and short-term schedules are exchanged with just a few, estimated to 15 out of 20 of which 4 of the 15 exchange short-term schedules. As for the freight forwarding agents on the landside this number is even lower. It is estimated to be 5 of the 20 agents that share long term schedules (Hatteland 2013). The maximum value is $N + N \times L_{max} = 40 + 40 \times 3 = 160$. Using the formula, the actual value of the shared and level metrics becomes 44 giving $ISI = 44/160 = 0.275$. Thus, by our estimates, the Port of Oslo can be seen to use information only 27.5% of the potential for information sharing.

In this manner, an Information Sharing Indicator would expose the level of information sharing to all the actors involved and to the relevant authorities. This calculation method is a first approach. We propose to refine it through an iterative process of applying it to a port case, refining, repeating the cycle until the model becomes stable. A calculation of the value of the Information Sharing Indicator together with other KPI's to form a combined indicator require substantial computing efforts due to its complexity, see e.g. Linn et al. (2007). We advocate using a qualitative approach to evaluate the combination of several KPIs, since a numerical weighting among indicators is hard to implement in practice.

4.2 Including the Information Sharing Indicator in the Performance Measurement Framework

We suggest adding information sharing between port users and port operators as an explicit parameter in the performance measurement framework developed by Woo et al. (2011) as shown in Fig. 5. The Information Sharing Indicator is added under the Port cooperation and networking category thereby completing the framework by having an operational indicator for all categories. One might argue that measuring information sharing is an input that influences the performance rather than a performance indicator. Similar reasoning on one of the traditional KPIs would be: is the

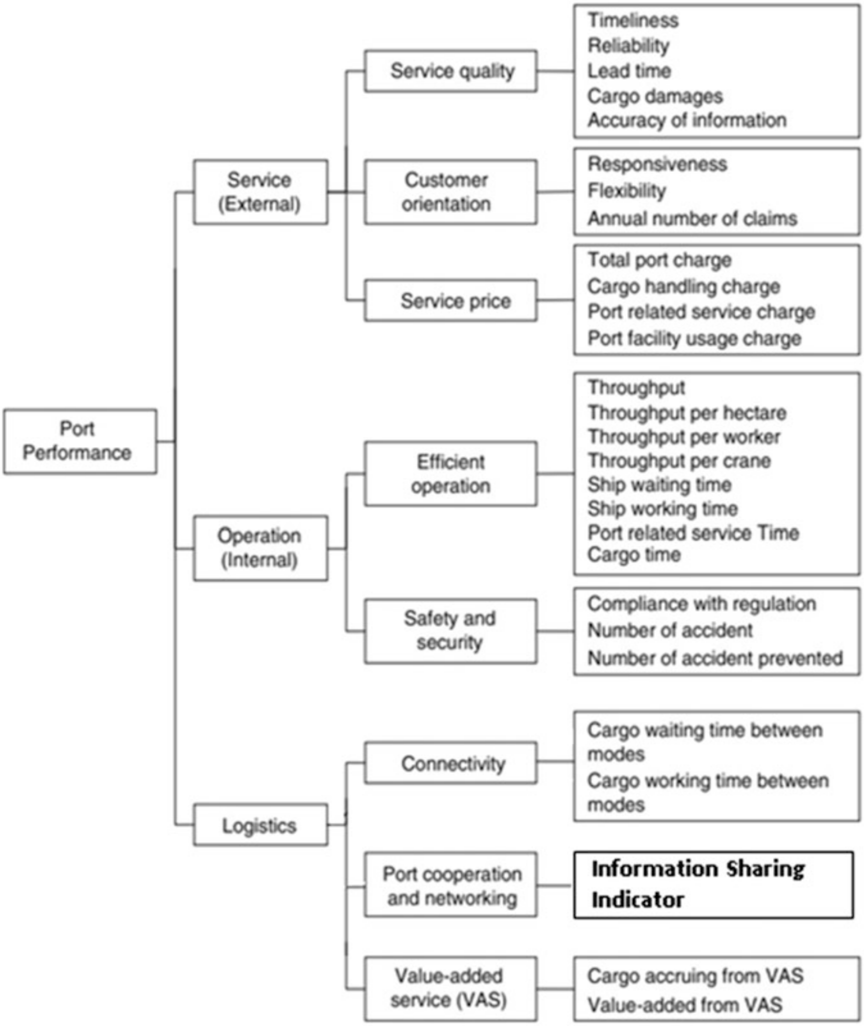


Fig. 5 The Information Sharing Indicator added to the general port performance measurement framework

number of cranes an input that influences the performance rather than a performance indicator? Since, in our case, the goal of using the KPIs is to guide managers towards increasing the performance of the port, we maintain that in the light of the breakthrough innovation (the digitized automated port), managers need the new indicator to guide them in making decisions. If using existing KPI’s only, the managers will have a hard time to figure out how to improve performance. Arguably, the most important indicator to make decisions in the emerging smart port environment is the Information Sharing Indicator since it captures the most important indicator for enhanced performance. It reflects the direct relationship: little information sharing, means low performance, and vice versa.

5 Conclusion

According to the analysis in this chapter, we discussed the problem of information sharing between terminal operators and forwarding agents and we argued for that a lack of sharing is a major cause hindering performance improvements of container terminals at Oslo port, including area efficiency, crane efficiency, throughput and gate-to-gate time. Although crane efficiency can be influenced by external factors to some extent, information sharing can also dramatically increase the terminals' performance by this indicator. That is to say, the enhanced information sharing between terminal operators and forwarding agents can improve the performance of container terminals in Oslo port. More specifically, information sharing can improve the container flow across the entire supply chain, thereby increasing area efficiency. Because the size of the stacking storage area is the constraint of container throughput in Oslo container terminals, increased area efficiency leads to increased container throughput. In addition, information provided by forwarding agents enables terminal operator to prepare containers before trucks come, which can dramatically reduce gate-to-gate time. Reduced gate-to-gate time leads to shorter queue in the stacking area which increases the possibility that port chassis coming from a ship can go back on time, thereby increasing SSG crane efficiency.

Due to the importance of information sharing shown in the case of container terminals of Oslo port, we suggest adding it as a new performance indicator in the performance measurement framework used by Oslo port authority and also include it in port performance measurement frameworks as shown for the framework by Woo et al. (2011). We have argued that standard key performance indicators leave ports in the region of maturity with only small incremental innovations in the maturity region of the technology diffusion model. Ports in this region receive a diminishing rate of return of investments, being stuck in the maturity region. We have proposed a new Information Sharing Indicator (ISI) that motivates ports to adopt breakthrough technological innovations that will lead ports towards a new rapid growth period.

References

Al-Eraqi, A. S., Mustafa, A., Khader, A. T., & Barros, C. P. (2008). Efficiency of Middle Eastern and East African seaports: application of DEA using window analysis. *European Journal of Scientific Research, 23*(4), 597–612.

Andersen, B. (1999). The hunt for S-shaped growth paths in technological innovation: a patent study. *Journal of Evolutionary Economics, 9*(4), 487–526.

Barros, C. P. (2012). Productivity assessment of African seaports. *African Development Review, 24*(1), 67–78.

Barros, C. P., Felício, J. A., & Fernandes, R. L. (2012). Productivity analysis of Brazilian seaports. *Maritime Policy & Management, 39*(5), 503–523.

Berg, G. (2013). Face to face interview with Geir Berg. In N. Lin (Ed).

Christensen, C. M., Raynor, M., & McDonald, R. (2015, December). What is disruptive innovations? *Harvard Business Review*.

Cullinane, K., & Wang, T. (2010). The efficiency analysis of container port production using DEA panel data approaches. *OR Spectrum, 32*(3), 717–738.

Cullinane, K., Song, D. -W., Ji, P., & Wang, T. -F. (2004). An application of DEA windows analysis to container port production efficiency. *Review of Network Economics, 3*(2).

Duranton, G., & Turner, M. A. (2012). Urban growth and transportation. *The Review of Economic Studies, 79*(4), 1407–1440.

Hatteland, C. J. (2013). Face to face interview with Carl Johan Hatteland. In N. Lin (Ed.).

Hung, S.-W., Lu, W.-M., & Wang, T.-P. (2010). Benchmarking the operating efficiency of Asia container ports. *European Journal of Operational Research, 203*(3), 706–713.

Jager, B., & Hjelle, H. M. (2015) Handling multi-party complexities in container flows in the upstream oil and gas supply chain: Potential lessons for an application to intercontinental container supply chains. In *Transportation information and safety (ICTIS), 2015 international conference on, 2015* (pp. 661–668). IEEE.

Kalbach, J. (2015). Clarifying innovation: Four zones of innovation. *Experiencing information* [Accessed: 10.1.2017].

Kalmar Container Handling Systems. (2015). Container handling systems brochure. http://www.rrtobe.com/salesmaterial_store_pdf_low_res/CHS_KIOY0309E-17.pdf

Kasypi, M., & Shah, M. (2013). Malmquist productivity index for container terminal. *European Journal of Business and Management, 5*(2), 58–70.

Koçoğlu, İ., İmamoğlu, S. Z., İnce, H., & Keskin, H. (2011). The effect of supply chain integration on information sharing: Enhancing the supply chain performance. *Procedia-Social and Behavioral Sciences, 24*, 1630–1649.

Lee, H. L., So, K. C., & Tang, C. S. (2000). The value of information sharing in a two-level supply chain. *Management Science, 46*(5), 626–643.

Lin, N. (2013). Port performance: Models and metrics supporting performance evaluation.

Linn, R., Liu, J., Wan, Y.-W., & Zhang, C. (2007). Predicting the performance of container terminal operations using artificial neural networks. In K. Bichou, H. M. G. Bell, & A. Evans (Eds.), *Risk management in port operations, logistics and supply-chain security* (pp. 117–134). London: Informa.

Madland, O. (2013). Unstructured telephone interview with Olav Madland. In N. Lin (Ed.).

Notteboom, T. E., & Winkelmans, W. (2001). Structural changes in logistics: how will port authorities face the challenge? *Maritime Policy & Management, 28*(1), 71–89.

Olesen, P. B., Hvolby, H.-H., & Dukovska-Popovska, I. (2012). Enabling information sharing in a port. In *IFIP international conference on advances in production management systems* (pp. 152–159). Springer.

Olesen, P. B., Damgaard, C. M., Hvolby, H. -H., Dukovska-Popovska, I., & Sommer, A. F. (2014). Framework for information sharing in a small-to-medium port system supply chain. In *IFIP international conference on advances in production management systems* (pp. 257–264). Springer.

Pacificmarine. (2013). How do container ships work? http://www.pacificmarine.net/marine-deck/cargo-securing/how-do-container-ships-work.htm.

PoShCoP. (2015). The port-ship coordinated planning project, supported by the Norwegian Research Council.

Prajogo, D., & Olhager, J. (2012). Supply chain integration and performance: The effects of long-term relationships, information technology and sharing, and logistics integration. *International Journal of Production Economics, 135*(1), 514–522.

Schøyen, H., & Odeck, J. (2013). The technical efficiency of Norwegian container ports: A comparison to some Nordic and UK container ports using Data Envelopment Analysis (DEA). Maritime Economics & Logistics, 15(2), 197–221.

SmartPort. (2014). Action Plan towards the SMART PORT concept in the Mediterranean Area, EU Project by Andalusian Institute of Technology, University of Cádiz, Institute of Communication and Computer Systems, and Prometni Institut Ljubljana, supported by European Regional Development Fund.

Sydney's Patrick terminal goes automated, with fewer staff but dancing robots. (2015, June 18). *The Sydney Morning Herald*.

To, H. (2006, May 16). The next big trend and the "double merit" scenario. *SafeHaven*.

Woo, S. H., Pettit, S. J., & Beresford, A. K. C. (2008, September). A new port performance measurement framework in a changing logistics environment. In *Proceedings of the LRN 2008 annual conference* (Vol. 6).

Woo, S. H., Pettit, S., & Beresford, A. K. (2011). Port evolution and performance in changing logistics environments. *Maritime Economics & Logistics, 13*(3), 250–277.

Wu, Y.-C. J., & Goh, M. (2010). Container port efficiency in emerging and more advanced markets. *Transportation Research Part E: Logistics and Transportation Review, 46*(6), 1030–1042.

Ye, F., & Wang, Z. (2013). Effects of information technology alignment and information sharing on supply chain operational performance. *Computers & Industrial Engineering, 65*(3), 370–377.

Yuen, A. C. -l., Zhang, A., & Cheung, W. (2013). Foreign participation and competition: A way to improve the container port efficiency in China? *Transportation Research Part A: Policy and Practice, 49*, 220–231.

Scheduling Periodical Deliveries from a Distribution Centre to Minimize the Fleet Size

Jiyin Liu and Aiying Rong

Abstract This chapter studies the delivery problem in which a distribution center delivers goods to customers periodically. Each customer has a specified delivery frequency. The deliveries to the same customer must be spaced over time as evenly as possible. The objective is to minimize the fleet size. We start from the special version with customers requiring the same delivery frequency, and propose a routing-then-scheduling approach: a routing problem for making one delivery to every customer is first solved and the resulting routes are then scheduled over the period. The study mainly focuses on the scheduling of the routes. Feasibility and optimality of the solution are analyzed. Based on the analysis, we develop a general integer programming model and a two-stage method for the problem with different delivery frequencies. Numerical experiments show that both methods solve the problem quickly. However, the delivery patterns generated by the two-stage models are more stable.

Keywords Periodical vehicle routing problem · Delivery frequency · Fleet size · Routing then scheduling

1 Introduction

In many real life physical distribution systems, the delivery orders are periodic. In these systems, the distribution firm delivers goods to a fixed set of customers. In a given *T*-day period, each customer must be visited at least once, with some customers requiring several visits for which minimum and maximum intervals

---

J. Liu (✉)
School of Business and Economics, Loughborough University, Loughborough, Leicestershire, UK
e-mail: j.y.liu@lboro.ac.uk

A. Rong
Department of Mechanical Engineering, Aalto University, Aalto, Finland

J. E. Hernández et al. (eds.), *Collaborative Logistics and Intermodality*,
https://doi.org/10.1007/978-3-030-50958-3_9

are imposed on any two successive deliveries. The distribution firm is interested in developing a set of daily delivery routes for the *T*-day period so that a certain criterion is optimized, while guaranteeing that each customer receives deliveries at the required frequency (the number of deliveries). This kind of problem is called periodic vehicle routing problem (PVRP). PVRP arises in various settings such as waste collection (Beltrami and Bodin 1974, Bommisetty et al. 1998; Coene et al. 2010), industrial gas distribution (Bell et al. 1983; Dror and Ball 1987), soft drink and beer distribution (Golden and Wasil 1987) and linen deliveries in hospitals (Banerea-Brodeur et al. 1998). Our study was motivated by the problem faced by a distribution center that delivers frozen food to restaurants. Each restaurant needs two deliveries a week. While they may accept deliveries on any days of the week, they require that the deliveries should be spaced over time as evenly as possible considering the freshness of the food and the storage capacity limit.

The subject of PVRP is the integration, in a unified model, of some related components of the decision making process in managing the distribution activities of a firm, such as the fleet size determination, the scheduling of the deliveries and the routing of vehicles. It is thus a multilevel combinatorial optimization problem. The periodicity requirement sets links between the deliveries of different days. Therefore, the decision problem for the deliveries of 1 day cannot be solved separately from those for other days in the period.

PVRP is often viewed as an extension of the classical vehicle routing problem (VRP) from 1 day to a *T*-day period with the objective of minimizing the total distance traveled over the period. Classical formulations of PVRP can be found in Christofides and Beasley (1984) and Ball (1988). Francis et al. (2007) considered service flexibility in the problem including the choice of customer delivery frequencies. Archetti et al. (2017) introduced a flexible PVRP to minimize the total routing cost, where each customer has a total demand for the planning period and there is a limit on the maximum delivery quantity at each visit instead of having a fixed delivery frequency. Michallet et al. (2014) addressed a highly constrained PVRP where visits to each customer must be within the customer's time window, no waiting is allowed and the arrival times of any two visits to the same customer must be separated by at least a minimum time interval.

Most of the solution methodologies for classical PVRP follow the line of an *assigning-then-routing* approach. That is, the customers are assigned to days of the *T*-day period first and the resulting VRP for each day is then solved. After this an improvement stage follows to exchange the customers between days or between the routes of the same day to minimize the total travel distance over the period. For any assignment of customers to the days in the period, the subproblem for each day is a classical VRP problem which is NP-hard implying that it is unlikely to have an efficient method to solve it optimally. In search for a good assignment of customers to different days, a large number of VRPs need to be solved. To make it computationally feasible, heuristics are used for the decisions.

Different heuristics have been developed to solve PVRP. Christofides and Beasley (1984) proposed two heuristics in which different relaxations of the VRP subproblem (*p*-median relaxation problem and traveling salesman relaxation problem) for each day was solved. Tan and Beasley (1984) developed heuristics based on the generalized assignment relaxation problem in which $K \cdot T$ seed points were chosen, where K is the number of vehicles for each day and T is the number of days in the period. Russell and Gribbin (1991) gave a four-stage heuristic to evaluate the results of different combinations for each day. Chao et al. (1995) tried to first balance the total amount of customer demand in each day by solving an integer programming problem that minimizes the maximum total amount of demand delivered in a single day, and then to form vehicle delivery routes for each day. Following this, a one-point movement method was adopted to make further improvement. Metaheuristics such as tabu search (Cordeau et al. 1997) and genetic algorithm (Drummond et al. 2001), and scatter search (Alegre et al. 2007) have also been applied for solving PVRP. Alonso et al. (2008) studied a PVRP allowing multiple trips for each vehicle and considering the accessibility constraints. They used an assigning-then-routing heuristic to generate an initial solution and then used tabu search for improvement to minimize total travel cost. Rahimi-Vahed et al. (2013) solved a multi-depot PVRP problem using a path relinking algorithm while Nguyen et al. (2014) proposed a hybrid genetic algorithm for PVRP with time windows. Cacchiani et al. (2014) presented a hybrid algorithm embedding both heuristic and exact components, and used it to solve PVRP where each customer needs to be served on a combination of days chosen from a set of valid day combinations. The objectives of the problems in the above three studies are also to minimize the total travel cost.

Shih and Lin (1999) and Shih and Chang (2001) used a *routing-then-scheduling* approach to solve the problem of collecting infectious wastes from hospitals. The problem is quite special where collection needs to be made only once in each 1-week period from every hospital. They first solved a standard vehicle routing problem to determine a set of individual routes for the collection. Mixed integer programming was then used to assign the routes to particular days of the week with the objective of minimizing either the maximal daily travel or the difference between the maximal and the minimal daily travels.

Although the objective to minimize the total distance traveled is important as it reduces the fuel costs, minimization of the fleet size (the maximum number of vehicles used for any 1 day) is often the primary objective for many delivery firms. This is because the fixed costs associated with the number of vehicles (capital investment, maintenance, wages, insurance, etc.) often outweigh the costs related to mileage. The exact settings of a PVRP may be different for different applications. Gaudioso and Paletta (1992) studied a PVRP with the objective of minimizing the fleet size and presented a model assuming that the planning horizon is divisible by the delivery frequencies of all customers. They proposed a heuristic algorithm that allocates deliveries of one customer at a time. Since there is no limit on daily travel distance or time, a bin-packing problem is solved for each day to determine the number of vehicles needed to serve the customers assigned to that day. When assigning the deliveries of each customer, the objective is to minimize the fleet size increase. Rahimi-Vahed et al. (2015) addressed a multi-depot PVRP to minimize fleet size. They considered a list of allowable visit patterns for each customer, as well as vehicle capacity, route duration and budget constraints. A modular heuristic algorithm was proposed to solve the problem.

Most previous studies on PVRP tried to minimize traveling cost. Only a few considered minimizing fleet size as objective. In addition, the majority of the PVRP studies assume that each customer has a given list of possible delivery patterns. In many practical situations such as the frozen food delivery problem mentioned earlier, the actual delivery days to a customer can be flexible but the deliveries need to be evenly spaced considering freshness of the food and storage capacity of the customer. In this chapter we study the PVRP with these features and allow different delivery frequencies for different customers.

Our problem is stated as follows. A distribution center delivers goods to a fixed set of customers periodically. One period includes T days. A customer needs at most one delivery on any day. If a customer requires E deliveries over the T-day period, we say that the delivery frequency of this customer is E. For all the customers, there is a total of n different delivery frequencies, $E_1, \ldots, E_n$. Without loss of generality, we assume $1 \leq E_1 < E_2 <, \ldots, < E_n \leq T$. The required delivery amount (the demand) for the same customer is the same for every delivery. The delivery days for the same customer must be distributed in the period as evenly as possible. That is, any two successive deliveries must be spaced at least $\lfloor T/E_i \rfloor$ days and at most $\lceil T/E_i \rceil$ days for a delivery frequency E_i. We will refer to this requirement as evenly-spacing requirement. Homogeneous vehicles are used to make the deliveries. The problem is to assign, over a delivery period T, a feasible combination of delivery days to each customer and to schedule the deliveries for every day in the period in order to minimize the fleet size.

The evenly-spacing requirement for the delivery days is consistent with the practice of many delivery problems, such as the problem of food delivery to restaurants in the example mentioned earlier. Moreover, to make practical implementation of the solution easier, we further make the assumption below.

Assumption 1

While customers can be grouped with any other customers in a delivery route, it is required that every delivery of any particular customer is made in a route with the same set of other customers.

Solutions under this assumption have practical advantages. The delivery route for every delivery to a customer is always the same. Therefore the customer can expect delivery around the same time on every delivery day and thus can be better prepared for receiving. This assumption can also make the delivery team more familiar with the routes and make the fleet management in the delivery firm easier.

The periodical nature of the delivery orders makes the daily delivery orders change in a cyclical pattern. Our task is therefore to schedule deliveries for one period. Then the schedule can be followed in every period.

In the remaining parts of this chapter, we first study the periodical delivery problem with the same delivery frequency, propose a routing-then-scheduling approach for the problem and analyze the performance of the solution. The method can be used to solve the problem in situations where the delivery frequencies required by all customers are the same. Based on the above analysis, the general problem with different delivery frequencies is studied. A general integer programming model is formulated and a two-stage method using two smaller integer programming models is proposed for more stable and efficient solution. An extended routing-then-scheduling approach is also presented to solve problems without assumption 1. Computational experiments testing the performance of the methods are then reported. Finally conclusion remarks are given.

2 Problem with the Same Delivery Frequency for All Customers

2.1 A Routing-then-Scheduling Approach

For the periodical delivery problem with the same delivery frequency E, two successive deliveries to the same customer must be spaced at least $\lfloor T/E \rfloor$ days and at most $\lceil T/E \rceil$ days. This special problem would not be solved effectively and efficiently if we followed the conventional procedures for a general PVRP: assigning customers to delivery days and then routing each day separately. In the improvement stage of the conventional heuristic procedure, it is hard to choose which customers should be moved because all the customers have the same delivery combination.

However, the special characteristics of this problem can be used to develop more efficient algorithms. We propose a routing-then-scheduling approach to solve the problem in two phases:

Phase 1. Solve a VRP to minimize fleet size, considering all the customers as if every customer requires a delivery on the same day. We will call the set of customers served by one vehicle in a day a *route*. Then the result of this VRP will be a set of delivery routes.

Phase 2. Assign these routes to delivery days over the T-day period. Each route will be assigned E times, spaced evenly over the period.

Here a route is viewed in a broad sense. It does not necessarily mean one physical vehicle trip. In particular, given the vehicle capacity, multiple trips may be performed by a vehicle within the limit of the working time in a day. A route here refers to all the delivery work done by one vehicle for 1 day, which includes all the trips of the vehicle and the associated loading and unloading activities in a day.

VRP has received extensive study. Many existing algorithms can be borrowed to solve the above phase-one problem (e.g., Achuthan et al. 1998; Vanderbeck 1999). In this chapter, we will not include this phase in the presentation of the algorithms. Instead, we will concentrate on the phase-two problem of scheduling the routes over the T-day period when the algorithms are developed.

In scheduling the delivery routes, any two successive deliveries of the same route must be spaced at least $\lfloor T/E \rfloor$ days and at most $\lceil T/E \rceil$ days. Note that this restriction also applies to the last delivery in one period and the first in the next period. If T is a multiple of E, any two successive deliveries of the same route are spaced exactly T/E ($= \lfloor T/E \rfloor = \lceil T/E \rceil$) days. If T is not a multiple of E, $\lceil T/E \rceil = \lfloor T/E \rfloor + 1$.

2.2 An Algorithm for Route Scheduling

Let P denote the optimal number of routes, obtained in the routing phase, which include all the customers exactly once. With the delivery frequency E, each route must be delivered E times in the planning period. We refer to each delivery of a route as a *route-delivery*. Then totally ($E \cdot P$) route-deliveries are required in the period to serve all the customers E times. On average, the number of routes delivered in each day is ($E \cdot P/T$). Thus, to balance the workloads on different days and hence minimize the fleet size, the number of routes delivered in each day should be either $\lfloor E \cdot P/T \rfloor$ or $\lceil E \cdot P/T \rceil$ routes.

We number the P different routes as 1, 2, …, P. We further number each of the $E \cdot P$ route-deliveries uniquely as follows:

$$k = j + m \cdot P, \quad j = 1, 2, \ldots, P, \quad m = 0, 1, \ldots, E - 1.$$

where j is route numbers, k is a route-delivery number. Therefore, $j + m_1 \cdot P$ and $j + m_2 \cdot P$ ($m_1 \neq m_2$, $0 \leq m_1 \leq E - 1$, $0 \leq m_2 \leq E - 1$) represent the same route j delivered on different days. While each of the P routes will be delivered E times in the T-day period, each of the $E \cdot P$ route-deliveries will be made exactly once in the T-day period. For illustration, consider an example problem in which three deliveries are required to each customer in a 5-day period and delivering to all customers once needs four routes, i.e., $T = 5$, $P = 4$, $E = 3$. Table 1 presents a delivery schedule and shows the relationship between the 4 routes and the 12 route-deliveries. To schedule the $E \cdot P$ route-deliveries to the T days in the period, we need to determine which days to have $\lfloor E \cdot P/T \rfloor$ route-deliveries and which days to have $\lceil E \cdot P/T \rceil$ route-deliveries in order to satisfy the delivery spacing requirement, because our approach does not have the restriction in Gaudioso and Paletta (1992) that requiring the planning period to be a multiple of the delivery frequency.

We present below a scheduling procedure that determines the assignment of the route-deliveries to each day in the period. The procedure considers 1 day at a time. In the procedure, i is the day number, f_i is the number of routes assigned to day i, f_0 is the accumulated number of assigned route-deliveries up to day i, f is the fleet size.

Table 1 Routes and route-deliveries for an example problem with $T = 5$, $P = 4$, $E = 3$.

Day	1	2	3	4	5
Route number (Route-delivery number)	1 (1)	3 (3)	1 (5)	4 (8)	2 (10)
	2 (2)	4 (4)	2 (6)	1 (9)	3 (11)
			3 (7)		4 (12)

Algorithm 1

```
Step 1: $f_0 = 0, f = 0, i = 1$.
Step 2: $f_i = \lfloor i \cdot P \cdot E/T - f_0 \rfloor$; assign the next $f_i$ route-deliveries to day $i$; if $f_i > f$,
    then let $f = f_i$.
Step 3: If $i < T$, then $f_0 = f_0 + f_i$, $i = i + 1$, go to step 2; otherwise, stop. $f$ is the
    fleet size.
```

This algorithm is computationally very efficient. Its computational complexity is O $(\max\{P \cdot E, T\})$.

2.3 Properties of the Solution

Algorithm 1 addresses the evenly-spacing requirement for the deliveries of the same route implicitly. We prove now the solution produced by this algorithm is indeed feasible, i.e., satisfying this requirement.

Proposition 1
The schedule generated by Algorithm 1 is a feasible solution to the problem, i.e., any two successive deliveries of a route in the schedule are $\lfloor T/E \rfloor$ or $\lceil T/E \rceil$ days apart.

Proof
Consider any route $R1$ that is scheduled on day i, and its position on that day is r (it is the rth route among those assigned to that day). Then its route-delivery number is $\lfloor (i-1) \cdot P \cdot E/T \rfloor + r$. Let k be the first day on which route $R1$ is scheduled after day i, and the position of route $R1$ on day k is s. Then the route-delivery number can be represented as $\lfloor (k-1) \cdot P \cdot E/T \rfloor + s$. Based on the algorithm procedure, we have the following relations.

(i) $\lfloor (i-1) \cdot P \cdot E/T \rfloor + r + P = \lfloor (k-1) P \cdot E/T \rfloor + s \le k \cdot P \cdot E/T$

$$\Rightarrow (i-1) \cdot P \cdot E/T - 1 + r + P < k \cdot P \cdot E/T$$
$$\Rightarrow (i-1) \cdot P \cdot E/T + P < k \cdot P \cdot E/T$$
$$\Rightarrow P - P \cdot E/T < (k-i) P \cdot E/T$$
$$\Rightarrow T/E - 1 < k - i$$
$$\Rightarrow \lfloor T/E \rfloor \le k - i.$$

(ii) $\lfloor (k-1) P \cdot E/T \rfloor + s = \lfloor (i-1) \cdot P \cdot E/T \rfloor + r + P \le i \cdot P \cdot E/T + P$

$$\Rightarrow (k-1) P \cdot E/T - 1 + s < i \cdot P \cdot E/T + P$$
$$\Rightarrow (k-1) P \cdot E/T < i \cdot P \cdot E/T + P$$
$$\Rightarrow (k-i) P \cdot E/T < P + P \cdot E/T$$
$$\Rightarrow k - i < T/E + 1$$
$$\Rightarrow k - i \le \lceil T/E \rceil.$$

Therefore, any two successive deliveries of a route in the schedule are $\lfloor T/E \rfloor$ or $\lceil T/E \rceil$ days apart, i.e., the schedule is feasible. □

In the following the optimality of Algorithm 1 is analyzed.

Proposition 2
In the solution generated by Algorithm 1, the number of routes delivered in each day is either $\lfloor E\cdot P/T \rfloor$ or $\lceil E\cdot P/T \rceil$. The fleet size required for the delivery is therefore $\lceil P\cdot E/T \rceil$.

Proof
For any day i in the schedule, the number of vehicles needed (number of routes scheduled) is $f_i = \lfloor i\cdot P\cdot E/T - \lfloor (i-1)P\cdot E/T \rfloor \rfloor < \lfloor i\cdot P\cdot E/T - (i-1)P\cdot E/T + 1 \rfloor = \lfloor P\cdot E/T + 1 \rfloor$. This implies that $f_i \leq \lceil P\cdot E/T \rceil$.

Similarly, $f_i = \lfloor i\cdot P\cdot E/T - \lfloor (i-1)P\cdot E/T \rfloor \rfloor \geq \lfloor i\cdot P\cdot E/T - (i-1)P\cdot E/T \rfloor = \lfloor P\cdot E/T \rfloor$.

Therefore, $\lfloor P\cdot E/T \rfloor \leq f_i \leq \lceil P\cdot E/T \rceil$.

That is, the number of routes delivered in each day is either $\lfloor E\cdot P/T \rfloor$ or $\lceil E\cdot P/T \rceil$. As the number of routes to be delivered is at most $\lceil E\cdot P/T \rceil$, the fleet size required is $\lceil P\cdot E/T \rceil$. □

Proposition 3
Under Assumption 1, the solution generated by Algorithm 1 is optimal provided that the VRP considering deliveries to all customers once is solved optimally.

Proof
P is the minimum number of routes for one delivery to all customers resulted from the VRP. Under the Assumption 1, the total number of deliveries needed for all routes in the period is $E\cdot P$. The minimum fleet size required to cover these routes in the T-day period is then $\lceil E\cdot P/T \rceil$. According to Proposition 2, the number of routes assigned by Algorithm 1 to any day is at most $\lceil E\cdot P/T \rceil$. Therefore, the solution is optimal. □

The customer orders are delivered E times in the period. Due to the requirement for delivery days of any order being evenly distributed, a new round of delivery will not start on a day if previous round has not completed on that day or the day before. Orders from two successive rounds may only be delivered on the same day for 1 day. Similar to the above proof, it can be shown that if customers of one round cannot be mixed with those of next round within a route, then the solution is optimal even without Assumption 1. In practice, the routing problem may be solved heuristically. In this case the final solution may not be optimal. The solution quality will depend on the quality of routing problem solution.

2.4 Alternative Schedules with the Same Fleet Size

Algorithm 1 generates one feasible schedule for the same-frequency problem with optimal fleet size. If $(P\cdot E)/T$ is integer then every day is assigned $(P\cdot E)/T$ routes and this optimal solution is unique. If $(P\cdot E)/T$ is not integer, there exist alternative feasible optimal solutions. In practice, the distribution company may be interested in these alternative solutions so that they have freedom to choose on which days of the period the number of $\lfloor E\cdot P/T\rfloor$ or $\lceil E\cdot P/T\rceil$ vehicles are scheduled based on availability of resources (vehicles, drivers). Furthermore, the alternative solutions will be useful when we deal with the problem with different delivery frequencies. The proposition below provides properties based on which we can generate alternative optimal feasible solutions.

Proposition 4
Given that the route-deliveries are assigned day-by-day sequentially according to their numbering and that every day is assigned at least $\lfloor P\cdot E/T\rfloor$ and at most $\lceil P\cdot E/T\rceil$ route-deliveries, any schedule with the following property is feasible:

Case 1, T is a multiple of E: Exactly P routes are assigned in the first T/E-day sub-period with each day assigned at most $\lceil (P\cdot E)/T\rceil$ routes, and the same pattern repeats in each of the following T/E-day sub-periods;

Case 2, T is not a multiple of E: Any two successive $\lceil (P\cdot E)/T\rceil$-route days are spaced either $\lfloor T/R\rfloor$ or $\lceil T/R\rceil$ days, and at most $\lceil (\lceil T/E\rceil - 1)R/T\rceil$ days are assigned $\lceil (P\cdot E)/T\rceil$ routes in any $(\lceil T/E\rceil - 1)$ days and at least $\lfloor \lceil T/E\rceil R/T\rfloor$ days are assigned $\lceil (P\cdot E)/T\rceil$ routes in any $\lceil T/E\rceil$ days, where $R = \text{mod}\,(P\cdot E, T)$ and thus $P\cdot E = T\,\lfloor P\cdot E/T\rfloor + R = R\,\lceil (P\cdot E)/T\rceil + (T - R)\,\lfloor P\cdot E/T\rfloor$.

Proof
Case 1: With the property specified, it can be seen that two successive deliveries of the same route are always spaced T/E days, i.e., two successive deliveries for any customer are always T/E days apart. So the schedule is feasible.

Case 2: In any $(\lceil T/E\rceil - 1)$ days the number of route-deliveries is at most

$$\begin{aligned}
&(\lceil T/E\rceil - 1)\lfloor P\cdot E/T\rfloor + \lceil (\lceil T/E\rceil - 1)R/T\rceil\\
&= \lceil (\lceil T/E\rceil - 1)\lfloor P\cdot E/T\rfloor + (\lceil T/E\rceil - 1)R/T\rceil\\
&= \lceil (\lceil T/E\rceil - 1)(\lfloor P\cdot E/T\rfloor + R/T)\rceil\\
&= \lceil (\lceil T/E\rceil - 1)P\cdot E/T\rceil\\
&< \lceil (T/E)P\cdot E/T\rceil = P
\end{aligned}$$

In any $\lceil T/E\rceil$ days the number of route-deliveries is at least

$$\begin{aligned}
&\lceil T/E\rceil\cdot\lfloor P\cdot E/T\rfloor + \lfloor \lceil T/E\rceil\cdot R/T\rfloor\\
&= \lfloor \lceil T/E\rceil\cdot\lfloor P\cdot E/T\rfloor + \lceil T/E\rceil\cdot R/T\rfloor\\
&= \lfloor \lceil T/E\rceil\cdot(\lfloor P\cdot E/T\rfloor + R/T)\rfloor\\
&= \lfloor \lceil T/E\rceil\cdot P\cdot E/T\rfloor > \lfloor (T/E)\cdot P\cdot E/T\rfloor = P
\end{aligned}$$

Two successive deliveries to any customer are in two route-deliveries that are P apart. The above relations indicate that the two routes are assigned at least $\lfloor T/E\rfloor$ days apart and at most $\lceil T/E\rceil$ days apart. Therefore, the schedule is feasible. □

Corollary 1
The evenly-spacing requirement is satisfied if the number of route-deliveries does not exceed P in any successive $\lfloor T/E \rfloor$ days and does not fall below P in any successive $\lceil T/E \rceil$ days.

3 Problem with Different Delivery Frequencies

Under Assumption 1, customers with different delivery frequencies cannot be mixed in the same route. To solve the problem with different delivery frequencies, we can still take the two-phase routing-then-scheduling approach. In phase 1, we first solve a VRP for each delivery frequency E_i to obtain the number of routes needed, P_i, for one delivery to all the customers with this frequency. The total number of route-deliveries for this frequency is then $E_i \cdot P_i$. The remaining task in phase 2 is then to make feasible assignments of all the route-deliveries for all frequencies to the days in the T-day period so that the fleet size is minimized. In the following two subsections, we present two methods for solving the phase-2 problem.

3.1 A General Integer Programming Model

We define the following variables.

y_{ij} = the number of route-deliveries for frequency E_i assigned on day j, $i = 1, \ldots, n, j = 1, \ldots, T$.
FZ = the fleet size.

Then the problem can be formulated as the integer programming model below.

$$(\textbf{IP0})\ \text{Minimize}\ FZ \tag{1}$$

Subject to

$$FZ \geq \sum_{i=1}^{n} y_{ij}, \quad j = 1, \ldots, T \tag{2}$$

$$\sum_{j=1}^{T} y_{ij} = P_i \cdot E_i, \quad i = 1, \ldots, n \tag{3}$$

$$\sum_{j=h}^{h+\lfloor T/E_i \rfloor - 1} y_{i,\mathrm{mod}(\ j-1,T)+1} \leq P_i, \quad i = 1, \ldots, n; h = 1, \ldots, T; E_i \neq 1 \tag{4}$$

$$\sum_{j=h}^{h+\lceil T/E_i \rceil -1} y_{i,\mathrm{mod}(\ j-1,T)+1} \geq P_i, \quad i = 1, \ldots, n; h = 1, \ldots, T; E_i \neq 1 \tag{5}$$

$$y_{ij} \geq 0 \text{ and integer}, i = 1, \ldots, n, j = 1, \ldots, T \tag{6}$$

In the model, the objective (1) is to minimize the fleet size required. Constraints (2) ensure that the number of routes delivered on each day does not exceed the fleet size. Constraints (3) guarantee that all the orders for each frequency are delivered. Constraints (4) and (5) guarantee that the schedule is feasible, i.e., any two successive deliveries of a route for a frequency (the two deliveries are numbered P_i apart) are delivered on 2 days that are either $\lceil T/E_i \rceil$ or $\lfloor T/E_i \rfloor$ apart. Note that these constraints are unnecessary for frequency 1 because orders with frequency 1 can be delivered on any 1 day in the period. Constraints (6) are nonnegative and integer constraints.

3.2 A Two-Stage Method

The above model minimizes the fleet size. In an optimal solution, however, the number of routes for a particular frequency assigned on different days can be significantly different. Therefore, y_{ij} may take any value from 0 to P_i. This implies that the delivery patterns (the number of routes delivered each day for each frequency) are sensitive to both adding (removing) a delivery frequency and the route variation for existing frequencies. For example, adding a new delivery frequency or reducing one route for a certain delivery frequency can cause the delivery patterns for other frequencies change greatly. To alleviate this drastic change, we limit the number of routes assigned to a day for delivery frequency E_i ($E_i \neq 1$) to be either $\lceil P_i E_i / T \rceil$ or $\lfloor P_i \cdot E_i / T \rfloor$. Then we can use the following binary variable, rather than a general integer variable, to represent the assignment of routes for a frequency to a day.

$$x_{ij} = \begin{cases} 1, & \text{if } \lceil P_i E_i / T \rceil \text{ routes for frequency } E_i \text{ are assigned on day } j \\ 0, & \text{if } \lfloor P_i E_i / T \rfloor \text{ routes for frequency } E_i \text{ are assigned on day } j \end{cases}, \quad i = 1, \ldots, n, j = 1, \ldots, T, E_i \neq 1.$$

Then we can obtain a solution in two stages.

The first stage tries to minimize the fleet size requirement $FZ1$, considering the routes with frequencies other than 1. The following 0-1 integer programming model does this using the above defined binary variables.

$$(\mathbf{IP1})\ \text{Minimize } FZ1 \tag{7}$$

Subject to

$$FZ1 \geq \sum_{\substack{i=1\\E_i \neq 1}}^{n} x_{ij} + \sum_{\substack{i=1\\E_i \neq 1}}^{n} \lfloor P_i E_i / T \rfloor, \quad j = 1, \ldots, T \tag{8}$$

$$\sum_{j=1}^{T} x_{ij} = \mathrm{mod}(P_i E_i, T), \quad i = 1, \ldots, n; E_i \neq 1 \tag{9}$$

$$\sum_{j=h}^{h+\lfloor T/E_i \rfloor -1} x_{i,\mathrm{mod}(\ j-1,T)+1} \leq \lceil \lfloor T/E_i \rfloor \mathrm{mod}(P_i E_i, T)/T \rceil, \quad i = 1, \ldots, n; h = 1, \ldots, T; E_i \neq 1 \tag{10}$$

$$\sum_{j=h}^{h+\lceil T/E_i \rceil -1} x_{i,\mathrm{mod}(\ j-1,T)+1} \geq \lfloor \lceil T/E_i \rceil \mathrm{mod}(P_i E_i, T)/T \rfloor, \quad i = 1, \ldots, n; h = 1, \ldots, T; E_i \neq 1, \tag{11}$$

$$x_{ij} = \{0, 1\}, i = 1, \ldots, n; j = 1, \ldots, T; E_i \neq 1 \tag{12}$$

The meanings of the constraints are similar to the corresponding constraints in the earlier IP (integer programming) model. Note that feasibility constraints (10) and (11) use the property given in Proposition 4. After solving this model, we can get the total number of routes assigned to each day, F_j, $j = 1,\ldots,T$, for all the frequencies other than 1.

The second stage is to assign the routes with frequency 1 on those days with fewer routes based on the solution to the first stage model so that the total fleet size can be minimized. Let P_1 denote the total number of routes for frequency 1. Define variable y_j as the number of routes for frequency 1 assigned to each day $j = 1,\ldots,T$. The second stage problem can then be formulated as the small IP model below.

$$(\mathbf{IP2})\ \text{Minimize } FZ \tag{13}$$

Subject to

$$FZ \geq F_j + y_j, \quad j = 1, \ldots, T \tag{14}$$

$$\sum_{j=1}^{T} y_j = P_1 \tag{15}$$

$$y_j \geq 0 \text{ and integer}, j = 1, \ldots, T. \tag{16}$$

Constraints (14) ensure that the fleet size is sufficient to cover all routes assigned to each day including those with frequency 1. Constraint (15) requires that all routes with frequency one are assigned. Constraints (16) are nonnegative and integer constraints.

Both the general IP model (IP0) and the two-stage models (IP1 and IP2) are standard IP models, which can be solved using a standard software package.

3.3 An Extended Routing-then-Scheduling Approach

Assumption 1 allows us to schedule routes rather than individual customers in the scheduling phase. This makes the problem simpler and the model size much smaller. Even in the situation where Assumption 1 does not holds, if the numbers of routes for different frequencies generated in phase 1 are large and the routes are all close to the vehicle's capacity of a day, then there may not be much room left for improvement by reorganizing the routes. Therefore the solution obtained under the assumption will be a close-to-optimal solution for the problem in this situation. If the number of routes is small and they are not close to the vehicle's capacity, then a better solution may be obtained using the following extended routing-then-scheduling approach.

Phase 1. Solve a VRP for each delivery frequency E_i to obtain the number of routes needed, P_i, for one delivery to all the customers with this frequency. While keeping the number of routes needed to a minimum, try to minimize the workload of the last route.

Phase 2. Use the two-stage method to schedule the E_i deliveries of the first ($P_i - 1$) routes, and the P_ith route if it is close to full capacity, for every frequency.

Phase 3. Schedule the E_i deliveries for individual customers in the unscheduled routes of all frequencies so that the total fleet size is minimized. The evenly-spacing requirement should be observed. Although the customers here are considered individually, the number of such customers is small given the objective of Phase 1. Therefore the problem of this phase is much simpler than the original problem.

4 Computational Experiments

4.1 Testing the Route Assignment Models

To test the performance of the models presented in the last section, we carry out numerical experiments on a variety of test problems with the planning period T set to

7, 14 and 30 days, which correspond to the common practice of weekly, bi-weekly and monthly delivery schedules respectively. For each T value, we consider several delivery frequencies in the delivery problem. For a delivery frequency, the number of routes required to make one delivery to all customers with this frequency is generated randomly from a uniform distribution [1, 2T]. Table 2 shows the parameter settings for the test problems.

For each value of the planning period T, we generate 10 problem instances. We solve each problem instance using both the general IP model (IP0) and the two-stage method with the first stage model (IP1) and the second stage model (IP2). The IP models are solved using ILOG CPLEX 10.2. Both methods take a very short time (in seconds) to solve a problem. For each problem instance, the fleet sizes obtained by the two methods are the same.

However, the delivery patterns generated by the two methods differ greatly. Especially, the delivery patterns generated by the two-stage method are less sensitive to problem parameter changes (changes in delivery frequency and route) than those by the general IP model. In the following, we illustrate the effects of parameter changes on the delivery patterns of the general IP model and the two-stage method using a problem instance with $T = 7$. The original problem has seven routes to be delivered once, nine routes to be delivered twice, ten routes to be delivered three times and one route to be delivered seven times in the 7-day period. Table 3 shows these data for the original problem and the numbers of routes for three variations of the problem.

For the data in Table 3, the number of routes for frequencies 1, 2 and 7 remain unchanged for all the variations considered. Because the frequency-7 route needs to be delivered every day and there is only one pattern for this, the delivery patterns for frequencies 1 and 2 are the best indicators to demonstrate the solution robustness of the models. Figures 1 and 2 show the delivery patterns generated by the general IP model and two-stage models, respectively, for the example problem instance and its variations.

Based on Fig. 1, we can see that the delivery patterns generated by the general IP model change significantly whenever there is a change in delivery frequency or in the number of routes for a delivery frequency. That is, to guarantee the minimization of the fleet size, the number of delivery routes for the other frequencies (frequency 1 and frequency 2) must be adjusted significantly to accommodate the disturbances. However, the delivery patterns generated by the two-stage method (Fig. 2) are much more robust. For each frequency, the maximum variation of delivered routes for each day is 1, as the constraints of the model (IP1) show.

In summary, the two-stage method solves the route scheduling problem very effectively. It gives optimal solutions for all the problems tested and the delivery patterns generated are more robust than those generated by the general IP model. In addition, the

Table 2 Parameter settings for the test problems

Planning period T	7	14	30
Delivery frequencies	1, 2, 3, 7	1, 2, 7, 14	1, 2, 3, 6, 15, 30
Number of routes needed to make one delivery	U[1, 14]	U[1, 28]	U[1, 60]

Table 3 Number of routes for a problem instance with $T = 7$ and its variations

Delivery frequencies	1	2	3	7	4
The original problem	7	9	10	1	–
Adding a new frequency 4	7	9	10	1	2
Changing routes for frequency 3	7	9	8	1	–
Changing frequency 3–4	7	9	–	1	10

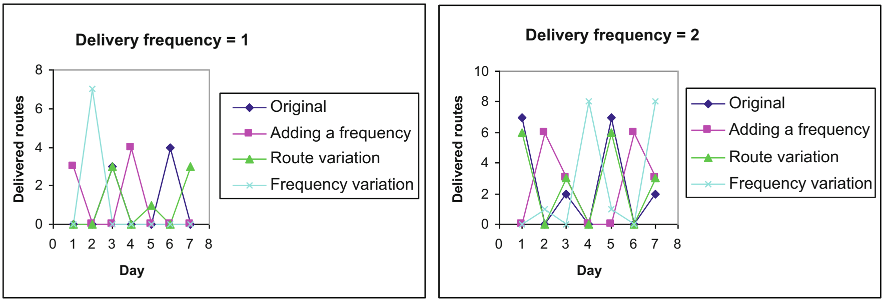


Fig. 1 Delivery patterns generated by the general IP model

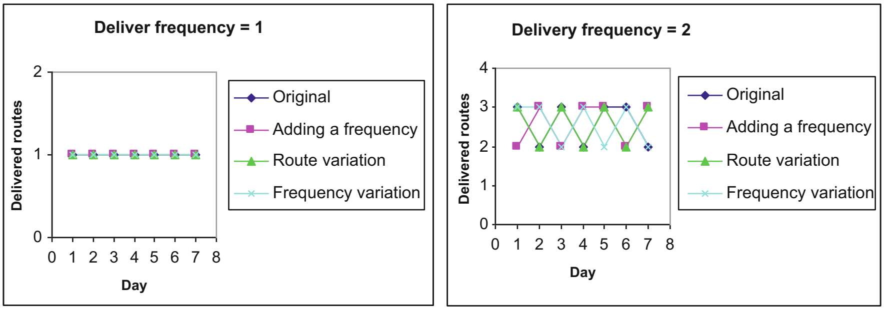


Fig. 2 Delivery patterns generated by the two-stage models

models in the two-stage method are much simpler and can solve large problems when the planning period is long and there are more different delivery frequencies.

4.2 *Test on Benchmark Examples*

Detailed data for three standard VRPs with 50, 75 and 100 customers respectively were provided in Christofides and Eilon (1969) and in Eilon et al. (1971). Christofides and Beasley (1984) generated ten instances of PVRPs from these data by setting periodical patterns for customer demand. The feasible periodical demand patterns in these PVRPs match with our problem setting which requires the deliveries to each customer to be spaced over time as evenly as possible. Gaudioso and Paletta (1992) tested their method on some of these PVRPs in which all customers have a delivery frequency of 1. Six of the ten problems are PVRPs with delivery frequency of 1, labeled as 50a, 50c, 75a, 75c, 100a, 100c in Christofides and Beasley (1984). We solved these six problems using our routing-then-scheduling approach and obtained solutions with the same fleet sizes as in the solutions by Christofides and Beasley (1984) and Gaudioso and Paletta (1992). The total distances traveled depend on the method used in the routing phase. In the routing phase we used a location-allocation model to cluster the customers into routes heuristically and then use a traveling salesman problem model to determine the actual trip of each route. The resulting routes are then scheduled to the days in the period using Algorithm 1. Table 4 shows the results on these problems by our approach (L&R) together with those by Christofides and Beasley (1984) (C&B) and by Gaudioso and Paletta (1992) (G&P). Since our objective is to minimize the fleet size, the distance in our solution could be longer than that in the C&B solution in some cases. However, the results in Table 4 show that in terms of distance our solution is also comparable to the C&B solution.

The rest four PVRPs in Christofides and Beasley (1984) are multi-frequency problems (labeled as 50b, 75b, 100b and 100d), all with a planning period of 5, generated by splitting the customers in the VRPs in Eilon et al. (1971) in groups requiring different delivery frequencies. These problems cannot be handled by the heuristic in Gaudioso and Paletta (1992). We applied our approach on these problems. Under Assumption 1, our method obtained solutions with the same fleet sizes as in the C&B solutions for problems 75b, 100b and 100d. For problem 50b, the solution with Assumption 1 needs a fleet size of 4, one more than in the C&B solution, while our extended routing-then-scheduling approach gives a solution with the same fleet size as in the C&B solution. This problem is an ideal example to illustrate the effect of Assumption 1 in an extreme situation, and hence worthy to discuss in detail. The planning period of the problem is 5 days. There are 50 customers in total, 17 of them with small demands need a delivery frequency of 1, 26 with medium demands need a delivery frequency of 2, and 7 with large demand need a delivery frequency of 5.

In the routing phase result, all the frequence-1 customers can be served in one route with about 80% full of the vehicle capacity; serving all the frequency-2

Table 4 Results on the benchmark problems with delivery frequency of 1

Problem number	No. of customers	Planning horizon	Fleet size	Distance		
				C&B	G&P	L&R
50a	50	2	3	558.4	601.6	541.7
50c	50	5	1	547.5	625.5	541.7
75a	75	2	5	855.4	949.4	920.1
75c	75	10	1	938.2	973.4	920.1
100a	100	2	4	839.2	902.2	886.5
100c	100	8	1	889.7	908.4	886.5

Table 5 Route schedule given by our extended routing-then-scheduling approach for Problem 50b

Day	1	2	3	4	5
Delivery routes scheduled	1	2	3	2	3
	4	4	4	4	4
	5	6	7	6	7

customers once needs 3 routes (two nearly full and one 70% full); and serving all the frequency-5 customers once needs two routes (one nearly full and one 36% full). Under Assumption 1, the total number of route-deliveries will be $1 + 3 \times 2 + 2 \times 5 = 17$ and scheduling them in 5 days will need a fleet size of 4, even without considering the evenly-spacing requirement. Applying our extended routing-then-scheduling approach, we can first schedule the deliveries of the close-to-full routes: the frequency-1 route (let us call it Route 1), the two full frequency-2 routes (Routes 2 and 3) and the full frequency-5 route (Route 4). All these together need a fleet size of 2. For the remaining customers, the customers in the 36% full frequency-5 route (Route 5) need to be delivered every day. We can separate the customers in the 70% full frequency-2 route into two groups and schedule them in 4 days, each group on 2 days spaced evenly. For each of these 4 days, these customers can be delivered together with those in Route 5 on that day. Since the customers are added to Route 5 on these days, the enlarged Route 5 on these days will be renamed as Route 6 and Route 7 respectively. The complete route schedule is shown in Table 5, while Assumption 1 is partially respected in the solution. The final fleet size needed is 3.

For relating the result easily to the problem data in Eilon et al. (1971) and Christofides and Beasley (1984), the customers in these routes are listed below.

Route 1: 1, 4, 10, 15, 17, 19, 21, 22, 24, 26, 29, 36, 37, 40, 45, 46, 50;
Route 2: 6, 13, 14, 23, 27, 43, 44, 47, 48;
Route 3: 5, 9, 11, 16, 30, 33, 38, 39, 42, 49;
Route 4: 12, 18, 25, 34, 41;
Route 5: 2, 20;
Route 6: 2, 20, 7, 8, 31, 32;
Route 7: 2, 20, 3, 28, 35.

The total distance travelled for the solution is 1967.1. If the customers in different routes on the same day can be mixed, we can mix all customers in different routes of each day together and solve a VRP to reorganize them into new routes. In this way the total distance can be shortened to 1586.3.

The above test on the benchmark problems shows that our approach is effective. We can also see that while Assumption 1 can simplify the problem and is convenient for the delivery team, it does not significantly affect the solution quality in the situation where this assumption is not required. In extreme cases where the assumption affects the solution, the problem can be solved effectively using our extended routing-then-scheduling approach to reduce the travel distance or cost while the fleet size remains the same or slightly improved. Managers can decide whether Assumption 1 should be observed in the specific situations.

5 Conclusions

In this chapter, we studied the periodical delivery problem in which delivery frequencies to different customers may be different, the deliveries to the same customer need to be evenly distributed over time and the objective is to minimize the fleet size. We first studied the problem with the same delivery frequency and proposed a routing-then-scheduling approach. Analysis was then done on the feasibility and optimality of the solution. Based on the result of the analysis, we then developed a general integer programming model and a two-stage method, with a smaller integer programming model for each stage, for the general problem with different delivery frequencies. The approach guarantees the resulting delivery plan satisfying the assumption that customers in the same route remain in the same route in every delivery. Such a plan is convenient for management and the delivery team. For the cases where this assumption is not necessary, we presented an extended routing-then-scheduling approach that can reduce traveling distance. Numerical experiments on problems with typical planning periods showed that both methods could solve the problem quickly, but the delivery patterns generated by the two-stage models were more robust than those generated by the general IP model. Numerical test on benchmark problems showed that our approach could generate solutions with the same fleet sizes as in previous studies. Our approach needs to solve much fewer VRPs in the solution process and will be efficient and useful for solving problems with long planning horizon and multiple frequencies.

References

Achuthan, N. R., Caccetta, L., & Hill, S. P. (1998). Capacitated vehicle routing problem; some new cutting planes. *Asian-Pacific Journal of Operational Research, 15*, 109–123.

Alegre, J., Laguna, M., & Pacheco, J. (2007). Optimizing the periodic pick-up of raw materials for a manufacture of auto part. *European Journal of Operational Research, 179*, 736–746.

Alonso, F., Alvarez, M. J., & Beasley, J. E. (2008). A tabu search algorithm for the periodic vehicle routing problem with multiple vehicle trips and accessibility restrictions. *Journal of the Operational Research Society, 59*, 963–976.

Archetti, C., Fernández, E., & Huerta-Muñoz, D. L. (2017). The flexible periodic vehicle routing problem. *Computers and Operations Research, 85*, 58–70.

Ball, M. (1988). Allocating/routing: models and algorithms. In B. L. Golden & A. A. Assad (Eds.), *Vehicle routing: Methods and studies*. Amsterdam: North-Holland.

Banerea-Brodeur, M., Cordeaul, J.-F., Laporte, G., & Lasry, A. (1998). Scheduling linen deliveries in a large hospital. *Journal of the Operational Research Society, 49*, 777–780.

Bell, W. J., Dalberto, L. M., Fisher, M. L., Greenfield, A. J., Jaikumar, R., Kedia, P., Mack, R. G., & Prutzman, P. J. (1983). Improving the distribution of industrial gases with an on-line computerized routing and scheduling optimizer. *Interfaces, 13*, 4–23.

Beltrami, E. J., & Bodin, L. D. (1974). Networks and vehicle routing for municipal waste collection. *Networks, 4*, 65–94.

Bommisetty, D., Dessouky, M., & Jacobs, L. (1998). Scheduling collection of recyclable material at Northern Illinois University Campus using a two-phase algorithm. *Computers and Industrial Engineering, 35*, 435–438.

Cacchiani, V., Hemmelmayr, V. C., & Tricoire, F. (2014). A set-covering based heuristic algorithm for the periodic vehicle routing problem. *Discrete Applied Mathematics, 163*, 53–64.

Chao, I. M., Golden, B. L., & Wasil, E. (1995). An improved heuristic for the period vehicle routing problem. *Networks, 26*, 25–44.

Christofides, N., & Beasley, J. E. (1984). The period routing problem. *Networks, 14*, 237–256.

Christofides, N., & Eilon, S. (1969). An algorithm for the vehicle dispatching problem. *Operational Research Quarterly, 20*, 309–318.

Coene, S., Arnout, A., & Spieksma, F. C. R. (2010). On a periodic vehicle routing problem. *Journal of the Operational Research Society, 61*, 1719–1728.

Cordeau, J. F., Gendreau, M., & Laporte, G. (1997). A tabu search heuristic for periodic and multi-depot vehicle routing problems. *Networks, 30*, 105–119.

Dror, M., & Ball, M. (1987). Inventory/routing: Reduction from an annual to a short-period problem. *Naval Research Logistics, 34*, 891–905.

Drummond, L. M. A., Ochi, L. S., & Vianna, D. S. (2001). An asynchronous parallel metaheuristic for the period vehicle routing problem. *Future Generation Computer Systems, 17*, 379–386.

Eilon, S., Watson-Dandy, C. D. T., & Christofides, N. (1971). *Distribution management: Mathematical modelling and practical analysis*. London: Griffin.

Francis, P., Smilowitz, K., & Tzur, M. (2007). Flexibility and complexity in periodic distribution problems. *Naval Research Logistics, 54*, 136–150.

Gaudioso, M., & Paletta, G. (1992). A heuristic for the periodic vehicle routing problem. *Transportation Science, 26*, 86–92.

Golden, B. L., & Wasil, E. A. (1987). Computerized vehicle routing in the soft drink industry. *Operations Research, 35*, 6–17.

Michallet, J., Prins, C., Amodeo, L., Yalaoui, F., & Vitry, G. (2014). Multi-start iterated local search for the periodic vehicle routing problem with time windows and time spread constraints on services. *Computers & Operations Research, 41*, 196–207.

Nguyen, P. K., Crainic, T. G., & Toulouse, M. (2014). A hybrid generational genetic algorithm for the periodic vehicle routing problem with time windows. *Journal of Heuristics, 20*, 383–416.

Rahimi-Vahed, A., Crainic, T. G., Gendreau, M., & Rei, W. (2013). A path relinking algorithm for a multi-depot periodic vehicle routing problem. *Journal of Heuristics, 19*, 497–524.

Rahimi-Vahed, A., Crainic, T. G., Gendreau, M., & Rei, W. (2015). Fleet-sizing for multi-depot and periodic vehicle routing problems using a modular heuristic algorithm. *Computers & Operations Research, 53*, 9–23.

Russell, R. A., & Gribbin, D. (1991). A multiphase approach to the period routing problem. *Networks, 21*, 747–765.

Shih, L. H., & Chang, H. C. (2001). A routing and scheduling system for infectious waste collection. *Environmental Modeling & Assessment, 6*, 261–269.

Shih, L. H., & Lin, Y. T. (1999). Optimal routing for infectious waste collection. *Journal of Environmental Engineering-ASCE, 125*, 479–484.

Tan, C. C. R., & Beasley, J. E. (1984). A heuristic algorithm for the period vehicle routing problem. *OMEGA, 12*, 497–504.

Vanderbeck, F. (1999). Computational study of a column generation algorithm for bin packing and cutting stock problems. *Mathematical Programming, 86*, 565–594.