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# Collaborative Logistics and Intermodality

## Integration in Supply Chain Network Models and Solutions for Global Environments

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

# 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

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# 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

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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,