Issue 20(2), 2020, pp. 1-35
https://doi.org/10.18757/ejtir.2020.20.2.3887

TU Delft OPEN

EJTIR

ISSN: 1567-7141
http://ejtir.tudelft.nl/

Reefer logistics and cold chain transport: a systematic review and multi-actor system analysis of an un-explored domain

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Reefer logistics is an important part of the cold chain in which reefer containers are involved as the packaging for transporting perishable goods. Reefer logistics is challenging, as it deals with cost and time constraints as well as the product quality and sustainability requirements. In many situations, there is a trade-off between these factors (e.g., between transportation cost and the quality of fresh products). Furthermore, considering the high value of reefers, the efficient logistics of reefers is as important as the efficient cargo flows. This causes technical complications and the conflicts of interests between actors, especially, between cargo owners (or shippers) and the asset owners (or transport/terminal operators). Improving the efficiency of reefer logistics calls for a thorough understanding of the trade-offs and complexities. This paper aims to help develop such an understanding using a systematic literature review and a socio-technical system analysis. The results can be used to provide managerial insights for actors involved in a cold chain to design tailored solutions for reefers.

Keywords: *reefer logistics, cold chain management, system analysis, multi-actor setting, review.*

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1. Introduction

A cold chain includes all steps/facilities for storing, handling and transportation of perishable products – for which controlled temperature conditions must be maintained from the point of production to the point of sale (Hundy et al., 2008). Reefer logistics is an important part of a cold chain dealing with the process of planning, and controlling the efficient, forward and backward logistics of reefer as well as products from the point-of-origin to the point-of-destination. Reefers have refrigeration units built into their structure that operate electrically, either from an external power supply during transportation or at a container yard (Rodrigue and Notteboom, 2015). A reefer is also equipped with a control system for temperature monitoring and alarm devices to ensure the safety of agri-food products. The modular and standard structure of reefer containers provides handling flexibility and efficiency for multi-modal transport and has been the main reason for a major shift from specialized reefer vessels to reefer containers in global transportation of perishable goods (Bömer and Tadeu, 2014). Seaborne reefer transport demand in 2007 was around 85 million tonnes and is growing with an average annual growth rate of 2.5% in the past ten years. By 2020, the demand for seaborne reefer logistics is forecasted to reach 120 million tonnes (Drewry, 2016). The increase in reefer demand is closely related to the growth of global agriculture trade, as consumers have been conditioned to a bounty of agri-food products from across the globe and across seasons (Kyriacou and Rouphael, 2018).

The growing demand puts pressure on industries to design (more) effective reefer logistics systems in order to fulfil the demand. Effective planning for reefer logistics is however challenging, because of distinctive technological features of reefer (compared with dry containers). Firstly, reefer logistics has high investment costs in refrigeration equipment. The price of a reefer is approximately five times higher than that of a dry container of the same size (Rodrigue and Notteboom, 2017a). Therefore, high asset utilization – through effective planning of reefer transportation, transhipment and repositioning – is an important factor. Secondly, reefers carry perishable goods, for which the product quality might degrade during the transportation; hence, transportation time is a crucial factor (Akkerman et al., 2010). Compared with high-value cargo – which also demands for fast transport –, the main difference is that fast transport helps to keep the quality of perishable cargo, thereby reduces food waste, while for high-value cargo, fast transport is mainly driven by the price of the products and high value of time. Furthermore, for perishable cargo, the time-dependent cost is distributed between actors involved in cold chain, e.g., shipper, terminal and transport operators while for high-value cargo, this cost is primarily for the shipper. To reduce the rate of quality decay in perishable goods, reefer containers use energy for refrigeration units during storage and transportation. Therefore, the availability of energy sources as well as (minimizing) the energy consumption are important in the reefer logistics. The need for cooling energy creates additional costs as well as more pollution to the environment. For instance, reefers are responsible for about 30-35% of the energy consumption at sea terminals (Geerlings and Van Duin, 2011). Another related issue is the maintenance of reefers which not only impacts the availability of reefers but also influences the energy consumption in the transport and storage processes (Hartmann, 2013). The interactions among cost, product quality, and environmental issues as well as the specific technical challenges in handling reefers make reefer logistics more complicated than dry container logistics.

Besides the technological features, many actors, e.g., shippers, transport operators, and port authorities, are involved in different segments of reefer logistics. These actors have different goals and interests, and the actions to achieve one actor's goals might negatively impact other actors in the chain. For instance, transportation carriers use different modes of the refrigeration systems to control the temperature in reefers, e.g., full capacity and on-off control. With the on-off control mode, the compressor and evaporator fans will go on and off according to a predetermined algorithm (Hamburg Süd, 2010). Using the on-off control mode can reduce the energy usage of transportation carriers (Lukasse et al., 2011); however, there will be temperature variations inside the reefers having undesired influences on the product quality, which might not be accepted by shippers (Jedermann et al., 2017). In order to improve the efficiency of reefer logistics, a thorough understanding of these trade-offs and complexities is needed.

In this study, we aim to identify the actions that can be taken to improve the efficiency of reefer logistics by different actors in a cold chain. We also study the factors that affects the objectives of different actors along the chain. The findings – as formalized in several system diagrams – help in understanding the overall system from other actors' perspective. It also aims to identify the possible trade-offs between different objectives of each actor as well as among the objective of different actors in a cold chain. The rest of this paper is organized as follows. Section 2 gives a literature survey on reefer logistics. Section 3 discusses the findings of reefer logistics techniques and actors in reefer logistics, as well as the interactions between actors. Section 4 discusses the concluding remarks and the managerial implications of this research.

2. Review methodology

A systematic literature review is conducted in this study. The primary objective of the literature review is to provide a systematic and contemporary review of research on the reefer logistics and cold chains. A distinctive factor – in comparison with dry containers – is that several technical aspects (primarily because of the nature of perishable cargo) are involved in the planning for efficient reefer logistics. Therefore, the reefer logistics deals with not only costs and time constraints but also product quality and sustainability requirements. Furthermore, many actors are involved in the reefer logistics system with different (and sometimes conflicting) goals. All these aspects together make reefer logistics a complex socio-technical system. As a result, with this systematic literature review, we further aim to provide a systemic understanding of (social and technical) characteristics of reefer logistics and cold chains (including actors, their objectives, technologies used, etc.). The detailed review methodology in this study is described in Appendix A.

3. Findings

3.1. Reefer logistics technical aspects

The existing literature on reefer logistics is quite scarce and scattered. The majority of studies are focused on a specific part or component of the of reefer system and provide (mainly technical) solutions. The framework of cold chain technology discussed by Rodrigue and Notteboom (2017a) specifies five issues, which are monitoring, fabrication, storage, terminal and transport. We include monitoring, terminal and transport as categories to classify the literature, since fabrication and storage – which focus on cargo – are out of the scope of our study. Furthermore, a number of studies focus on reefer redesign, refrigeration units and atmosphere control in reefers. 'Reefer design and characteristics' is also considered as one category. The share of papers in each category is shown in Figure 1.

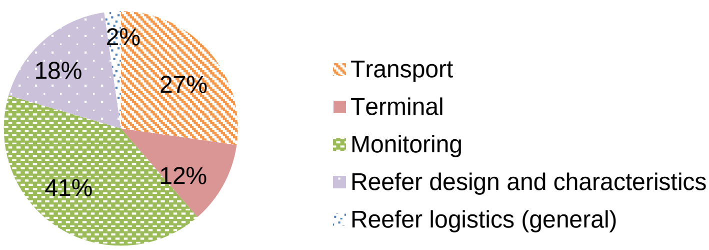

Figure 1. Categorization of articles on reefer logistics based on reefer logistics technology

A number of researchers have focused on “transport” issues. Cheaitou and Cariou (2012) analyse the slow steaming strategy of liner shipping operators. They find that this strategy reduces energy consumption of ships’ main engine, while increasing energy usage for the refrigeration units due to longer transit time. Ambrosino et al. (2015) propose a heuristic for multi-port stowage planning problem considering reefer containers in order to reduce re-handles. Besides maritime transport, a limited number of studies have discussed hinterland transport. Menesatti et al. (2014) present a case study of reefer transportation to compare the costs and transit time of single-mode road transport versus intermodal transport. Their results show that intermodality can reduce operational costs and CO_2 emission. They suggest further research is needed to design integrated networks and schedules for multiple modes and to analyse the impacts on product quality and sustainability. Fan et al. (2019) develop a model to analyse the benefit of using intermodal transport and flow consolidation to reduce costs and emission for reefer hinterland transportation. Lütjen, et al. (2013) and Haass et al. (2015) discuss a concept of quality-driven logistics supported by intelligent reefer containers. This concept is evaluated from the perspective of a shipper. The willingness of maritime carriers (i.e., reefer owners) to invest in intelligent reefers and to share cargo information is not covered in these studies.

With regard to the “terminal”, some studies have focused on the terminal design. For instance, Wiese, et al. (2011) discuss container terminal layouts designs considering the impact of the reefer racks distribution on the yard performance. Some other research has focused on operation. Filina-Dawidowicz et al (2015) identify the risks of loading loss during terminal handling; Hartmann (2013) propose a hybrid optimization-simulation approach for the scheduling of reefer mechanics at a container terminal. The objective is minimizing the weighted sum of total tardiness and total travel time.

A large part of existing research has focused on “monitoring”, which refers to the devices for tracking internal reefer conditions, such as temperature and humidity (Rodrigue and Notteboom, 2017a). The monitoring devices/systems and the applications are covered by these studies, which are especially discussed around the intelligent container concept. An intelligent container/reefer is a reefer equipped with additional monitoring and control units (Lütjen et al., 2013). Using an intelligent container, atmospheric conditions of perishable products can be continuously monitored and adjusted. Data gathered can be used, for example, to analyse product shelf-life (Jedermann et al., 2014a) or predict product quality (Bollen et al., 2015). Although several studies discussed the technical aspects of an intelligent container, the financial aspects are hardly addressed. In practice, extra investment is needed to implement wireless sensor networks or communication systems and risk/gain sharing are issues that need further analysis (Haass et al., 2015). This is especially important since the investment in the intelligent containers must be done by asset owners (mostly shipping companies) while the primary value of the technology is for product owners (mostly shippers or trading companies). To maintain product quality, some studies have particularly focused on managing air flow in reefer containers; for instance, Tutar et al. (2009) and Alptekin et al. (2014).

Another focus is on reefer itself – called the “reefer design and characteristics” category in Table 1. Accorsi et al. (2014) compare the technical aspects of standard dry containers, thermal liner containers, and reefer containers based on “thermal protection ability” – i.e., the ability of a specific container to protect the cargo from critical temperature fluctuations. They discuss that the adoption of the thermal liner containers system for long-range maritime shipments is a good trade-off between technical and economic features to protect the quality of temperature-sensitive products and would cause a lower environmental impact than reefer containers. Some researchers focus on redesigning the bin or the envelope of a container; for example, Copertaro et al. (2016) analyse the potential to use phase change materials (PCMs) in the envelope of a container to maintain temperature homogeneity inside the reefer and to reduce energy usage. Sepe et al. (2015) propose to use PCMs in containers to achieve lower manufacturing costs and energy consumption. Another research direction is the efficiency of refrigeration units, (e.g., Jolly et al. (2000) and Lukasse et al. (2011)).

Table 1. A classification of publications that have been reviewed

Technology	Subdivision	Article	Focus
Transport	Maritime	Imai and Rivera (2001)	Fleet size planning for refrigerated containers
		Blanke (2008)	Energy balance for fruit imports over sea
		Fitzgerald et al. (2011)	Energy use of refrigerated containers in maritime transportation
		Cheaitou and Cariou (2012)	Optimal sailing speed for perishable products
		Ambrosino et al. (2015)	Multi-port stowage planning including reefers
		Chao and Chen (2015)	Empty reefer repositioning among Asian ports
		Bömer and Tadeu (2014)	Reefer cargo maritime shipping characteristics
		Arduino et al (2015)	Reefer container vs. bulk reefer ship
	Hinterland	Menesatti et al. (2014)	Intermodal vs. trucking for reefer cargo
		Lütjen et al. (2013)	Quality driven distribution of intelligent reefers
		Haass et al. (2015)	Reducing food loss and CO_2 by intelligent reefers in hinterland transportation
		Fan et al. (2019)	Flow consolidation in reefer hinterland transportation
Terminal	Design	Wiese et al. (2011)	Terminal layout planning including reefer racks
		Filina-Dawidowicz et al. (2016)	Infrastructure requirements for reefers terminal handling
	Operation	Filina and Filin (2008)	The impact of disconnection of power supply on cargo in seaports
		van Duin (2018)	Intermittent supply of power for reefers to reduce energy consumption at terminal
		Hartmann (2013)	Scheduling reefer mechanics at terminals
		Filina-Dawidowicz et al. (2015)	Risk analysis of load loss during reefer terminal handling
Monitoring	Devices/ systems	Ruiz-Garcia et al. (2007)	Communication technologies and wireless sensor networks
		Lang et al. (2011)	The concept "Intelligent container"
		Wessels et al. (2010)	Required soft- and hardware for autonomous supervision of intelligent container
		Heidmann et al. (2012)	a Low-Power UHF/LF wireless sensor network for intelligent container
		Huh et al. (2016)	Reefer monitoring system using PLC
		Verdijck and van Straten (2002)	Controller design to keep climate variables as possible to set points to maximize product quality
		van der Sman and Verdijck (2003)	Controller design to adjust the set points to reduce energy usage
	Applications	Jedermann et al. (2014a)	Monitoring changes in product shelf life by intelligent container
		Jedermann et al. (2014b)	Remote quality monitoring in the banana chain
		Jiménez-Ariza et al. (2015)	Analyzing the distribution and spatial gradients of temperatures during reefer transport
		Bollen et al. (2015)	Wireless temperature monitoring of kiwi transport
		Punt and Huysamer (2005)	Temperature monitoring in reefer transportation
		Defraeye et al (2015)	Temperature monitoring during maritime transport for the concept "ambient loading"
		Defraeye et al (2016)	Internal condition evaluation of the concept "ambient loading"
		Morris et al. (2003)	Shelf life prediction model for cargoes transported by reefers

		Palafox-Albarrán et al. (2010)	Temperature prediction in reefers
		Palafox-Albarrán et al. (2011)	A model to predict temperature profile in spatial points inside a reefer
		Tutar et al. (2009)	A model to determining airflow patterns and temperature distribution in a reefer
		Alptekin et al. (2014)	Analysis of the airflow distribution inside a reefer container
Reefer design and characteristics	Comparison of containers	Accorsi et al. (2014)	Comparison between standard container, integral reefer and thermal liner container
	Redesign	Sepe and Armentani (2015)	Engineering development of a reefer with PCM and a remote control system
		Copertaro et al. (2016)	The application of PCMs to a reefer envelope
		Dodd (2013)	Changing internal architecture to manage airflow inside reefer
	Refrigeration unit	Yan-Qiao and Shi-Liang (1996)	Analysis of reliability of container refrigeration units
		Jolly et al. (2000)	Thermal performance model of a refrigeration system in a reefer container
		Lukasse et al. (2011)	Using ON/OFF compressor control to reduce energy consumption
		Sørensen et al. (2014)	A simulation model for refrigeration system of a reefer container
Reefer logistics (general)		Rodrigue and Notteboom (2015)	Facts of containerization of commodities and cold chain

Table 1 shows an overview of the literature on reefer logistics. In general, the existing studies have developed a number of solutions that can improve cost-efficiency, product quality or environmental impacts. However, most of the studies have not considered the trade-offs of costs, quality and environmental impacts of different technologies or solutions. The solutions are also proposed from one actor's perspective (mainly shippers and maritime carriers) and it is unclear how the other actors, such as hinterland operators and port authorities may react to those solutions. In the remainder of this paper, we aim to contribute to filling the gap by further analysis of actors involved in the reefer logistics domain. For this purpose, we extend our literature analysis and also include the grey literature including the reports by governmental bodies as well as the annual reports of ports. The aim is understanding the reefer logistics systems from a system perspective in which the actors in the system, their objective and interests, and their interactions through their policies and decisions are established. This helps to study reefer logistics as a whole system, enabling a better understanding of the characteristics of reefer logistics in a multi-actor setting. Additional publications on dry container logistics are also reviewed in order to fill the missing part about reefer logistics in the system analysis. This system analysis provides policy makers with a basis for analysing the impact of policies and industry with guidelines for making better informed decisions as further discussed in Section 4.

3.2. Actors in reefer logistics and their characteristics

As shown in Figure 2, reefer logistics is divided into several segments. A number of actors are involved in each segment. These actors can be generally classified in two groups: market players and public parties (Table 2). In general, shippers own the perishable cargo that needs to be delivered from an origin to a destination. Freight forwarders organize the transport services on behalf of shippers. They make agreements with transport operators and terminal operators in order to fulfil the requirements of shippers. In this way, shippers and freight forwarders expect to have control over (or be informed about) the whole process of reefer logistics. Maritime carriers own or rent the needed assets (e.g., deep-sea vessels and reefer containers) to transport perishable cargo over sea. Terminal operators handle reefer containers (including loading, unloading and stacking) at a sea or an inland terminal. Hinterland transport operators use trucks, trains, and barges to transport reefer containers from a sea terminal to cool warehouses and vice versa.

Besides the market players, several public parties are involved in the reefer logistics system. Port authorities are responsible for the port's infrastructure development/management (Van der Lugt et al., 2014). They have landlord function that consists of elements such as the development of the port estate (Verhoeven, 2010). Port authorities also have the regulator function and the operator function that covers the provision of port services. Customs protect people and facilitate trade, in terms of security, safety, and health (European Commission, 2014). Furthermore, several other governmental parties – such as ministry of transport, environmental office, and food and consumer product safety authority – are involved in the regulatory issues influencing the reefer logistics system.

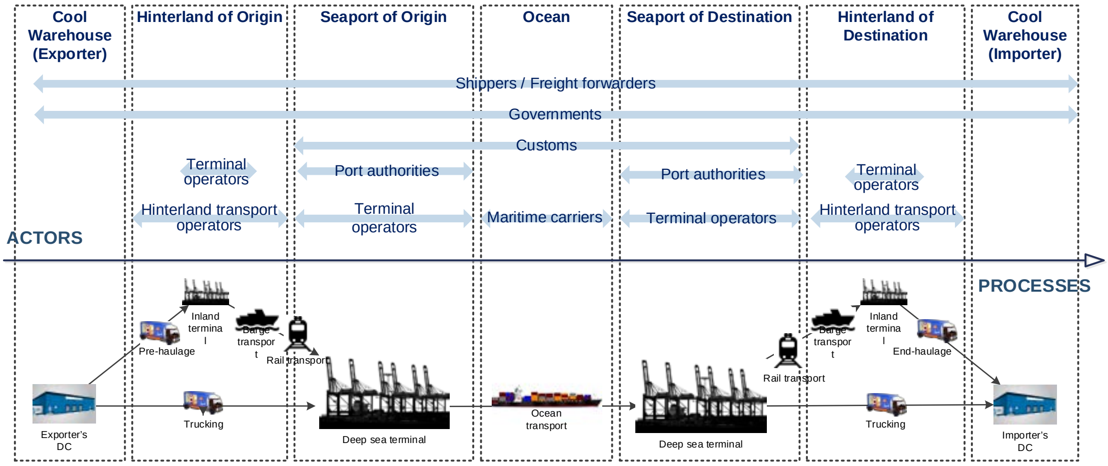

Figure 2. Reefer logistics process and segments

Fundamental objectives of each actor are shown in Table 2. For market players, a fundamental objective is maximizing profit. Besides, there is a growing interest in the sustainable transport (Castelein et al., 2019). Also, public parties increasingly stimulate market players to operate cleaner with policies and strategies. Thus, the environmental objective is another fundamental objective for the market players. For the government parties, the fundamental objective is sustainable development. The main goal of a port authority is to create economic and social value in the port (Port of Rotterdam, 2016). Customs aims to protect citizens, prosper businesses and promote trade by providing timely services (European Commission, 2014).

Table 2. Fundamental objectives of each actor

Actor		Fundamental objectives
Market players	Maritime carrier Terminal operator Hinterland transport operator Shipper Freight forwarder	Maximize profit Minimize environmental impacts (Castelein et al., 2019)
Public parties	Port authority	Create economic and social value in the port (Van der Lugt et al., 2014)
	Customs	Protect citizens, prosper businesses and promote trade (European Commission, 2014)
	Government (and governmental bodies)	Promote the local and national sustainable development

Different actors may adopt different actions and policies to achieve these objectives. In the system analysis and policy design for multi-actor systems, these actions and decisions are sometimes called "means" (Enserink et al., 2010). Means of an actor represent what an actor can do to influence the system and increase the chance to achieve his objectives. The means and policies found for different actors in the literature are summarized in Table 3 and further explained in the following. Each of these means may contribute in achieving one objective and potentially failing to achieve another, or partly achieving both.

Table 3. Summary of objectives, means and criteria of actors

Actor	Objectives	Means	Criteria
Maritime carrier	• Maximize shipping service quality (Mansouri et al., 2015) • Minimize operational cost (Cheaitou and Cariou, 2012) • Minimize emission (Haass et al., 2015)	• Conduct container pre-cleaning (Rodrigue and Notteboom, 2015) • Execute pre/post-trip inspection (Hamburg Süd, 2010) • Use controller to adjust set points remotely (Verdijck and Van Straten, 2002) • Reduce number of transhipment (Rodrigue and Notteboom, 2015) • Switch on and off reefer power connection (Fitzgerald et al., 2011) • Realize container monitoring system (Huh et al., 2016) • Use intelligent containers (Lang et al., 2011) • Use triangulation scheme (Van den Berg and De Langen, 2014) • Make decision on container leasing (Chao and Chen, 2015) • Apply vessel pooling (World Shipping Council, 2015) • Apply slow steaming strategy (Cheaitou and Cariou, 2012) • Realize vessel size leverage (Bömer and Tadeu, 2014) • Use energy efficient refrigeration unit (Haass et al., 2015)	• Schedule reliability (Haass et al., 2015) • Shipping cost (Cheaitou and Cariou, 2012) • Resource investment cost (Haass et al., 2015) • Number of container handling, e.g., pre-cleaning, manual inspection (Sørensen et al., 2014) • Fuel usage for cooling (Fitzgerald et al., 2011) • Fuel usage for shipment (Cheaitou and Cariou, 2012) • Transit time (Cheaitou and Cariou, 2012) • Reefer unconnected time (Rodrigue and Notteboom, 2015) • Empty movements (Chao and Chen, 2015)
Terminal operator	• Maximize service quality (Hsu, 2013) • Minimize operational cost (Wiese et al., 2011) • Minimize emission (Geerlings and Van Duin, 2011)	• Optimize reefer handling and stacking plan (Ambrosino et al., 2015) • Apply intermitted distribution of power among the reefer racks (van Duin et al., 2018) • Provide extended gate services (Van der Lugt et al., 2014) • Increase reefer handling and storage capacity (Rodrigue and Notteboom, 2009) • Reduce free storage time (Rodrigue and Notteboom, 2009) • Provide reefer monitoring service, e.g. PTI of reefer engine, repair (Expert)	• Reefer unconnected time (Rodrigue and Notteboom, 2015) • Container dwell time (Rodrigue and Notteboom, 2015) • Number of re-handles (Ambrosino et al., 2015) • Labour cost (Hartmann, 2013) • Facility cost (Wiese et al., 2011) • Energy usage (van Duin et al., 2018)
Hinterland transport operator	• Maximize service level (Menesatti et al., 2014) • Minimize operational cost (Menesatti et al., 2014) • Minimize emission (Menesatti et al., 2014)	• Switch on and off cooling compressor to regulate temperature in reefers (Rodrigue and Notteboom, 2015) • Operate intermodal transportation service (Menesatti et al., 2014) • Realize transport capacity pool (Van Der Horst and De Langen, 2008) • Realize intelligent freight transport system (Crainic et al., 2009)	• Schedule reliability and flexibility (Steadieseifi et al., 2014) • Modal split (Menesatti et al., 2014) • Transportation cost (Menesatti et al., 2014) • Fixed investment cost (Steadieseifi et al., 2014) • Fuel usage for cooling and shipment (Menesatti et al., 2014) • Transportation time (Menesatti et al., 2014)

			• Number of trans-loading of reefers (Rodrigue and Notteboom, 2015)
Shipper	• Maximize product shelf life (Jedermann et al., 2017) • Minimize operational cost (Haass et al., 2015) • Minimize emission (Haass et al., 2015)	• Realize controlled atmosphere in reefer (Snowdon, 2010) • Improve package design (Jedermann et al., 2014b) • Optimize stacking pattern of boxes on pallets (Jedermann et al., 2014b) • Optimize pallet stowage schemes in reefers (Jedermann et al., 2014b) • Give products a cold disinfestation treatment (Defraeye et al., 2016) • Apply ambient loading (Defraeye et al., 2016) • Give products post-harvest treatment, e.g. waxing or fungicide (Snowdon, 2010) • Execute pre-cooling for products (Tutar et al., 2009) • Apply quality driven distribution (Lütjen et al., 2013) • Order frequently with small product quantity (Kuo and Chen, 2010) • Realize remote reefer condition monitoring and model dynamic temperature in reefers (Jedermann et al., 2014b) • Add extra sensors in packages (Jedermann et al., 2014b)	• Airflow rate and accessibility in reefers (Jedermann et al., 2014b) • 7/8 cooling time (Defraeye et al., 2015) • Deliver time (Defraeye et al., 2015) • Loss of quality (Lütjen et al., 2013) • Material cost, e.g., packing, fungicides (Snowdon, 2010) • Labour cost (Snowdon, 2010) • Transportation cost (Haass et al., 2015) • Products storage cost (Blanke, 2008) • Facility cost (Jedermann et al., 2014b) • Utilization of reefer internal capacity (Jedermann et al., 2014b) • Energy usage for cooling (Blanke, 2008) • Energy usage for shipment (Blanke, 2008)
Freight forwarder	• Maximize logistics service quality (Selviaridis and Spring, 2007) • Minimize operational cost (Van Der Horst and De Langen, 2008) • Minimize emission (Van den Berg and De Langen, 2017)	• Manage real-time logistics information for transportation, tracking, and food quality tracing (Kuo and Chen, 2010) • Integrate demand of multiple shippers (Hesse and Rodrigue, 2004) • Form horizontal logistics alliances (Van Der Horst and De Langen, 2008) • Provide customized services (Kuo and Chen, 2010) • Provide value-added service, e.g., cold storage quality inspection and packaging (Expert)	• Door-to-door delivery time (Lütjen et al., 2013) • Energy usage for cooling (Blanke, 2008) • Energy usage for shipment (Blanke, 2008) • Transportation cost (Selviaridis and Spring, 2007) • Facility cost (Expert)
Port authority	• New business for client cluster (Expert) • Competitiveness of the port (Van der Lugt et al., 2014) • Regional economic growth (Van der Lugt et al., 2014) • Green reefer and green chain (Port of Rotterdam, 2011)	• Provide space for reefer growth (Port of Rotterdam, 2011) • Work together with market parties to develop a new hub for reefer containers (Van der Lugt et al., 2014) • Invest in information exchange platform (Van der Lugt et al., 2014) • Strengthen hinterland network by investing rail or inland waterway infrastructure together with market players (Van der Lugt et al., 2014) • Introduce modal split clauses in concession contracts with terminal operators to promote a more sustainable use of port (Van der Lugt et al., 2014)	• Number of clients (Expert) • Amount of information provided for clients (Expert) • Port-hinterland accessibility (Van der Lugt et al., 2014) • Air quality (Expert) • Modal split for hinterland transportation (Van der Lugt et al., 2014) • Congestion in port area (Ambrosino et al., 2015)

Customs	• Accurate, timely and complete tax revenues (Douane NL, 2016) • Protecting import and export goods to support safety, public health, economics and environmental issues (Douane NL, 2016) • Time of custom process (Douane NL, 2016) • National and international economic growth (Douane NL, 2016)	• Request import declaration from both freight forwarders and liner shipping companies (Expert) • Request ship manifest (Expert) • Form European Union Customs Union (EUCU) (European Commission, 2014) • Communicate with operators the release status of reefers (Expert) • Make agreement between export and import countries (Expert) • Certificate trusted trade lanes (Douane NL, 2016) • Promote new technology for inspection, e.g., smart seal (European Commission, 2014) • Use remote scanner to allow flexible reefer inspection (Expert)	• Import duty (European Commission, 2014) • Information transparency (Douane NL, 2016) • Amount of historical information of exporter/importer (Douane NL, 2016) • Interruption of logistics (Douane NL, 2016)
Government parties	• Achieve national economic growth (Expert) • Realize national societal growth (Expert) • Reduce environmental impact (Expert)	• Provide a pool of supply chain professionals to support industry (Top Sector Logistics, 2012) • Simplify and harmonize laws and regulations (Top Sector Logistics, 2011) • Facilitate information exchange (Yin et al., 2012) • Develop high quality infrastructure network and multimodal hubs for (inter)national flows (Top Sector Logistics, 2011) • Provide subsidy, tax incentive and soft loans for renewable energy and eco-friendly modes (Macharis and Pekin, 2009)	• Contribution of reefer logistics sector to GDP (Top Sector Logistics, 2011) • Number of jobs (Top Sector Logistics, 2011) • Road congestion (Ruiz-Garcia et al., 2007) • Traffic death toll (Ruiz-Garcia et al., 2007) • Usage of eco-friendly modes (Macharis and Pekin, 2009) • Usage of renewable energy (Castelein et al., 2019) • Emission (Rodrigue and Notteboom, 2015)

Maritime Carriers

Higher profit and sustainability (as the main objectives of a maritime carrier) are achieved by a number of means and activities. *Reefer pre-cleaning and pre/post-trip inspections (PTI)* are conducted by most of the maritime carriers in order to protect product quality (Rodrigue and Notteboom, 2015). As a result, the contamination of products can be reduced. Additionally, PTI aims to identify potential defects and allow preventive maintenance of reefers (Sørensen et al., 2014). This can reduce the chance of cooling system failure and keep the product quality (Sørensen et al., 2014). Additionally, it improves the asset availability and subsequently, the profit of carriers.

Energy consumption is another factor considered by a maritime carrier to minimize the operational costs and emission (Cheaitou and Cariou, 2012). Different means are used by maritime carriers to reduce fuel usage for cooling. Using *energy efficient refrigeration units* can increase cooling efficiency (Haass et al., 2015). Another way to reduce cooling energy is to regulate the power supply during transportation; for example, maritime carriers can *switch on and off the cooling compressor* (Fitzgerald et al., 2011) or *use controllers to adjust set points of reefers remotely* (Verdijck and Van Straten, 2002). These processes help to avoid over-circulation and over-ventilation that control the temperature and save energy. For frozen goods, small temperature fluctuation is insignificant. So the cooling compressor can be switched on and off to regulate the temperature. However, for chilled goods, small temperature fluctuation can damage the product quality (Fitzgerald et al., 2011). Furthermore, investment is needed in remote control devices.

Vessel size leverage is investing to replace the small vessels with large ones (Bömer and Tadeu, 2014). This increases the economies of scale and reduces the fuel usage per shipped unit. However, a large-sized vessel is more often used under vessel pooling, since in many cases a single carrier does not have enough customers or cargo to fill large ships (World Shipping Council, 2015). Thus, additional transport time might be caused due to requirements, such as transshipments to specific hubs. More cranes (with higher speed) are required in order to avoid increasing discharge time. Furthermore, vessel size leverage can lead to an increase of shipping time because a large vessel is usually designed for a slower sailing. To wisely apply the strategy, shipping lines should stow ships efficiently, provide reasonable cargo volume forecasts, and try to keep vessel arriving on schedule so that berth availability can be managed efficiently. Another popular method to reduce energy consumption for shipments is applying *slow steaming strategy* (Cheaitou and Cariou, 2012). Although this may save the direct fuel usage in transportation, more energy is consumed for cooling since shipping time is increased. Longer shipping time might also adversely influence the quality of products inside the reefer and reduce the product shelf-life.

Less number of transhipment is one way to reduce the number of terminal handling and shipping time, which further reduces the possibility that reefers are unconnected from a power supply (Rodrigue and Notteboom, 2015). Therefore, it would improve product quality. However, economies of scale and scope are difficult to realize without transhipment. As a consequence, vessel utilization may reduce; and fuel usage per loading unit is increased, which further increases operational costs and emission.

The other means for a carrier is *making reefer leasing decisions*. This reduces empty movements of reefer and increases reefer availability (Chao and Chen, 2015). However, the unit rent rate – and consequently, the operational cost – might be higher (Lu et al., 2010). Using a *triangulation scheme* is another way to reduce empty movements (Van den Berg and De Langen, 2014). Triangulation is matching the nearby origins of container journeys and sending empty containers directly from an importer to the exporter – without returning/stacking at a port or inland depot. With a triangulation scheme, empty container movements are decreased that leads to a reduction in fuel consumption. Triangulation also increases the reefer availability – and consequently, the service quality.

Information exchange is another important means considered by a maritime carrier. *Realizing a container monitoring system* provides more accurate cargo information and reduces the number of manual inspection (Huh et al., 2016). With more accurate information, the reliability of temperature control in reefers can be improved and the product quality loss is reduced (Lütjen et al., 2013). Furthermore, decision-making process is more efficient with more accurate cargo information (Haass et al., 2015). Another method to increase information exchange is *using intelligent containers* (Lang et al., 2014). In intelligent containers, wireless sensor nodes measure the environmental parameters inside a reefer and send the information to a central computer that calculates the shelf-life of the goods (Lang et al., 2014). One advantage of an intelligent container is high transparency of food supply chain which increases customer trust (Haass et al., 2015). Furthermore, intelligent containers reduce the human intervention and inspection which further reduces on-board accidents (Huh et al., 2016). Despite all these advantages, it is necessary to evaluate the costs and potential savings when making decision to implement intelligent containers.

Terminal Operators

As mentioned, for a terminal operator profitability and (partly) sustainability are the main objectives. The profit of a terminal operator is also influenced by the cost of operation and the service quality to the customers (which would lead to attracting more flows). For reefer sector, energy consumption is an essential factor that influences the operational cost as well as the emission levels at a terminal (van Duin et al., 2018). *Applying intermitted distribution of power among the reefer racks* is a means which enables to reduce the peak power demand by coordinating the reefer power connection (van Duin et al., 2018). However, this may result in temperature variability in a reefer and also influence the product quality. Coordinating power connections also requires high labour costs (since reefers need to be connected and disconnected by reefer mechanics). Additionally, the number of re-handles is an important indicator of terminal handling, which is not only relevant to energy usage, but also relevant to container dwell time and labour cost. These can be realized by *optimization reefer handling and stacking planning* (Geerlings and Van Duin, 2011).

One other important factor influencing the cost and profit of a terminal operator is the container dwell time. It can be reduced by *an extended gateway service* (EGS) in which direct rail and inland-waterway shuttle services are organized to carry reefers to an inland terminal (Van der Lugt et al., 2014). This would also improve the quality of perishable cargos by shortening the delivery time. Service reliability is also increased with less delay during terminal operation, which reduces operational costs and keeps product shelf-life. Indeed, EGS needs facility investment and increases the logistics costs since inland terminals need to be rented and operated (Van der Lugt et al., 2014). Reefer terminal dwell time can also be improved by *increasing handling and storage capacity*. However, this entails extra investment costs. Another policy to increase terminal throughput is to *reduce free storage time* for reefers – i.e., the time that a terminal operator offers to a customer to take delivery of the reefers from the port without any additional charge (Rodrigue and Notteboom, 2009). This, however, influences the service quality and may have a negative impact on the customer relationship and the reputation of a terminal operator. Additionally, a terminal operator can *provide value-added service*, such as reefer maintenance and PTI to attract more customers (Port of Rotterdam, 2015).

Hinterland Transport Operators

The means for a transport operator to improve the profitability and contribute to the sustainability of a cold chain are quite limited. One way to reduce the operational costs and CO_2 emission is to *switch on and off the cooling compressor* to regulate temperature in reefers (Rodrigue and Notteboom, 2015). Additionally, operating *intermodal transportation service* can reduce transportation costs and CO_2 emission. However, intermodal transport may lead to a longer transportation time and consequently more energy usage for cooling. It might also adversely influence the product quality for the shippers. Furthermore, hinterland operators can reduce operational costs and emission by economies of scale which is achieved by *transport capacity pool* (Van Der Horst and De Langen, 2008). An example of transport capacity pool in the concept of synchromodality (Behdani et al., 2016). Synchromodality aims at integrating multiple transport modalities to provide flexibility in handling transport demand. This integrated view is expected to reduce the under-utilization of transportation assets and also improve the reliability of intermodal transport services.

The other approach to improve hinterland logistics is *intelligent freight transport* (Crainic et al., 2009). The core of intelligent transport system (ITS) is obtaining, processing and distributing information to improve the efficiency of the transportation system or offer a better service. With improved information provided by a freight ITS system, it is possible to reduce the uncertainty and make planning based on real-time information. Enhancement of information and decision systems also help in a modal shift to more eco-friendly transport modalities. Furthermore, reduction of human intervention improves the service quality. Of course, the cost of freight ITS should also be considered in using this means by a transport operator.

Shippers

The fundamental goals of a shipper are to maximize profit and to minimize environmental impacts. To achieve high profit margin, it aims at increasing revenue and reducing operational costs. The product quality (that is represented by high shelf-life) is a main factor influencing the revenue of shippers (Morris et al., 2003). With high shelf-life, shippers can increase the sales and gain profit.

One means to reduce the quality loss in a cold chain is applying *Controlled Atmosphere (CA)* in reefers (Jedermann et al., 2014b). Maintaining appropriate level of CO_2 and O_2 within the reefers reduces the biological processes – and consequently, reduces the quality degradation of the products (Jedermann et al., 2014a). Furthermore, the low O_2 and high CO_2 levels reduces the products' sensitivity to ethylene, thereby reducing the microbiological activity and respiration rate, which finally extends the shelf-life (Snowdon, 2010). However, to provide the optimal atmosphere, special devices are needed which can be considerably expensive (Jedermann et al., 2014b). Therefore, there is a trade-off between the operational costs and shelf-life extension using CA technologies. A similar method is *Modified Atmosphere (MA)* in which polyethylene bags of the products are evacuated and, a modified atmosphere is created using thicker polyfilms (Snowdon, 2010). With thicker polyfilms, other gases outside the cardboard take longer to permeate through boxes, which results in a low O_2 and high CO_2 atmosphere. Compared with fully controlled atmosphere, the modified atmosphere does not need specific apparatus to supply optimal atmosphere which reduces the investment and operational costs. Additional handling is still needed to pack products in specific materials, to evacuate the package and to tightly seal the package (Snowdon, 2010).

Improving package design is another means to maintain the product quality (Defraeye et al., 2016). Package design is different for chilled and frozen goods. For chilled goods, it is important to distribute temperature-controlled air throughout the storage room and around the products. Airflow rate and accessibility can be improved by additional vent holes on the boxes forming horizontal and vertical ventilation pathways (Defraeye et al., 2016). This can potentially improve the effectiveness of cooling by 15% (Jedermann et al., 2014b). Airflow rate is a significant factor, since it influences the seven-eighths cooling time (SECT). SECT is the time used to reduce seven-eighths of the temperature difference between the product and cooling air and represents the energy usage for cooling and preserving product quality (Defraeye et al., 2016). For frozen goods, vent holes are not needed, since temperature-controlled air only has to flow around the load (Hamburg Süd, 2010). Furthermore, for frozen food, use suitable packaging can eliminate freezer burn and in-packaging frosting problems, which are caused by water loss from the surface during storage (James and James, 2014). *Optimizing stacking pattern in box* and *optimizing pallet stowage scheme* in reefers can also increase the airflow rate (Jedermann et al., 2014b). By optimizing the pallet stowage scheme inside the reefers, air short-circuits between pallets can be closed, which further improves the cooling effectiveness and reduces the energy usage (Defraeye et al., 2016). For chilled goods, air channels can be left out during stowage. However, the utilization of the cardboards and reefers is reduced. The cooling efficiency can be improved by approximately 50% with a reduction of capacity utilization of 4% (Jedermann et al., 2014b). For frozen goods, a block stow, i.e., one that has no deliberate spacing between any of the packages or pallets, is required, since no heat has to be dissipated from the cargo (Hamburg Süd, 2010).

Perishable products, especially fruits, can be treated before transportation, for instance using *cold disinfestation* (Defraeye et al., 2015). Cold disinfestation treatment cools the fruits in order to destroy target pest, which is a required process by some import countries (Defraeye et al., 2016). By destroying target pest, the loss of quality of the fruits can be reduced. However, more energy is used for cooling, which increases operational cost and causes more CO_2 emission. A chill injury might also occur due to the low temperature during the treatment (Defraeye et al., 2015). Furthermore, a cold disinfestation treatment needs additional handling, which increases labour costs (Defraeye et al., 2015). Cold disinfestation also reduces the throughput of the pre-cooling facility, which leads to higher pre-treatment time and door-to-door delivery time (Defraeye et al., 2015). Other types of *post-harvest treatment* can be waxing or fungicide that control diseases and the ripeness rate of products (Snowdon, 2010). Similar to cold disinfestation, extra handling is required, which increases the labour costs.

Pre-cooling is a common means used by shippers to preserve the product quality. Pre-cooling means to cool the products to the desired transport temperature before loading them into a reefer (Tutar et al., 2009). Pre-cooling reduces the microbiological activity and respiration rate, thereby enhancing the product shelf-life. Indeed, pre-cooling requires specific facilities and additional energy, which increases operational costs and CO_2 emission (Van Der Waal and Zongo, 2011). Defraeye et al. (2016) conduct studies that analyse the potential of the *ambient loading protocol*, which means to load products into reefers without pre-cooling process. The products are cooled by reefers (Defraeye et al., 2015). Ambient loading is not common in practice. The cooling rate of a reefer is lower but also the cooling heterogeneity is larger compared with force air cooling at a pre-cooling facility (Defraeye et al., 2015). In order to improve the cooling performance, the ambient loading protocol should be combined with the package design and an optimized stowage scheme in reefers to optimize the airflow (Defraeye et al. 2016). Obviously, with ambient loading, no facilities and energy are consumed for pre-cooling. Furthermore, delivery time is also reduced (Defraeye et al., 2015). However, SECT is increased, which increases the energy consumption for cooling during transportation and increases the loss of quality (Defraeye et al., 2015). Thus, there are trade-offs between product quality, operational costs and CO_2 emission.

The other means for a shipper is *remote reefer condition monitoring* (Jedermann et al., 2014b). System identification techniques are used to model dynamic temperature in the reefers. Subsequently, a warning is sent if an unexpected temperature situation is detected in the reefer. This can potentially minimize the product quality loss. Yet, additional investment is needed. Furthermore, *extra sensors* (like temperature and humidity sensors) can be added to the reefers or packages in order to retrieve more accurate information of product quality. Size, the energy supply and battery life of sensing technology, and cost are the factors to be considered in this case (Jedermann et al., 2014b).

Quality driven distribution is another means or concept used by shippers. This method allocates goods to customer orders based on the product quality. In case of changes in the product quality, a new allocation is made to distribute goods with a lower shelf-life to the nearby customers (Lütjen et al., 2013). This is expected to minimize the product spoilage (Haass et al., 2015). Also, when a reefer is detected with a spoiled product, it is not necessary to complete the distribution; therefore, the total number of movements is reduced, which decreases the energy usage and further operational costs and CO_2 emission.

A shipper can also *order more frequently with small order quantity*, which is a common trend – especially by adopting JIT by more shippers (Kuo and Chen, 2010). Storage quantity is reduced with smaller order quantity. However, the economies of scale is also reduced which may increase the shipping costs and energy consumption. Therefore, it is important to determine the optimal order quantity, in order to balance transportation cost and inventory holding cost.

Freight Forwarders
The main means to make the profit for a freight forwarder is to *integrate demand of multiple shippers* (Van Der Horst and De Langen, 2008). This enables a freight forwarder to select rail, inland-waterway and short-sea shipping and achieve economies of scale and scope (Hesse and Rodrigue, 2004). Costs and CO_2 emission on the shipments are saved by using rail, inland-waterway and short-sea shipping. However, the door-to-door delivery time is longer compared with the road transport (Selviaridis and Spring, 2007). It is mainly because of: (1) extra handling at an inland terminal and (2) increased terminal dwell time because of consolidation of reefer batches. Increased door-to-door delivery time leads to more energy consumption for cooling, which might also reduce the product shelf-life. On the contrary, *direct service* from port to port is preferable for chilled cargoes – less than 10% of chilled goods are transhipped; however, approximately 40% of frozen products are transhipped. This is because chilled goods are more sensitive to temperature variation than frozen goods (Aung and Chang, 2014), therefore chilled products have a higher shipping rate than frozen goods (Rodrigue and Notteboom, 2017b). Another way to achieve economies of scale is to *form horizontal logistics alliances* (Van Der Horst and De Langen, 2008). With horizontal collaboration, demands of different freight forwarders are pooled, which makes it easier to reach the volumes of operating a shipment.

In reefer logistics, freight forwarders may gain more profit by providing *customized services* to their customers (Kuo and Chen, 2010). Service diversification can be achieved by, for instance, offering reefers with different sizes and temperature ranges. This aims at building better relationships with clients, and consequently, gaining more profit. However, it reduces the chance to combine demand and decreases the economies of scale, which may lead to an increase in operational costs. *Providing value-added service*, such as cold storage, quality inspection and packaging is another way to realize service diversification.

Managing real-time logistics information is also important for freight forwarders to make an accurate planning (Kuo and Chen, 2010). An accurate planning helps to reduce door-to-door delivery time. By reducing the delivery time, shelf-life can be extended and energy usage for shipment and cooling is reduced. Operational costs and pollution are also reduced due to less energy consumption. Therefore, it is essential for freight forwarders to get access to the information about transportation and product conditions.

Port Authorities
In most cases, port authorities have the landlord function that *plans the space for reefer growth* (Verhoeven, 2010). Reefer logistics has more added value than the dry container logistics and can create new businesses – e.g., for the maintenance or PTI check of reefers – which indirectly benefit the port authority. However, developing more facilities puts more financial as well as land/infrastructure availability (especially the electricity for string and handling reefers at the port) pressure on the port. In order to create new business practices, a port authority can also *work together with market parties to develop a new hub for reefer logistics* – like Rotterdam Cool Port (Van der Lugt et al., 2014).

Port authorities also have the regulatory functions (Verhoeven, 2010). For example, the port of Rotterdam *introduces modal split clauses in concession contracts* with terminal operators to enforce a more sustainable use of port's hinterland transportation network (Van der Lugt et al., 2014). Another way to achieve modal shift is to *strengthen hinterland network by investing rail and inland-waterway infrastructure* together with market parties (Verhoeven, 2010). Improved rail and inland-waterway infrastructure could increase the port-hinterland accessibility which further increases the port competitiveness (Verhoeven, 2010).

Finally, port authorities have the operator function to provide value-added services (Verhoeven, 2010). They can invest in *information exchange platform* that improves the information provided for clients and increases the port-hinterland accessibility (Port of Rotterdam, 2011). Furthermore, port authorities, as neutral parties, can balance the conflicting interests of market players and facilitate information sharing in the chains (Verhoeven, 2010).

Customs administration
Most of fresh products that are imported in reefers to EU market are from countries (like Latin America) which have higher custom inspection rates. The process includes cargo scanning, veterinary check, and clearance (European Commission, 2014). An efficient customs procedure is important to avoid operational delays. Customs can *request import declaration from both freight forwarders and liner shipping companies* to realize information transparency. In practice, freight forwarders might not be willing to share cargo information with maritime carriers due to confidential terms in their customer contracts (European Commission, 2014). Furthermore, customs can realize transparency by *requesting ship manifest* and *certificating trusted trade line*. When a trusted trade lane is certificated by customs, there will be less control by customs and more control by shippers (Douane NL, 2016). This increases the speed of customs procedure, reduces costs, and increases the port competitiveness. Additionally, efficient control procedure can be realized by *forming customs union (e.g., EUCU), communicating with operators the release status of reefers,* and *making agreements between export and import countries*. Furthermore, the interruption of logistics can be reduced by *promoting new technology for inspection, such as smart seal* (Customs Administration of the Netherlands, 2016). The smart seals are used to protect the cargo and inform shippers and customs of any opening of reefers along the chain. In general, each smart seal costs around 25-30 dollar and is reusable for several times (Douane NL, 2016). Investing in smart seals would be attractive to the shippers and liner shipping companies if – with some arrangements – it leads to reducing the customs control rate. The other means that can increase the speed of the custom process is *remote scanners.* Especially, in cases that a terminal does not have fixed scanners, *remote scanners* allows reefer to be checked at a closest location. Additionally, remote scanners are generally less expensive, compared with fixed scanners.

Government authority
The main goal for the government parties is achieving sustainable (regional/national) development which includes: economic growth, societal growth, and environmental growth. Their criteria are the contribution to GDP, number of jobs, road congestion, CO_2 emission (Top Sector Logistics, 2011). Government parties can *provide a pool of supply chain professionals to support the industry* (Top Sector Logistics, 2012). Considering the specific knowledge needed for the management/maintenance of reefer chains, this is expected to increase the contribution of reefer sector to GDP. Furthermore, it stimulates the national investment in reefer logistics, which can also be achieved by *simplifying and harmonizing laws and regulations* related to reefer logistics. Government parties – as neutral parties – can also *supervise the information exchange* that will increase the operational efficiency of reefer logistics (Yin et al., 2012). *Subsidy, tax incentive and soft loans* can also be provided for renewable energy and eco-friendly modes (Macharis and Pekin, 2009). *Investment in Infrastructure network* is the other role of the government parties to facilitate reefer logistics.

3.3. Multi-actor system analysis
After identifying the means of all the actors, they are analysed to highlight the impact on other actors. There can be trade-offs between the decisions of different actors along the chain. A multi-actor analysis will help the actors to understand the systems from the perspective of others in the cold chain which could facilitate communication in finding options to handle the potential conflicts. An example of multi-actor analysis is shown in Figure 3, which presents the impacts of switching on and off cooling compressor by a hinterland operator. The fuel usage for cooling is decreased which further reduces the operational costs and emission. However, the temperature variability in reefer is increased which adversely influences the product quality. As a result,

although the hinterland operator might save in its operational cost, shippers might lose profit – because of product quality loss. The detailed multi-actor analysis is presented in the appendix B.

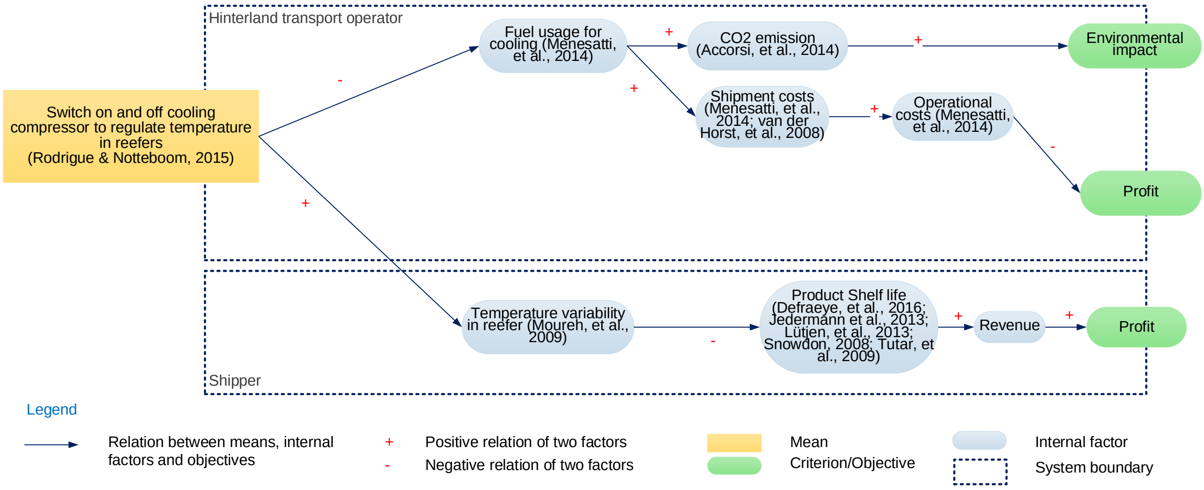

Figure 3. Multi-actor analysis of switching on and off cooling compressor to regulate temperature in reefers[4]

To cope with conflicting interests, actors often introduce coordination mechanisms. Coordination arrangements in container transportation can be classified into four types (Van Der Horst and De Langen, 2008). First is the introduction of incentives, for instance, the market price – based on the quality of products at the point of arrival. This requires the logistics operators to deploy resources to preserve product quality. The second mechanism is the creation of an interfirm alliance. For example, exporters work in close partnership with transportation carriers to deal with the demand volatility and trade imbalance, which is a major issue for fresh produces. Furthermore, flow consolidation of perishable cargo is necessary for hinterland transportation which leads to more consistency and efficiency (Fan et al., 2019). The third option is changing the scope of the organization; for instance, several liner shipping companies integrate hinterland transportation (and freight forwarding services) into the scope of their service to provide door-to-door delivery for perishable cargo (Notteboom and Merckx, 2006). Accordingly, the trade-offs between cost during maritime transport and hinterland transport can be managed within their own organization. The last one is a collective action, which is especially relevant when investments have some collective rather than individual benefits (Van Der Horst and De Langen, 2008). One example is the emergence of container track and tracing technologies, e.g., intelligent containers. Carriers and leasing companies invest in intelligent containers which leads to information sharing. By sharing the information, shipping lines get paid; and shippers could get benefit by improved distribution and product quality. In general, collaboration could provide better visibility and control of the cold chain.

4. Conclusion and discussion

4.1. Concluding remarks

This research presents an analysis on the actions that can be taken by different actors in a cold chain to improve the efficiency of reefer logistics based on a systematic literature review and expert

[4] Means are presented at the left side of the diagrams and criteria and objectives are at the right side. The internal factors are placed inside the system boundary. The arrows link the means with objectives through internal factors. The plus and minus on the arrows show the positive and negative relationships between two elements. The impact of a mean on an objective can be read by counting the number of minus on the arrows from the mean to the objective. If there are odd number of minus, the mean has negative impact on the objective, while if there are even number of minus, the mean has positive impact on the objective.

interviews. This analysis reveals the trade-offs in achieving different objectives by each actor and also among the objectives of different actors along the chain. The system analysis is useful for the actors along the chain to understand the entire system (as well as other actors' views), which *enables finding a globally-optimal solution during (joint) decision-making processes*. It also supports *exploring the possibilities of synergy between the objectives of different actors* in improving chain performance. Furthermore, the system diagrams can facilitate communication, and accordingly, collaboration along the chain. A better understanding of the entire system and improved communication helps actors to find out new arrangements to achieve cold chain coordination. Especially for port authorities, the findings can support designing sustainable and feasible strategies. In general, the reefer flows create more added value than dry containers for a port. Also, ports need to invest in the necessary infrastructure – like energy infrastructure and cold storage facilities. Additionally, they need to align the interests, activities, and objectives of different actors (Hollen et al., 2015). The system analysis in this paper can help port authorities understand the perspective of each actor and design proper coordination/governance schemes. Furthermore, among the operators, maritime carriers – as asset owners – are the strong market players and their decisions would usually influence the terminal and hinterland operations. Additionally, the acceptance of intermodal transport for perishable cargo highly depends on the infrastructure availability/accessibility, and calls for efforts from both government parties and logistics operators.

4.2. Research agenda

Based on the literature review, we propose the following research areas for cold chains and reefer logistics.

- The value of information in cold chains and reefer logistics

Some means are related to data collection and information sharing. For reefer logistics, besides general logistics information (e.g., the location of transportation fleet), data about the internal condition of a reefer (e.g., temperature and humidity), is gathered along the chain. In practice, shipping lines also launch remote container management systems that allow customers to have access to reefer's real-time data on location, temperature, humidity and power status (Maersk Line, 2017). With real-time product information, the product quality can be monitored along the chain and good flows can be controlled in a pro-active manner. Accordingly, logistics decisions can be adapted based on real-time cargo information. Furthermore, with the information on container status, an intelligent trip inspection can be realized to replace the traditional PTI (Jedermann et al., 2017). This can also potentially reduce the empty movement to a reefer service centre. With abundant information available, efficiently using that information to improve the decision-making in the cold chain is an important topic, which has received limited attention in the literature. Especially some *modelling and data analysis studies are needed to estimate the value of real-time data* along the chain.

- Energy management and sustainability in cold chains

Addressing sustainability is more important for reefer logistics, since – besides fuel use for shipment - energy is used for cooling during storage and transportation (Blanke, 2008). It is estimated that around 30-35% of energy consumption at a terminal is related to reefer containers storage and handling (van Duin et al. 2018). Minimizing the energy consumption can be a challenge though. Classical means to reduce energy consumption, e.g., slow steaming or using intermodal freight transportation, might not be optimal for reefer logistics since they lead to longer transit time, and more energy usage for cooling. There is a need for *models capturing the trade-off between energy consumption of cooling and shipment and impacts on cost and sustainability*.

- The value of collaboration in cold chain and reefer logistics:

The multi-actor system analysis reveals the potential conflicts among the actors. For example, transport operators switch on and off the cooling compressor in order to reduce their operational cost, which reduces the product quality and increases food losses. Minimizing the operational cost of transport operators will reduce the profit of shippers. *Modelling efforts to manage these conflicts and foster collaboration can be a direction for further research.* Additionally, efficient reefer triangulation scheme and vessel pooling strategies need to be further studied. In the analysis of reefer triangulation, it is necessary to take into account the maintenance and PTI. In addition, aligning the conflicting objectives of actors in a cold chain calls for the coordination mechanisms. Although the coordination mechanisms for container transport chains are generally discussed (Van Der Horst and De Langen, 2008), specific coordination methods for reefer logistics and cold chains need to be further studied – considering the specific characteristics of perishable cargo transport. Yet, the existing coordination mechanism may serve as a benchmark for new coordination mechanisms. Additionally, the underlying processes in the networks and the viewpoint of multiple actors should be taken into account in designing proper coordination schemes.

- Reefer availability/maintenance and its influence on cold chain

In reefer logistics, an important issue is the maintenance of reefer containers that constitutes a significant part of the operational cost. Since reefers are often operated at remote locations around the world, unplanned maintenance require significant logistics effort and hence is very costly. Furthermore, labours and equipment are needed for reefer inspection and maintenance, which can only be done at specific locations (Sørensen et al., 2014), which makes it more difficult to design an efficient maintenance strategy. Despite its influence on the performance on product quality and operational cost, the literature on reefer maintenance is quite limited. *New concepts such as intelligent trip inspection (ITI) in which reefers can do a self-diagnostic during its operation on product quality, asset utilization, and logistics performance of cold chains* call for further studies.

- Need for (multi-criteria) decision making tools to integrate different aspects like quality, sustainability and cost in cold chains

Involving a variety of stakeholders, both market players and public parties in reefer logistics implies that the performance need to be measured across different dimensions, such as economic, social, and environmental dimensions (Zuidwijk and Veenstra, 2015), as well as the product quality dimension Therefore, decision making tools are needed to integrate all these aspects addressing the trade-offs between different conflicting objectives. The system diagrams in this paper can be a basis for *quantitative models (e.g., multi-criteria multi-actor models) and decision-making tools to optimize the specific processes of reefer logistics.*

- Impact of increasing transparency of reefer logistics

Currently, there are delays in customs clearance procedures and food safety authority inspection due to a lack of integration of systems, which is a potential bottleneck in the cold chains. Adopting new technologies such as intelligent container, remote container monitoring system and IoT, will increase the transparency of reefer logistics. Thus, the impact of customs inspection and food quality/safety check could be moderated by the transparency of product location and quality throughout the supply chain. It is necessary to further study *the relevant future scenarios of quality management/inspection and customs check for reefer logistics and how the future scenarios* can be realized by the new technologies. Furthermore, it is important to evaluate the influence of each scenario on the performance of a cold chain in terms of cost, quality and sustainability aspects. The other initiative is the development of trusted trade lines. This may also imply that the responsibility for customs related activities are transferred to other actors in the chain – e.g., the shippers. The analysis of such initiatives and their impact on the performance of cold chains can also call for further research.

Acknowledgements

This study is part of the research project: Effective Use of Reefer Containers for conditioned products through the Port of Rotterdam (EURECA) funded by the Netherlands Organisation for Scientific Research (NWO). The authors would like to thank all the experts for their cooperation.

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Appendix A. Review methodology

Defining the search strategy:
Selection of the literature started with the formulation of inclusion and exclusion criteria. There were three inclusion criteria used in the literature search:

1. The source of information for the present research were scientific journals; as further discussed in the next section, in a later stage we extended the search to include grey literature (e.g. theses, doctoral dissertations, official publications, reports from scientific research groups) or/and reliable website (e.g. international organization, company website, etc.)
2. The time frame is publications since 1960, as the first refrigerated marine containers, based upon converted truck units, came into use in the 60's (Maersk Line, 2010).
3. The scope of literature review is all segments and actors in reefer logistics.

The exclusion criteria were as follows:

1. Publications that are not written in English are not included.
2. Publication with the main topic of container management in non-food product distribution are not considered in this literature analysis.
3. Publication with the main topic of food produces distribution with non-container assets are excluded from our analysis.

Literature search and selection:
After defining the inclusion and exclusion criteria, the next stage was literature searching. For the literature search, keywords are formulated and classified into two groups:

1. Reefer: reefer, refrigerated container, temperature-controlled container, climate-controlled container, environment-controlled container and insulated container
2. Logistics: logistics, cold chain, supply chain, transport, intermodal, hinterland transport, shipping, inland-waterways, road, and rail.

The searching strategy was to combine the keywords in these two groups using the Boolean operator "OR" and "AND", and wildcards, e.g., an asterisk (*).We used Scopus as the data sources for our search. The detailed process of paper selection is shown in Figure A.1. In total, 46 articles have been selected for full paper review.

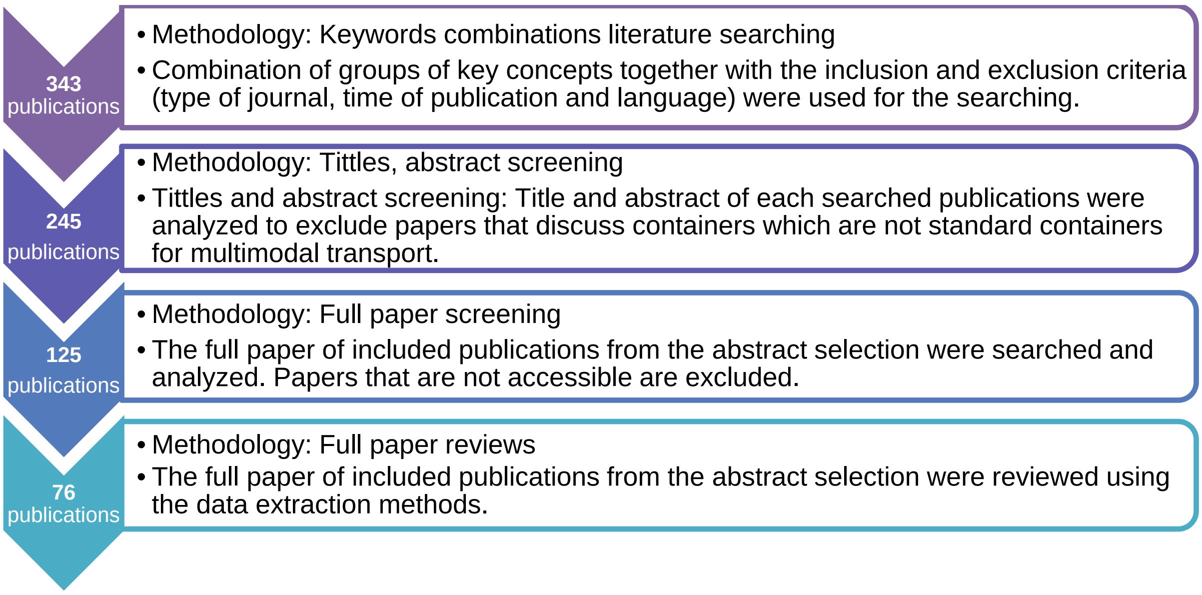

Figure A.1. Paper selection steps and number of publications

Literature analysis and data extraction:
A data extraction form was used to collect the information from the sources. The form includes the generic information about the paper (i.e., the title, author, and key words) and the specific information about the contribution of paper in terms of technical aspects (classified into transport, transhipment, and packaging) and social aspects (i.e., the actor(s) described in the paper, the objective of actor, the means or policies discussed for that actor).

Appendix B. Multi-actor analysis

Multi-actor analyses are discussed in the following. The diagrams are shown in additional material due to the limitation of space. The system diagrams are further discussed and verified by interviewing experts in the reefer logistics domain. A list of experts and their expertise are shown in table B.1. From the experts' discussions, some means used in the industry – which are not covered in the existing literature – are obtained and discussed (especially, for customs operations which has limited focus in the literature). Furthermore, the relationship between means and objectives are discussed and verified by the experts.

Decisions made by maritime carriers influence the shippers, terminal operators and hinterland transport operators. In addition to slow steaming strategy that mentioned before, maritime carriers *conduct pre-cleaning and PTI*. Although additional handling and equipment are needed by carriers, the product quality and the profit of shippers are expected to increase. Furthermore, *investing in and using intelligent containers* would protect the product quality. In some cases, maritime carriers *switch off the power supply* of reefers a few hours before arriving at the seaport of destination (Fitzgerald et al., 2011). This saves costs and pollution for maritime carriers, while it may jeopardize product quality and reduces the profit of shippers.

Terminal operators handle reefers and supply electricity for reefers during terminal storage. Some means of terminal operators influence shippers, hinterland operators and maritime carriers. By *regulating the power supply*, peak power demand is controlled. However, the temperature variability in reefers is increased that might influence the cargo quality and the profit of shippers. By *optimizing reefer handling and stacking planning*, handling time is reduced that provides additional time for hinterland transport operators to choose rail and inland-waterway – instead of trucking. Additionally, applying the *extended gate services* (EGS) allows direct shipments of containers from the maritime terminal to an inland terminal. Since terminal operators arrange shuttle service of rail and inland-waterway to deliver containers to inland terminals in batches, the possibility to bundle containers increases, which supports a modal shift to rail and inland-waterway. However, shippers might not prefer the usage of rail and inland-waterway due to longer transport time and more terminal handling (Behdani et al., 2016). Furthermore, EGS shows a change of roles in the transportation chain that terminal operators arrange the hinterland transport – instead of traditional hinterland operators. Therefore, the profit for hinterland operators may reduce by this new business model. For the port authority, the congestion in the port area can be reduced that increases competitiveness of the port (Rodrigue and Notteboom, 2009).

Applying quality-driven distribution by shippers aim at allocating the cargo with relatively-low quality to a nearby customer. This will improve the average product quality for a shipper and subsequently increases the revenue. However, to make re-allocation decision, shippers need to know the real-time and accurate product information inside a reefer, which requires investment in information collection and sharing equipment (like intelligent containers by maritime carriers). This further increases the investment costs of maritime carriers (Huh et al., 2016). At the same time *applying quality-driven distribution would* reduce the number of hinterland movements. In fact, shippers can better align the product quality with the expectation of its customers and avoid product rejection due to inconsistent quality. This would reduce the operational cost for reefers.

Fuel usage for cooling, shipments and handlings are also reduced, which further reduces the environmental pollutions. However, quality-driven distribution requires flexible transportation service, which makes hinterland operators to use single-mode road transport rather than rail and inland-waterways (Crainic et al., 2009). Road transportation, in general, increases operational costs and pollution.

A number of means of a port authority are related to a more efficient port-hinterland connection, such as *introducing modal split clauses in concession contract*, *strengthen hinterland network*, and *developing a new hub for reefer chain*. An example of such initiatives is Rotterdam Cool Port which is a storage and cross-docking facility for temperature-controlled cargo – like fruit, vegetables, meat, and fish – at the existing ECT City Terminal (Port of Rotterdam, 2015). Improved infrastructure stimulates the train and barge transport, which reduces the road congestion and the transportation cost. Improving the reliability of service may also convince shippers to accept intermodal transport – with lower costs (Behdani et al., 2016). Besides the rail/inland-waterway infrastructure, port authorities can invest in or work as a facilitator for *information sharing* actors in a reefer chain. In general, information exchange is beneficial to all logistics operators and improves the efficiency of logistics processes. As neutral parties, the port authority and government parties can support the realization of information exchange between parties in the chain.

According to the expert interview, customs inspection is a main bottleneck in reefer logistics. Most of the means of customs can improve the efficiency of control procedure, reduce the delay and improve the logistics performance of all operators.

Table B.1. Expert list

No.	Role in the system	Description of the organization	Function and expertise
1	Maritime carrier, hinterland transport operator	A global logistics company offering transport and related service by land, sea, rail and air.	Business development – Reefer
2	Terminal operator	An advanced container terminal operator in port of Rotterdam	Business and product development/ Strategy & digital/ Data analysis & process optimization
3	Shipper	An association represents the interests of companies active in the sales of fruit and vegetables.	Director
4	Shipper	Research institute for healthy food, fresh food chains and biobased products	Project manager – post-harvest quality
5	Freight forwarder	A company provides logistics and warehousing services in cold chain	Director
6	Port authority	Port of Rotterdam	Project manager sustainable development
7	Port authority	Port of Rotterdam	Business manager argofood & distribution
8	Customs	Customs port of Rotterdam	Client manager

Additional material. Multi-actor system diagrams

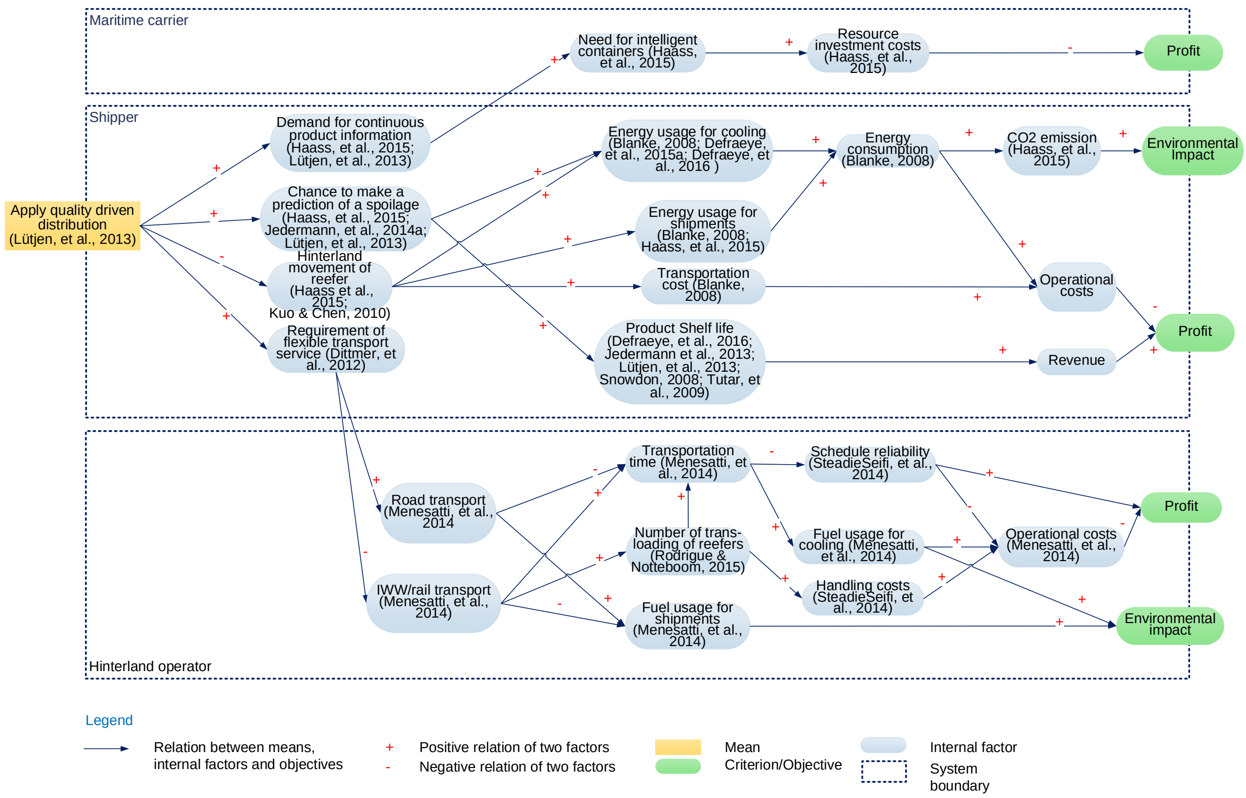

Figure 1. *Multi-actor system analysis of applying quality driven distribution*

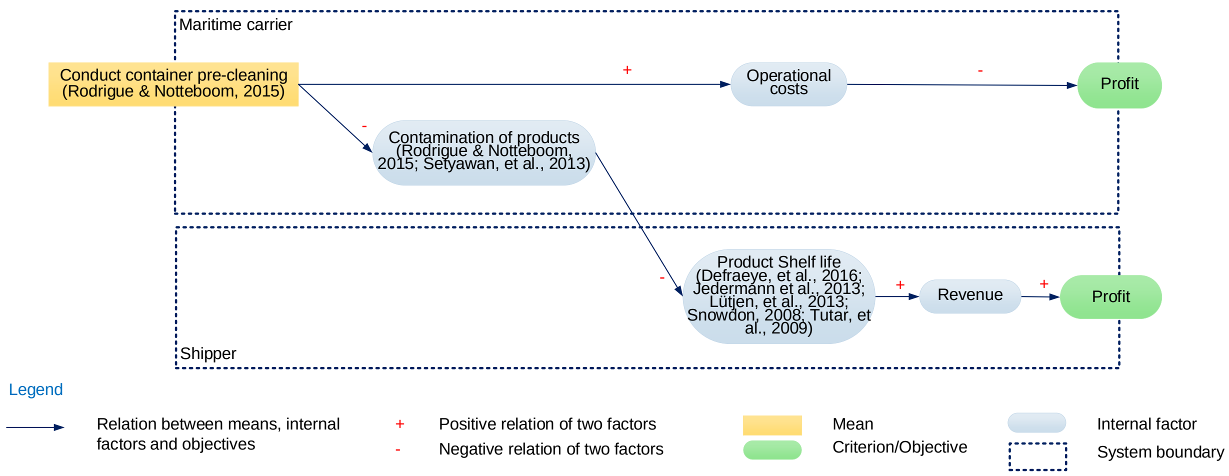

Figure 2. *Multi-actor system analysis of conducting container pre-cleaning*

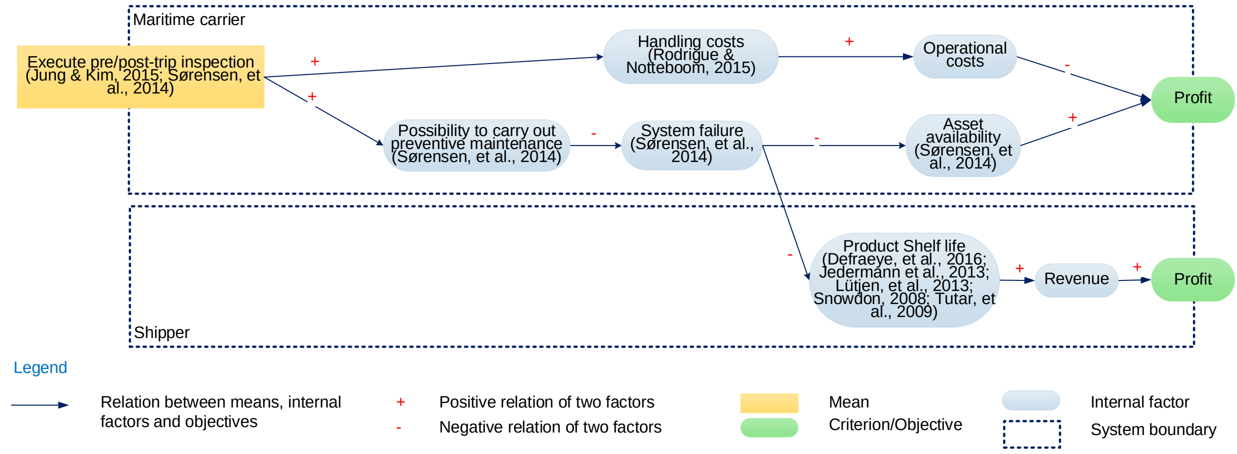

Figure 3. *Multi-actor system analysis of executing pre/post-trip inspection*

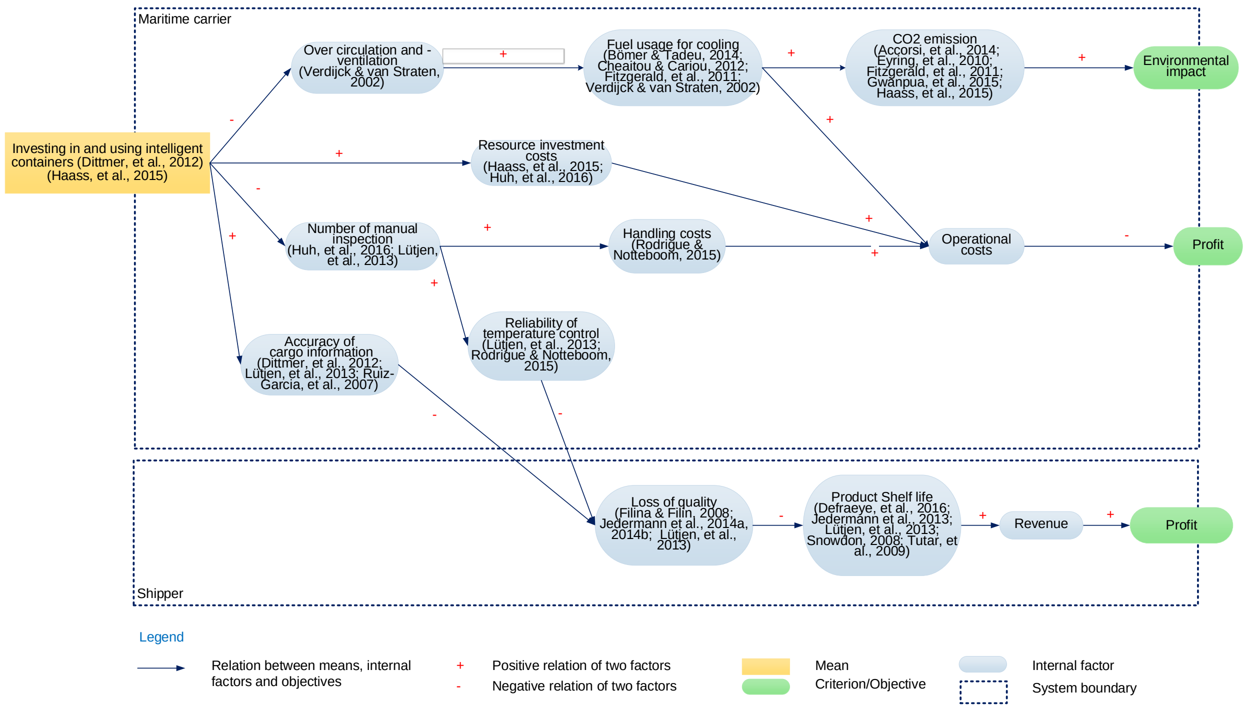

Figure 4. Multi-actor system analysis of investing in and using intelligent containers

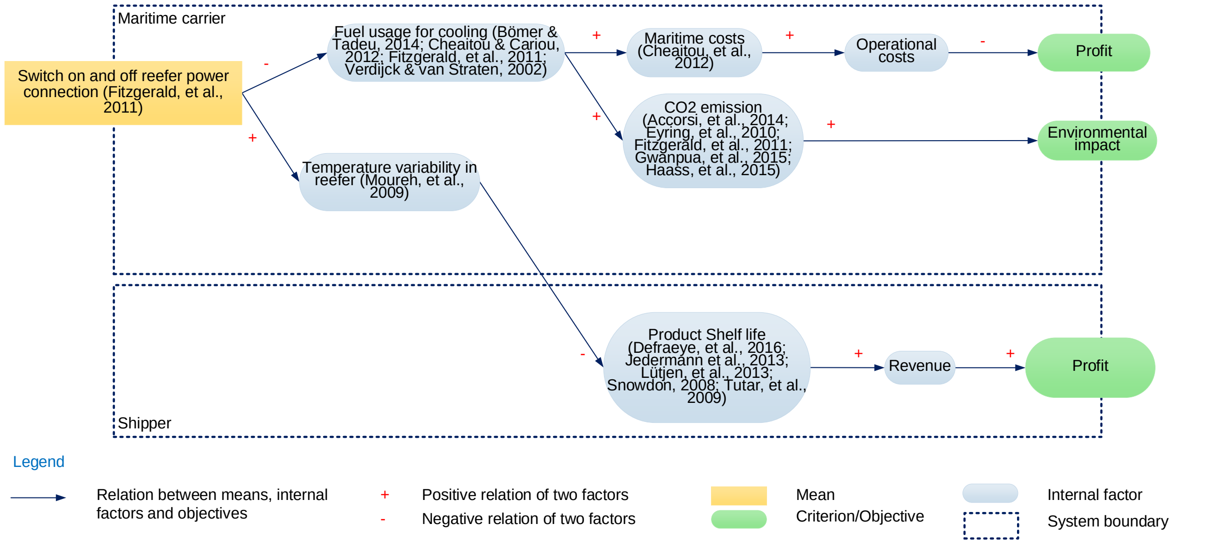

Figure 5. *Multi-actor system analysis of switching on and off reefer power connection*

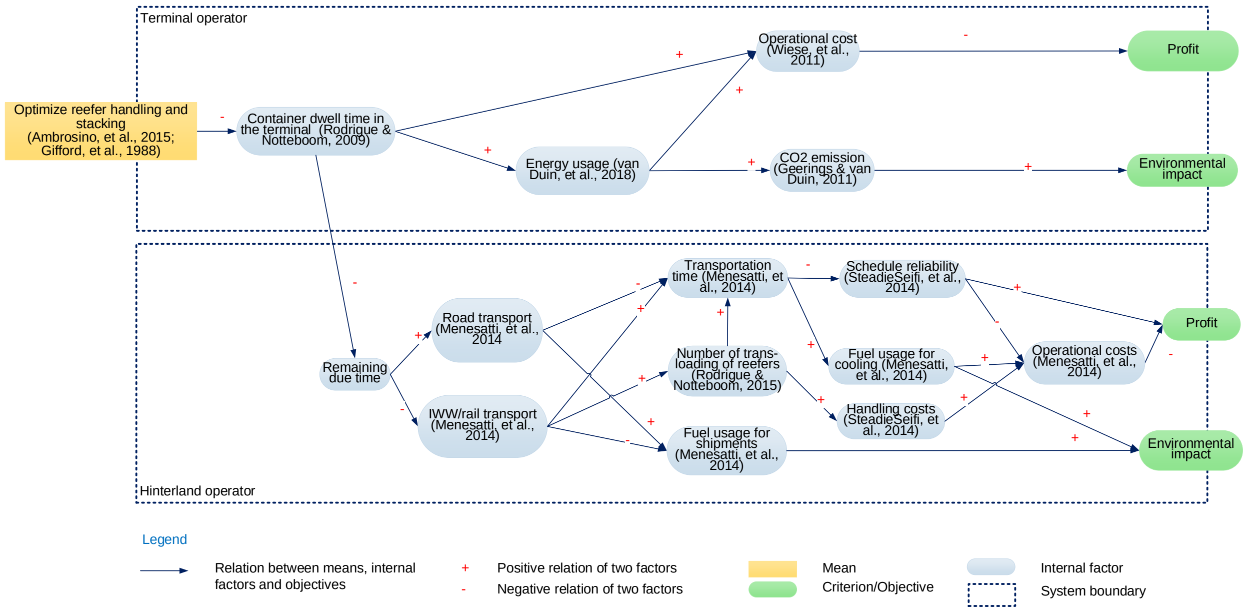

Figure 6. *Multi-actor system analysis of optimizing reefer handling and stacking*

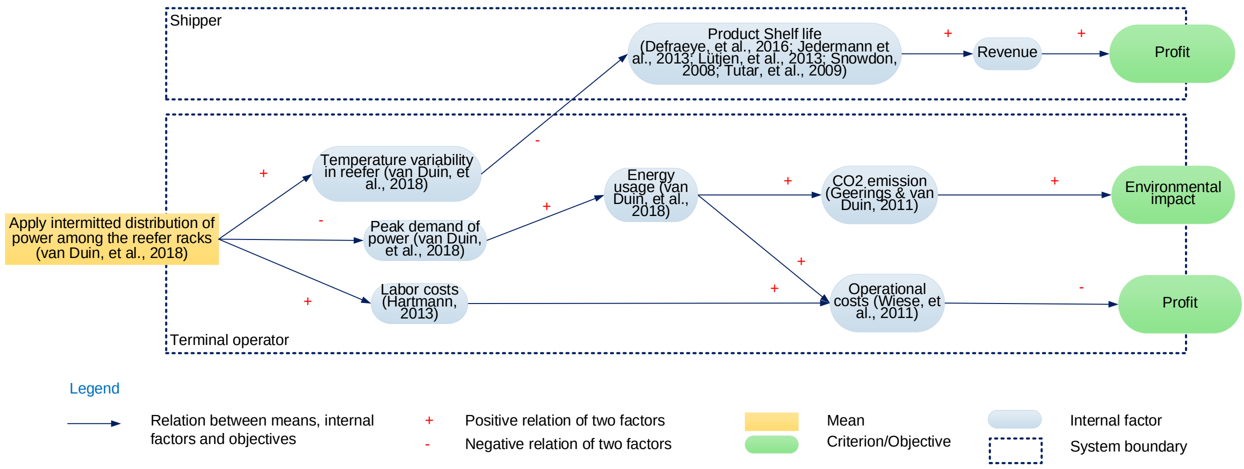

Figure 7. *Multi-actor system analysis of applying intermitted distribution of power among the reefer racks*

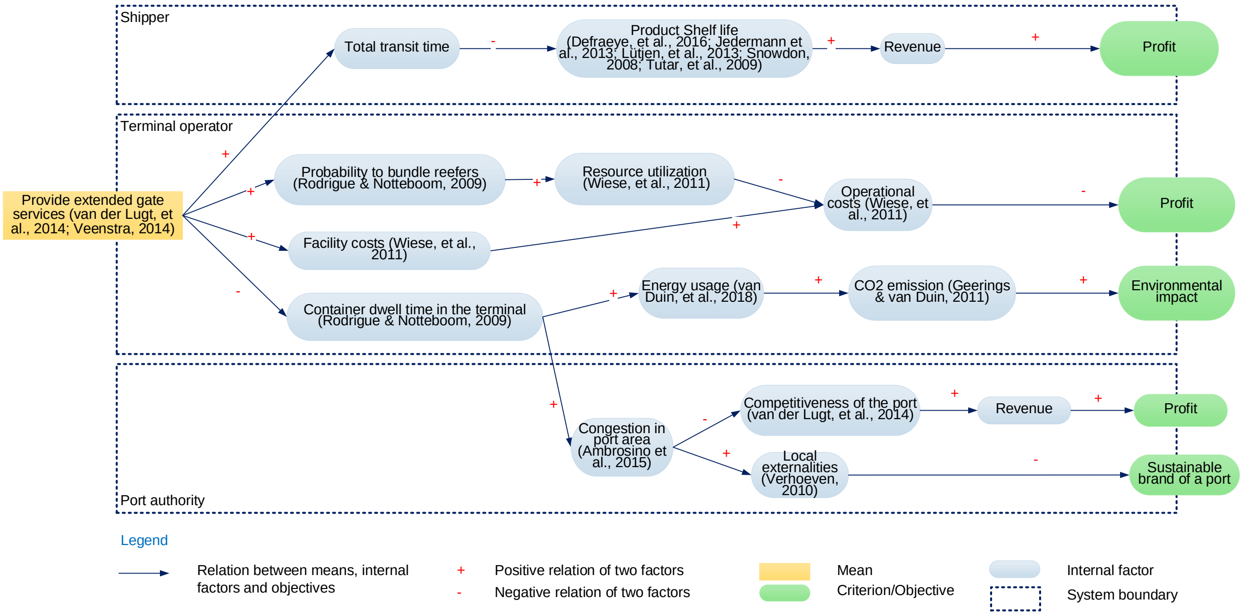

Figure 8. Multi-actor system analysis of providing extended gate services

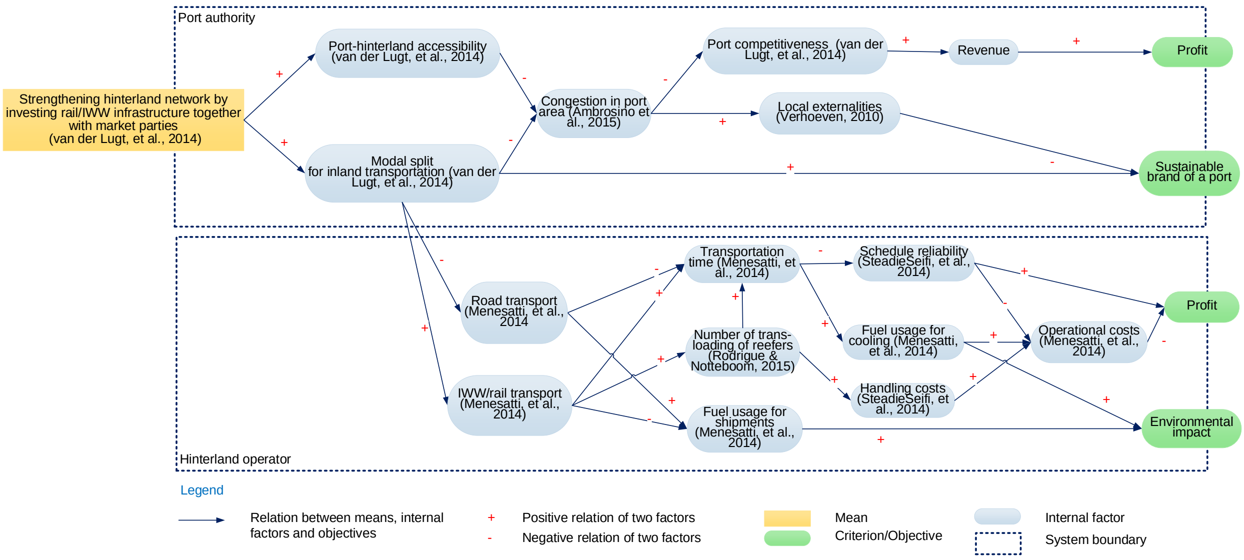

Figure 9. Multi-actor system analysis of strengthening hinterland network

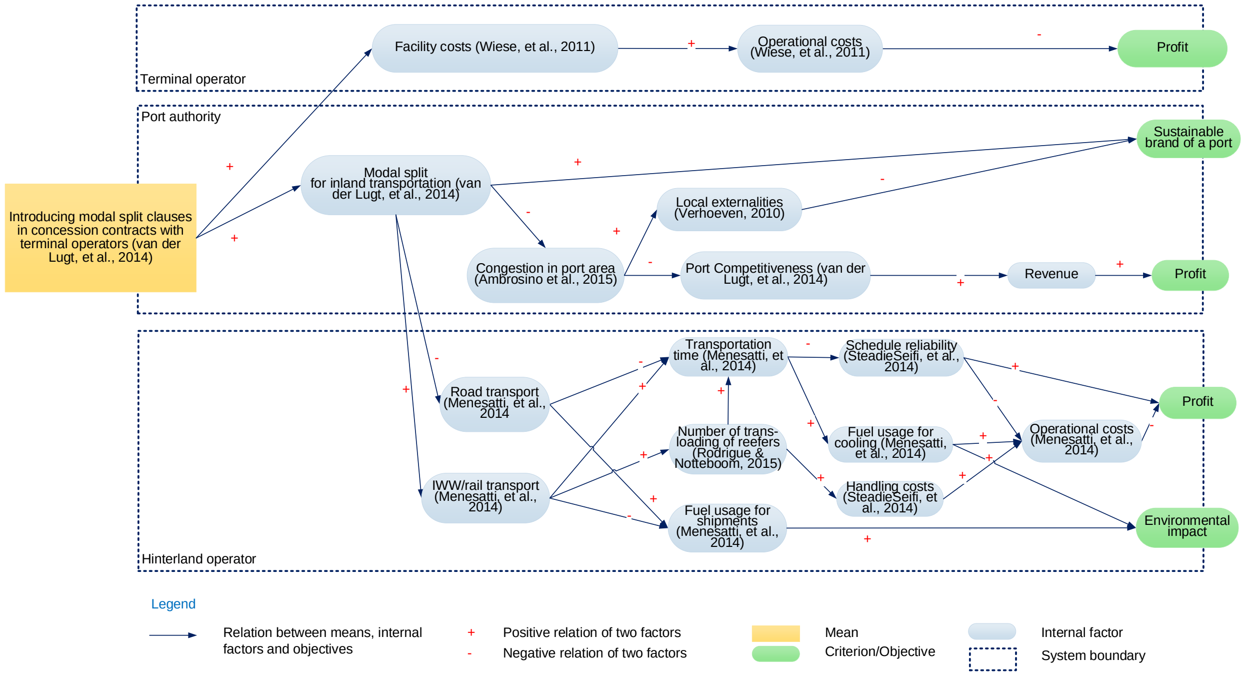

Figure 10. Multi-actor system analysis of introducing modal split clauses in concession contracts with terminal operator

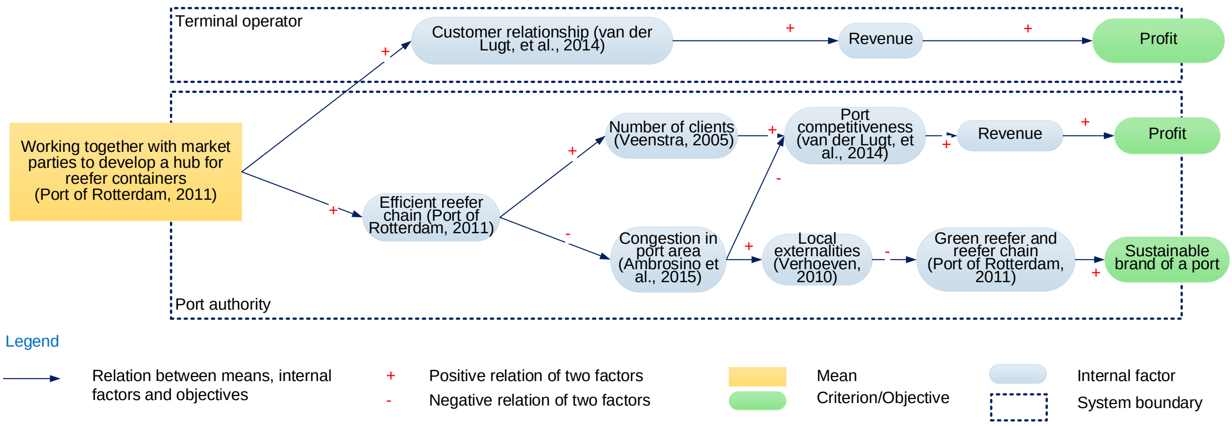

Figure 11. Multi-actor system analysis of working together with market parties to develop a hub for reefer containers

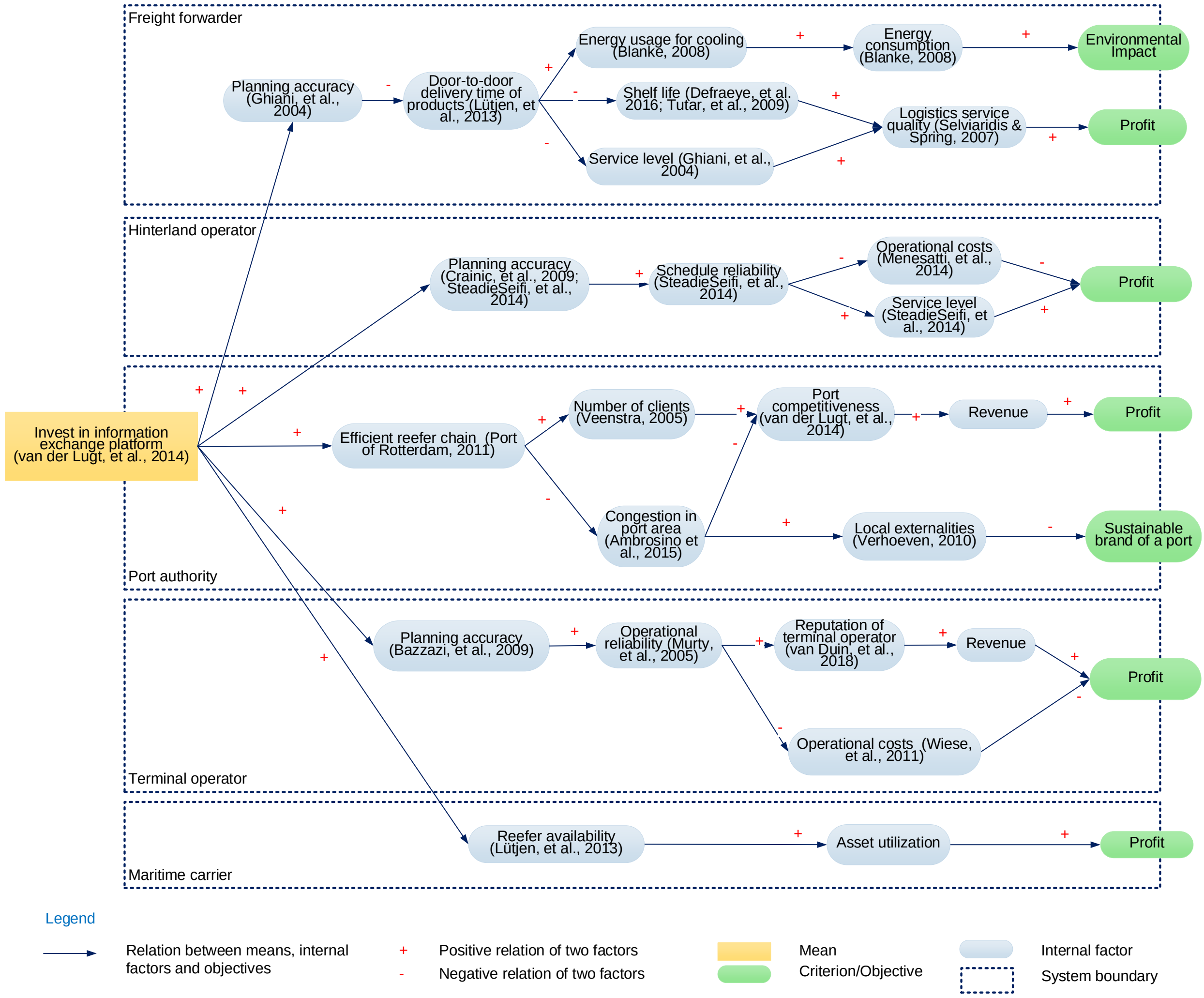

Figure 12. Multi-actor system analysis of investing in information exchange platform

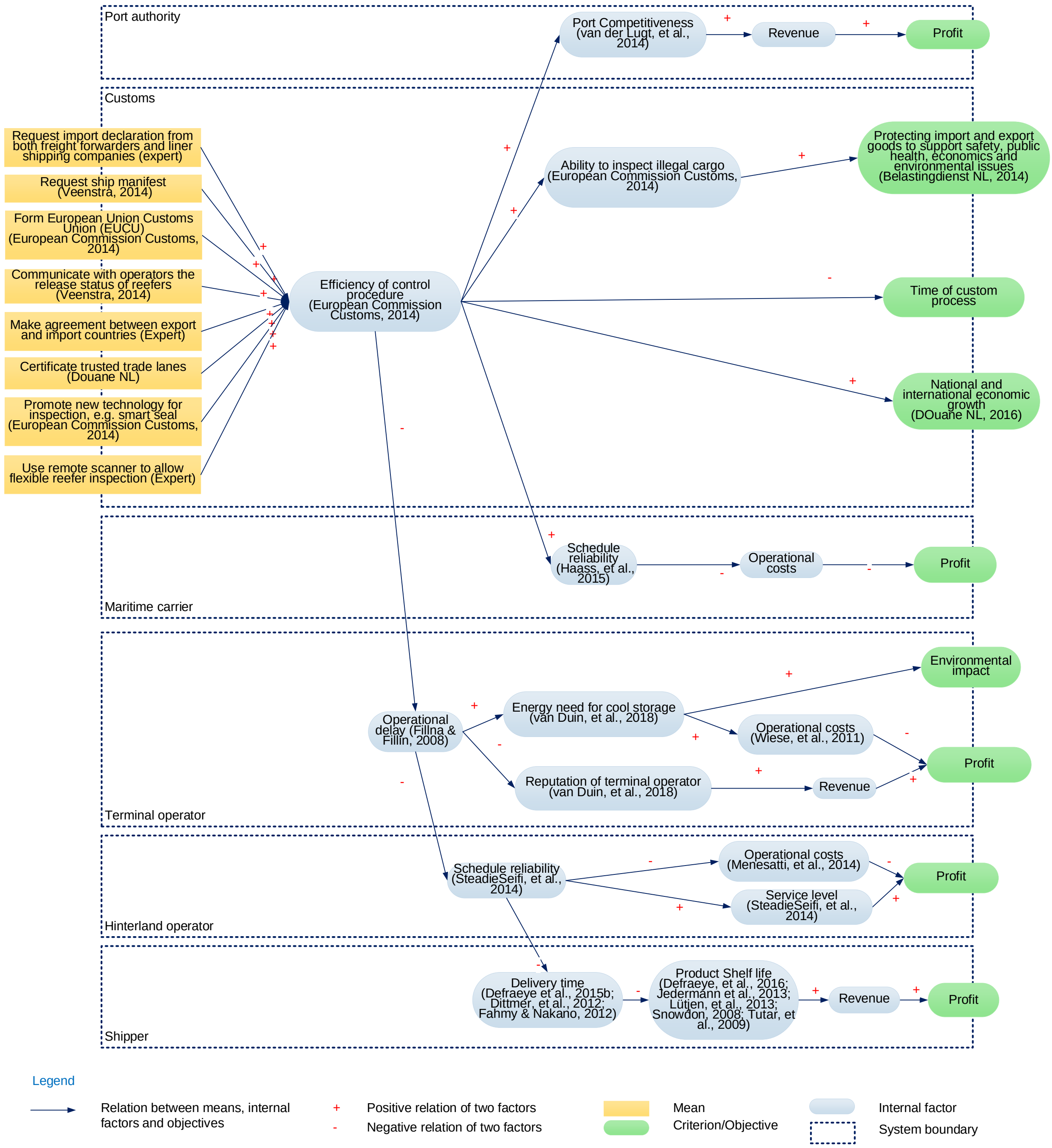

Figure 13. Multi-actor system analysis of the means of customs

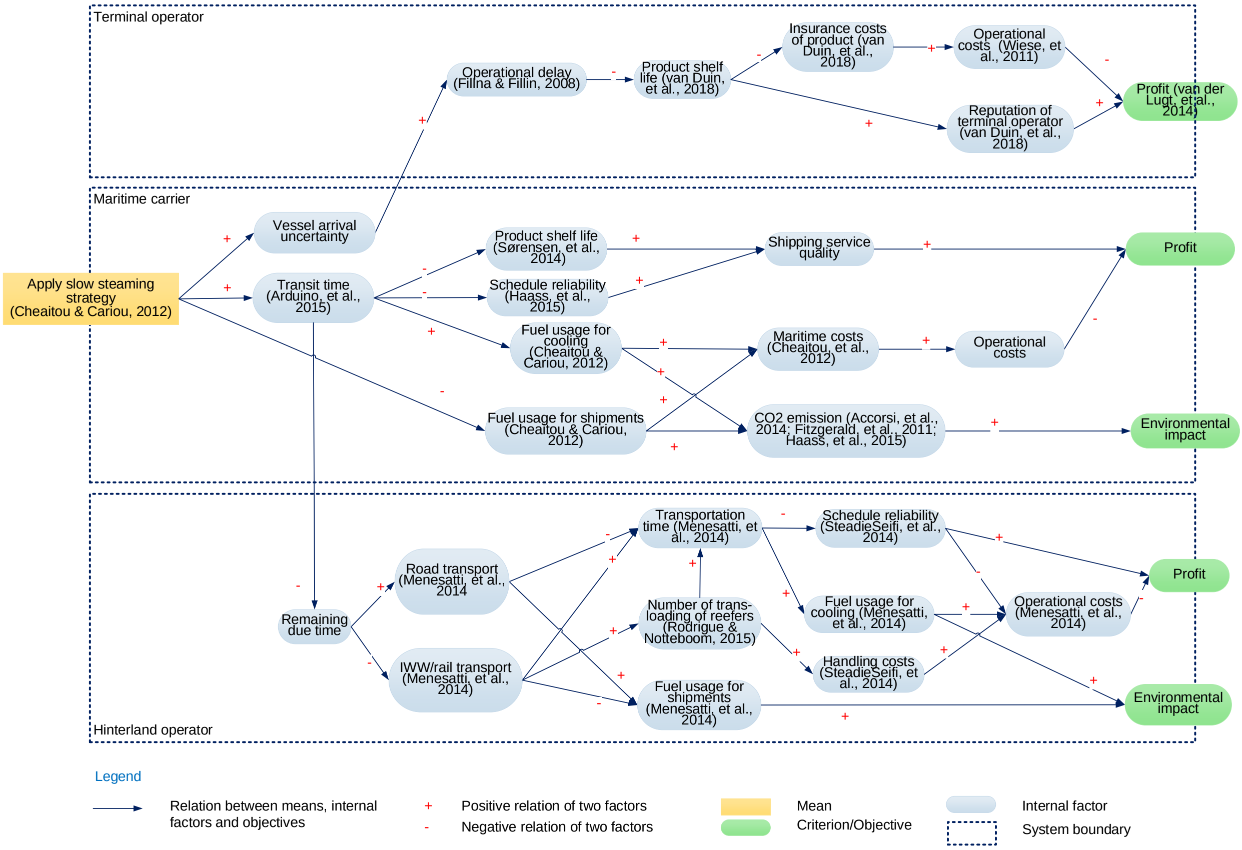

Figure 14. Multi-actor analysis of applying slow steaming strategy