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Sustainable Freight Transport

Theory, Models, and Case Studies

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Contents

Introduction

Vasileios Zeimpekis, Emel Aktas, Michael Bourlakis, and Ioannis Minis

Abstract Despite the slow-moving recovery in world merchandise trade since the big recession of 2008, trade flows continue to expand with projected growth set to accelerate in the coming years (UNCTAD 2015). In tandem, trade-related international freight is expected to grow by a factor of 4.3 by 2050 compared to 2010 volumes, with patterns also shifting – one third of trade in 2050 will occur among developing economies (OECD 2015).

Keywords Sustainable freight transport · Carbon footprint · Supply chain · City logistics · OR algorithms

Despite the slow-moving recovery in world merchandise trade since the big recession of 2008, trade flows continue to expand with projected growth set to accelerate in the coming years (UNCTAD 2015). In tandem, trade-related international freight is expected to grow by a factor of 4.3 by 2050 compared to 2010 volumes, with patterns also shifting – one third of trade in 2050 will occur among developing economies (OECD 2015).

On the other hand, the movement of freight is the source of numerous externalities, mainly air pollution, noise, accidents, and CO_2 emissions. It is estimated that freight transport accounts for around 10% of energy-related carbon emissions (IPCC 2014). To this end, by taking into consideration the trends of global trade for the next years as well as the negative impact of freight movement, it is evident that the adoption of a sustainable transport system is vital to contribute to the global social and economic development.

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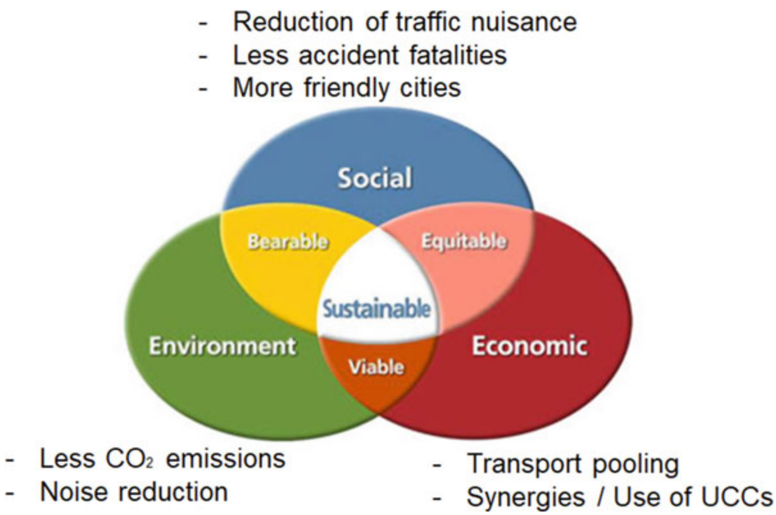

Fig. 1 Sustainable freight transportation (Arbury 2011)

Sustainable transport considers economic, social, environmental, and climate impacts of transport operations and the associated energy requirements. Figure 1 illustrates the intersection between the economic, social, and environmental dimensions of sustainable development as applicable to freight transport.

While not intended as an exhaustive list, sustainable freight systems entail, among other features, the ability to provide transportation that is safe, socially inclusive, accessible, reliable, affordable, fuel-efficient, environmentally friendly, low-carbon, and resilient to shocks and disruptions, including those caused by climate change and natural disasters.

Freight transport has traditionally focused on decreasing costs and increasing service levels. However, it is no longer possible or socially responsible to neglect the environmental, social, climate, and energy implications of the freight moving globally. This is the motivation for this edited volume which attempts to place sustainability to the forefront of the freight transport agenda. The contributed chapters span the spectrum of key issues and activities from transport planning to execution. This volume also presents the implementation of state-of-the-art methods and systems through appropriate case studies.

Significant issues in planning and execution of sustainable freight transportation discussed in this volume include the following:

- A systems-thinking approach to sustainable freight transport
- Operational models for scheduling and vehicle routing
- Short food supply chains and urban consolidation centers for city logistics
- Supplier development for sustainability

Specifically, chapter "Logistics and Freight Transport as the Kernel of Resilient Airport-Driven Development; a Survey on Basic Interactivities and Causalities" focuses on airport-driven economic development, identifying the cause-effect relationships in the airport – freight transport – logistics triad and their implications for the economy. This chapter draws attention to the expected growth in air transport for both passengers and freight in connection with the growing urbanization and increasing population. Air transport's competitive advantage of short transit times is contrasted with its negative impact on the environment. Since most business activities are concentrated in cities, airports play a key role in the movements of goods and people. Indeed, the links between airport development, freight transport, and logistics are strong; the author follow a systems approach to examine the interactions between factors that affect these links. Conclusions suggest strong collaboration among stakeholders, continued emphasis on negative environmental and social effects, and availability of access routes and surface connections to other modes for resilient and robust airport-driven economic development.

Shifting the focus from air to sea transport, chapter "Sustainability Management in Smaller UK Ports to Promote More Sustainable Freight Transport" addresses sustainability management in smaller UK ports. Small ports are vital but usually neglected freight interchanges; the author aim to support such ports regarding sustainability management through freight performance assessment, while providing examples of port planning and reporting. Managers of smaller ports rely on simple solutions when planning for sustainability, and this chapter offers practical guidelines on aspects ranging from port master plan, to, environmental technology, internal processes, monitoring and improvement, sustainability reports, and cooperation and communication. Implementation of port sustainability management systems should recognize the unique nature of operations in each port along with its different planning priorities and stakeholders. Knowledge capture and transfer poses a significant challenge, which can be addressed with support from professional bodies such as the British Port Authority, UK Harbor Masters' Association, or the European Sea Ports Organisation as well as other regional and supranational bodies.

Chapter "A Bi-objective Problem of Scheduling Fuel Supply Vessels" develops a mathematical model for bi-objective scheduling of fuel supply vessels. This is an interesting problem encountered in every major port, and the authors develop a practical schedule generation methodology that assists decision makers in accepting or rejecting unscheduled fuel supply requests while considering the system constraints such as time and fuel availability. The proposals in this chapter aspire to support fleet scheduler in their demanding task that is characterized by a 24-h, 365-day operation, as well as significant penalties for violations, delays, and non-conformance. The proposed algorithm supports the decision process while improving decision outcomes in terms of lower costs and higher environmental savings.

In a similar approach, chapter "Value Creation Through Green Vehicle Routing" focuses on green vehicle routing. The author elaborates on minimizing negative externalities and increasing the brand value of logistics companies through implementing green vehicle routing concepts. Negative externalities are investigated considering air pollution, greenhouse gases, noise pollution, congestion, accidents, and land use. Macroscopic and microscopic models for estimating emissions are synthesized, and key parameters are introduced together with online tools and calculators. The pollution-routing problem is defined and typical values for its parameters are provided. This chapter concludes by underlining that green vehicle routing problems that focus on minimizing negative externalities of road freight transport help companies to extract additional value from their operations.

Chapter "Environmental Benefits of Collaboration and Allocation of Emissions in Road Freight Transportation" focuses on emissions allocation in road freight transport nicely complementing the previous work on green vehicle routing. Collaborative transport has been proposed as a green and cost-efficient way of transporting goods that share either origins or destinations in shared vehicles. Although the theoretical implications are clear, the practicalities are yet to be established, especially in terms of cost savings and environmental impacts. This chapter quantifies environmental benefits from collaboration at 11–54% CO_2 emission reduction and proposes a new method for emissions allocation building on previous methods used for cost allocation. The author provides an illustrative numerical example and highlights the opportunity for further research on quantifying the environmental impact of collaboration in freight transport.

Chapter "Short Supply Chains as a Viable Alternative for the Distribution of Food in Urban Areas? Investigation of the Performance of Several Distribution Schemes" investigates the viability of short food supply chains in urban areas. Changes in demand for food products and the evolution of consumers' preferences put new pressures on food supply chains, such as shortening the journey from farm to fork while maintaining price levels and product variability. This chapter presents a state-of-the-art literature review on short food supply chains and underpins the differences between short and traditional food supply chains. Although positioned as a more sustainable business model due to lower distances and fewer intermediaries in the chain, short food supply chains do not automatically reduce negative externalities. This chapter highlights many regulatory, commercial, and logistics challenges that should be addressed for the viability of short food supply chains.

On a related topic, chapter "Sustainable Solutions for Urban Freight Transport and Logistics: An Analysis of Urban Consolidation Centers" examines the Urban Consolidation Center (UCC) concept as a sustainable solution for city logistics. Urban freight transport is a major contributor to increased emissions in cities coupled with congestion, noise, and traffic safety concerns. This chapter critically reviews UCC implementations in Europe, eliciting the related key benefits and limitations. The author provides details on a successful UCC implementation in Bristol and Bath, and summarizes the key criteria for success: strong public sector involvement and regulatory framework that encourage the use of UCCs, significant transport problems in the area that can be addressed by implementing a UCC, a pull system rather than a push system from stakeholders (bottom-up pressure from local interested parties), single decision maker and unified management approach for the UCC, and the availability of funding to shift from existing means of transport to new ones to be supported by a UCC.

Continuing the city aspects of freight transport, the next chapter focuses on urban vehicle access regulations. Any discussion of sustainable freight transport will be incomplete without considering regulatory aspects of urban transport. Chapter

"Urban Vehicle Access Regulations" summarizes urban vehicle access regulations with respect to access time, vehicle characteristics, and load factors with examples from cities in Europe. Further examples are provided elaborating on regulatory schemes such as low emission zones, congestion charging, and a decision-making framework to assist in devising an appropriate regulatory scheme depending on the main problem in the urban area, characteristics (number of entry points, size, population density) of the vehicle access restricted zone, and availability of alternative modes. The author also reviews UCCs, cargo bikes, and off-hour deliveries as possible solutions that mitigate the unwanted side effects of urban vehicle access restrictions.

Chapter "The Importance of Supplier Development for Sustainability" draws attention to supplier development for sustainability. As an emerging concept over the last decades, sustainable supply chain management incorporates climate change, environmental pollution, energy price fluctuations, and changing consumer behavior into strategic, tactical, and operational models used for coordinating the supply chain. Suppliers are a key part of a company's supply chain, and subsequently, their development plays a significant role in improving the sustainability of the focal company and its supply chain. Focusing on environmental supplier development, this chapter provides a critical review of recent works and summarizes interesting supplier development activities. The authors synthesize buyer- and supplier-originated barriers to supplier development to inform the critical success factors for supplier development programs. This chapter concludes with specific guidance to managers and future research directions.

The chapters presented in this volume underpin the importance of sustainable freight transport for global sustainability, livable cities, and continued economic progress. Since it is expected that significantly higher volumes of freight will be transported across the globe, it is important to recognize and act accordingly to make this growth sustainable by adopting new transport and distribution models with participation and contribution by key stakeholders. Sustainable transport is relevant to policies at national and local/city levels and it is anticipated to influence individual business/company strategies too. We hope this volume will pave the way for further research on sustainability of freight transport.

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Logistics and Freight Transport as the Kernel of Resilient Airport-Driven Development; A Survey on Basic Interactivities and Causalities

Rouzbeh Boloukian

Abstract Air transportation has experienced an almost steady growth in recent decades, in response to the global economic growth and to the trade interaction demand. With the largest part of the world's population living in emerging economies and the continuous growth of urbanization, the future growth of air transport can be guaranteed. Other modes of transport cannot compete with its key competitive advantage– travel time for long distances. Therefore, most airports have been subject to expansion and development as well as efficiency enhancement strategies to keep themselves alive and profitable in the air transport market, to serve their catchment area more efficiently, and to support the economy of connected regions. They are not small take-off and landing ports anymore; a revolutionary transformation has been changing their functionality, while businesses gravitate toward them causing economic, social, and environmental changes in their surrounding regions. A mutual relationship between the airport and its surrounding is formed to gain more economic benefits, which can lead to more aeronautical and non- aeronautical revenues for the airport. The existence of significant links between the airport operation and economic development has been proven in several studies; it has also been reviewed in this chapter. To make airports and their surroundings more fetching environments for business activities, decision makers have been planning to add diversified -especially non-aeronautical- services, and are planning to strengthen the economic ties between airport services and business activities. Most of the business activities are concentrated in cities, accompanied by the movement of goods and productions. The availability of the airport and the reliability of its services heighten the efficiency of freight transport chains and logistics networks and reinforce the competitive advantage of its region. Different concepts have been developed to conceptualize the relation of airports with their surroundings, acknowledging the strong ties between airport development,

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freight transport, and logistics. However, different interactions between airport and logistics/freight-transport within the catchment area arises the necessity of applying system approach to conduct more comprehensive analysis and to move toward implementing integrated approaches in planning. This necessity is crucial because other systems such as regional and urban economy, urban transport, land-use, environment, etc. also must be involved in integrated planning for the purpose of addressing sustainability and resiliency. In this study, which is a part of author's PhD research, a detail review on Airport-Delated Development concept(s) and the centrality of freight transport and logistics is provided. The complexity of planning is mainly addressed as an initial step for further research and system modeling.

Keywords Airport-centric development · Freight transportation · Logistics · System thinking · Dynamic behaviour

1 Airport Operations: On Course for Growth

Air transport has experienced an almost steady growth in recent decades in response to the global economic growth and various kinds of trade interactions (goods transport, business travel, and tourism) between countries and regions. Figure 1 shows the growth and resemblance pattern between 1992 and 2015 based on the data extracted from WB indicators (The World Bank 2016). Compared with other modes of transport, air transport provides competitive advantages notably in travel time, delivery time, frequency, security, and quality of service (Morrell 2011). These basic factors have been stably giving an upper hand to this mode and almost certainly will guarantee its continuous growth and future market share.

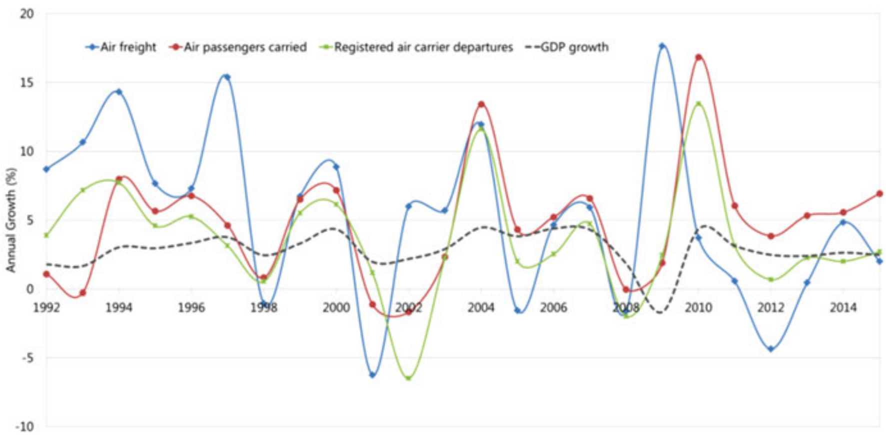

Fig. 1 The growth of global air transport versus global GDP (Adapted data are from World Bank (2016))

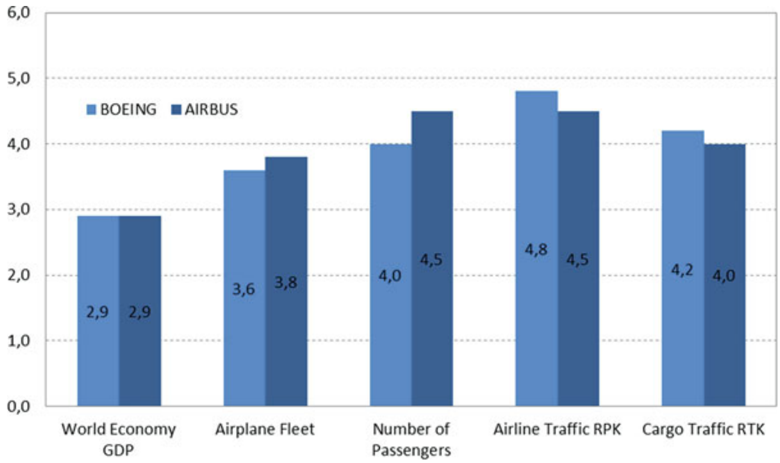

Fig. 2 Commercial aviation market outlook (Adapted data are from AIRBUS (2016) and BOEING (2016))

In its recent market outlook, Airbus foresees the commercial aviation market with average annual growth of 4.5% CAGR (Compound Annual Growth Rate) for passenger and 4.0% CAGR for Freight traffic between 2016 and 2035, with more than doubled in-service needed airplanes, while prosperity to travel in developing countries and emerging markets is forecasted to reach from 25% to 75% (AIRBUS 2016). The projection of the same time-period by BOEING also shows the average annual growths of 4.8%, 3.6% in airline traffic (Revenue Passenger Kilometers; RPKs) and airplane fleet, respectively (BOEING 2016). They both, as their key outlooks are graphed in Fig. 2, presuppose that the aviation market growth would happen in consonance with 2.9% average annual growth of global GDP (Gross Domestic Product).

By 2036, 6.2 of 7.0 billion people will live in emerging economies, while 62% of total world population will live in cities. One-fourth of the population in emerging economies took an air trip in 2016; it would triple in 2035 (AIRBUS 2016). The process of urbanization and the emergence of a middle-class are demographic components of global economic growth and the demand for air travel of middle-class passengers is a result of urban agglomeration (EMBRAER 2015). The urban population of the world has grown rapidly since 1950, from 0.7 to 3.9 billion in 2014. Continuing population growth and urbanization is projected to add 2.5 billion people to the world's urban population by 2050 (UN 2014). Urbanization is the key to the expansion of the airline industry (EMBRAER 2015). Over 2016–2035, the number of aviation mega-cities will expand from 55 to 93; these cities will handle daily around 2.5 million long-haul traffic passengers (AIRBUS 2016).

Since airports handle the ever-growing air traffic demand of passengers and cargos, they are required to expand and simultaneously achieve greater efficiency in their operations. The number of airports with more that 40 million handled passengers rose from 9 in 2000 to 37 in 2015 (ACI 2016) and (ACI 2000–2016). Many national governments face a surge in air transport demand which is outstripping available airport infrastructure (ACI 2016). The developing operations of most airports have been continuing to extend their externalities into their nearby and connected regions.

Along with infrastructures such as water supply, power supply, and telecommunication, whose availability are essential to modern societies, transport infrastructure provides services that cannot not be avoided, and puts its roots down to the economic development of its proximity. Airports have been playing a progressive, important role in connecting cities and regions around the world and in facilitating globalization. The organization and provision of services of an airport have a wide range of effects on the economy of the region and for the whole country (Zak and Getzner 2014). Therefore, the development and prosperity of each region can be affected by the availability of airports, the variety and reliability of their services, and their potential for development.

2 Airport-Driven Development: An Integrated Planning Framework

Because of basic air traffic operations and diversity of services provided by an airport in its area, it becomes a cluster of different activities – whether it is a very simple airport which serves a small number of passengers or a regional hub which proposes a multitude of services to origin-destination and transfer passengers and cargos at regional and international level. The so-called non-aviation activities range from a few small shops and restaurants to large complexes of businesses, manufacturing, and logistical activities. Airports seek to maximize their benefits through these sources. They are not anymore small take-off and landing ports, where just the air-land connection occurs. A revolutionary transformation has been changing their functionality while businesses gravitate toward them and they cause economic, social, and environmental changes in their surrounding regions.

This transformation is basically the result of interactions formed between airports and their surroundings. Airports initially provide services to cover the demand for air travel existing in their impact area. Besides this basic function, they try to stay economically alive in the regional, national, or international air transport market by maximizing their profitability. Diversification and quality increment of services are on top of the business strategies being adopted by airport managements toward coping with financial challenges and market competitions. However, it cannot be a lasting strategy as the development potentials and capacities inside the airport area are limited. This leads to a reciprocal coherence between airports and their surroundings, depending on the development potentials (geographical, social, economic, etc.) offered by each region.

2.1 Causality Between Airport and Economic Development

Numerous studies and reports certify generally the positive effect of airports on the economy at different geographical levels, but still, the exact way of contribution in economic development is a challenging issue for researchers and economists. The causal relation between aviation and economic growth has been investigated recently by Hakim and Merkert (2016) in the South Asian context (low income, large populations) confirming the long-run uni-directional causality running from economic growth (GDP) to air passenger traffic and also from GDP to air freight activity. They conclude that incremental changes in the relatively small aviation sector do not have a significant impact on the large sized GDPs of the relevant countries. While the direction of the relationship was of interest in a study on Australian airports by Baker et al. (2015), the magnitude and significance of the impacts were found as relevant, and it is clearly demonstrated that bi-directional causal relationship exists between air transport and regional economy.

Confirming the existing economic output of airports, Allroggen and Malina (2014) investigated the contribution of airports to economic development and proved its dependence on the supply of air services, which cater to business travelers. The existence of significant links between air transport and economic development has been statistically proven by Debbage and Delk (2001) in US metropolitan and the stability of this causality has been justified as high over time. Yao and Yang (2008) also collected and scrutinized empirical data for all the main airports in China during 1995–2006, as well as regional level economic and geographical information directly or indirectly related to airport development. They came to the conclusion that airport development is positively related with economic growth, industrial structure, population density, and openness, but negatively related to ground transportation.

In Sheard's (2014) estimation of the effects of airport infrastructure on relative sectoral employment at the metropolitan-area level in the US, a positive effect on the employment share of tradable services, controlling for overall local employment, and no measurable effect on manufacturing or most non-tradable sectors has been found. Thus, the results of this study certify that airport construction or improvement projects aim to benefit the local economy by making travel to and from the metropolitan area more convenient. Using an extended input–output model, Hakfoort et al. (2001) could present that the growth of the Amsterdam Schiphol airport between 1987 and 1998 led to additional employment in the Greater Amsterdam region of 42,000 jobs in 1998. It was interpreted as a considerable economic impact, but the authors noted that the economic impacts of the airport might be much wider than in the study area concerned, as Schiphol is the only major airport in the country.

In the area of air passengers, van de Vijver et al. (2014) surveyed the Asia-Pacific region and found that although among most developed economies there is no significant causality between air passenger travel and trade, but a significant causality runs from air passenger connections to trade for relations between more developed and less developed economies (e.g. Australia–Thailand), and from trade to air passenger connections for countries that have adopted very liberal approaches towards the air transport industry (e.g., Singapore). Based on a metropolitan production function framework, a panel data analysis of 33 airports over the 7-year period of 2001–2007 came to the conclusion that increase in maximum runway length leads to greater real GMP (Gross Metropolitan Product) and adding a new runway corresponds to an increase in real GMP. Also, average flight delays were an important determinant of economic development, decreasing GMP (Tittle et al. 2013). Button and Taylor (2000) also studied a relatively large number of US airports and confirmed that more international air transport is likely to stimulate further growth in the new economy.

Kasarda and Green (2005) confirmed the positive role that air cargo plays in economic development as well as three factors that can enhance this positive impact (air service liberalization, improving customs quality, and reducing corruption); they modeled and assessed on per-capita net inward foreign investment and gross domestic product per-capita in 63 countries around the world. Causal relationship between air cargo expansion and economic growth in Taiwan is tested by Chang and Chang (2009) confirming that these are co-integrated while a bi-directional causality exists between them. Statistically significant levels of correlations between business travel and air cargo for all samples at national and state level in Australia found through the recent analytical attempt of Tan and Tsui (2016) resulted in the fact that the landscape of Australia's local economy has a significant impact on the air cargo and business travel relationship.

2.2 Airport-Driven Development Concepts

However, the level of contribution of airports in regional economic development is an issue which deserves to be further scrutinized, but it is not disputable that airports facilitate the economic development of their surrounding areas. Several models have already been developed; each one introduces a type of airport's contribution in development of its surrounding area and tries to benefit from more passenger and cargo operations guaranteed by commercial activities that occur within its close proximity. The increasing commercial activities in the airport area, whether directly or indirectly related to the air freight, lead to increased activities of logistics since they stimulate direct, catalytic, and induced demand for air transport. Airports tend to deal and cope with this condition to increase their profitability and strengthen their role in air transportation network and regional economy. Decoplex, Airport-City, Airfront, Airport-Corridor, Aerotropolis, and Airea are the developed and introduced concepts of Airport-Led Development or type of development that relies on airport operations and its facilitating and supporting character to the regional development.

The **decoplex**, which stands for development ecology complex, is of an intermediate urban scale featuring a jetport alongside planned industrial sites, offices, hotels, and waste treatment facilities with all core units having direct runways / taxiways. An idealistic anticipation of the Airport-City idea, the ideal site area is up to 20,000 acres (Conway 1993). **Airport-city** is seen by most actors as an agglomeration of mixed-use property developments in and around airports, and that, in fact, the "city" part of the term seems to relate only to the variety of land-uses present, which can typically be seen only in cities (Peneda et al. 2011), while Freestone and Baker (2011) summarize it as a generalization of, notably, the marketing concept for Amsterdam's Schiphol airport from the 1980s. The **Airport-Corridor** links airport and central city as a band of integrated road/rail infrastructure and property development and considers an integrated development along a corridor between business core of the city (CBD) and the airport. The corridors most clearly defined are in city regions with close proximity between major airport and CBD (Sydney), made-to-measure governance structures (Paris and Zurich) and massive public investment in infrastructure (Kuala Lumpur, Singapore, and Hong Kong) (Freestone and Baker 2011).

The **airfront** is defined as the myriad commercial, industrial, and transportation facilities and services intrinsically tied to the airport while airports and their surrounding commercial districts are playing an increasingly important role in shaping urban and regional growth patterns (Blanton 2004). As described by Schlaack (2010), focusing on Berlin-Brandenburg new airport and Denver International Airport, the concept of the **Airea** delivers an approach, a toolkit, and a spatial and functional category to analyze and describe processes of airport related development within the metropolitan region. The Airea is, unlike the other concepts, a rather objective term which refers to the various fragmented islands of development within a certain space of opportunity in relation to the airport, which means it refers to those parts of the metropolitan area which are predominantly influenced by the airport, or which, in reverse, influence the airport directly.

The **Aerotropolis** consists of a core 'Airport-City' at the epicenter of a wider metropolis and interconnected by dedicated motorways, Aerolanes, high-speed rail links, Aerotrains, with outlying aviation-oriented business precincts such as e-commerce fulfillment centers, business and logistic parks, retail complexes, hotels, and free trade zones (Freestone and Baker 2011). Accessibility is the most important commercial real estate organizing principle. Basic drivers for Aerotropolis development are advanced telecommunications, new supply-chain management systems, time-based competition, production flexibility and mass customization, and perishability (Schaafsma 2003). Kasarda (2013); who developed the concept, emphasizes that the Aerotropolis represents the physical manifestation of globalization made concrete in the form of aviation-oriented, airport-centric urban development where many local businesses are more dependent on distant suppliers and customers than on those in their own region. Its competitiveness rests with its aviation connectivity and corresponding ability to move people and products quickly around the world.

All these concepts encompass the existing geographical and spatial opportunities in the surrounding areas of the airport to build up an integrated development platform and placing airport as a magnet of business and economic activities. They depict airports as economic gateways, capturing and translating economic growth into on- and off-airport jobs (Freestone and Baker 2011). Airport, as the central part of Airport-Driven Development, and the supporting transportation network connected to the airport, such as railway connections, highway network, and terminals are the basics while connectivity is a core factor for economic development in urban and regional areas. In addition to the air and surface connectivity, Romero (2013) enlists development of an airport, funding sources for development, development in the region, and collaboration among stakeholders as key factors that facilitate the Airport-Centric Development or Airport-Driven Development.

3 Complexity of Freight Transport and Logistics: A Challenge in Integrated Planning

The continuous growth of freight transport, named by Leinbach and Capineri (2007) as the integral component of economic development, is a result of diversifying human needs for the well-being and the constant growth of the economy. It is now the main element supporting global commodities, and more generally supply chains (Capineri et al. 2006), while the growing flows of freight have been a fundamental component of contemporary changes in economic systems at the global, regional, and local scales (Hesse and Rodrigue 2004). Freight transport has emerged as one of the most critical and dynamic aspects of the transport sector where change has become the norm (Leinbach and Capineri 2007), since it is derived from a very normal but continuous and dynamic demand, and movement of goods between supply-points and consumption-points. Logistics and supply chain management have been developed to support and manage the ever-growing demands and to meet the dynamic needs of different parties.

Freight transport, which is physically responsible for material flow and goods movement, is intertwiningly connected to logistics and supply chain management, discussed in several studies (see: Rodrigue et al. 2006; Lummus et al. 2001; Lummus and Vokurka 1999). Based on the latter two works on the definition of logistics and supply chain management, logistics involves planning, implementing, and controlling efficient and effective flow and storage of goods and services from the beginning point of external origin to the company and from the company to the point of consumption for the purpose of conforming to customer requirements (Lummus et al. 2001) while supply chain management brings a broader view in order to provide a seamless process through linked partners in the chain including departments within an organization and the external partners including suppliers, carriers, third-party companies, and information systems providers (Lummus and Vokurka 1999).

Logistics systems and supply chains are sophisticated systems, made up of several interlacing and dependent sub-systems, while the whole system encompasses different facilities with related and unrelated but complementary and goal-seeking functionalities as well as transport linkages among these facilities. Depicted

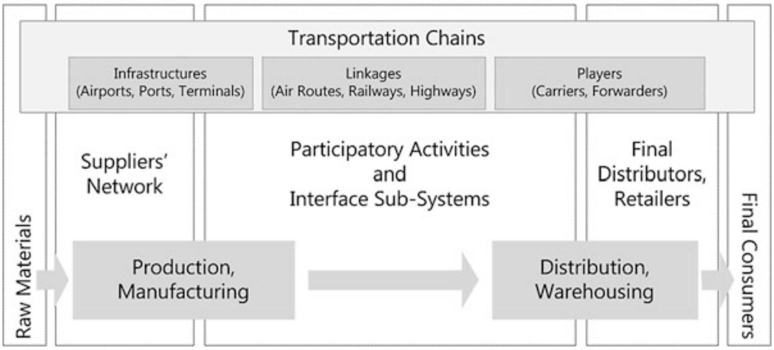

Fig. 3 A general schematic view on supply chain management, logistics, and transportation

schematically in Fig. 3 are the main sub-systems and activity chains of supply chains which are based on logistics management. Each of these concepts is sophisticated enough to be scrutinized by itself and it leads to more challenges when these systems should be analyzed while fenced in or linked with other systems. The complexity exists, but its level depends on the objectives that are being pursued by analyzers or planners.

Cities are the locations of most business and commercial activities. Urban activities are accompanied by large movements of freight moving between industries, distribution centers, warehouses, and retail activities as well as from major terminals such as ports, rail-yards, distribution centers, and airports (Rodrigue et al. 2006). Based on the urban freight movement, the concept of city logistics has been developed which deals with the optimization of all activities in this realm. This optimization considers the traffic environment, the traffic congestion, the traffic safety, and the energy savings within the framework of a market economy (Taniguchi 2001) that are necessary for quality of life in urban areas and the sustainability of the living-system. Interaction between urban freight with other urban sub-systems is shown in Fig. 4 schematically.

Moreover, urban freight has interactions with systems beyond the urban boundaries at regional, national, and international levels, such as environment, economy, and transport. Freight movements are complex; in many jurisdictions, they are increasing in number, and their direct and wider impact on urban life can be substantial. Growing volumes imply increasing scale and complexity due to the impact of freight on cities (Cui et al. 2015). While city logistics encompasses the urban freight transport activities and service provided by businesses, it is potentially a big contributor to the urban and local economy and the competitiveness of the city. In cities, where transport infrastructure and facilities are provided at an appropriate level of functionality, city logistics can increase the competitiveness of the city in the regional or global economy. Any competitive disadvantage compared to other cities causes investors to move to other regions with a more competitive infrastructure (Herzug 2010) which can translate into reduced effectiveness of the urban economy.

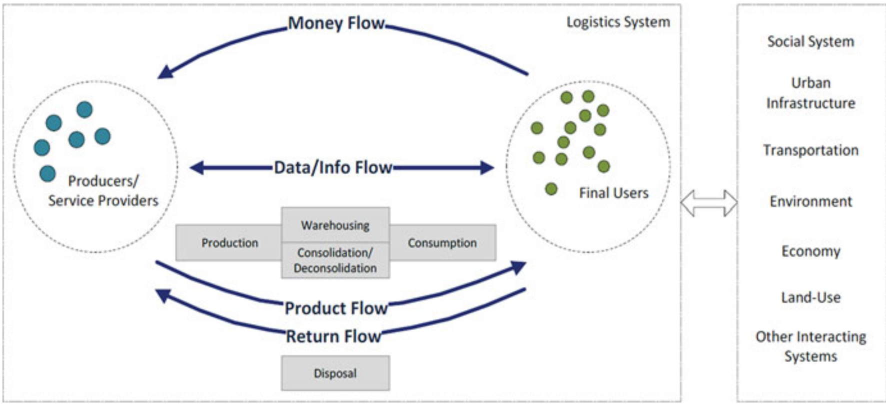

Fig. 4 The schematic complexity of the urban freight and logistics system (Boloukian and Siegmann 2016)

Studies on freight transport and logistics systems toward providing a higher level of systemic integration with infrastructures, such as airports, can be conducted at regional and urban level. But since airports first and foremost serve nearby urban areas, urban sub-systems must be considered as depending on their existing interactions with airport and freight transport systems (e.g., urban freight transport and logistics, urban land-use, urban environment, urban economy). Much freight research emphasizes questions of operations and network management, but is less attentive to the links between freight transport and urban development (Cui et al. 2015).

4 Airport-Driven Development Encompasses More Than Air Freight

According to the details provided in Sect. 2.2, Airport-Driven Development is a concept which acknowledges the airport as the centroid of the development of its surrounding region while it stresses on the potentials of the airport, a so-called trade magnet, and on the roots, which can be put down to the trade and economy of area or region. The function of commercial aviation in freight transport and logistics networks at different geographical scales provides the platform for development in catchment areas of airports.

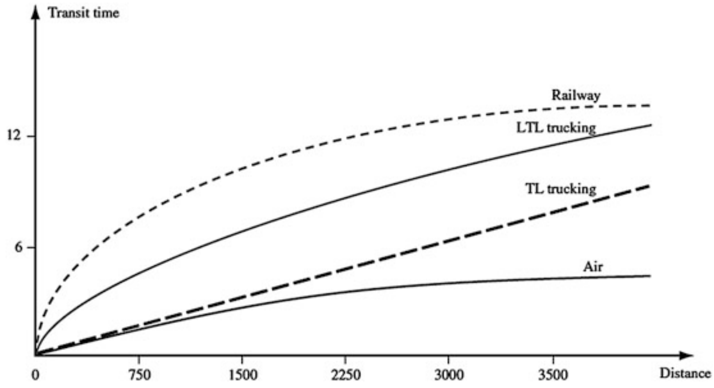

Fig. 5 Average transit time (in days) as a function of distance (in kilometres) between origin and destination (Ghiani et al. 2004)

4.1 Value of Air Transport to Logistics

Compared to the other modes of transport, air transport has an evident advantage, speed, which is a decisive factor in passenger and cargo movements. The longer the distance between the point of origin and the point of destination is, the greater is the likelihood of using air transport mode. The fact is also shown in Fig. 5 based on distance-transit time function. This feature of air transport has served to offset many of its limitations, among which operating costs, fuel consumption, and limited carrying capacities are the most significant (Rodrigue et al. 2006) although technology advancements have so far led to aircrafts such as the Boeing 747-8F, the Boeing 777F, and the Airbus A330-200F, with maximum payloads of 130, 100, and 70 tons, respectively.

The high value of goods, with their time-sensitive characteristics, to be delivered to the consumer or next-step user, are also two main factors that leave little choice but to be transported by air mode. An efficient logistics industry enables nations, regardless of location, to efficiently connect to distant markets and global supply chains in a speedy and reliable manner (Yuan et al. 2010) and the role of commercial aviation is not negligible. Air transportation offers many cost advantages – lower lead times, quicker customer response times, improved flexibility, and reduced inventory (Wensveen 2011).

These advantages made the growth of air cargo a significant contributor to global freight traffic (Leinbach and Capineri 2007) so that over the past 30 years, growth in the value of cargo shipped by air has significantly outstripped the growth of global trade generally (Kasarda and Green 2005). Although air cargo only accounts for less than 1% of world trade shipments by volume, it makes up around 35% by value (Raj et al. 2016). In the new fast-cycle logistics era, nations with good air cargo connectivity have competitive trade and production advantage over those without such capability (Kasarda and Green 2005).

With economic deregulation of airlines in the late 1970s, air cargo networks were able to facilitate just-in-time shipping, providing expanded services at lower costs (Wensveen 2011) and, now, air cargo plays a particularly important role in enabling countries to integrate and move up Global Value Chains (Raj et al. 2016), which is a highly interconnected concept with logistics and supply chain management as it refers to fragmentation of production. Over 70% of global trade is in intermediate goods and services and in capital goods. The income created within GVCs has doubled, on average, over the last 15 years (OECD, WTO and World Bank Group 2014).

Passenger air transport also provides a magnificent supporting role in freight and logistics industry. The most visible effect of air passenger traffic on air cargo transport is providing belly capacity, which has a considerable share in freight movement in air transport market. As shown in Fig. 6, it is even forecasted that the share of belly cargo will experience an approximate 10% boost from 2015 to 2035. More passenger traffic and more air passenger connections can potentially be translated into more air cargo. Furthermore, passenger traffic is made up of business travelers and the general public, many of whom are holiday-makers and tourists (Rodrigue et al. 2006) who facilitate trade interactions in catchment areas of airports.

4.2 Stimulated Logistics Activities in Airport-Driven Development

Reciting the reviewed concepts of Airport-Centered Developments, it should be stressed that airport potentially is the radial point of regional development and logistics activities interact with this so-called central point in direct and indirect forms. As pointed out, the support of freight transport and logistics for business

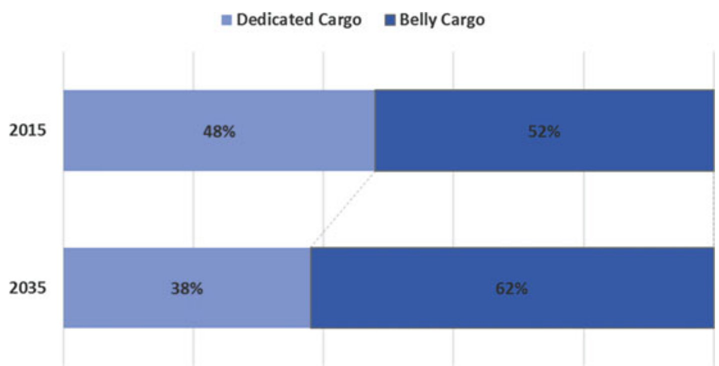

Fig. 6 Worldwide share of dedicated freighters versus belly cargo (Adapted data are from AIRBUS 2016)

activities, ranging from small retailers to large logistics parks, is indispensable. Studies on growth around airports have found businesses that require or benefit from air transport seek locations near the airport, extending as far as 20 miles (Romero 2013). Two types of airport-related industries have been described by most part. Knippenberger (2014) as those that rely on short time distances (up to 30 min) and are not necessarily located inside the airport fence: companies which are active in the field of air cargo transport and the adjacent service industry close to airport operation. Consulting companies, pharmaceuticals, high-value producers, and logistics companies are among those that prefer to be located within a reasonable distance from the airport, depending on its level of network coverage.

Formation and emergence of airport industrial parks have also been an outgrowth of interactions between the airport and surrounding areas in recent decades. This occurs in the realm of logistics, where delivery reliability and reliable supply chain are decisive and meaningful to active companies in industrial parks. Airport industrial parks, as an element of the expanding postindustrial economy, were increasingly characterized by high-technology research and development industries that required substantial investment, planning, and lead time to produce their high-value specialized products (Karsner 1997). Freestone and Baker (2011) describe them as more than traditional air cargo facilities, while they are conceived as assemblages of time-sensitive economic activities based around transport hubs with direct intermodal loading and unloading capabilities, advanced telecommunication services, and business-friendly government taxes and customs processing.

Defining differences between the economic profiles of Airport-City developments, such as logistics and services at Amsterdam, logistics and industrial production or leisure/entertainment/ tourism in many US cases, services and tourism in Hong Kong and Seoul, and technology in Kuala Lumpur, Schaafsma (2003) highlights their contribution to maximizing the economic effect of the presence of the airport. Also, it is pointed out that by the continuity of globalization and the importance of air travel growth, a local network of airport-cities, central business districts, and technology parks bound into the global networks by airline alliances may become a global space of concentration of management, production, and innovation, especially at hub airports.

Clustering activities around the area of Schiphol airport and developed location forces which interplay in the making of the EDC (European Distribution Center) cluster are examined by Warffemius (2007) and defined as location endowments, agglomeration economies, and locked-in logistics. Neiberger (2008) explains that the development of flexible global production networks through mergers and acquisitions as well as partnerships and agreements amongst logistical service providers changes the position of the airports within international goods chains, as today they are actors within the global networks. They found that large distribution centers do locate close to airports – among other locations – but do not carry air cargo goods for the most part. Knippenberger (2014) stresses that airports are usually well placed within land-traffic corridors of road and railway lines, which make them ideal places to locate a logistics center.

Airport passenger and cargo operation provides the development basis and competitive advantage for businesses. Whether a business benefits mainly from passenger operation or air cargo movement or just tries to develop its roots into the broad formed market around the airport, it uses the proximity to the airport as an advantage. However, air cargo operation remains the booster of logistics activities in Airport-Driven Development. Kasarda and Sullivan (2006) believe that historically, air cargo traffic, when subjected to downturns impacting the aviation sector, has typically recovered at a much quicker rate than passenger flows, just as it has from the most recent aviation downturn.

Freight transport and logistics, as well as the activities related to them, form a radial network around the airport. Generally, all these activities can be classified into three principal categories. The airport, as the centroid of network, propagates logistics- and business-inviting signals outwards into the region which stimulates freight transport and logistics companies as well as business enterprises to bring parts of their activities near the airport. Stimulated business activities are translated into more freight transport and logistics via inward feedbacks which consequently raise the cargo and passenger operation of Airport. The three principal categories and their linkages and feedback directions are depicted in Fig. 7 as shown below:

- linked/associated logistics activities which are directly linked to the airport operation, such as air cargo operation and catering;

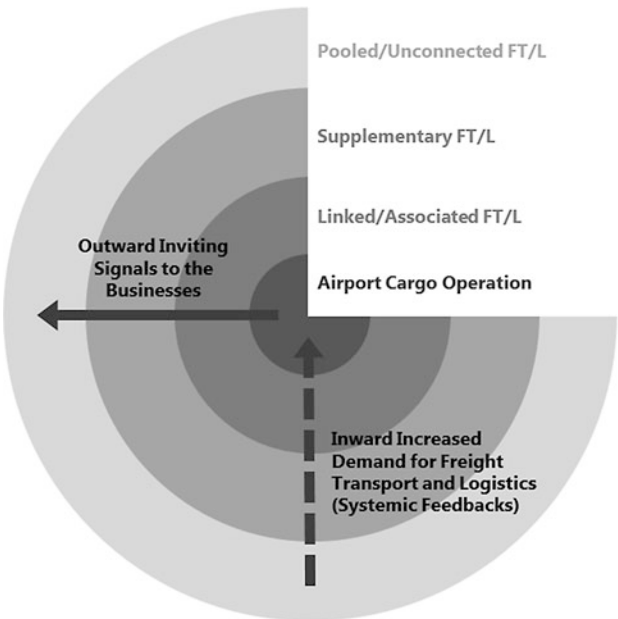

Fig. 7 Principal categories of freight transport and logistics activities and their systemic feedback

- supplementary logistics activities that have close access to the airport services and are essential to their activities in business and supply chain; and
- Pooled but unconnected logistics activities which just benefit from the economic advantages of business and industrial clusters around the airport.

5 Simple Prevailing Loop: Complicated Underlying Dynamics

According to the existing causality between airport operation and economic development (regardless of the vastness of the airport catchment area), it can be inferred that there is a powerful reinforcing loop, hereinafter named the development loop in Fig. 8, which is the bedrock of Airport-Driven Development. Air connections drag out the demand from the airport catchment area, while the primary goal is generally to serve the existing demand in its region. Passenger and cargo operation stimulate the demand further and facilitate the development in the region because of drawn, developed, or diversified businesses. This causes new demands (direct, catalytic, and induced) to air transport in the region that the airport tries to cope with. It is a dominant loop based on facts reviewed in Sect. 2.1; nevertheless, it is controlled and balanced by the limitations and constraints (negative loops and feedbacks).

Availability of land for development, especially in the case of airports located close to a densely populated area, is one of the strongest balancing factors of that reinforcing loop. Environmental concerns; e.g., noise and water pollution, are the other powerful balancing factors which decrease the power of the reinforcing development loop. Competition among airports in the network, especially those that compete to gain more regional market share, is another balancing item. There are many other factors that depend on the geographical location of the airport and its

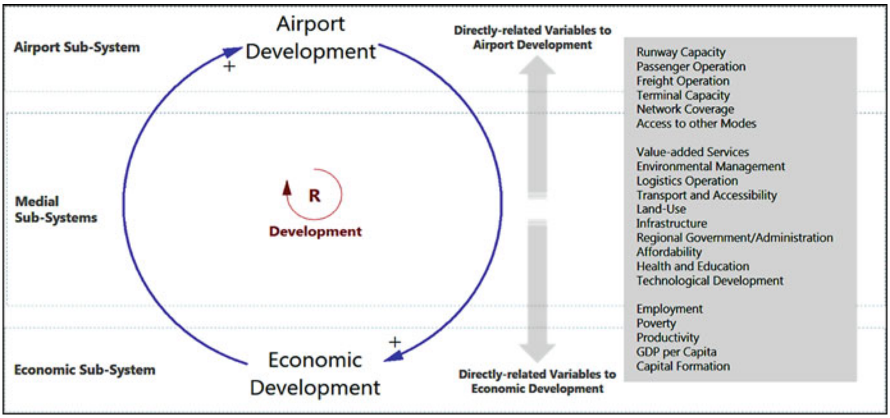

Fig. 8 Systemic approach to the Airport-Driven Development

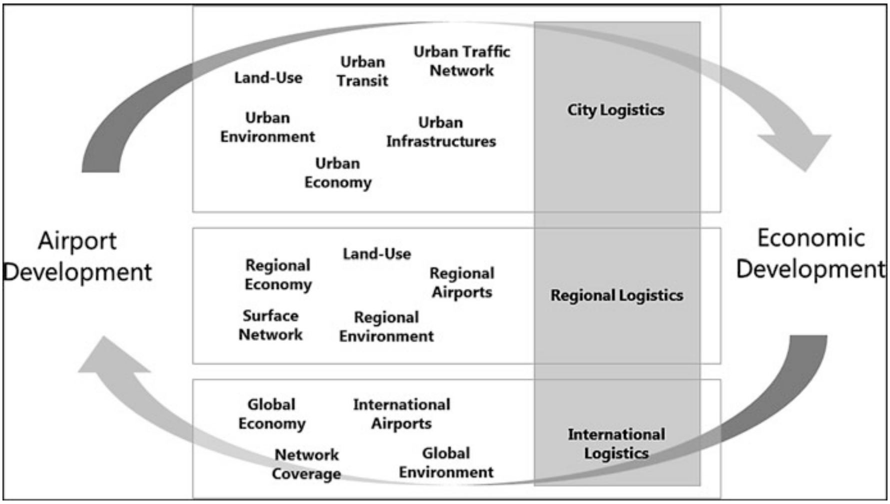

Fig. 9 Key medial sub-systems within the concept of Airport-Driven Development

market characteristics, but the reinforcing loop continues to dominate the overall system around an airport. The growing air transport demand and airport operation is the firm evidence of this continuing dominance.

The Dynamic system of Airport-Driven Development incorporates a spectrum of activities: from airport operation to tangible economic results. Two main subsystems of this development pattern are the airport system (including the air-side and land-side area inside the airport fence) and the economic system. The economic system benefits from airport passenger and cargo operation. The large contribution of the airport to the economic development of the city or region comes into effect via pulling and supporting urban and regional businesses. Several medial systems, of which the most visible ones within the concept of Airport-Driven Development are presented in Fig. 9 interact with the airport system and economic system to create value for the whole region. Freight transport and logistics activities are highly interwoven in these two main systems.

6 Causalities Within the Airport-Driven Development

Airports bring great potentials into their proximities via increasing the connectivity of their regions. Cities, which are normally the primary catchment area of airports, interact with airports through their subsystems at different levels. Beyond cities, systems in the catchment region interact with airports, especially when the airport serves a region which includes multiple cities. All interactions, regardless of their intensity and influence, shape a mixture of balancing and reinforcing loops with

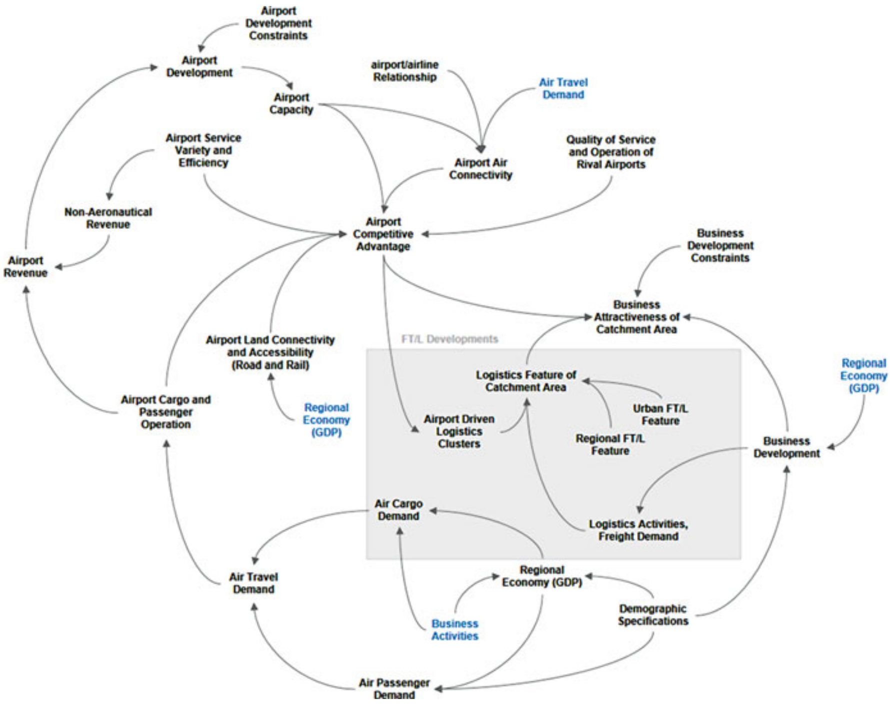

Fig. 10 A general model of causalities within the Airport-Driven Development

inevitable accompaniment of productive and counter-productive effects that should be subjected to scrutiny in the systemic study on Airport-Driven Development.

6.1 Productive Interactions

Figure 10 demonstrates a basic causal model between airport, freight transport and logistics in the airport proximity, and the economy of the region. An airport's competitive advantage represents the quality of the airport in serving its surrounding region. Existing demand for air travel (passenger and cargo) in the catchment area, primarily the nearby urban area, is the basic stimulant of airport development, but it is controlled via feedbacks from the airport itself, business characteristics, and economy of the region. Development in businesses and consequently in freight transport and logistics gives a strong, positive feedback to the airport operation through more stimulated demand and reinforces the basic loop of airport and economy development, which was discussed in the previous section.

Existing potentials for capacity enhancement and efficiency improvement inside the airport area as well as possibilities of development beyond the airport fence lead to form business clusters. The robustness of the economy of the nearby city and the region (catchment area) supports the effectiveness of these business clusters whose main field of activity is logistics and freight transport. Some businesses decide to come closer to the airport, especially logistics companies and, in some cases, companies that are active in value-added services, and other downstream businesses that prefer to use the opportunity of being close to other companies and businesses as well as the airport.

6.2 Counterproductive Interactions

Among most considerable negative feedbacks are that propagate their effects across the system loops are environmental effects of airport operation and airport expansion. These feedbacks may impose new restrictions on airport and economic development while the sustainable development of airport and its surrounding region are crucial for social welfare and consequently for competitive advantage of region. Hakfoort et al. (2001) mark that the economic and environmental impact of the airport on the region combined with the continued growth of air traffic has led to a considerable public debate around the planned expansion of airports in many Western countries. This debate has mostly centered on the trade-off between the negative external effects on the region such as noise, pollution, and safety risks and the economic benefits of the expansion for the region. Knippenberger (2014) also notes that airports exist in a reciprocal relation with their surroundings and produce negative impacts on their neighboring communities as the secondary and spatial effects of economic activities which have been rarely discussed in other studies. The negative effects of Frankfurt Airport on the neighborhood of Mörfelden-Walldorf (concentration of low-skilled workers, high rate of population exchange, and high incidence of noise and traffic) are analyzed in this study.

Higher noise annoyance than predicted from general exposure-response curves also found through the assessment done by Schreckenberg et al. (2010) on the residential areas near Frankfurt International Airport. Results from a study on an airport in Iran, obtained by Kord Tamini and Mirbaluchzahi Pak (2016), indicate that the airport neighboring residents suffer from slightly higher anxiety, stress and overall scores of DASS (Depression, Anxiety, and Stress Scale) compared with other city residents. As a result of annoyance, Espey and Lopez (2000) suggested in their study on Reno-Spark area that airport expansion would also have a negative impact on property values which can be important for local airport authorities interested in expansion and for those negatively impacted by such expansion such as property owners and public agencies dependent on property. Another recent study shows the same results for residential areas close to Beijing Capital International Airport. The results suggest that a 1 dB increase in noise exposure leads to a 1.05–1.28% depreciation of property values (Nguy et al. 2013).

The reinforcing development loop (Fig. 8) is balanced through the negative loops and counterproductive interactions. Sources of resistance inside the system and the limitation of resources bound the development process. Systemic conflicts among players and sub-systems are completely normal as they are matters of routine in sophisticated systems with different players, and where each one has its own interest. Particularly, airport authorities always tend to extend their operation during nights to gain more benefit, but the inhabitants always pressure the airports to extend their curfew time during the night. Environmental and social needs limit the development process as it increases negative impacts of airport and logistics operation in the surrounding area. Beside the conflicting interactions inside the system, the previously mentioned negative impacts, caused by airport operation and airport expansion, also balance or even harm the development process which should be studied toward gaining more sustainable development.

7 Final Discussion

A revolutionary transformation has been changing airports' functionality while businesses gravitate toward them, causing economic, social, and environmental changes in their surrounding regions. This transformation is the result of interactions formed between airports and their surroundings. Development of airports through providing linkages between airport activities and businesses around the airports establishes a platform for regional collaborations between different parties and differing ambitions. Because of the causal relationship between airport operation and economic development, patterns should be more matured toward maintaining higher levels of integration between airport development and development in their surroundings. This can heighten the competitive advantage of catchment area via mutually beneficial interaction.

Over the last three decades, some airports have begun to provide a greater range of passenger and business services and increase their concessions to maximize their revenue stream. By the early 2000s, many airports focused on upscale concessions, such as exclusive restaurants and designer boutiques, and other premium services, such as rental car facilities and parking facilities linked to the airport, to help maximize revenue generation (Romero 2013). Developed concepts, which place airport as the center of regional development (e.g. Decoplex, Airea, Airfront, Airport-Corridor, Aerotropolis, and Airport-City) try to use the opportunities that exist in the airport and in its surrounding area to attract business and commercial activities and support them via offered connections to other cities and regions. Freight transport and logistics activities are among businesses that are initially pulled to the airport proximity while cargo operation of airports is important for them.

Airport-Driven Development system is a dynamic system which incorporates a wide range of activities; it is a spectrum from airport operation to tangible economic results. Airport passenger and cargo operation provides the development basis and competitive advantage for businesses. Air cargo operation remains the booster of logistics activities in Airport-Driven Development. The logistics system (including the regional logistics and urban logistics) interacts with other subsystems at the urban and regional levels (and even international). Different interests of players inside the system as well as existing negative feedbacks and continuous restrictions produce counterproductive interactions. Environmental concerns, social constraints, and land-use limitations are among sources of balancing feedbacks. Through Airport-Driven Development, mitigating the power of counterproductive interactions and coping with social and environmental restrictions toward reaching a higher level of sustainability besides the economic development is crucial because it improves the area's competitiveness, which in turn plays a central role in economic development, business attractions, and livability of the area.

Conclusively, the continuity of Airport-Driven Development and its robustness depends mainly on:

- The level of collaboration between all stakeholders, public authorities, private companies, airport administration, and local governors;
- Continuous minimization of negative environmental and social effects toward gaining higher level of sustainability;
- Providing accessibility and surface connections with other modes of transport, especially highway and railway network,
- Keeping the overall and sectional efficiency of the airport at a customer satisfying level to offer a fair advantage over its competitors in the commercial aviation market,
- The availability of financial sources and economic supports.

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Sustainability Management in Smaller UK Ports to Promote More Sustainable Freight Transport

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Abstract This chapter aims to promote more sustainable freight transport by discussing processes to assist smaller UK ports as vital but neglected freight interchanges, to embrace and embed sustainability management. Discussion spans aspects of freight performance, examples of port planning and reporting, and some available sustainability management systems. In time, more systematic sustainability management methodologies will probably permeate port management, but the processes and mechanisms for change remain uncertain. Increasing adoption is likely as managerial awareness increases, driven by internal corporate strategic initiatives. External drivers will involve abduction from disciplines in which sustainability management is more mature. Diffusion of values and operating practices from adjacent supply chains, or pragmatism arising from requirements to safeguard critical revenue streams is likely. Support from research and professional bodies is essential to design strategies to guide the implementation of sustainability management in smaller UK ports to ensure more sustainable freight transport.

Keywords Port sustainability management · Smaller UK ports · Sustainability management processes

1 Sustainability Management, Freight Performance and Ports

Burgeoning international trade has fostered unprecedented growth in the throughput of port traffic, principally freight, as most international trade passes through ports (UNCTAD 2015, Fig. 1.1). Freight transport systems embrace ports as vital nodes in international supply chains (Mangan et al. 2008; Gibbs et al. 2014). As key decision

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regulators, ports influence the sustainability performance of supply chains whether inbound or outbound, forward or reverse, marine or inland. Sustainability planning is commonplace in supply chains (Schaltegger and Burritt 2014) but neglected in ports. This section introduces port sustainability planning and links with freight transport performance including competitive advantage, competitiveness, operational and quantitative measures.

Most graduates and managers are aware that sustainable development must "meet the needs of the present generation without compromising the ability of future generations to meet their own needs" (UN 1987). Equally familiar are requirements for managers to ensure that organisations satisfy the needs of people, planet and profit in a "triple bottom line" interpretation of the societal, environmental and economic dimensions of sustainability (Tullbeg 2012). Within the maritime sector, a social dimension including International Maritime Organisation (IMO) "Safety of Life at Sea" (IMO 2016) regulations and complex Health and Safety at Work Legislation (HSE 2015) is instilled into seafarers from their recruitment. More recently, growing awareness of environmental issues (OECD 2008; ESPO 2012; Ecoports 2016) coupled with increasing regulation of shipping's emissions (IMO Annex 6) and promotion of green port strategies (Green Ports 2016; Davarzani et al. 2016) testify to a maturing environmental dimension. Despite the financial volatility of maritime commerce growing pressures to modernise port ownership, governance and management systems evidence a vigorous economic dimension. Port strategies and policies acknowledge all three dimensions and Harbour Commissioners' mission statements embed each of them (Kuznetsov et al. 2015), but the three dimensions are rarely integrated and holistic sustainability planning is rare. Within the maritime sector, managers of smaller ports must rely on instinct to guide sustainability planning with little support from published research or bespoke port sustainability management systems (PSMS).

Active sustainability management often enhances competitive performance (Tan et al. 2011; Schaltegger and Wagner 2011), which affects freight transport. Offering high quality services may create new opportunities to achieve competitive advantage or to sustain a competitive position. Savings in cost and energy efficiency may accrue, as may security improvements, with reduced risks. New markets and new customers may emerge alongside an improved image and reputation. Improved ethics and greater social responsibility may reduce the environmental impacts of operations, and sustainability management transmits clear organizational intentions to continue and survive into the future. The management and application of technologies to resolve environmental problems through prevention, mitigation and restoration may create opportunities for new business. Greater economic stability may arise from continuous improvements in subsequent performance, creating proactive industry leaders, rather than reactively compliant ports.

Regulatory compliance represents satisfactory performance but where port competitiveness is associated with environmental management (Adams et al. 2010, 5) aspirations often extend beyond compliance. The drivers of investment in sustainability management in ports include international marine and environmental legislation (ESPO 2012, Annex 2), local and provincial environmental legislation, environmental protection and quality improvement issues and environmental management perhaps involving pollution prevention. Development and planning issues included coastal zone planning, and port sustainable development programs. Societal pressures can result in direct economic benefits, and striving for corporate and social responsibility may drive investment. Other drivers include economic incentives through tax exemption, subsidies, capitalization and revenues and operational issues related to performance and health and safety issues and process standardization. Sustainable investment may also arise from strivings for competitive advantage, competition between regional ports, promotion of short sea shipping, promotion of “green logistics”, external business pressures from shipping lines and terminal operators and commercial and marketing interests.

Operational performance in logistics may reflect investment in integrated technology and may include sustainability management. Ninikas et al. (2014) for example, designed an integrated system to support planners and dispatchers to deliver enhanced courier operations based on typical routes of everyday operations, which incorporated optimization algorithms to ensure integrated and balanced operations. Similarly, effective sustainability management in ports is integrated. Information technology frequently underpins integrated system design, including EU programs to develop integrated transportation systems to support co-modality operations capable of delivering near optimality on multiple dimensions including cost, customer satisfaction, energy and emissions (Zeimpekis et al. 2012). Governance structures may encourage innovation to exceed regulatory compliance, perhaps in a trust port system where stakeholder pressures may drive innovation (Dinwoodie et al. 2012). Managerial decision making may drive the adoption of sustainability practice, where management perceives that good environmental practice can impact corporate performance. More recently, such awareness has spread to container terminal operations in ports (Lun 2011). Finally, although firm size probably affects performance measurement, the key relationships may vary. Within the context of food supply chains, sustainability performance measurement in SMEs is known to vary, but the impact of how size differences between micro, small and medium-sized firms impact performance is not well understood (Bourlakis et al. 2014). Similar issues are likely to attain in the UK’s 800 ports, many of which employ under ten people.

Much recent research into port sustainability has applied quantitative performance management to generate performance indices (Acciaro et al. 2014; Lam 2015; Lam and Notteboom 2014). Environmental and economic measures dominate social issues in studies of large UK ports (Asgari et al. 2015) and even a social construction index of port sustainability in Keelung, Taiwan (Shiau and Chuang 2015). Indices offer ports some limited benchmarking, although research conclusions that heed ports to realign their strategy to embed sustainability management but offer little practical guidance, are of limited relevance.

To enhance freight transport performance the next section reviews examples of port sustainability management, some available systems, building awareness in smaller ports and practical strategies to embed sustainability management. Discussion then moves to the drivers of sustainability awareness including internal strategies and pressures from supply chains and other sectors. Alternatively, pragmatic pressures to safeguard critical revenue streams may promote measures to embed sustainability management. An effective implementation strategy will require peer support and further research.

2 Examples of Port Sustainability Management

Smaller ports require exemplars of effective sustainability management to raise freight transport performance. This section considers UK government requirements to prepare strategic masterplans (Dft 2008), and to promote awareness of sustainability practice it introduces sustainability reporting, exemplary practice from megaports, environmental management systems (EMS) and PSMS for smaller ports.

2.1 Port Masterplanning

A port masterplan "outlines the objectives of the port and how they are expected to be achieved" (Taneja et al. 2010, 222). For many years masterplanning stated a port's strategy, articulated its role in the marketplace, identified areas to be developed, and their function (Frankel 1989). Formal guidance on preparing strategic masterplans for ports in England and Wales appeared 4 years after guidance for airport masterplans. Because ports are "highly disparate" (Dft 2008, 3) preparation advice centered on consultation with statutory authorities in local, regional and national hierarchies, and key stakeholders. Given that existing development around ports imposes land-use constraints that severely inhibit the scope for major new port developments, port masterplans were encouraged to complement land-use, transportation and marine plans. Comprehensive masterplans embrace issues of future demand and infrastructural provision, access, connectivity and social and economic impacts, safety and security, impacts on the environment, habitats, pollution, local and global emissions, and noise (e.g. ABP 2016; Shoreham Port 2016). Understanding and addressing the risks inherent in masterplans is paramount (Shingles 2016, 31) because traditional plans emphasize the operational requirements of people, property and resources in a port's business, and an alternative view addresses a wider changing context which considers diversification, raising values and communication to maximize the business advantage associated with change. Neither mentions sustainability planning explicitly.

2.2 Sustainability Reporting

Increasing awareness of sustainability issues in larger ports (Green Ports 2016) generated excellent examples of best practice, guidelines and benchmarking initiatives. Aside from the U.S. (Port of Los Angeles 2011) Sydney Port's sustainability report identified various corporate objectives (Sydneyports 2011). Activity headings include resource management, environmental management and community management. Human resource management aims to increase employee satisfaction, to attract and retain staff and to ensure a diverse, healthy and safe workplace. Sustainable growth objectives relate to growth, trade and infrastructure. Finally, port operator and supply chain management objectives advocate sustainable practices in planning, developing and operating port operations and supply chains. Some larger ports now produce annual sustainability reports using Global Reporting Initiative (GRI 2011) international Sustainability Reporting Guidelines (the G4 Guidelines). Sustainability reporting is "the practice of measuring, disclosing, and being accountable to internal and external stakeholders for organizational performance towards the goal of sustainable development" (GRI 2011, version 3.1, p.3). Where ports have adopted sustainability as a core value a triple-bottom line conception of sustainable development often underpins reporting (e.g. Port of Gothenburg 2015).

2.3 Exemplary Sustainability Practice: Container Megaports

Sustainability practice in Northeast Asia's container megaports including Shanghai, Busan, and Hong Kong provides exemplars to raise managers' awareness in resource-starved smaller ports (Kim 2014). Annual sustainability reports, compliance with environmental regulations and operational capacity utilization monitoring are predictable measures. Less obvious actions include employee training and satisfaction monitoring to attract and retain the brightest and the best staff, careful management of movement-sensitive lighting systems, green energy sourcing, and monitoring of equipment routing decisions. Loan availability for equipment updating may depend on bank assessments of a port's eco-performance, and supply chain cooperation may bypass ports lacking certified green credentials. Table 1 summarizes items involved in sustainability planning of container port operations. Sustainable development in port operations spans 'business strategies and activities' to accommodate current and future needs of the port and its stakeholders, protecting and sustaining human and natural resource (Denktas and Karatas 2012).

2.4 EMS in Ports

EMS illustrate how port processes can be certified even though most ports focus on statutory compliance with environmental impact monitoring rather than holistic sustainability management. Beyond basic compliance, EMS aimed to mitigate the environmental impacts of maritime operations, but many emphasized large-scale impacts (Wooldridge et al. 1999). In ports EMS typically follow the principles of ISO14001 or associated certification. EcoPorts tools include a Self-Diagnosis

Table 1 Sustainability practice in container port operations

Environmental technology
Renewable and alternative sources of energy
Eco-friendly and socially responsible image
Sustainable building construction
Introduces new equipment and technology
Expansion of coastal region facilities
Internal process improvement
Joint planning and supply chain integration
Saves resource and energy costs
Uses the port area efficiently
Optimized vehicle routing
Simplified procedures
IT integration
Monitoring and improvement
Reliability and risk reduction
Training and education
Existing and new facilities upgrades
Service quality improvement
Service differentiation
Cooperation and communication
Satisfied stakeholders
Good working environment
Operations are transparent
Exchanges knowledge and information
Employees participate actively
Good use of incentives

Adapted from Kim (2014, Fig. 6.3)

Method (SDM), a tool to self-audit a checklist of environmental issues against European benchmarks, offering a "methodology for identifying environmental risk and establishing priorities for action and compliance" (EcoPorts 2016). Port Environmental Review System (PERS) consists of guidelines and example documents for implementing EMS. SDM and PERS aim to guide a port incrementally towards meeting ISO or European Eco-Management and Audit Scheme requirements and eventually to become certified although EcoPorts tools also offer independent methodologies. Within the UK 10 ports are EcoPorts members including five which are ISO14001 certified, and three with PERS certification (EcoPorts 2016).

The ISO14001 (2013) framework for environmental management aims to reduce the environmental footprint of corporate operations by establishing better controls over operations which generate environmental impacts, and certifying participating organisations. The framework aims to incorporate all the important activities and ensure that all parties involved are clear about their role and their associated tasks. A statement of corporate responsibilities becomes a strategic tool on which to base an EMS, incorporating a set of guidelines to promote continual improvement.

Companies adapt these principles to recognise and identify how their practices affect the environment, thereby encouraging integrated management and improved control over environmental impacts. A first step is to identify all the major environmental impacts that a company controls and those that it can influence. ISO14001 proposes a spiral of continual improvement, involving five stages of defining environmental policy, planning, implementation and operation, checking and management review. Tests of the environmental policy statement relate to whether it is appropriate, whether it commits to continual improvement and compliance, whether it provides a framework for setting objectives and targets, whether it is documented, implemented and maintained, and how well it is communicated internally and externally. Planning requires the establishment, implementation and maintenance of procedures relating to environmental aspects such as, identifying them and determining the scale of impacts; legal requirements such as accessing applicable legislation; establishing objectives, targets and programme(s). Implementation and operation involves defining resources, roles, responsibility and authority; competence, training and awareness; communication; documentation; control of documents; operational control; emergency preparedness and response. Checking involves regular monitoring and measurement, evaluation of compliance, nonconformity, corrective action and preventive action, control of records and internal audit. Finally, continual improvement involves management review at planned intervals to ensure ongoing suitability, appropriateness and effectiveness. ISO presents a Plan, Do, Check, Act cycle (PDCA). Planning establishes objectives and processes required to deliver results in accordance with policy; doing implements the processes; checking involves monitoring and measuring processes against policy, objectives, targets and legal requirements and reporting the results; acting involves actions to improve performance continually. Ports interlink with external organisations, and control of some controllable impacts may necessitate collaboration with partners.

2.5 PSMS and Smaller UK Ports

Excepting primarily environmental data (e.g. Portland Port 2016) the author was unaware of any PSMS freely available to smaller UK ports in 2014. Most harbor masters lack the expertise, resources, communication systems and time required to formulate, design, implement and monitor a bespoke PSMS. Accordingly, qualitative research within this environment aimed to identify key sustainability themes (Kuznetsov 2014). A checklist of eleven themes emerged. These themes were shared with harbor masters in a "green bullseye" in either spreadsheet or hard copy format. A five-point self-rating score on each sustainability theme ranged from low = 1 to high = 5, such that for example assets with cracks, significant wear and tear or significant erosion scored 1 (Table 2).

Table 2 Sustainability themes in the PSMS

Sustainability theme	Score	Description
Asset management and maintenance	1	A lot of our assets are in poor condition. Immediate attention is required.
	2	Some assets will be needing renewal or extensive maintenance within the next 5 years
	3	Our assets have good future life expectancy
	4	Our assets have good life expectancy and have a financed plan for repairs and maintenance
	5	An asset development plan is in place with funding identified
Safety management		
Environmental knowledge and awareness		
Environmental management		
Stakeholder engagement		
Business planning and management		
Effectiveness of management processes		
Customer service and satisfaction		
Proactive partnerships		
Change management		
Strategic planning for the future		

Adapted from Kuznetsov et al. (2015, Fig. 2)

3 How Might Sustainability Management Permeate the UK Ports Industry?

Interlinking of freight transport performance with sustainable port management and examples of PSMS are helpful but how can smaller UK ports embed sustainability management? This section reviews some drivers of sustainability awareness, some strategies to embed awareness internally and some external drivers. Pragmatics, professional bodies and research will influence implementation strategies.

3.1 Potential Drivers of Sustainability Awareness in Smaller UK Ports

Smaller UK ports are SMEs which employ few people and have limited turnovers; many are microbusinesses (Kuznetsov 2014). If findings from research into environmental awareness practice in SMEs are transferable to sustainability management awareness, major motivation factors include competitiveness, legitimation and individual concerns (Gadenne et al. 2009). Competitiveness relates to associating adoption with economic gains arising from positive marketing strategies and increased market share rather than representing a financial cost of compliance. Legitimation creates awareness amongst SME managers, who value clarity in knowing the exact requirements placed upon them. Finally, where managers exhibit individual concerns they may behave responsibly regardless of legal obligations or revenue concerns (Gadenne et al. 2009).

Sustainability management systems may become attractive to ports threatened with exclusion from green supply chains by supply chain leaders who insist on environmental certification for all partners (Gadenne et al. 2009). However, the environmental awareness of managers who outsource environmental management processes is reduced (Dinwoodie et al. 2012). Recent obligations to comply with Port Waste Reception Facilities Regulations have enhanced awareness and generated additional data through stakeholder collaboration (DfT 2013; Gadenne et al. 2009). Conversely, communal knowledge of who is not undertaking environmental initiatives may encourage environmental passivity, to save time and costs.

3.2 Internal Strategies to Embed Sustainability Management

This sub-section considers some strategies available internally to organisations seeking to embed sustainability management practices into formalised management systems including Total Quality Management (TQM) and Business Process Re-Engineering (BPR). TQM seeks "zero defects via continuous improvements" which demands both gradual implementation of improvement activities that embrace each employee, and "reduced variation in production processes" (Naslund 2008, 272). If TQM raises customer satisfaction systematically, competitive standards should rise. Gunasekaran et al. (1998) observed that TQM aimed to motivate employees to do a better job, which would in turn satisfy more customers. Successful implementations require changed attitudes and a new organisational culture. Outcome orientation, teamwork and respect, and innovation factors correlated positively with the extent of using TQM practices. The degree of data accuracy and quality, as well as reporting related to outcome orientation, teamwork and respect. Employees may contribute skills and knowledge and foster a joint effort to raise quality. A reinvigorated organisational focus and better teamwork could result in offering better quality products to customers. Customised systems are required to manage information locally, which demand institutional change, and realignment of organisational goals towards customer expectations of high quality output.

Business process re-engineering (BPR) seeks to refocus corporate business processes towards satisfying customer needs and involves identifying and rejecting some existing business processes and finding creative new ways to accomplish work. BPR has delivered significant reductions in cost, delivery times and inventory levels (Ligus 1993). Successful implementations are embedded into corporate strategy, and although relatively small scale they require top management support, employee involvement, and effective communication (Shen and Chou 2010). Even where reengineering of internal processes is feasible, reengineering of complex intercorporate processes may be problematic unless an organisation has significant brand value, market share and is potentially an industry leader capable of persuading other companies to mimic it in changing their business practices (Cameron and Braiden 2004). Reconfiguring of internal processes is more feasible relating to information flows, environmental monitoring, environmental checks and controls, and communicating with environmental stakeholders. By implication, if manufacturers or shippers as supply chain leaders promote sustainability management, diffusion to ports as supply chain partners is more likely.

Environmental management is an internal organisational process to ensure regulatory compliance. Sustainability management extends far beyond compliance, but is similarly internal. Within the context of smaller UK ports, Kuznetsov (2014) identified eleven pillars of sustainability. Persistent failure to manage any one pillar satisfactorily implies an unsustainable organization which performs sub-standard operations and which will eventually cease operations and close. Some pillars are regulated including safety management, environmental management and to some extent, asset management but the rest are not. Requirements to establish strategies, tactics and everyday operational procedures to achieve sustainability on other pillars are solely an organisational responsibility. These pillars include environmental knowledge and awareness, stakeholder engagement, business planning and management, the effectiveness of management processes, customer service and satisfaction, proactive partnerships, change management and strategic planning.

3.3 Supply Chain and Other Sectoral Pressures

In this sub-section, debate centers on external pressures to embed sustainability management processes into port management, arising from abduction involving partners and supply chains. Within supply chains, Beske-Janssen et al. (2015) observed that seminal investigations into sustainability management aimed to investigate how performance highlighted various financial and operational metrics. Later research spread in three directions. A focus on conventional supply chains deployed accounting metrics to identify the positive and negative social and environmental impacts of management practice in supply chains; some abduction into the ports literature is apparent. A second approach aimed to create more sustainable supply chains, whilst a third searched for mitigation strategies to manage the effects of measures to improve supply chains. To date, ports research has abducted neither.

Abduction of growing awareness of the need for sustainability management in supply chains has increased pressures on partner ports to comply (Cheon and Deakin 2010; Denktas and Karatas 2012; Gosling et al. 2016). Growing environmental and social concerns regarding potential environmental impacts thrust sustainability concepts into the port operations and development literature (Cheon and Deakin 2010). Sustainable port development strategies now embrace the safe handling of goods, environmental management, capacity development in ports, and regional training capacities (Asean-German Technical Cooperation 2012). However, overriding preoccupations with environmental management, environmental performance management and delays in linking port operational sustainability with competitiveness and performance, have inhibited the diffusion of port sustainability management in regions such as North East Asia (Kim 2014).

Ports link inextricably with production, distribution and supply chain systems and research into sustainability management in these academic disciplines is relatively mature. In supply chain management initial interest in sustainability management focused on defining key concepts (Seuring and Muller 2008). Later, attention shifted to issues of measuring and managing performance in sustainable supply chains (Schaltegger and Burritt 2014; Beske-Janssen et al. 2015) and how they should be governed (Gosling et al. 2016; Lenssen et al. 2014). Because ports intertwine with complex supply chains, a process of diffusion will eventually stimulate rudimentary awareness of sustainability management practice in ports. However, given the uniqueness and diversity of ports, diffusion of sustainability concepts from other disciplines requires significant local adaptations to develop and embed sustainable practices to preserve port revenue streams.

3.4 Pragmatism and Requirements to Safeguard Critical Revenue Streams

This sub-section questions whether pragmatic reasons will promote the adoption of a PSMS, including substantial benefits and peer pressure. Because smaller ports risk closure if they conduct maritime operations unsustainably, managers must safeguard critical revenue streams. This creates pragmatic interest in sustainability management especially in smaller ports where the economic impacts of a PSMS are substantial. In a regional UK case study, Kuznetsov et al. (2015) found that the benefits of implementing a self-assessed PSMS typically equated to two entry-level jobs. Aside from saving the costs of developing a bespoke sustainability management system, self-assessment removed the cost of paying annual membership fees and benchmarking assessments to third parties. Savings included management time and fees spent on attending specialist meetings, and improved stakeholder management reduced the costs of managing public relations. Fewer fees leaked out to specialist management consultants and because the number of complaints reduced, so did the costs of responding to them. Major benefits accrued from safeguarding maritime operations that were critical to the commercial survival of the port, and a review of material operations identified new streams of commercial revenues that also generated new employment. Numerous benefits to society accrued from implementing PSMS including enhanced engagement with local environmental interest groups, training of specialist port users that generated increased personal commitment to sustainable behaviour environmental and involvement by local schools enhanced the social capital. Environmental benefits included reduced risks of environmental dis-benefits arising from mishaps in environmentally sensitive and protected areas and a greater awareness and commitment by ports users of the potential environmental impacts of their actions.

Sustainability management systems may emanate from internal corporate sources, specialist agencies, government or professional and trade associations. Internal corporate management processes may create management systems, perhaps based on BPR or TQM strategies, or ad hoc spreadsheets. Research suggests that unless senior management is aware of and committed to sustainability, implementation is unlikely. Given the limited role of the state in most UK ports, government initiatives are unlikely to stimulate adoption except perhaps in naval bases or a few municipal ports. Particularly within smaller ports, systematic change will probably arise as processes devised by supply chain leaders, key customers or stakeholders to manage other statutory processes diffuse to ports. Within the European Union, specialist sectoral agencies such as the European Seaports Organisation and EcoPorts are committed to promoting change and disseminating best practice. Beyond this, informal practitioner networks of professional port managers, harbor masters and professional bodies, present important opportunities to promote best practice. EcoPorts initiated robust management processes to assist ports to manage the potential environmental impacts of port activities and members are offered assistance to identify port activities and their potential impacts, expert reviews and monitoring of proposed EMS, benchmarking services, and dissemination of best practices. With few statutory sustainability obligations in ports, few ports would join a “UK Port Sustainability Institute”. Ten of the UK’s 800 ports are EcoPorts members and smaller ports cannot afford the time and costs of participation, or perceive insufficient benefits from membership.

3.5 Towards an Implementation Strategy

This section notes that the prospects for successful implementation of a strategy for PSMS adoption to deliver more sustainable freight transport increase with support from professional groups, local adaptation and more research. Within the UK, extensive networking already engages port managers via the British Ports Authority (BPA) and the UK Harbour Masters Association (UKHMA), and various regional and supranational bodies. Regular local meetings, national conferences, specialist websites and visits to member ports facilitate the discussion and dissemination of best practice. Adoption of a PSMS requires a relevant, comprehensive, comprehensible and cost effective system. For cash-hungry smaller ports, PSMS must be low-cost, requiring minimal technical knowledge or management time to apply and must offer significant new insights. The assistance of BPA, UKHMA and professional bodies could be crucial.

Because each port is unique involving different commercial maritime operations, different planning priorities and different stakeholders the challenges facing each harbor master are unique, as are the knowledge available locally and the suitability of mechanisms for implementing a PSMS. This complexity creates problems of knowledge capture and knowledge transfer. Local port knowledge and industrial practice may take years to acquire, never be explicit and remain tacit within local practitioners. A major research challenge remains to capture local knowledge, to understand the mechanisms of acquisition and to use these mechanisms to facilitate ongoing transfer of effective sustainability management practice. Governance structures may influence such processes. Within private sector bodies, corporate standardisation policies already engage corporate experts and specialists who establish processes, procedures and best practice to disseminate throughout their organisation. Within the UK ports sector, Associated British Ports applies uniform procedures at all member ports. Similarly, within municipal ports, a countywide specialist coordinator may establish best practice within the coordinator's bailiwick, including the promotion of sustainability management practice, as in Devon or Cornwall (Kuznetsov 2014). Trust ports are managed by independent Harbour Commissioners amongst whom awareness and commitment is a prerequisite to PSMS adoption. The challenge is to maximise awareness of any systems that are available.

Ongoing research priorities include requirements to clarify local activities that constitute "maritime operations" and "sustainable maritime development", as predicates of PSMS development. Research is required to investigate the mechanisms, be they social or professional, whereby awareness of sustainability and sustainability management systems diffuses to ports, any barriers to PSMS adoption, and how to overcome them. Beyond individual local ports, widespread adoption will vary with governance regimes and stakeholder interests. Academic research to facilitate and promote PSMS adoption is required to increase the chances of smaller UK ports surviving for longer to contribute to a sustainable freight transport system.

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A Bi-objective Problem of Scheduling Fuel Supply Vessels

N. P. Rachaniotis, N. S. Koutsoukis, J. C. Mourmouris, and G. T. Tsoulfas

Abstract Fleets of fuel supply vessels are used to provide ships anchored in ports with different oil products. Demand is satisfied based on a pull system, where oil shipments are triggered by orders placed by customers and delivered on a specific agreed time window. The aim of this paper is to suggest proper scheduling policies for a fleet of fuel supply vessels, under the vessels' availability/capacity and the customers' demand constraints, so as to obtain the Pareto optimal solutions that minimize the cost and the total environmental burden expressed in CO_2 emissions. The methodology employed for solving the problem is the $\in$-constraint approach combined with a heuristic algorithm. The model is tested and evaluated for a small Hellenic oil company's data. The model can be easily instantiated according to the input data and adjusted to the fleet scheduler's needs, thus making the decision process faster and leading to lower costs and higher environmental savings.

Keywords Maritime OR · Transportation · Scheduling · Bi-objective modelling

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1 Introduction: Problem Definition

1.1 Introduction

Shipping is currently the principal carrier of world trade (about 90% by volume and 70% by value according to UNCTAD 2015) and the major activity of the shipping industry, i.e. the transportation of large volumes of cargo and passengers through sea routes, is expected to increase in the future due to the continuous world population growth, people's rising standard of living, globalization, product specialization, growing economics, etc. Shipping companies' structure and fleet size may differ, but they have one common major objective: to utilize their fleets optimally. A ship's operating costs are high, thus there is a significant potential for reducing them, combined with less damage to the environment due to the minimization of redundant travels in terms of the number and the size of ships in use. Thus, developing and solving a mathematical model to generate an efficient vessel operation schedule is of academic and practical interest. This belief is enhanced on one hand by the revenue figures in the bunkering industry globally, which exceed USD 100 billion annually (www.bunkerworld.com 2016). On the other hand, the natural environment is directly affected throughout the entire life cycle of a marine vessel, "from cradle to grave". The depletion of natural resources and the environmental pollution associated with maritime transport has attracted increasing attention globally. According to the estimates presented in the 3rd International Maritime Organization (IMO) Greenhouse Gas Emissions (GHG) Study, the CO_2 emissions attributed to international shipping in 2012 were about 796 million tons, 2.2% of the total emission volume.[1] In 2007 the CO_2 emissions from international shipping reached 885 million tons, about 2.8% of the total emission volume (IMO 2015). The nature of international shipping operations makes it difficult to take global decisions and enforce them at local or regional level. Therefore, international shipping was left out of the Kyoto Protocol because it is impossible to allocate emissions to individual countries (Oberthür and Ott 1999). This responsibility was outsourced to the IMO and some of its responses include: regulations to address air pollutants from international shipping, mandatory Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships (Shi 2016). In addition to regulated and mandated measures, the maritime transport industry has also engaged in the development and adoption of voluntary practices towards sustainability, such as the Clean Cargo Working Group, the World Ports Climate Initiative, the IAPH Air Quality and Greenhouse Gas Tool Box and the Sustainable Shipping Initiative (UNCTAD 2015). Thus, it is obvious that enhanced efficiency and reduced environmental impacts of vessels will contribute to all sustainability pillars (Mansouri et al. 2015).

[1]The International Maritime Organization is the UN's specialized agency responsible for the global regulation of issues such as safety, security, and environmental performance of international shipping.

The present paper aims to contribute in scheduling a fleet of fuel supply vessels that provide ships anchored in ports with different oil products so as to obtain the Pareto optimal solutions that minimize the cost and the total environmental burden expressed in CO_2 emissions.

1.2 Problem Definition

The operation of supplying ships in ports with fuel is performed by competing oil companies that usually own small heterogeneous fleets of fuel supply vessels (bunker barges) and serve the ships anchored in the port with various fuel types. Demand is described by a pull system, since oil shipments are triggered by customers' orders. In addition to long-term mandatory contracts, customers may request optional spot cargoes ahead of delivery by a phone call or a fax message (e-mails are not normally used due to the possibility of their late arrival). The company's fleet scheduler is responsible for deciding if the oil company will make an offer for those optional orders and if the quantities demanded will be served in part or in full, depending on whether the fleet is short on capacity at the time of the delivery. In the latter case, the customer might be given a new offer that is a fraction of the originally demanded one. An order is not accepted, even if it seems that the capacity is sufficient, in the case the fleet scheduler does not feel confident that he can serve it or if it does not contribute adequately to the company's profits. If the spot orders are accepted, they become mandatory contract orders. Fleet schedulers normally make plans every time a new spot cargo becomes available and they must generate schedules specifying which vessels will supply which customer, when and with what type and quantities of oil, dynamically updating their fleet availability and capacity (Fig. 1).

The supply vessels have fixed compartments of various sizes, carrying different oil products. The most common ones are four Fuel Oil (FO) types, namely two low sulfide and two high sulfide varieties (FOLS180/FOLS380 and FOHS180/FOHS380 respectively) and one Gas Oil (GO) type (GO is used in generators for producing electricity and heat, while FOs are used as propellant, therefore GO order sizes are usually much smaller). Customers may place orders for different types of FO and GO simultaneously and they may specify a time window of a single day for their supply.

Contract cargoes are served by one or more vessels, since a large shipment may be split between compartments and/or vessels. All vessels can carry all fuel types, but the various fuel types cannot be blended within a compartment and compartments cannot be used for carrying other fuel types, either in the short or in the long term (for example by cleaning them). Orders of the same fuel type may be allocated to the same compartment. The bunker barges load in refineries usually located in the broader port area, which are providing different types of fuels. When they do not operate, they moor in a specific berth.

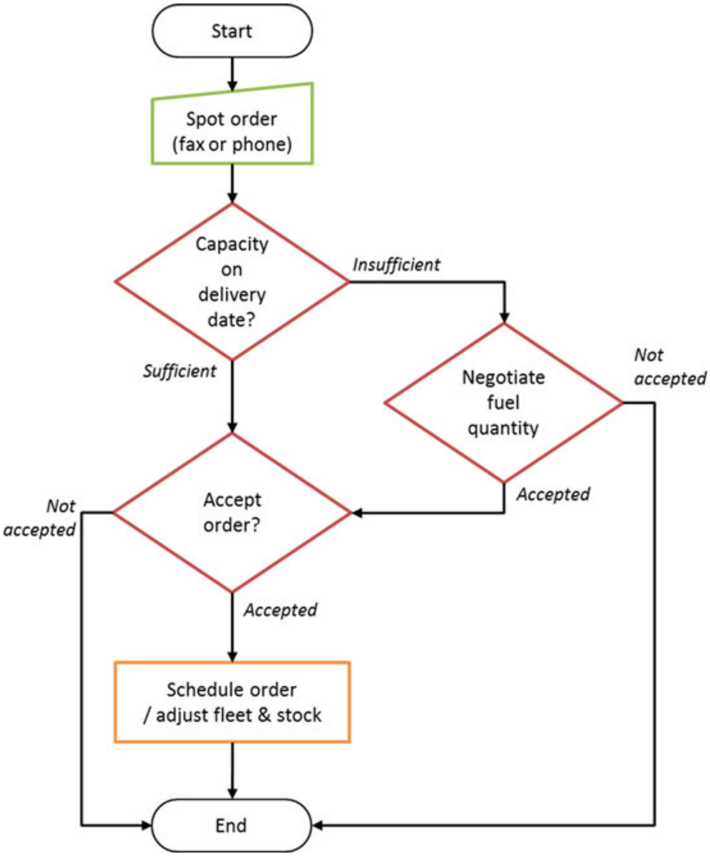

Fig. 1 The problem's illustrative flowchart

Fleet scheduling is performed according to a short-period (up to 1 month) rolling planning horizon principle. The plan can be updated when new important information becomes available (e.g. new orders or information about ship delays). This means that the schedule made at a time instance may change after starting to execute the plan and the fleet scheduler tries to solve the problem with only minor changes to the current plan (Fig. 2).

The objective is to suggest proper scheduling policies for a fleet of fuel supply vessels, under the vessels' availability/capacity and the customers' demand constraints, which obtains the Pareto optimal solutions that minimize the total fuel shipment cost and the total environmental burden expressed in CO_2 emissions.

Since travelling times are usually up to 1 h the problem previously described is a short-sea cargo routing and scheduling operation (Fagerholt and Lindstad 2007) addressed at a tactical/operational level (Al-Khayyal and Hwang 2007). The interested reader can refer for an overview of maritime transportation to

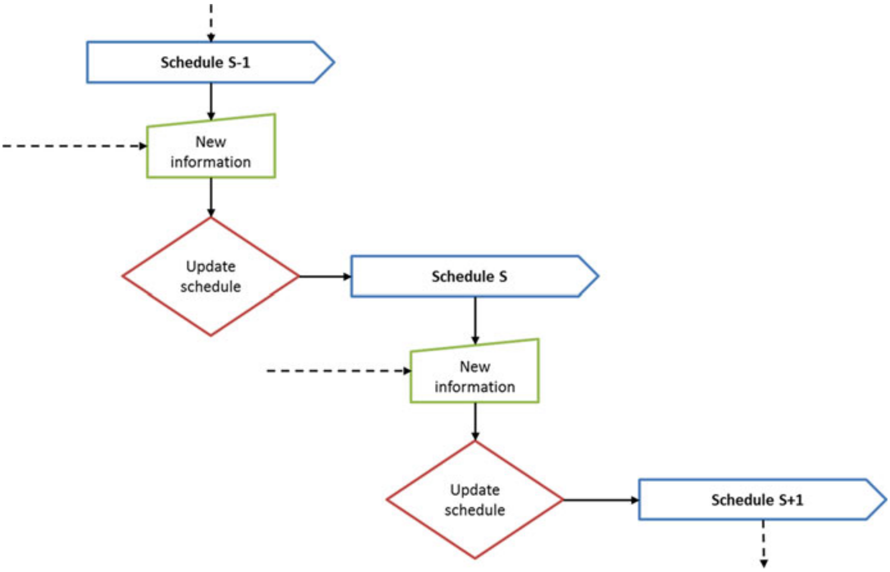

Fig. 2 Schedules' generation

Christiansen et al. (2007) and for surveys of ship routing and scheduling problems to Christiansen et al. (2004) and (2013).

The majority of the relevant studies consider the problem from the perspective of customer ships. The examined problem focuses on supply vessels and Table 1 illustrates its features compared to the relevant literature in terms of its description and classification (Tveit and Overdal 2013).

Only a few studies in maritime transportation combine routing with allocation decisions. For instance, Kobayashi and Kubo (2010) study routing a fleet of oil tankers, where each tanker has several fixed compartments and different cargoes cannot be in the same compartment. Al-Khayyal and Hwang (2007) expand the idea with the assumption that each compartment is dedicated to specific products. Agra et al. (2012a, b) consider both cases, first without allowing different fuel products into different cargo tanks and second the case of dedicated tanks for families of products. The ship routing and scheduling problem studied by Fagerholt and Christiansen (2000) is also a combined routing and allocating problem, where different dry bulk products cannot be stored together. However, in contrast to this paper, the tanks to be used are not known in advance as the cargo hold can be divided into a number of different configurations.

The single objective function problem for minimizing the total fuel shipment cost (or equivalently maximizing the profit from the vessels' operation) is studied in Tveit and Overdal (2013), Christiansen et al. (2015, 2016) and Rachaniotis and Masvoula (2015) where alternative modelling strategies have been used. In Tveit and Overdal (2013) and Christiansen et al. (2015) an arc-flow MIP model was

Table 1 Comparative literature overview

Problem	Maritime routing/scheduling	Short sea shipping	Vessels utilization	Time dependent parameters	Products	Loads	Allocation
Examined problem	**TP**	**YES**	**Multiple**	**YES**	**Multiple**	**Flexible**	**YES**
Agra et al. (2012a)	VRP	N/A	Single	NO	Single	Flexible	NO
Agra et al. (2012b)	MIRP	YES	Single	NO	Multiple	Flexible	NO
Al-Khayyal and Hwang (2007)	MIRP	YES	Multiple	NO	Multiple	Flexible	YES
Bronmo et al. (2007)	PDP	N/A	Single	NO	Single	Flexible	NO
Christiansen (1999)	PDP	NO	Single	NO	Single	Flexible	NO
Fagerholt and Christiansen (2000)	PDP	YES	Single	NO	Multiple	Fixed	YES
Halvorsen-Weare (2012)	YES	YES	Multiple	NO	Single	Fixed	NO
Hvattum et al. (2009)	TAP	N/A	N/A	NO	Multiple	Flexible	YES
Kobayashi and Kubo (2010)	PDP	NO	Single	NO	Single	Fixed	YES
Pang et al. (2011)	PDP	YES	Single	NO	Single	Fixed	NO

Source: Tveit and Overdal (2013), modified by the authors
Multiple vessels' utilization: vessels may do several routes during the planning horizon
Time dependent parameters: travel times, production and consumption rates, time-windows, etc
Flexible loads: The loads where cargo quantities are represented by variables and not constant parameters
Cargo allocation: Loads of different types are allocated in separate vessels' compartments
TP transportation Problem, *VRP* vehicle routing problem, *MIRP* maritime inventory routing problems, *PDP* pickup and delivery problems, *TAP* tank allocation problems, *N/A* no available information

used to describe and solve the problem. In Christiansen et al. (2016) a path-flow model was additionally developed and compared to the previous arc-flow model. Finally, in Rachaniotis and Masvoula (2015) a simplified version of the problem was examined to develop a time-effective Decision Support System (DSS) to aid the fleet schedulers in their decisions to accept optional spot orders in a few minutes. The bi-objective problem is introduced here for the first time.

The remainder of the paper is structured as follows: The problem's mathematical formulation is presented in Sect. 2 and its solution methodology in Sect. 3. The model is tested and evaluated with a small Hellenic oil company's data in Sect. 4 (due to confidentiality reasons the name of the company cannot be used). The paper is concluded in Sect. 5.

2 Problem's Mathematical Formulation

The model formulation is based on Rachaniotis and Masvoula (2015), using the following simplifying assumptions:

- There are three time windows of 8 h each per day and a vessel can supply only one ship in each time window. This simplification is effective since it is empirically proven that a vessel can supply a maximum of three customer ships per day, taking into consideration the fuel quantities requested and the barge compartment capacities and average fuel pumping rates. Customer ships are rarely supplied only with small volumes of GO, which is the only case when the supply of more than three ships per day from a vessel is possible. Moreover, the time window notion includes the vessels' refueling process, although this aspect is not explicitly examined in the present formulation.
- The times and distances the vessels travel are assumed to be negligible, except when an additional trip is necessary as described in the previous section.
- There is a fixed daily cost (salaries, insurance, mooring costs, etc.) and a variable sailing cost (fuel cost, etc.) for each supply vessel.
- An additional fuel load is considered to have negligible effects to a vessel's CO_2 emissions. This is a simplification but in general ships' environmental burden does not take into account differences in its cargo volumes but rather their size (Walsh and Bows 2012).

These constraints simplify the problem to a variation of the 3-index (or "solid") transportation problem (Haley 1962) (supply vessel, fuel type, customer ship). The latter is used in this paper, along with a calculation of the environmental burden caused by the utilization of the fleet's vessels. The formulation is for a single day, but it can easily be modified in order to address the problem for a rolling horizon.

2.1 Notation

Sets

V: supply vessels
U: customer ships
F: fuel types
T: time windows per day

Indices

v: supply vessel, $v = 1, \ldots, V$
u: customer ship, $u = 1, \ldots, U$
f: fuel type, $f = 1, \ldots, F$
c: compartment, $c = 1, \ldots, C_V$ (compartments of the *v-th* supply vessel)
t: time window, $t = 1, \ldots, T$

Parameters

A_{uft}: demand for fuel type *f* from customer ship *u* in time window *t*
B_{uvt}: total maximum quantity of all types of fuel that can be delivered from vessel *v* to customer ship *u* in time window *t*
E_{vft}: available quantity of fuel type *f* in vessel *v* at time window *t*
FC_v: fixed cost of using vessel *v* per utilization
c_{uvf}: cost of carrying a ton of fuel type *f* to customer ship *u* with vessel *v*
G_v: CO_2 emissions when using vessel *v*

Variables

x_{uvft}: quantity of fuel type *f* delivered to customer ship *u* from vessel *v* at time window *t*
y_{uvt}: 1, if vessel *v* serves customer ship *u* at time window t; 0, otherwise

Since the problem is bi-objective, it is necessary to obtain the Pareto optimal solutions of the following mixed-integer linear model:

$$\min \left\{ \sum_u \sum_v \sum_f \sum_t c_{uvf} x_{uvft} + \sum_u \sum_v \sum_t FC_v y_{uvt}, \ \sum_u \sum_v \sum_t G_v y_{uvt} \right\}$$

s.t.

$$\sum_{u} x_{uvft} \leq E_{vft} \quad \forall v, f, t \tag{1}$$

$$\sum_{f} x_{uvft} \leq B_{uvt} \quad \forall u, v, t \tag{2}$$

$$\sum_{v} x_{uvft} = A_{uft} \quad \forall u, f, t \tag{3}$$

$$x_{uvft} \leq B_{uvt} y_{uvt} \quad \forall u, v, f, t \tag{4}$$

$$\sum_{t} y_{uvt} \leq 1 \qquad \forall u, v \tag{5}$$

$$\sum_{u} y_{uvt} \leq 1 \qquad \forall v, t \tag{6}$$

$$x_{uvft} \geq 0, y_{uvt} \in \{0, 1\}$$

The objective is to simultaneously minimize the fleet's utilization cost and its CO_2 emissions. Constraint set (1) ensures that the total quantity of every fuel type delivered to all customer ships is less or equal than the vessel's capacity at that time window. Constraint set (2) presents the maximum total quantity for all types of fuel delivered from vessel v to customer ship u. Constraint set (3) states that the total quantity of a fuel type delivered from all vessels to a customer ship equals to its agreed order. Constraint set (4) ensures that a quantity of fuel is delivered from a vessel to a customer ship only if the vessel is decided to serve this customer ship. Constraint set (5) states that a customer ship is served only in one time window. Finally, constraint set (6) ensures that a vessel can supply only one customer ship during a time window.

3 Solution Methodology

The methodology employed for solving the problem is the ∈-constraint approach, i.e. the cost objective function is selected for optimization and the environmental burden is set as a constraint with an upper bound∈. Then the problem in the case examined is formulated as follows:

$$\min_{\underline{x}^* \in X} \sum_u \sum_v \sum_f \sum_t c_{uvf} x_{uvft} + \sum_u \sum_v \sum_t FC_v y_{uvt} \quad (7)$$

s.t.:

Additional constraint: $\sum_u \sum_v \sum_t G_v y_{uvt} \leq \in$ where:

$\underline{\mathbf{x}} = (x_{uvft}, y_{uvt})^{\mathrm{T}}$: is the vector of variables
$\underline{\mathbf{x}}^*$: is the Pareto optimal solution
X: is the feasible region defined by the constraints (1), (2), (3), (4), (5), and (6)

A decision is *strict Pareto optimal* if there does not exist another decision which yields objective function values less than or equal to it, with at least one strict inequality. A decision is *weakly Pareto optimal* if there is no other decision, which yields objective function values less than it.

Theorem (Miettinen 1999) All the solutions of the ∈-constraint problem are weakly Pareto optimal. The solution $\underline{\mathbf{x}}^*$ of the ∈-constraint problem is strict Pareto optimal if it solves the ∈-constraint problem for both objective functions or if it is a unique solution of the ∈-constraint problem for one objective function, where every time ∈ equals the value of the respective objective function for the solution.

Vessels' remaining compartmental capacity after delivering a quantity of any type of fuel cannot be calculated by subtracting it as in the simple transportation problem case due to the compartments' fuel loading constraints. Allocating different types of fuels to a vessels' fixed compartments, is similar to the one studied in Hvattum et al. (2009). It is *NP*-Complete and in some cases computationally intractable. To solve this problem, a smallest allocation heuristic is proposed, implementing a rule of thumb that the fleet schedulers apply in this case. The idea behind it is to use the smallest possible number of available supply vessels and occupy the smallest number of the smallest size available compartments. This involves the calculation of all possible combinations of vessels and tank allocations that can serve the order(s). Then the remaining fleet availability and capacity after the fuel allocation is calculated. The heuristic, whose pseudocode is illustrated in Fig. 3, provides the fleet scheduler a tool for calculating an approximation of the remaining fleet capacities for all types of fuels, thus generating a sub-optimal schedule. It is simple and can be easily modified to consider the needs for balancing fuel loads in the vessels' compartments to secure stability and safe navigation (Hvattum et al. 2009).

4 Empirical Evaluation

Piraeus, Athens' port, Hellas (Greece), is one of the largest passenger and freight ports in Europe serving about 17.5 million passengers and 3.4 million TEUs (Twenty-foot-Equivalent-Units) annually (Piraeus Port Authority 2016). A fuel

Let:
k_{vcf}: **1, if fuel type f is allocated to compartment c of vessel v;0, otherwise.**
F_{vc}: **fuel types allowed on compartment c of vessel v**
Q_{vc}: **load capacity of compartment c on vessel v.**

For t=1 to T do;
Calculate $S_r=\left\{\sum Q_{vc}\right\}$, **summing for all r combinations {v,c} of vessels' compartments out of** $\sum_{v}|C_V|$ **with the same F_{vc};**
Sort $s_r \in S_r$ in non-descending order;
For all orders A_{uf} do
  r=1;
  If $A_{uft} - s_r$d0, then k_{vcf}=1 for these combinations {v,c}; else
    k_{vcf}=0;
    r=r+1;
  If $A_{uft} - s_r>0$ $\forall r$ then
  (* The order cannot be served. The excess quantity is $A_{uft} - s_r$ of fuel type f *)
 $E_{vft}=\sum_{c} Q_{vc}$ **-A_{uft}, for these combinations {v,c}.**

Fig. 3 Smallest allocation heuristic algorithm

supply company that operates in Piraeus port owns a small fleet of two bunker barges named Type 1 and Type 2 respectively, with seven fixed compartments of various sizes carrying FO and GO. They are loading fuel in two refineries in the broader area of the port, where the first refinery offers the two types of low sulfide FO while the second type offers high sulfide FO; GO is offered in both refineries. Between 06.00–21.00 during the summer and 07.30–17.30 during the winter the travelling times between the berth, the customer ships and the refineries are less than 1 h, thus are considered negligible. Otherwise, an additional 3 h trip is necessary, since vessels have to travel around the Hellenic Naval base in Salamina Island.

The fixed vessel operational cost, according to the company's data and the fleet scheduler's estimations, was calculated to 2200 € per day for the smaller Type 1 vessel and 2500 € per day for the Type 2 vessel. The variable cost was calculated to 0.35€ for Type 1 vessel and 0.22 € for Type 2 vessel per fuel ton. Finally, the average CO_2 emissions were estimated to 175 kg CO_2 per customer ship served for Type 1 vessel and 250 kg CO_2 per customer ship served for Type 2 vessel (Walsh and Bows 2012 and fleet scheduler's calculations based on the vessels characteristics).

First, the single objective (total shipment cost) model was tested for a period of 2 months (August and September, 2013) with the data provided by the fleet scheduler of the company. The actual number of customer ships served, number of days the vessels delivered at least one order ("utilization days") and volumes of FO and GO delivered for the two supply vessels together with the ones generated by the single objective model are illustrated in Table 2.

Table 2 Company's business volume for August and September 2013 (Implemented) and the single objective model generated schedule (Model)

Vessels			August 2013		September 2013	
			Implemented	Model	Implemented	Model
Type 1	Customer ships		31	35	30	33
	Utilization days		24	28	21	24
	Fuel (tonnes)	FO	9959	12,972	9711	11,711
		GO	1100	1500	872	1088
Type 2	Customer ships		24	20	31	28
	Utilization days		21	17	18	15
	Fuel (tonnes)	FO	17,676	14,662	17,590	15,590
		GO	685	285	1129	913

Table 3 Results from applying the bi-objective ∈-constraint model

Vessels		August 2013		September 2013	
		v = 0.97	v = 0.96	v = 0.97	v = 0.96
Type 1	Customer ships	36	37	37	38
	Utilization days	29	30	28	29
Type 2	Customer ships	19	18	24	23
	Utilization days	15	15	15	14

The total shipment cost for the implemented schedule was calculated for both vessels, summing up to 212,232 € for the examined 2 months. The cost reduction according to the single objective model generated schedule is something less than 2000€ (an approximate 0.8%) for the same period. This is not a very impressive gain because the tested fleet size is very small, therefore an experienced fleet scheduler can make accurate decisions manually. Nevertheless, it is an improvement and the single objective model could be tested for larger fleet sizes to examine if it can yield more satisfying results.

The total emissions for the implemented and the proposed single objective model schedules were calculated for both vessels, summing up to 24,425 kg CO_2 and 23,900 kg CO_2 respectively for the examined 2 months, thus yielding an approximate 2.1% environmental saving.

The results from applying the bi-objective model are presented in Table 3, where the ∈-constraint approach was utilized for the problem's solution. Two threshold upper bounds were set for the CO_2 emissions, i.e. $\in = \nu \cdot \in'$, where ∈' stands for the total CO_2 emissions that the single objective model yielded and $\nu = 0.96$ or 0.97 (since aiming at a 3–4% environmental saving was considered a reasonable target and it generated feasible solutions for the mixed integer linear programming problems. The minimum upper bound for ∈ for the schedule to be feasible was calculated to be approximately 0.957∈').

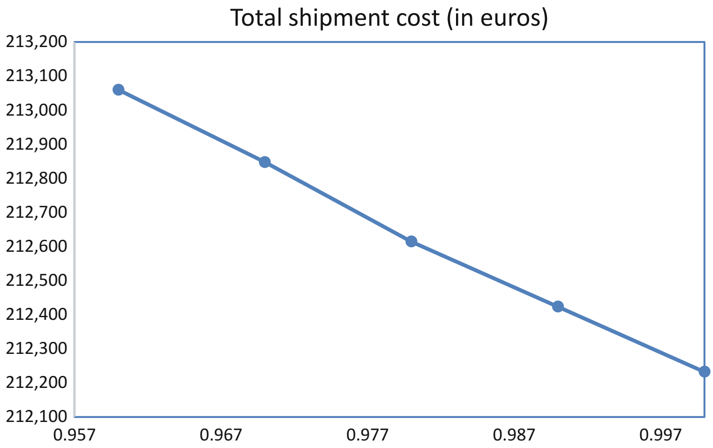

Fig. 4 Pareto chart of total shipment cost vs. total CO_2 emissions percentage reduction

The results obtained show the following:

- By decreasing the values of the total CO_2 emissions upper bounds, the number of customer ships served and utilization days increases for the smaller vessel Type 1 and decreases for the larger vessel Type 2.
- The schedules' total shipment cost does not increase significantly compared to the one that the single objective model yields as the environmental savings increase (there is a difference of 0.29% in the case of $v = 0.97$ and a 0.39% in the case of $v = 0.96$), still lower than the cost of the implemented schedule for the examined period (Fig. 4).

5 Conclusions

The aim of this paper is to construct scheduling policies for a fleet of fuel supply vessels, constrained by the vessels' availability/capacity and the customers' demand, to obtain the Pareto optimal solutions for minimizing their cost and the total environmental burden expressed in CO_2 emissions.

There is a number of operational constraints and challenges in the examined problem that make its mathematical modelling/formulation quite complex and are either partially addressed or not captured at all in the presented model: Refineries' pipelines and marine customs offices may be unavailable when needed since they are shared with other operators; supplying and demanding vessels have different oil pumping rates; time dependent sailing times between the mooring berth and the customer ships may occur (a new feature in maritime routing problems); a vessel may load more than one type of fuel at one or both refineries according to customers' orders, etc.

Fuel supply companies' fleet schedulers' workload is extremely demanding since their operations are on 24 h a day/365 days per year and penalties for all kinds of violations, delays, non-conformations, etc. are very strict. The developed model seems to be promising due to speeding up the planning process, providing the proposed schedules within a few seconds. Moreover, the model can be easily instantiated according to the input data and adjusted to the scheduler's needs each time, making the decision process faster and less stressful. Due to the high penalties for not serving a customer ship, fleet schedulers are always risk averse when accepting a spot order. The proposed model can increase their level of confidence, thus leading to lower costs and higher environmental savings in the port of Piraeus and globally.

Finally, future research efforts could be concentrated first on introducing larger instances (fleets) and back up the model with concrete calculations and second incorporating CO_2 emissions that depend on the vessels' fuel load.

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Value Creation Through Green Vehicle Routing

Emrah Demir

Abstract Logistics companies need to create and deliver value in an efficient way so that they generate profit in a highly competitive and demanding market. Green thinking can help companies to take required actions to minimize negative externalities of their transportation activities and enhance their brand value. Green vehicle routing, for example, is one of the opportunities where negative externalities are explicitly considered so that these externalities are reduced or eliminated through improved planning. This chapter provides an overview of some of the current developments in road transportation, including the description of negative externalities and some of their applications in vehicle routing and scheduling.

Keywords Green logistics · Freight transportation · Negative externalities

1 Introduction

A traditional focus on planning the road freight transport activities is to minimize costs and increase profitability by considering internal costs only (i.e., fuel costs, drivers' wages). Recently, the governments and non-governmental organizations have started to understand the importance of the environmental and social impacts related to transportation on the society as a whole. Such impacts are termed as externalities, where other parties are entities that did not choose to incur the impact (Demir et al. 2015).

The most well-known negative externalities of relevance to road transportation includes emissions (i.e., air pollution, greenhouse gases (GHGs)), noise, congestion, accidents and land use. Air pollutants are carbon monoxide, particulate matter,

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ozone, and hazardous air pollutants. The emissions of GHGs is probably the most studied externality of road transportation due to its global effects.

Road transportation has many levels, when viewed from the multiple stages of decision making. The Vehicle Routing Problem (VRP) is an operational level problem that has been studied at least since the work by Dantzig and Ramser (1959), and aims to find optimal delivery or collection routes for a set of vehicles from a central depot to a set of customers. The VRP often includes a number of constraints, such as those related to capacity, route distance, customer time windows, precedence relations between customers, etc. The minimization of the total traveled distance has been accepted as the most relevant objective in the field of vehicle routing. However, the interaction of operations research with mechanical and traffic engineering shows that there exist factors which are very important to explain fuel consumption in a more accurate way. This triggered the development of the green logistics studies in operations research (see, e.g., Dekker et al. 2012; Salimifard et al. 2012; Lin et al. 2013; Demir et al. 2014; Bektaş et al. 2016).

Green logistics is concerned with manufacturing and delivering freight in a sustainable way, while considering environmental and social factors. The objectives of green logistics are not only based on economical factors, but also target at considerably reducing other detrimental effects on people and on the environment. Green vehicle routing is a branch of green logistics which refers to vehicle routing problems where externalities of using vehicles, such as GHG emissions (carbon dioxide equivalent (CO_2e)), are explicitly taken into account so that they are reduced through better planning.

There are two key success factors to transforming a traditional transport planning into a green value for logistics service providers and freight forwarders. It is important to see the whole picture of negative externalities and the current requirements of the customers. There must be a strategic alignment between these two factors. The key in creating a green logistics value is to focus on the long-term strategies, combining the environmental and other monetary objectives of the organisation.

The current chapter discusses the principles of green vehicle routing required in designing models and algorithms which truly represent the characteristics of green logistics. The scientific contribution of this chapter is two-fold: (i) to present the negative externalities of freight transportation and an overview of the available vehicle emission models, (ii) to review the relevant green vehicle routing studies. The remainder of the chapter is organized as follows. Sections 2 and 3 review negative externalities and emissions modeling, respectively. In Sect. 4, we investigate routing formulations with regard to fuel consumption. Conclusions are stated in Sect. 5.

2 Negative Externalities of Road Transportation

Road transportation is the most dominant mode of freight transportation. European road haulage is accounted for 76% of the total inland freight movements in 2011 (Sanchez Vicente 2013).

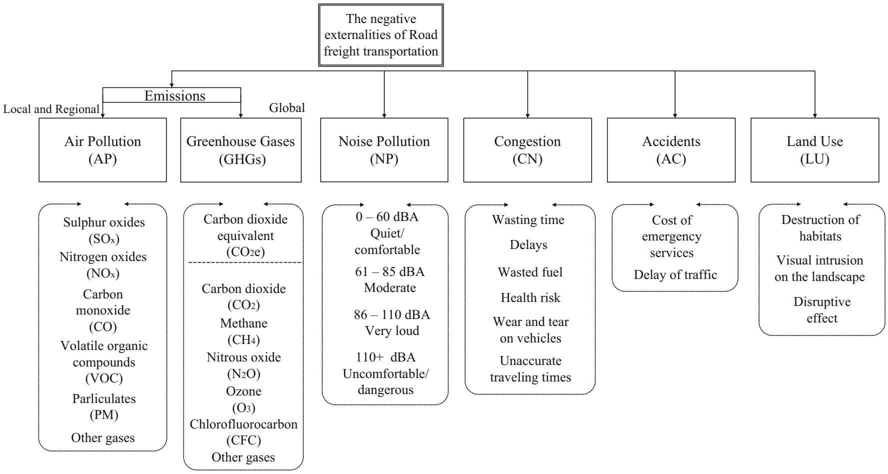

Fig. 1 The negative externalities of freight transportation (Adapted from Demir et al. 2015)

The ongoing research in externalities of freight transportation has continuously increased in the last decade. The reasons behind the increase are its impacts on economy, environment, climate, and society. Several negative externalities of relevance to road freight transportation are described in the literature (see, e.g., McAuley 2010; Ranaiefar and Regan 2011; Brons and Christidis 2012); this part of the chapter categorizes the externalities in six branches as illustrated in Fig. 1. Interested readers for the negative externalities of freight transportation are refereed to Demir et al. (2015).

Figure 1 illustrates an overview of the negative externalities of freight transportation. Each group of externalities is briefly discussed in the rest of the sections: whilst GHGs and land use mostly incur external costs to the environment and climate, others such as air pollution, noise, congestion, accidents impose harms to human life and generate unnecessary costs to economy. The negative externalities of the transportation are briefly described below.

- Emissions can be categorized based on three levels; local, regional and global. The first level affects human health, and leads to material damage to buildings and vegetation. These emissions, also called as conservative pollutants, are harmful in terms of their direct damage to environment and health as well as some of those being precursors to other detrimental pollutants (McAuley 2010). These includes carbon monoxide (CO), VOCs and NO_x. Besides the direct harms of CO, VOCs and NO_x as conservative pollutants, they are precursors to ozone (O_3) formation (Placet et al. 2000) and indirect contributors to global warming. Sulphur oxides (SO_x) cause breathing problems and acid rain. Regional impacts derive from acidification and ground level ozone. Greenhouse gases (GHGs) emissions are well-known at a global level. They are classically excluded from air pollutants and discussed in the next paragraph.

- GHGs are the most studied externality of freight transportation. GHGs are not classified as a pollutant in the classical sense. However, the United States Environmental Protection Agency (EPA) recognized that GHGs pose a danger to human health and welfare in 2009. The primary transportation-related man-made GHGs in the atmosphere are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and etc. As CO_2 is the dominant man-made GHG, the impacts of other gases can also be calculated based on carbon dioxide equivalent (CO_2e) (Wright et al. 2011).
- Noise pollution is a nuisance for people that have to deal with it frequently. When the noises are severe or the duration of the noises are long enough, several health problems might occur, such as stress, sleep disturbance, and cardiovascular disease (Van Essen et al. 2011). Measuring the noise pollution is not straightforward. Noise can be measured in A-weighted decibels (dBA, dB(A) or dB(a)) in terms of their volumes. Besides the volume of the noise, other factors (e.g., pitch, frequency, duration and variability) should also be considered.
- Congestion is a situation where transport users compete individually for a limited capacity. Congestion causes increased travel times, operating costs, and unreliability in travel activities (Banfi et al. 2000). The direct impact of congestion, as a road freight transportation externality, refers to increased travel times to other entities in the transportation system. Congestion could also indirectly result in increased fuel costs, air pollution, noise pollution and stress levels.
- Road accidents include the costs of emergency services attending the accidents, delay of traffic, and the costs to the victim's family in pain and suffering (McAuley 2010).
- Road transportation planning decisions influence land use directly by affecting the amount of land used for transport facilities, and indirectly by affecting the locations and designs of infrastructure development (Litman 2004).

3 Models and Calculators for Estimating Emissions

This section reviews emission models. We look at three different groups of emissions modeling. These are macroscopic, microscopic and online tools. More discussion on micro- and macro-level calculators can be found in the literature (see e.g., Demir et al. 2011, 2014).

3.1 Macroscopic Models

We present four well-known macroscopic emission models. These models are used to calculate a national or regional emission inventory. With this type of modeling, emission rates are measured for a variety of trips, each with a different average speed.

- The European Commission delivered a methodology by Hickman et al. (1999) for calculating transportation emissions and energy consumption (MEET) of heavy good vehicles. MEET is based on on-road measurements and its parameters are extracted from real-life experiments. It covers several vehicle technologies for different types or classes of road vehicles. Emission factors and functions of MEET refer to standard testing conditions and are typically calculated as a function of the average vehicle speed. Depending on the vehicle type, a number of corrections may be needed to allow for the effects of road gradient and vehicle load on the emissions, once a rough estimate is done.
- A network for transport and environment (NTM) is a non-profit Swedish organization that was established in 1993 (NTM Road 2010). The aim of the organization is to establish a common based value on how to estimate the environmental impact of various transportation modes. The method is mainly developed for logistics service providers, making it possible for them to evaluate their own individual carbon footprint. The model takes into account road distance, payload, transport mode, positioning, empty return trips, and type of road.
- A computer programme to calculate emissions from road transportation (COPERT) is an EEA funded emissions model (Kouridis et al. 2010). The model calculates emissions for a range of vehicles by engine classification and vehicle type. COPERT uses a number of regression functions to calculate fuel consumption, which are specific to vehicles of different weights.
- The ECOTRANSIT was developed in 2003 with a regional scope limited to Europ (Knörr et al. 2011), including the environmental impact of freight transport for any route and any transport mode. It covers energy consumption, GHG emissions and air pollutants.

3.2 *Microscopic Models*

This section reviews an microscopic emission models for the estimation of hot-stabilized vehicle emissions. These models are based on instantaneous vehicle kinematic variables, such as speed and acceleration, or on more aggregated modal variables, such as time spent in each traffic mode, cruise and acceleration (Demir et al. 2014).

In order to increase the readability of all models we use similar notations for specific definitions. The standardized notations are: v is the speed of the vehicle (m/s), M is the total weight of the vehicle (kg), a is the instantaneous acceleration (m/s^2), ω is the gradient (%), and g is the gravitational constant (m/s^2). Moreover, ρ is the air density (in kg/m^3), A is the frontal surface area (in m^2). In addition, C_d is the coefficient of aerodynamic drag, and C_r is the coefficient of rolling resistance.

- The passenger car and heavy duty emission model (PHEM) is designed for simulating fuel consumption. Due to the co-operation between ARTEMIS

(Boulter and McCrae 2009) and HBEFA (Hausberger et al. 2009) the measurement program covered different engines and vehicles. The PHEM is interpolating the fuel consumption from the engine maps according to the course of engine power demand and engine speed in the driving cycles. The actual engine power (P) can be calculated as $P = P_{rr} + P_{ar} + P_{acc} + P_{gr} + P_{au} + P_{tl}$, where P_{rr} is the rolling resistance and can be calculated as $P_{rr} = Mg(fr_0 + fr_1 v + fr_2 v^2 + fr_3 v^3 + fr_4 v^4)v$, P_{ar} is the air resistance and can be calculated as $P_{ar} = 0.5 C_d A \rho v^3$, and P_{acc} is the acceleration and can be calculated as $P_{acc} = (M + m_{rot})av$. Moreover, P_{gr} is the gradient resistance and can be calculated as $P_{gr} = Mg\omega 0.01v$, P_{au} is the power demand for auxiliaries $P_{au} = P_0 P_{rated}$ and P_{tl} is the transmission losses $P_{tl} = P_{dr}/\eta_t - -P_{dr}$ where fr_0-fr_4 are the rolling resistance coefficients, m_{rot} is the reduced mass for rational accelerated part, P_0 is the power demand of the auxiliaries as ratio to the rated power P_{rated}, and P_{dr} is the power to overcome the driving resistances. The total emission value can be calculated under transient conditions:

$$E_{trans} = E_{qs} + P_{rated} + F_{trans}. \tag{1}$$

where E_{qs} is the quasi-steady-state emission value interpolated from steady-state emission map (in g/h), P_{rated} is the rated engine power (kW) (since emission values are normalized to the rated power), F_{trans} is the dynamic correction function ((g/h)/kW rated power). More information can be found in Boulter and McCrae (2009).

- A comprehensive modal emission model (CMEM) for heavy-good vehicles was developed and presented by Scora and Barth (2006), Barth et al. (2005) and Barth and Boriboonsomsin (2008). The CMEM requires detailed vehicle specific parameters for the estimations such as the engine friction coefficient, and the vehicle engine speed. The CMEM is composed of three modules, namely engine power, engine speed and fuel rate. The engine power module: The power demand function for a vehicle is obtained from the total tractive power requirements P_{tract} (kW) placed on the vehicle at the wheels:

$$P_{tract} = (Ma + Mg\sin\omega(\theta) + 0.5C_d\rho A v^2 + MgC_r\cos\omega(\theta))v/1000. \tag{2}$$

To translate the tractive requirement into engine power requirement, the following relationship is used:

$$P = P_{tract}/\eta_{tf} + P_{acc},$$

where P is the second-by-second engine power output (kW), η_{tf} is the vehicle drive train efficiency. The engine speed module: Engine speed is approximated in terms of vehicle speed as

$$N = S(R(L)/R(L_g))v,$$

where N is the engine speed (in rpm), S is the engine-speed/vehicle-speed ratio in top gear L_g, $R(L)$ is the gear ratio in gear $L = 1,\ldots,L_g$, and η is the efficiency parameter for diesel engines. The fuel rate module:

The fuel rate (g/s) is given by the expression

$$FR = \phi(kNV + P/\eta)/43.2, \tag{3}$$

where ϕ is fuel-to-air mass ratio, k is the engine friction factor, and V is the engine displacement (in liters). The CMEM model can be seen as one of the mostly used microscopic emission model because of its easy applicability.

3.3 Online Tools and Calculators

The acute need for low-carbon economy and reduced environmental effects are the reasons for the creation of different online emission calculators. The tools can be categorized as simple, more sophisticated and advanced tools. Factors that influence this distinction were the quality of input data that each calculator needed, and the quantity and quality of results that generate. The fuel consumption is influenced by several factors like the type of fuel, the vehicle age, the quality of the road pavement etc. Thus, a calculator that requires diverse and detailed input of data can generate more specific and qualitative results. We now review the well-known online tools and calculators which can be used for logistics companies to estimate their carbon footprint as discussed in Auvinen et al. (2013) and Demir et al. (2014).

- **Freight emissions calculator** by the program "Delivered GrEAN" of EA Logistics is a simple and comprehensive way to estimate CO_2 emissions (Logistics 2016). Based on the shipment weight and the distance of shipping, it is straightforward to estimate CO_2 emissions in metric tons. It is possible to estimate the emissions of a shipment and decide to implement the program in order not only to achieve CO_2 reduction but also a competitive advantage over competitors.
- **Carbon footprint calculator** is a calculator developed by Carbonica (Footprint 2016), which is an organization with mission to combat global warming and work towards a low-carbon economy. For road freight transportation, it is needed to input data with regard to the fuel type and the units of fuel used to estimate tons of CO_2 and the cost.
- **LOG-NET carbon calculator** is a tool developed by Log-Net (LOG-NET 2016) for calculating CO_2 emissions for intermodal freight movements. The calculator produces a graph where anyone can identify the overall carbon footprint of the freight movement. It gets location data and other additional details, such as transport modes and specific transport parameters as input.
- **CO_2 emissions calculator** created by P&O Ferrymasters (Ferrymasters 2016) estimates the total kilogram of CO_2 emissions when the mode of transport, the

distance (km), the size of the load (kg) and the number of the trips are chosen. The calculation of emissions are based on governmental researches Defra/DECC's Greenhouse gas conversion factors (NAEI 2012).

- **OOCL carbon calculator** is one of the most-used calculators in the market (OOCL 2016). The users of this calculator could track orders and details about shipments and modes of transport and estimate their emissions. With the calculator, it is possible to input the origin and destination, and the volume in tonne or twenty-foot unit. The carbon emission details will then be calculated based on this input.
- **Urban transportation emission calculator (UTEC)** is a calculator launched by the government of Canada for the project "Transport Canada" (OpenEI 2016). UTEC allows users to create scenarios. Each scenario has its own input and results screens, and a comparison of the scenarios is also possible. The tool estimates GHGs and criteria air contaminant (CAC) emissions from the operation of vehicles. It also estimates upstream GHG emissions from the production, refining and transportation of transportation fuels, as well as from production of electricity used by electric vehicles.

We note that the European committee for standardization introduced a new standard EN 16258 "Methodology for calculation and declaration of energy consumption and GHG emissions of transport services" at the beginning of 2013 to quantify the environmental footprint of logistic activities. This standard provides a common methodology for the calculation, declaration and reporting on energy use and GHG emissions of transport services. The standardization will help increase the accuracy and ensure consistency between different methodologies in calculating negative externalities and particularly CO_2e emissions.

4 Green Vehicle Routing Problems

This part of the chapter provides the green vehicle routing problems introduced in the literature. These include the Pollution-Routing Problem (PRP) by Bektaş and Laporte (2011), the homogeneous and heterogeneous emissions VRP by Figliozzi (2010), the energy-minimizing VRP by Kara et al. (2007) and the VRP with fuel consumption rate by Xiao et al. (2012).

4.1 The Pollution-Routing Problem

The PRP is an extension of the VRPTW, where the aim is to route a number of vehicles to serve a set of customers *and* to determine their speed on each route segment, so as to minimize a function comprising fuel, emission and driver costs. In the PRP, it is assumed that in a vehicle trip all parameters remain constant on a given arc, but load and speed may change from one arc to another. The model approximates the total amount of energy consumed on an arc, which directly translates into fuel consumption and further into GHG emissions.

The PRP is defined on a complete directed graph $\mathscr{G} = (\mathscr{N}, \mathscr{A})$ where $\mathscr{N} = \{0, \ldots, n\}$ is the set of nodes, 0 is a depot and $\mathscr{A} = \{(i,j) : i,j \in \mathscr{N} \text{ and } i \neq j\}$ is the set of arcs. The distance from i to j is denoted by d_{ij}. A fixed-size fleet of vehicles denoted by the set $\mathscr{K} = \{1, \ldots, m\}$ is available, and each vehicle has capacity Q. The set $\mathscr{N}_0 = \mathscr{N} \backslash \{0\}$ is a customer set, and each customer $i \in \mathscr{N}_0$ has a non-negative demand q_i as well as a time interval $[a_i, b_i]$ for service. Early arrivals are permitted but the vehicle has to wait until time a_i before service can start. The service time of customer i is denoted by t_i.

An integer programming formulation for the PRP presented first by Bektaş and Laporte (2011), which was subsequently extended by Demir et al. (2012) to allow for low travel speeds. The formulation works with a discretized speed function defined by R non-decreasing speed levels $\overline{v}^r$ $(r = 1, \ldots, R)$. Binary variables x_{ij} are equal to 1 if and only if arc (i,j) appears in solution. Continuous variables f_{ij} represent the total amount of flow on each arc $(i,j) \in \mathscr{A}$. Continuous variables y_j represent the time at which service starts at node $j \in \mathscr{N}_0$. Moreover, s_j represents the total time spent on a route that has a node $j \in \mathscr{N}_0$ as last visited before returning to the depot. Finally, binary variables z_{ij}^r indicate whether or not arc $(i,j) \in \mathscr{A}$ is traversed at a speed level r. An integer linear programming formulation of the PRP is shown below:

$$\text{Minimize} \quad \sum_{(i,j)\in\mathscr{A}} f_c k N V \lambda d_{ij} \sum_{r=1}^{R} z_{ij}^r / \bar{v}^r \tag{4}$$

$$+ \sum_{(i,j)\in\mathscr{A}} f_c w \gamma \lambda \alpha_{ij} d_{ij} x_{ij} \tag{5}$$

$$+ \sum_{(i,j)\in\mathscr{A}} f_c \gamma \lambda \alpha_{ij} d_{ij} f_{ij} \tag{6}$$

$$+ \sum_{(i,j)\in\mathscr{A}} f_c \beta \gamma \lambda d_{ij} \sum_{r=1}^{R} z_{ij}^r (\bar{v}^r)^2 \tag{7}$$

$$+ \sum_{j\in\mathscr{N}_0} f_d s_j \tag{8}$$

subject to

$$\sum_{j\in\mathscr{N}} x_{0j} = m \tag{9}$$

$$\sum_{j\in\mathscr{N}} x_{ij} = 1 \qquad \forall i \in \mathscr{N}_0 \tag{10}$$

$$\sum_{i \in \mathcal{N}} x_{ij} = 1 \qquad \forall j \in \mathcal{N}_0 \tag{11}$$

$$\sum_{j \in \mathcal{N}} f_{ji} - \sum_{j \in \mathcal{N}} f_{ij} = q_i \qquad \forall i \in \mathcal{N}_0 \tag{12}$$

$$q_j x_{ij} \leq f_{ij} \leq (Q - q_i) x_{ij} \qquad \forall (i,j) \in \mathcal{A} \tag{13}$$

$$y_i - y_j + t_i + \sum_{r \in \mathcal{R}} d_{ij} z_{ij}^r / \bar{v}^r \leq K_{ij}(1 - x_{ij}) \qquad \forall i \in \mathcal{N}, j \in \mathcal{N}_0, i \neq j \tag{14}$$

$$a_i \leq y_i \leq b_i \qquad \forall i \in \mathcal{N}_0 \tag{15}$$

$$y_j + t_j - s_j + \sum_{r \in \mathcal{R}} d_{j0} z_{j0}^r / \bar{v}^r \leq L(1 - x_{j0}) \qquad \forall j \in \mathcal{N}_0 \tag{16}$$

$$\sum_{r=1}^{R} z_{ij}^r = x_{ij} \qquad \forall (i,j) \in \mathcal{A} \tag{17}$$

$$x_{ij} \in \{0, 1\} \qquad \forall (i,j) \in \mathcal{A} \tag{18}$$

$$f_{ij} \geq 0 \qquad \forall (i,j) \in \mathcal{A} \tag{19}$$

$$y_i \geq 0 \qquad \forall i \in \mathcal{N}_0 \tag{20}$$

$$z_{ij}^r \in \{0, 1\} \qquad \forall (i,j) \in \mathcal{A}, r = 1, \ldots, R. \tag{21}$$

The objective function (4), (5), (6), and (7) is derived from (3). The term (8) measures the total driver wages. Constraints (9) state that each vehicle must leave the depot. Constraints (10) and (11) are the degree constraints which ensure that each customer is visited exactly once. Constraints (12) and (13) define the arc flows. Constraints (14), (15), and (16), where $K_{ij} = \max\{0, b_i + t_i + d_{ij}/v^l - a_j\}$, and L is a large number, enforce the time window restrictions. Constraints (17) ensure that only one speed level is selected for each arc. Constraints (18), (19), (20), and (21) define the domain of decision variables. Table 1 presents the typical values of the parameters used in the PRP.

The formulation presented above only allows to solve small-scale instances to optimality (Bektaş and Laporte 2011). To solve larger PRP instances, Demir et al. (2012) present an algorithm which iterates between the solving a vehicle routing problem with time windows (VRPTW) and a speed optimization problem. Computational results were presented on benchmark instances generated by randomly sampling cities from the United Kingdom which use real geographical distances. Demir et al. (2012) show that, through the approach presented, CO_2e emissions can be reduced by 10% on average.

Table 1 Required parameters for the PRP

Notation	Description	Typical values
w	Curb-weight (kg)	6,350
ξ	Fuel-to-air mass ratio	1
k	Engine friction factor (kJ/rev/liter)	0.2
N	Engine speed (rev/s)	33
V	Engine displacement (liters)	5
g	Gravitational constant (m/s^2)	9.81
C_d	Coefficient of aerodynamic drag	0.7
ρ	Air density (kg/m^3)	1.2041
A	Frontal surface area (m^2)	3.912
C_r	Coefficient of rolling resistance	0.01
n_{tf}	Vehicle drive train efficiency	0.4
η	Efficiency parameter for diesel engines	0.9
f_c	Fuel and CO_2e emissions cost per liter (€)	1.4
f_d	Driver wage per (€/s)	0.0022
κ	Heating value of a typical diesel fuel (kJ/g)	43.2
ψ	Conversion factor (g/s to L/s)	737
v^l	Lower speed limit (m/s)	5.5 (or 20 km/h)
v^u	Upper speed limit (m/s)	25 (or 90 km/h)

4.2 *The Homogeneous and Heterogeneous Emissions VRP*

Figliozzi (2010) introduced the emissions vehicle routing problem (EVRP) which concerns minimization of emissions and fuel consumption using of MEET model. According to this model, The volume of emissions generated by traveling from node i to node j and departing at time b_i is calculated as $(v_{ij}(bi))$

$$v_{ij}(b_i) = \sum_{l=0}^{l=p}(\alpha_0 + \alpha_1 s_{ij}^l + \alpha_2 (s_{ij}^l)^3 + \alpha_3/(s_{ij}^l)^2) d_{ij}^l, \tag{22}$$

where α_0–α_3 are the emission coefficients, s_{ij}^l represents the traveling speed between node i and j at time interval l and d_{ij}^l is the distance between node i and j at time interval l.

The EVRP is an extension of the time-dependent VRP (TDVRP). The objective of the EVRP is the minimization of emission cost, which is proportional to the amount of GHG emitted, which in turn is a function of travel speed and distance traveled. Figliozzi (2010) described a formulation and a solution algorithm for the EVRP. In the proposed algorithm, a partial EVRP is first solved to minimize the number of vehicles by means of a TDVRP algorithm, following which and emissions are optimized subject to a fleet size constraint. The departure times are also optimized using the proposed algorithm for any pair of customers. The results presented on the Solomon (1987) instances suggested that uncongested travel speeds tend to reduce emissions on average; however, this is not always the case, and the opposite trend is sometimes observed. The author suggests that a 20% reduction is possible by optimizing departure times.

4.3 The Energy-Minimizing VRP

The energy-minimizing vehicle routing problem was introduced and formulated by Kara et al. (2007). The objective of the EMVRP is to minimize a weighted load function as a way of estimating fuel consumption. This function is based on a physics rule stating that on a flat surface work equals force times distance. The work done by a vehicle over an arc (i, j) is calculated as (W_{ij})

$$W_{ij} = q_{ij} d_{ij}, \tag{23}$$

where q_{ij} is the weight of the load between node i and j and d_{ij} is the distance traveled between node i and j.

The integer linear programming model proposed for the EMVRP is based on that of the capacitated VRP. Since the model minimizes the total work done on the road, the authors argue that this leads to minimizing the total energy requirements, at least in terms of total fuel consumption. They study the differences between distance-minimizing and energy-minimizing solutions on benchmark capacitated VRP instances and observe that energy usage increases as total distance decreases. The authors conclude that there is considerable difference between solutions that minimize energy and distance, and that the cost of the resulting routes minimizing total distance may be up to 13% less than those minimizing energy.

4.4 The VRP with Fuel Consumption Rate

Xiao et al. (2012) incorporated fuel consumption into the capacitated VRP by using a regression model based on statistical data proposed by the Ministry of Land, Infrastructure, Transport and Tourism of Japan. According to this model, the fuel consumption between node i and j for a given load q is calculated $(p_{ij}(q))$ as

$$p_{ij}(q) = \alpha Q_0 + b + ((\alpha(Q_0 + Q) + b) - (\alpha Q_0 + b))q/Q, \tag{24}$$

where Q_0 is the curb weight of the vehicle, Q is the maximal weight it can carry, q is the carried load between node i and j and b is a constant. Xiao et al. (2012) introduce a mathematical model for this problem and describe a solution algorithm based on simulated annealing. Their computational experiments show that the algorithm is both effective and efficient for solving the problem.

5 Conclusions

This chapter reviewed green vehicle routing studies that aim to reduce or eliminate negative externalities of road freight transportation. This help companies to create green value for their businesses and customers.

The review has shown that a good understanding of the ways in which the externalities can be modeled, which allows for a more accurate representation in the transport planning process. We presented a number of emission models that are extracted from the literature, and shown a number of studies where they are embedded within the classical models and algorithms available for the vehicle routing and scheduling.

The actual fuel consumption depends on several factors, as discussed in Demir et al. (2011, 2014). It is very difficult to quantify some parameters, which is one reason why none of the models proposed in the literature provides a complete solution for the estimation of fuel consumption. Moreover, our study has shown that a majority of the existing studies focus only on the routing aspect of green logistics. Other problems which can be linked to routing may offer former reductions in emissions. Summarizing current studies in the domain of green vehicle routing, the following two areas are identified as further research directions.

- Since the technological developments are taking place rapidly, the corresponding business models are evolving with various opportunities for shippers, logistics companies and customers. Several new technological developments have appeared or scheduled to appear in the domain of transportation. Examples of technology include drone, autonomous ground vehicles, 3D Printing, vehicles with alternative fuels, trunk delivery and bike couriers. It is important to investigate these technological developments along with new business models in a structured manner.
- It might be convenient to consider other transportation alternatives than only road transportation. One of the alternatives is the intermodal transportation in which goods are transported in standardized loading units that are transshipped between different modes of transportation (Demir et al. 2016; Hrušovský et al. 2017). Although organizing and monitoring of intermodal transportation chains requires more coordination effort and the reliability of the system might be lower in comparison to single mode transportation, there exist technological opportunities to reduce the complexity of transportation plans with green logistics approach.

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Environmental Benefits of Collaboration and Allocation of Emissions in Road Freight Transportation

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Abstract Despite the growing interest in green logistics over the last years, the cost savings perspective in collaborative transportation prevails. As environmental concerns increase, it is worthwhile to address collaboration from a green perspective. This chapter highlights the effectiveness of collaborative transportation to achieve environmental goals in road freight transportation. First, it overviews several cases that quantify the environmental benefits of collaborative transportation. The benefits range from 11% to 54% reduction of CO_2 emissions, and also include potential improvements in biomass logistics for increasing the use of bioenergy. Second, it studies the problem of how to allocate emissions to different objects involved in joint transport activities. These objects can be, for example, companies in a coalition or customers on a route. By a numerical example on a vehicle routing problem and an overview of other applications, it is illustrated how methods used to allocate cost can also be used to allocate emissions. The chapter also includes a brief overview of the methods to calculate emissions and the optimization criteria used in the literature on collaborative transportation and emission allocation. Overall, this chapter contributes with a first compilation of the emergent stream of literature that incorporates environmental concerns in collaborative road freight transportation.

Keywords Collaborative transportation · Emissions · Allocation · Game theory

1 Introduction

In collaborative transportation, two or more entities join efforts to coordinate their transport activities and improve their performance relative to acting alone. The collaboration can be *horizontal*, when the entities operate on the same level of the

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supply chain, or *vertical*, when the entities operate on different levels. The benefits in cost savings of collaborative transportation have been identified early in the literature (Fishburn and Pollak 1983; Samet et al. 1984). The current state-of-the-art includes collaborative approaches for a variety of transportation problems such as traveling salesman, vehicle routing and inventory routing. Although the interest in the area has increased over the last years and the green logistics literature has grown notably, the cost savings perspective prevails in collaborative transportation. A recent survey on cost allocation methods in collaborative transportation by Guajardo and Rönnqvist (2016) gathered 55 articles. Among these, 41 do not even mention the potential benefits of collaboration to the environment. The other 14 articles, all of them published between 2010 and 2015, refer to environmental concerns merely as a motivation. The majority of them omits the actual incorporation of environmental aspects into the optimization problems and the assessment of methods and solutions. The only two exceptions are Frisk et al. (2010) and Özener et al. (2013). The former briefly reports on the reduction of CO_2 emissions and the latter considers CO_2 emissions explicitly as a cost in a collaborative vehicle routing problem and assesses methods not only in terms of allocating cost but also in terms of allocating emissions.

As environmental concerns increase, it is worthwhile to address collaborative transportation and allocation problems beyond the traditional cost perspective. This chapter is dedicated to these problems, particularly focused on environmental perspectives in road freight transportation. The contribution of the chapter is twofold. First, it surveys the applications of collaborative transportation that have assessed environmental impacts. In such collaborative settings or when a route involves different customers, the question arises of how to allocate the total emissions to all involved parties. As second contribution, the chapter addresses this question by applying a cooperative game theory framework which is illustrated in an asymmetric vehicle routing problem with multiple depots.

The remainder of this chapter is organized in four sections. Section 2 aims at showing the effectiveness of collaborative transportation in achieving environmental benefits, by a comprehensive overview of cases with quantified effects. Section 3 illustrates how methods traditionally used to allocate costs can also be used to allocate emissions, and surveys the related applications. Section 4 provides an overview on methods to calculate emissions and the optimization criteria used in the literature of collaborative transportation and emission allocation. The chapter closes in Sect. 5 with some concluding remarks and directions for further research.

2 Environmental Benefits of Collaborative Transportation

The latest report on transport figures by the European Union reveals that road transportation is responsible for 72% of the total CO_2 emissions of the transportation sector (EU 2015). The "20-20-20" plan sets targets of 20% cut in greenhouse gas emissions (from 1990 levels), 20% of energy generation from renewable sources and 20% improvement in energy efficiency by 2020. The more recent "40-27-27" sets even higher targets for 2030. It is, therefore, relevant to develop road freight transportation solutions that contribute to achieving the targets. The present decade has seen the emergence of new applications of collaborative transportation that report environmental benefits. This section provides an overview of these applications. Most of them, gathered in the first part of this section, assess the environmental benefits of collaborative transportation by quantifying the emission reduction of greenhouse gases, in particular of CO_2. An alternative case is presented in the second part of this section, where the environmental benefits relate to making forest fuels an economically viable source of renewable energy.

2.1 Reducing Emissions

The earliest reference quantifying the environmental impact of collaborative transportation appears to be Frisk et al. (2010). This work is motivated by a case involving eight forestry companies in southern Sweden. The collaboration takes place by wood bartering or by combining supply and demand points of different companies in a same route with backhauls. These mechanisms help to reduce the distances travelled by the trucks. The environmental effect is estimated to about 20% reduction of emissions.

Xu et al. (2012) perform a case study with data provided by *Club Déméter*, the association of major logistics players in France. The case involves the supply chains of two French retailers, served by four suppliers across a network of four warehouses and 32 distribution centers. A mixed integer linear problem is used to assess the potential of pooling these supply chains. The results show that a reduction of about 13.6 tonnes of CO_2 emissions can be achieved over a 33-week horizon. These come along with 26% savings of the total cost, which includes a tax for CO_2 emissions. A larger version of this case, involving two retailers and 106 suppliers, is reported by Pan et al. (2013). Here, the CO_2 emission reduction in road freight transportation ranges from 11% to 18% depending on the type of products carried (50–53% when not only the road but also the rail transport mode is included).

Verstrepen and Jacobs (2012) report a collaborative approach for co-loading goods of two manufacturer companies with operations in Czech Republic, namely *JSP* and *HF-Czechforge*. JSP produces lightweight and voluminous plastic beads bags, used in the automotive, packaging and consumer goods industries. HF-Czechforge produces heavy metal components for the automotive and aviation industry. Both companies perform shipments regularly from Czech Republic to Germany. Because of the characteristics of their respective products, neither JSP nor HF-Czechforge are able to utilize full transport capacity when shipping only their own freight. In contrast, by synchronizing and consolidating their overlapping freight flows, the companies can share trucks that are loaded to maximum capacity in terms of both volume and weight. The preliminary estimations for this alliance were about 11% reduction of CO_2 emissions. After pilot shipments were implemented in practice, the emission reduction increased up to 34%.

Another successful example of complementarity for co-loading between light and heavy products is the alliance between *Tupperware* and *Procter & Gamble*, outlined in Muylaert and Stofferis (2014). By performing joint transports from Belgium to Greece, the two companies achieve an increase from 55% to 85% in vehicle capacity utilization, together with a reduction of 150,000 km travelled and 200 tonnes of CO_2 emissions yearly.

Jacobs et al. (2014) report the horizontal collaboration case between *Pepsico* and *Nestlé*. These companies produce fresh and chilled products and distribute them to a number of retailers in Belgium. The authors studied collaboration in two scenarios. In the first one, referred to as *unsynchronized collaboration*, only the use of trucks is shared between the companies while their orders and delivery schedules stay according to their independent plans. In the second one, referred to as *synchronized collaboration*, the companies coordinate the orders and delivery schedules in addition to sharing trucks. In the preliminaries of the project, simulations based on real data estimated CO_2 reduction of 38% by unsynchronized collaboration and 54% by synchronized collaboration. Although these estimations included other two companies that finally did not participate in the implementation of the alliance, the report points out that the collaboration between Pepsico and Nestlé has realized double digit percentage reductions in practice.

Danloup et al. (2015) study a case of collaborative distribution in the food sector. They use data from a food distributor of UK, which involves deliveries from a distribution center to 27 retailers' warehouses of three different companies. The collaboration is assessed by a mixed integer linear model, which combines flow variables with routing variables. The main findings are reductions of CO_2 emissions ranging from 26% to 30% on average per month, depending on the type of vehicles used.

Zhu et al. (2016) study a case of repositioning transportation for a logistics service provider called *Grieg Logistics*. The case involves transport services for *Elkjøp* and *REKOM AS*. Elkjøp is a retail company that procures services to ship electronics from a warehouse in Sweden to eight different sales points in Norway. REKOM AS is a waste company that procures services to ship residual waste and woodchips from Norway to Sweden. While Elkjøp's shipments are regarded as primary cargo, offering very competitive prices to REKOM AS allows Grieg Logistics to reposition its fleet with freight instead of empty returns from Norway to Sweden. The results show that repositioning reduces CO_2 emissions by about 41%.

All previous cases have estimated the environmental impact of collaboration using real-world data. A summary is presented in Table 1. Besides these, the effectiveness of collaboration in reducing emissions is also supported by recent computational experiments in vehicle routing problems. In the experiments by Pérez-Bernabeu et al. (2015), the impact of collaborative transportation ranges from 5% to 92% reduction of gas emissions. In the experiments by Sanchez et al. (2016), the impact is quantified as 60% reduction of greenhouse gas emissions. Danloup et al. (2015) also perform computational experiments, finding an average reduction of CO_2 emissions by 20%.

Table 1 Real-world cases reporting quantified impact of the effectiveness of collaboration in emissions reduction

Reference	Case	CO_2 reduction
Frisk et al. (2010)	8 forestry companies (Sweden)	20%
Verstrepen and Jacobs (2012)	2 manufacturers (Czech Republic, Germany)	11–34%
Xu et al. (2012)	2 retailers, 4 suppliers (France)	0.41 tonnes/week
Pan et al. (2013)	2 retailers, 116 suppliers (France)	11–18%
Muylaert and Stofferis (2014)	2 manufacturers (Belgium, Greece)	200 tonnes/year
Jacobs et al. (2014)	2 companies of fresh and chilled products (Belgium)	38–54%
Danloup et al. (2015)	1 food distributor, 27 retailers (UK)	26–29%
Zhu et al. (2016)	1 logistics provider serving 2 companies (Sweden, Norway)	41%

2.2 Improving Transport of Biomass

While the previous cases show the effectiveness in reducing emissions, collaborative transportation may also contribute to other environmental impacts when applied in relevant industries. This is illustrated by a case of collaborative transportation in the Swedish forest biomass industry, as recently reported by Flisberg et al. (2015). The forest biomass or, in particular, the so called *forest fuels* are an important source of renewable energy. These account for about 14% of the biofuels or about 4% of Sweden's total energy. The forest biomass is processed in several plants for cogeneration of district heating and electricity across the country. These plants provide heating and electricity in 270 out of 290 municipalities in Sweden, covering more than 50% of the households. The forest fuels are, however, a low-value commodity and replaceable by other energy sources. Therefore, making it profitable is very sensitive to logistics cost. As usually long distances separate forest areas from the heating plants and the operation of several forestry companies overlap with each other, a collaborative transportation approach in this case has great potential to help forest fuels be an economically viable source of bioenergy. Flisberg et al. (2015) studied 200,000 transports performed by 61 companies in a year, involving about 6.1 million tons of forest biomass, equivalent to 17.4 TWh of energy consumption. An optimization toolkit, including a decision support system, is deployed to assess the potential of collaborative transportation in this case. When comparing the optimal collaborative solution with the realized non-collaborative solution, the potential cost savings are about 12%. This is equivalent to a reduction from 61.55 to 48.66 km in the average distance travelled and from 36.36 to 32.15 Swedish kronor (SEK) in the cost per MWh. Converting these savings into energy, it means that collaborative transportation can contribute to about 2.3 TWh of renewable energy consumption yearly. Moreover, when collaboration is combined with more flexibility in the scheduling of the operations and the mix of assortments, the potential cost savings are about 22%, the average distance is reduced to 39 km, and the cost per MWh to SEK 28.30.

3 Emission Allocation

A fair allocation of the benefits of collaboration among partners is crucial for the stability of a coalition. In such a collaborative setting, the allocation of emissions is emerging as an important problem recently. Even in a non-collaborative setting, when a single carrier distributes to different customers on a same route, it may become important to compute a fair allocation of the total emissions among the customers. Leonardi et al. (2010) discuss a variety of reasons for this, such as adhering to government and industry best practices, having a basis for setting targets, or providing valuable information to the customers. Retailers in particular are increasingly looking to identify their emissions, as consumers show greater interest in the climate impact of the products they buy. In the same way, Zhu et al. (2016) observe that several shipping companies have started to add value to their services by providing a carbon calculator to help their customers determine the carbon footprints from transporting their products.

The emission allocation problem can be addressed by several methods. These go from simple proportional rules to more sophisticated methods borrowed from cooperative game theory. While these are well established in the transportation literature on cost allocation, their application to emission allocation is more incipient. The remainder of this section outlines some important concepts and methods, illustrates them in a numerical example on a vehicle routing problem, and overviews their application in recent literature.

3.1 Cooperative Game Theory Concepts

The following paragraphs introduce some standard concepts in cooperative game theory (Myerson 1991). Let $N = \{1, \ldots, n\}$ be the set of companies (or *players*), usually referred to as the *grand coalition*. Let K be the set of all subsets of N. The characteristic function $v : K \to \mathbb{R}$ assigns to each coalition S in K the *cost* of coalition S. Here, cost may refer to either a monetary cost function or an emission function incurred by coalition S. By convention, $v(\emptyset) = 0$. The pair (N, v) defines a transferable utility game.

A preimputation or cost allocation vector $u = (u_1, \ldots, u_n)$ assigns to each player j in N a quantity $u_j \in \mathbb{R}$ such that the following condition holds:

$$\sum_{j \in N} u_j = v(N) \tag{1}$$

Equation (1), so called *efficiency* condition, states that the cost of the grand coalition N is split among its members according to the allocation u.

An allocation vector u satisfies *rationality* if the following constraints hold:

$$\sum_{j \in S} u_j \leq v(S) \ \forall S \in K. \tag{2}$$

Constraints (2) state that there is no subset S of players such that should they form a coalition separately from the rest they would perceive less total cost than the total cost allocated to them by u. If S contains only one player, this corresponds to the so called *individual rationality condition*, which requires that the cost allocated to each player j must not be greater than its stand alone cost $v(\{j\})$.

The core of the game is the set of preimputations that satisfy rationality, that is,

$$Core(v) = \{u \in \mathbb{R}^n : \sum_{j \in N} u_j = v(N), \ \sum_{j \in S} u_j \leq v(S) \ \forall S \in K\}. \tag{3}$$

An allocation in the core provides *stability*, in the sense that there is no subset S whose players would get a better outcome by deviating from the grand coalition N.

3.2 Allocation Methods

There is a vast list of allocation methods. Guajardo and Rönnqvist (2016) find that more than 40 methods have been used to allocate costs in the collaborative transportation literature. In the following, three methods are described. One is the proportional method, which is relatively easy to compute. The other two are the Shapley value and the nucleolus, both among the most frequently used in the cooperative game theory literature.

Proportional methods. Proportional methods are those where each player j is assigned a share α_j of the total cost $v(N)$, that is

$$u_j = \alpha_j \cdot v(N) \quad \forall j \in N, \tag{4}$$

where $\sum_{j \in N} \alpha_j = 1$. The share values α_j can be defined according to different criteria. A common approach is to use $\alpha_j = v(\{j\}) / \sum_{i \in N} v(\{i\})$, so that the allocation is proportional to the stand alone cost (or emission) of the players. Another common approach is to define shares proportional to the demand quantities of the players. Because of the simplicity of these formulae and the small input they require, proportional methods are easy to use and communicate to practitioners. However, evidence in the literature reveals that these methods often violate rationality (Özener and Ergun 2008; Frisk et al. 2010; Özener et al. 2013; Flisberg et al. 2015).

Shapley value. The Shapley value (Shapley 1953) allocates to each player j a weighted average of the marginal cost implied by the player, as follows:

$$u_j = \sum_{S \subseteq N : j \in S} \left[\frac{(n - |S|)!(|S| - 1)!}{n!} \right] \cdot [v(S) - v(S \setminus \{j\})] \quad \forall j \in N \tag{5}$$

Although this allocation does not necessarily satisfy rationality, it satisfies efficiency and has several other appealing properties derived from axiomatic characterizations (e.g., see a survey by Tijs and Driessen 1986).

Nucleolus. Introduced by Schmeidler (1969), the nucleolus is based on the notion of *excess*, which can be interpreted as a measure of satisfaction of the coalitions with respect to an allocation. The excess of coalition S at allocation u in the cost game (N, v) can be defined as $\varepsilon(x, v, S) = v(S) - \sum_{j \in S} u_j$. The larger the excess of S, the more satisfied coalition S is, in the sense that it achieves larger savings. The excess vector at x is defined as $e(x, v) = (\varepsilon(x, v, S_1), \ldots, \varepsilon(x, v, S_p))$, where the sets S_i represent the coalitions in $K \setminus \{N\}$ and $p = 2^n - 2$. The nucleolus of the cost sharing game (N, v) is defined as the set of imputations that lexicographically maximizes the excess vector. Appealing features of the nucleolus are that it is unique and that it always belong to the core whenever the core is non-empty. In contrast to the proportional methods and the Shapley values, the computation of the nucleolus is a bit more complex than applying a closed formula. Due to this reason, its use is commonly mistaken (Guajardo and Jörnsten 2015). Several algorithms have been proposed to compute the nucleolus, usually based on a sequence of linear programs, as in Kopelowitz (1967) and Fromen (1997).

3.3 Example

The following example, recreated in the forest industry of southern Sweden, illustrates how the allocation methods apply in both cost and emission problems. The example studies collaboration possibilities in an asymmetric vehicle routing problem with multiple depots.

Suppose there are three forestry companies ($N = \{A,B,C\}$) transporting wood over the region shown in Fig. 1. Each company has one supply point and three demand points. The supply point of Company A is located in Skoghall (SA) and its demand points in Norrköping (A1), Jönköping (A2) and Karlsborg (A3). The supply point of Company B is located in Karlshamn (SB) and its demand points in Bodafors (B1), Ringarum (B2) and Tranemo (B3). The supply point of Company C is located in Varberg (SC) and its demand points in Laholm (C1), Vetlanda (C2) and Trollhättan (C3).

Suppose that each demand point has a daily demand of 10 tonne of pulp wood, and each supply point has 30 tonne available per day. Each company has one truck available. The capacity of a truck is 30 tonne. Each truck can do only tour per day. The tour of a company's truck starts and ends at the supply point of the corresponding company. Each tour must visit three demand points, in order to satisfy all demand quantities.

Let $d_{i,j}$ be the distance from point i to point j. A matrix with distances (km) is given in Table 2. For $i < j$, the value in position (i,j) of the matrix is the distance retrieved from *Google Maps*. For $i > j$, such values have been modified randomly, 3% on average, so that the resulting matrix is asymmetric.

Define I_S and J_S as the set of supply points and demand points of companies in coalition S, respectively. Let H_S be the set of all points of companies in coalition S ($H_S = I_S \cup J_S$), and K_S the set of trucks of companies in coalition S.

3.3.1 Min Cost Problem

In a first approach, a traditional min cost perspective is adopted, assuming the cost per km is a constant value c. Define binary variables $x_{i,j,k}$ equal to 1 if truck k travels from i to j, and zero otherwise ($i, j \in H_S : i \neq j$). The following integer linear model finds the optimal routes for a generic coalition S.

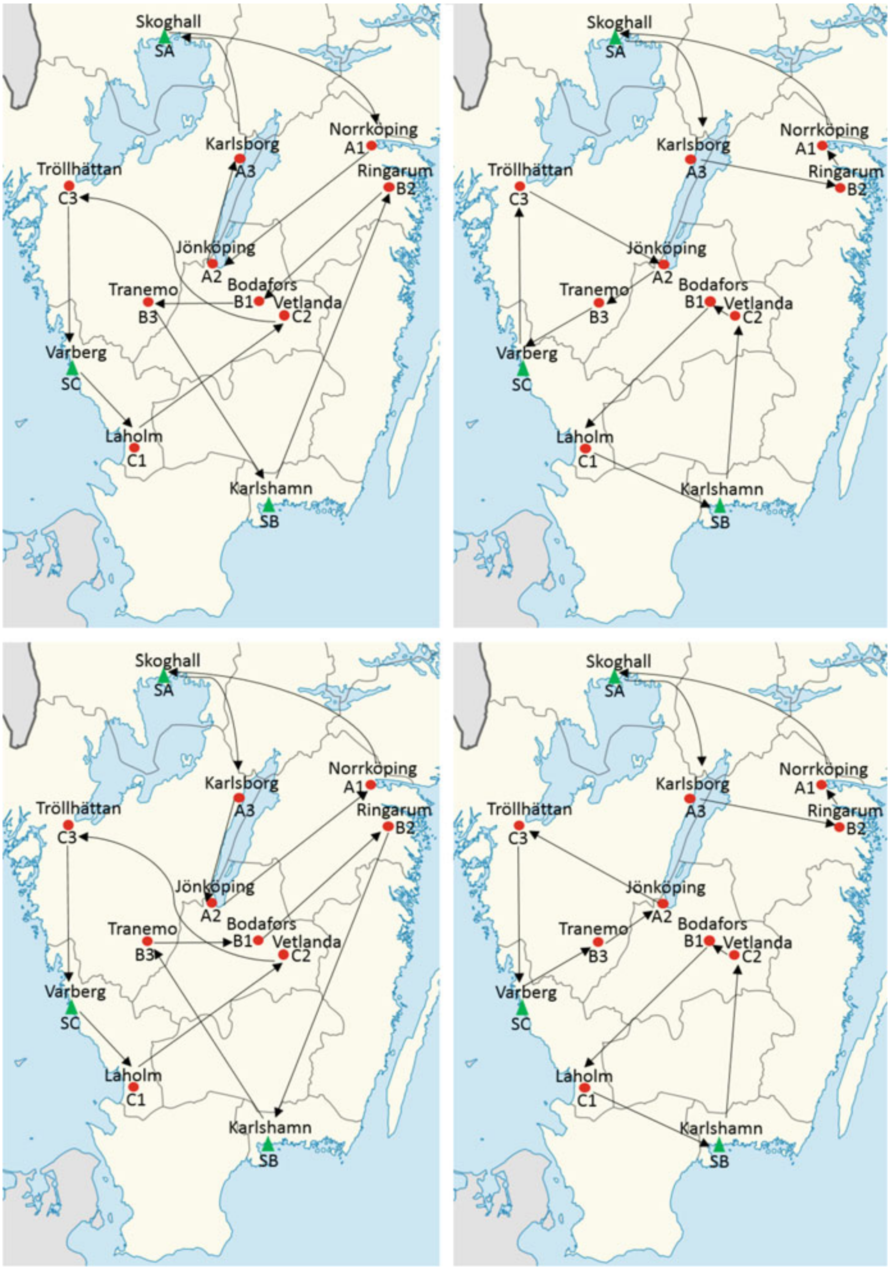

Fig. 1 Min cost non-collaborative (upper left) and collaborative (upper right) solutions, and min emission non-collaborative (bottom left) and collaborative (bottom right) solutions

Table 2 Distance (in km) matrix used in the numerical example

	SA	SB	SC	A1	A2	A3	B1	B2	B3	C1	C2	C3
SA	0	–	–	229	250	159	309	269	294	412	314	175
SB	–	0	–	375	211	311	182	316	206	158	163	370
SC	–	–	0	336	170	273	192	360	101	96	203	148
A1	226	388	344	0	167	168	183	34	236	362	185	321
A2	262	217	172	162	0	99	54	191	69	198	77	149
A3	160	308	246	171	109	0	157	191	160	297	179	150
B1	314	185	197	183	57	161	0	188	111	193	32	209
B2	275	332	370	34	203	191	189	0	261	387	171	345
B3	295	210	99	252	77	163	111	269	0	140	143	176
C1	422	141	98	370	204	289	195	396	143	0	202	235
C2	320	174	209	181	85	183	39	168	148	214	0	230
C3	182	379	150	330	156	161	220	345	189	242	229	0

$$\min C(S) = \sum_{i \in H_S} \sum_{\substack{j \in H_S \\ j \neq i}} \sum_{k \in K_S} c \cdot d_{i,j} \cdot x_{i,j,k} \tag{6}$$

s.t.

$$\sum_{i \in I_S} \sum_{\substack{j \in J_S \\ j \neq i}} x_{i,j,k} = 1 \quad \forall k \in K_S \tag{7}$$

$$\sum_{i \in H_S} \sum_{\substack{j \in J_S \\ j \neq i}} x_{i,j,k} = 3 \quad \forall k \in K_S \tag{8}$$

$$\sum_{\substack{i \in H_S \\ i \neq j}} \sum_{k \in K_S} x_{i,j,k} = 1 \quad \forall j \in H_S \tag{9}$$

$$\sum_{\substack{i \in H_S \\ i \neq j}} x_{i,j,k} = \sum_{\substack{i \in H_S \\ i \neq j}} x_{j,i,k} \quad \forall j \in H_S, k \in K_S \tag{10}$$

$$x_{i,j,k} + x_{j,i,k} \leq 1 \quad \forall k \in K_S, i \in H_S, j \in H_S : i \neq j \tag{11}$$

$$x_{i,j,k} \in \{0, 1\} \quad \forall k \in K_S, i \in H_S, j \in H_S : i \neq j \tag{12}$$

Objective function (6) minimizes total cost. Constraints (7) and (8) impose that every truck starts from one supply point and visits three demand points, respectively.

Constraints (9) impose that every point is visited once by exactly one truck. Constraints (10) state that if a vehicle visits a point, it exits from this to another point. Constraints (11) avoid subtours for every pair of points. Constraints (12) express the binary nature of the variables. Solving model (6), (7), (8), (9), (10), (11) and (12) for each coalition S provides the values $C(S)$ to define the characteristic function of the cost game (N, C). This game is *sub-additive*, that is, $C(S \cup T) \leq C(S) + C(T)\ \forall S, T \subset N : S \cap T = \emptyset$. This is because the optimal solution to two separated instances involving two disjoint coalitions S and T defines a feasible solution to the instance corresponding to the union of these coalitions. Thus, the optimal solution for a coalition of companies achieves an optimal cost which is at least as good as the sum of the optimal costs resulting from the companies solving the model separately.

3.3.2 Min Emission Problem

In a second approach, the problem is addressed from a min emission perspective. The emissions per km are calculated by multiplying an emission factor e by a fuel consumption index that depends on the load of the truck. Since the load varies for each segment on a tour, the set $P = \{1, 2, 3, 4\}$ is defined to represent the segments. Let f_p be the fuel consumption per km on the pth segment of the tour. Define the decision variables $x_{i,j,k,p}$ equal to 1 if the pth segment traversed by truck k goes from point i to point j, and zero otherwise $(i, j \in H_S : i \neq j)$. The integer linear model below addresses the new situation for a generic coalition S.

$$\min E(S) = \sum_{i \in H_S} \sum_{\substack{j \in H_S \\ j \neq i}} \sum_{k \in K_S} \sum_{p \in P} e \cdot f_p \cdot d_{i,j} \cdot x_{i,j,k,p} \tag{13}$$

s.t.

$$\sum_{i \in I_S} \sum_{\substack{j \in J_S \\ j \neq i}} x_{i,j,k,1} = 1 \quad \forall k \in K_S \tag{14}$$

$$\sum_{i \in H_S} \sum_{\substack{j \in J_S \\ j \neq i}} \sum_{p \in P} x_{i,j,k,p} = 3 \quad \forall k \in K_S \tag{15}$$

$$\sum_{\substack{i \in H_S \\ i \neq j}} \sum_{k \in K_S} \sum_{p \in P} x_{i,j,k,p} = 1 \quad \forall j \in H_S \tag{16}$$

$$\sum_{\substack{i \in H_S \\ i \neq j}} x_{i,j,k,p} = \sum_{\substack{i \in H_S \\ i \neq j}} x_{j,i,k,p+1} \quad \forall k \in K_S, j \in H_S, p \in P : p < |P| \tag{17}$$

$$\sum_{\substack{i \in J_S \\ i \neq j}} x_{j,i,k,1} = \sum_{\substack{i \in J_S \\ i \neq j}} x_{i,j,k,4} \quad \forall k \in K_S, j \in I_S \tag{18}$$

$$\sum_{p \in P} x_{i,j,k,p} + \sum_{p \in P} x_{j,i,k,p} \leq 1 \quad \forall k \in K_S, i \in H_S, j \in H_S : i \neq j \tag{19}$$

$$\sum_{i \in H_S} \sum_{\substack{j \in H_S \\ j \neq i}} x_{i,j,k,p} = 1 \quad \forall k \in K_S, p \in P \tag{20}$$

$$x_{i,j,k,p} \in \{0, 1\} \quad \forall k \in K_S, p \in P, i \in H_S, j \in H_S : i \neq j \tag{21}$$

Objective function (13) minimizes total emissions. Constraints (14) and (15) impose that every vehicle starts from one supply point and visits three demand points, respectively. Constraints (16) impose that every point is visited once in a segment of the tour of exactly one truck. Constraints (17) state that if the pth segment travelled by a truck ends at a demand point j, the $(p + 1)$th starts from point j. Constraints (18) state that a truck must start and finish its tour at the same supply point. Constraints (19) avoid subtours for every pair of points. Constraints (20) state that every truck completes $|P|$ segments. Constraints (21) express the binary nature of the variables. Solving model (13), (14), (15), (16), (17), (18), (19), (20) and (21) for each coalition S provides the values $E(S)$ to define the characteristic function of the emission game (N, E). This game is *sub-additive*, due to the same reason explained for game (N, C).

3.3.3 Results

In the numerical implementation of the models, the cost per km has been set as c = €0.45. The emission factor has been set as $e = 2.69$ kgCO_2/L, according to Zhu et al. (2016) for a 30 tonne truck. The fuel consumption for the four different loads are also based on Zhu et al. (2016), assuming the fuel consumption decreases linearly from its laden to empty values, that is: $f_1 = 0.45$ L/km (when the truck is laden with 30 tonne), $f_2 = 0.40$ L/km (when the truck is laden with 20 tonne), $f_3 = 0.35$ L/km (when the truck is laden with 10 tonne), and $f_4 = 0.30$ L/km (when the truck is empty).

The models were implemented in the mathematical programming language AMPL and solved using the optimization solver CPLEX 12.6. The solutions were obtained in a matter of a second. Figure 1 illustrates the optimal solutions to both the min cost and min emission models. The optimal cost and the optimal emissions for each coalition are shown in Table 3. A first observation is that in the non-collaborative solution some routes of different companies cross each

Table 3 Optimal objective values and allocations in the numerical example

	Min cost problem				Min emission problem			
Coalition	C	Proportional	Shapley	Nucleolus	E	Proportional	Shapley	Nucleolus
{A}	295	221	219	226	645	488	494	510
{B}	372	279	254	240	814	617	557	525
{C}	305	229	256	263	671	509	562	578
{A,B}	508	499	472	465	1128	1105	1051	1035
{A,C}	578	450	474	488	1281	997	1056	1088
{B,C}	572	507	510	502	1238	1125	1119	1103
{A,B,C}	728	728	728	728	1614	1614	1614	1614

other. In contrast, in the collaborative solution there is no such overlap. The total distance travelled in the collaborative solution is 1618 km, which reduces by 25% the 2159 km travelled in the non-collaborative solution. Although very similar, the min cost and min emission solutions differ slightly in the order in which the demand points are visited. For example, in the collaborative min cost solution, the tour departing from SC starts with a first segment to C3, while in the min emission solution the first segment goes from SC to B3, which is shorter. This is because starting by the shorter segment (fully loaded) is environmentally more convenient than starting by the longer one in this example.

As for the allocations, Table 3 reveals that the three methods provide stable solutions in both the cost and the emission games for this example. In fact, by comparing the optimal cost (emission) of each coalition with the sum of the allocated cost (emission) to its players, it is easy to verify that the efficiency and rationality conditions are satisfied.

3.4 Applications

The literature on emissions in road freight transportation includes applications where the emissions are directly allocated to different objects (cargoes, companies, customers) or where the emissions are part of the total cost that is allocated to the objects. Among the first type of problems, Leenders (2012) allocates emissions to customers in traveling salesman problems, motivated by the case of the logistics service provider *Kuehne + Nagel*. This company combines the transport requests of different customers on a same route. Four allocation methods are tested. One of them is proportional to the product between distances and carried loads, and is the one used in practice by the company. Another one is the τ-value, a concept by Tijs and Driessen (1986) that allocates every player j its separable cost (the cost of the grand coalition minus the cost of a coalition that contains all players except j) plus a share of the non-separable costs (the cost of the grand coalition minus the sum of the separable costs of all players). The two other methods are based on proportions to the stand alone emissions. A similar case is addressed by Sichwardt (2011), who allocates emissions to different products delivered on a same route. This case arises in the operations of a Swedish company called *Alwex Transport AB*. The allocation method is proportional to the distance between the terminal and the location where a product is dropped. Every stop in the route, however, involves a single shipment. Another similar case is addressed by Kellner and Otto (2012), who test 15 methods to allocate emissions to shipments on a same route. Several of these methods are proportional, and others come from cooperative game theory literature, such as the Shapley values and the nucleolus.

Naber et al. (2015) allocate emissions to customers on a distribution route. The route is fixed (not necessarily according to an optimization criterion), and the problem consists of allocating emissions after the route has been completed. Five allocation methods are tested in real-world instances from a Dutch logistics service provider, involving between 9 and 11 customers, and in randomly generated instances involving 5, 10 and 15 customers. A first method is proportional to the stand alone emissions of the customers and is the one used in practice by the company. The other methods tested are the Shapley values, the nucleolus, and slightly modified versions of the Lorenz allocation (Arin 2007) and the Equal Profit Method (Frisk et al. 2010).

Zhu et al. (2016) allocate emissions to two cargoes combined in a four-segment trip. The trip consists of two laden segments and two empty segments. They use three allocation methods that differ in how the emissions of the empty segments are distributed among the cargoes. One method allocates these arbitrarily to the first cargo. The second method distributes them among the two cargoes according to a factor that can be calculated, for example, by the Shapley values. The third method allocates to the first cargo the emissions of a trip between the origin and the first destination, and to the second cargo the marginal of the empty segments with respect to the trip between the origin and the first destination.

The remainder references relate to the type of problems where the allocation is not of emissions directly but of total costs that include a cost for emissions. Xu et al. (2012) and Sanchez et al. (2016) allocate costs to companies in a collaborative setting by using the Shapley values. Özener (2014) allocates costs to customers in a vehicle routing problem by four methods. Two of them are proportional methods (either to the distance between customers and depots or to the stand alone costs). Another one is based on duality. The last one is a modified version of the Shapley values, in which only some characteristic function values are needed. Niknamfar and Niaki (2016) allocate cost to two entities: a holding company and a group of carriers. The overall problem is a hub-and-spoke network with soft time-windows, in which the holding company defines location of the hubs and assigns routes to the carriers, and the carriers select a vehicle type to serve the routes. The cost allocation, which includes emission costs, is done by a dual lexicographic max-min method. This method is based on Pareto optimality and the sequential maximization of the worst outcomes among the entities, analogously to the sequential maximization of the excesses in the nucleolus.

4 Quantifying the Inputs

Quantifying environmental benefits and allocating emissions as presented in the previous sections, require a method to calculate emissions. This may serve as input in an optimization problem that incorporates emissions explicitly or to assess the output of a model constructed according to other criteria. On its hand, the optimal objective values of the optimization problem for every coalition are used as input in the definition of the characteristic function of the transferrable utility games. This section provides an overview of the emission calculation methods and the optimization criteria used in the literature on collaboration and allocation of emissions in road freight transportation.

4.1 Calculating Emissions

There is a vast variety of methods to calculate emissions. An exhaustive review of methods used in the literature on green road freight transportation can be found in Demir et al. (2014). The following paragraphs are limited only to summarize the methods used in the literature on collaborative transportation and emission allocation.

A frequently used approach is to calculate emissions E (kgCO_2) according to the factor model $E = e \cdot d \cdot f$, where e is the emission factor (kgCO_2/L), d is the travelled distance (km), and f is a fuel consumption index (L/km). Often the fuel consumption index takes different values depending on the payload of the vehicle. These methods are used by Sichwardt (2011), Özener (2014), Pérez-Bernabeu et al. (2015), Sanchez et al. (2016), and Zhu et al. (2016). Niknamfar and Niaki (2016) use a similar method, but the fuel consumption depends on the distance and the speed according to the so called *comprehensive modal emission model* (Demir et al. 2012).

Another common approach is to combine the emissions caused by an empty truck and a fully loaded truck in the single expression $E = e \cdot d \cdot (F_{empty} + (F_{full} - F_{empty}) \cdot P_{load})$. Here, F_{empty} is the fuel consumption of an empty vehicle (L/km), F_{full} is the fuel consumption of a fully loaded vehicle (L/km), and P_{load} is the fill rate or load factor at which the vehicle is used (e.g. $P_{load} = x/c$, where x is the load in pallets carried by the vehicle and c is the capacity in pallets of the vehicle). This formula, developed by the Swedish non-profit organization *NTM*, has been used by Kellner and Otto (2012), Leenders (2012), Verstrepen and Jacobs (2012), Xu et al. (2012), Pan et al. (2013), and Danloup et al. (2015). Jacobs et al. (2014) use the same approach, but multiply the expression by 1.1, assuming a 10% is added due to the cooling of reefer trucks.

Naber et al. (2015) calculate emissions according to a model by Ligterink et al. (2012), which incorporates explicitly the velocity at which the trucks travel. The emission of a truck transporting x loading units and traveling one kilometer with velocity V is given by a nonlinear expression of the type $\frac{A+a\cdot kWt}{V} + B + b \cdot kWt + (C + c \cdot kWt) \cdot V + (D + d \cdot kWt) \cdot V^2$. Here, A, a, B, b, C, c, D, and d are parameters determined per emission component and kWt is specific power (kW/ton), which Naber et al. (2015) calculate as a decreasing (fractional) function of x.

4.2 Optimization Criteria

Finding an effective solution in road freight transportation often requires solving an optimization problem. In the vehicle routing problem of Sect. 3.1, the solutions were obtained by solving two integer models whose main difference was the optimization criteria: minimization of costs and minimization of emissions. The latter is rather unusual in the literature on collaborative transportation and emission allocation. In fact, the majority of this literature does not incorporate emissions into the optimization problem, and the environmental assessment is rather a retrospective calculation of emissions given a transportation plan or route. This is the case in Frisk et al. (2010), Sichwardt (2011), Leenders (2012), Verstrepen and Jacobs (2012), Jacobs et al. (2014), Naber et al. (2015), Pérez-Bernabeu et al. (2015), and Zhu et al. (2016). Only Kellner and Otto (2012), Pan et al. (2013) and Danloup et al. (2015) have used the minimization of emissions as objective function in collaborative transportation problems.

An intermediate approach is to penalize emissions as a cost term in a min cost objective function. Collaborative transportation problems using this approach are studied in Xu et al. (2012), Özener (2014), Niknamfar and Niaki (2016), and Sanchez et al. (2016). The functional term on cost emissions varies, but usually reduces to a linear form in the quantity of emissions.

5 Conclusions

This chapter has provided a first overview on collaborative transportation from an environmental perspective. While a growing body of literature has positioned collaboration as an effective way to reduce costs, its environmental impact has been considerably less studied. The chapter has gathered recent experiences showing that collaboration is an effective way to reduce CO_2 emissions in road freight transportation. The reduction in cases using real-world data ranges from 11% to 54%. Moreover, a case of collaborative transportation of forest fuels shows that collaborative transportation can also increase the use of renewable energy, when applied to relevant industries.

Sharing the savings from collaboration in a fair manner is crucial to sustain the stability of collaboration. As usually cargoes of different customers interact on a same tour, allocating emissions in transportation has become an important problem even in non-collaborative settings. The chapter illustrated how the same methods used to allocate cost, can also be used to allocate emissions. Several of these methods come from cooperative game theory. Although its application is well established in the transportation literature on cost allocation, its application to emission allocation is rather incipient. Overall, the literature on collaborative transportation taking emissions into account is currently much more scarce and fragmentary than its equivalent on cost. Counting all references on case studies and emission allocation overviewed in this chapter, the number of works amount to 17. All of these are dated between 2010 and 2016, and include not only journal articles, but also technical reports and theses. In particular, the contributions from Operations Research (OR) are few in comparison to its more numerous contributions to cost-driven collaborative transportation. There are important challenges where OR tools can be helpful. One is in the incorporation of environmental concerns in the optimization problems underlying collaborative transportation. The chapter unveiled that the cost perspective prevails substantially in the literature. With only a few exceptions, the environmental assessment (when included) is an additional analysis or discussion on the solution to an optimization problem that does not include environmental concerns. Even such retrospective analysis has value to quantify the environmental impact and there appears to be no reasons for not doing it, as the chapter also illustrated there are several methods to calculate emissions.

Optimization methods are required not only to find good collaborative solutions but also to allocate the benefits of collaboration. In practice-oriented literature, it has been argued that finding a correct allocation is "almost unworkably complex" (Leonardi et al. 2010), so that the use of simple proportional rules prevail. An illustrative example is the case of Nestlé and Pepsico, which deemed it fair to divide cost savings according to the share of pallets in a joint delivery. In the conclusions of the case, Jacobs et al. (2014) point out that more sophisticated methods, such as the Shapley values, need continued dissemination and promotion to have it accepted by market players as standard solution and best practice for gain sharing. OR techniques may alleviate the burden of computation of fair allocation concepts, especially in cases when the number of partners increases and a full description of the characteristic function needs to solve an exponential number of optimization problems. Also, conciliating min cost and min emission functions (which do not necessarily oppose each other) might eventually lead to games where stability must be assessed in more than one dimension. Besides allocating costs and emissions, other decision problems in collaboration concern coalition formation and finding the right combination partners. While some literature has progressively studied these problems in transportation (Audy et al. 2012; Guajardo and Rönnqvist 2015; Cuervo et al. 2016; Guajardo et al. 2016), the incorporation of environmental perspectives is rather absent.

Finally, it is perhaps alarming that almost all efforts for incorporating environmental concerns in collaborative transportation appear to be concentrated in Europe. In fact, all cases overviewed in this chapter take place on this continent. While some articles also point out practices of collaborative transportation in North America (Fugate et al. 2009; Audy et al. 2011), these do not address environmental concerns. More worrying, however, is the lack of literature on similar cases in other regions, such as Africa or Latin America. Exploring possibilities of collaborative transportation in these regions is also an opportunity for further research.

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Short Supply Chains as a Viable Alternative for the Distribution of Food in Urban Areas? Investigation of the Performance of Several Distribution Schemes

A. Nsamzinshuti, M. Janjevic, N. Rigo, and A. B. Ndiaye

Abstract In recent years, alternative forms of consumption in conventional food systems have emerged across the world. Specifically, the concept of short food supply chains advocates consumption of local products and distribution with maximum one (or ideally none) intermediary between the producer and the consumer. The objective of these consumption patterns is to reduce the externalities caused by conventional consumption modes, bring closer consumers and producers, and allow small-scale farmers to diversify their production, capturing greater value added, and ensuring more stable incomes. A large variety of typology of short supply chains can be distinguished, ranging from direct sales and distribution by producers to Internet sales through e-commerce operators.

However, consumption of local products does not automatically reduce the negative externalities. Indeed, the short food supply chain still faces many logistics, regulatory, and commercial challenges to constitute a real alternative to the globalized food model. Logistics is currently one of the main bottlenecks for the development of this sector. It has become even more complex in urban areas where the transportation of goods is subject to many constraints, such as the time spent on the road due to traffic, the difficulty in finding the right delivery point, and the lack of unloading areas or access restrictions.

Keywords Local food system · Short food system · Performance · Logistic schemes

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1 Introduction

Over the last few years, conventional food supply system has been subject to much criticism, including concerns about its negative impact on the environment and health, fears about food security, and low pay of small-scale farmers (Bosona 2013; Green and Phillips 2014). In addition, consumers are increasingly demanding greater quality and traceability in the food supply chains (Bantham and Oldham 2003; Bosona and Gebresenbet 2011). To address these new requirements, new forms of consumption have emerged across the world, presenting an alternative to the conventional food system. In recent years, interest in local food has increased significantly with the emergence of the "short food supply chains" that aim at delivering local products directly from farmers to consumers. For example, in a survey of 26,713 European consumers, 90% of respondents have agreed to buy more local food (DG AGRI 2011). These alternative modes of consumption aim at reducing environmental externalities caused by conventional consumption modes, bringing closer consumers and producers, building relationships of trust, and enabling small-scale farmers to diversify their production, increase the added-value, and consequently secure more stable incomes (Policy Commission 2002). Benefits of local food systems have been identified in numerous studies across social, economic, and environmental dimensions (CoR 2011; Kneafsey et al. 2013; Malandrin and Dvortsin 2015).

However, short food supply chains still face many challenges including the cost of logistics, difficulties of complying with regulations, difficulties in meeting customers' requirements in terms of quality, responsiveness, product availability as well as the administrative burden. Among these, logistical organization and in particular the transport and distribution operations are currently the main bottlenecks hindering the development of this sector (Ljungberg et al. 2013). Indeed, while the conventional food chains have adopted best practices in this field (e.g. supply chain integration, transportation coordination and route optimization (Bosona and Gebresenbet 2011; Engelseth 2016; Lacombe 2013; Ljungberg et al. 2013)), the short food supply chains are still characterized by ineffective operations resulting in suboptimal logistics organization and high transportation costs. Consequently, regardless of the intended benefits of the short food supply chains, numerous authors have shown through analysis of specific case studies that the consumption of local products does not automatically reduce the negative externalities (Martinez 2010; Mastronardi et al. 2015; Renting et al. 2003) and does not contribute to improving the economic and social performance of the food supply system. Moreover, studies show that distribution costs can represent over 40% of turnover, while the average in the food sector vary between 10% and 15%.

These inefficiencies result primarily from the absence of formal logistics and a lack of optimization of logistics activities (Blanquart et al. 2010). However, the environmental, social, and economic impacts of the distribution of short food supply chains will depend on the characteristics of the underlying operating models. Indeed, short food supply chain distribution can vary according to several dimensions such as the type of receiver (e.g. private customers, community-supported agriculture groups (CSA), grocery stores, conventional supermarkets, restaurants, and collective restaurants), the presence of sales intermediaries (i.e. food wholesalers, distributors), and organization of producers (e.g. individual producers or producer cooperatives). The most cited typology, which was proposed by Chiffoleau et al. (2013), classify the short food supply chains into two categories: (1) the absence or presence of sales intermediaries between producer and consumer, and the corresponding direct and indirect distribution; (2) an individual or collective dimension of the distribution (Chiffoleau et al. 2013).

One emerging type of organization is the direct sales from producers to community-supported agriculture groups (CSA) who are mostly situated in urban areas (Volz et al. 2016). In this model, the short food supply chain transport and distribution operations are typically not managed by third party logistics professionals, but directly by farmers who perform own-account deliveries by their own personal vehicles. Given the fact that the local food system is essentially composed of small businesses with low financial resources and limited access to knowledge, this specific form of organization can result in suboptimal organization, negative environmental impact and high costs for producers who often do not properly account for the costs of transport and distribution. Moreover, the completion of deliveries in an urban environment puts an additional pressure on the logistics organization. Indeed, urban deliveries take place in a highly-constrained environment, characterized by the scarcity of space, congested roads, lack of loading and unloading infrastructure, and delivery time windows and access regulations, restricting the efficiency and quality of urban logistics operations.

City logistics literature has already made significant progress in the identification and evaluation of logistics schemes for last mile deliveries that can be of significant interest for the study of the short food supply chains. Indeed, short food supply chains and urban freight transport share some characteristics such as the presence of many small geographically dispersed entities buying small quantities and a highly fragmented transportation market. However, regardless of the rising interesting in the short food supply chains and city logistics research, we are not aware of any contributions that address specifically the issue of the urban distribution of local food products.

To address this gap, this research aims to understand the specificities and the constraints of the short food supply chains in urban areas with a focus on delivery towards to community-supported agriculture groups (CSA).

The research addresses the following research questions:

- What are the different distribution schemes for the deliveries of local food in urban areas?
- How to assess the operational, economic, and environmental impacts of these distribution schemes?
- What is the most suitable distribution scheme of delivering community-supported agriculture groups (CSA) in urban areas?

To answer these research questions, authors have first conducted a literature review to identify alternative distribution schemes used for direct short food supply chains, without sales intermediaries. This has led to the elaboration of several distribution scenarios for short food supply chains in urban areas. Secondly, authors have developed several models that aim at assessing the operational, economic, and environmental performance of those scenarios. Thirdly, authors have applied these models to the specific case of delivering the CSA located in Brussels Capital Region to evaluate the logistic performance.

2 Identification of Distribution Models for Short Food Supply Chains in Urban Areas

In this section, we focus on distribution models for short food supply chains used in the framework of direct deliveries in urban environment.

A review of the scientific literature in the field of city logistics and short food supply chains as allowed us to identify three major alternatives with regard to the distribution schemes for this type of short food supply chains: (1) direct distribution, (2) horizontal collaboration and (3) distribution through a logistics service provider (LSP). Figure 1 provides a schematic representation of these schemes that will be described next.

3 Direct Distribution

Direct distribution is the most basic form of logistical organization where local producers use their own vehicles to transport directly to the receivers without intermediaries. The main motivation of self-distribution is the flexibility that it provides. Indeed, according to the local procurers, they use this opportunity to do

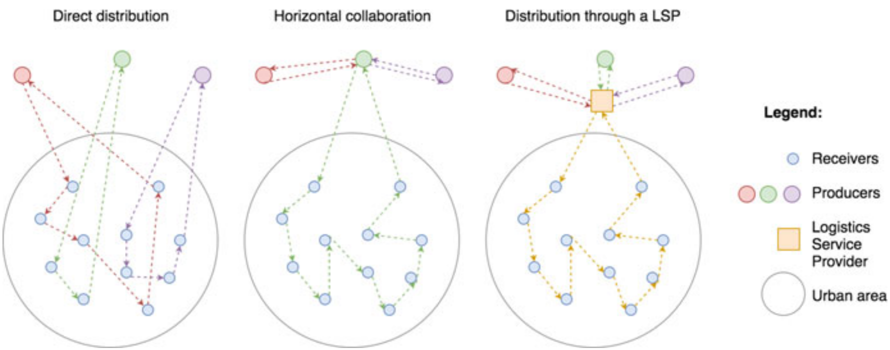


Fig. 1 Distribution schemes for short food supply chains

other things during the distribution such as shopping, personal and professional meetings, etc. (Engelseth and Hogset 2016). Moreover, they want to keep control of their process and also have the ability to meet consumers. However, city logistics research shows that this type of transportation is less efficient than the hired transport since shippers transporting for their own account tend to perform fewer deliveries per delivery round than professional transport operators (Gerardin et al. 2000), leading to lower load factors of vehicles and consequently higher costs and environmental impacts.

4 Horizontal Collaboration

Horizontal collaboration refers to collaboration between several producers to optimize their distribution activities. Much research has already been carried out on the potential for collaboration to improve logistics in the short food supply chains (Blanquart et al. 2015; Duault 2014). This research has clearly shown interest in collaboration in terms of cost reduction, reduction of externalities and the impact on competitiveness (Christopher 1999). Case analysis of logistics collaborative studies on the conventional supply chain was able to show that it is possible to reduce on average 30% of logistics costs (Guinouet et al. 2012; Lacombe 2013). The surveys of farmers show that they are generally reluctant to collaborate. The main reasons include lack of trust between stakeholders, fear of the loss of their independence, singularity of their distribution network, lack of tools and cost-sharing methods (Blanquart et al. 2015; Duault 2014). The main benefit of transport collaboration is increasing vehicle fill rates and thus reducing transport costs (Ozener 2008). Transportation and distribution management remain the most expensive and complicated process for the actors of the SFSC. Some studies show that these processes can represent over 40% of turnover, while on average in the food sector they are more than 10–15% (Raton et al. 2015). Many actors, especially farmers, do not calculate the costs of transport (MESSMER 2013). Therefore, they have no idea of these costs, so they cannot undertake this process. To improve transport performance, collaboration is the solution most cited in the literature. On average a 30% reduction in kilometers traveled compared to individual transport is observed (Lacombe 2013). There are many forms of collaboration in transport for producers. These range from sharing an under-exploited vehicle with other producers to the joint purchase and management of a vehicle by a farmers' cooperative (Blanquart et al. 2015).

Sharing a vehicle involves using a vehicle that belongs to a farmer to transport products from other farmers. Either a farmer makes a tour to get products from other farmers or everyone brings products to the farmer-transporter. This type of collaboration requires effective organization and implementation of cost-sharing methods to avoid potential conflicts and ensure sustainability of this system. Moreover, this system is only possible for farmers who are in the same area and are confident enough to avoid competition problems.

Another form collaboration is a joint purchase of a vehicle. This form of transport under collaboration consists of the acquisition of a transport vehicle by a cooperative or group of farmers. In France and Belgium, this form of jointly purchased agricultural equipment is called CUMA (Coopérative d'Utilisation de Matériel). One of the main advantages is that this collaboration can benefit from public aid. In the Wallonia Region (Belgium), this aid is equal to 25% of eligible investments (Élevages 2012). At the organizational level, farmers can use the vehicle in turns or go further by hiring a driver as in the case of CUMA "Terroirs sur la route" in the Loire-Atlantique in France. This CUMA acquires a truck and hires an employee driver for the transport of goods of farmers who are members of this CUMA (Terroirs44 2016; Lacombe 2013). The latter organization is more complicated to implement, because it requires a management system to be set up considering the constraints of each member. Other advantages are: a faster return on investment, the offloading of transport activities for the farmer (if the CUMA hires a driver). However, to succeed, lessons learned from other experiences show that it is necessary to establish information flow management systems to establish precise timetables and vehicle usage monitoring. This avoids conflicts of use and results in better cost allocation. Despite the interests and benefits of collaboration, it faces many challenges. The main barriers are the incompatibility of distribution systems, the lack of trust between producers and the fear of losing of independence (Duault 2014a).

5 Direct Distribution Through a Logistics Service Provider (LSP)

LSPs are companies that provide logistics services to stakeholders of supply chains. Many studies have shown that the producers are interested in using LSPs to optimize their logistics. This allows reduced costs, reduced workload, visibility of products, gains new markets and increase sales (Martikainen et al. 2014). According to the survey by Blanquart et al. (2015) conducted among farmers, logistic service providers are mainly used to reach new customers and not for distribution optimization of existing customers. Thus 75% of farmers interviewed in this study were not ready to use LSP. The main obstacles to using LSP are the cost, the need to have a direct contact with the customer, and the lack of confidence in these companies (Blanquart et al. 2015). We can highlight two main stakeholders of direct distribution through an LSP: logistics platforms and specialized transportation companies.

Logistics platforms are solutions that emerge increasingly in the management and optimization of distribution networks. City logistics research addresses extensively Urban Consolidation Centers (UCCs) which are the most well-known type of urban consolidation platforms and a popular measure (Verlinde et al. 2012; Ville et al. 2013). Allen et al. (2007) define a UCC as a logistics facility situated relatively close to the geographic area that it serves, to which many logistics companies deliver goods destined for the area, from which consolidated deliveries are carried out within that area and in which a range of other value-added logistics and retail services can be provided. The main benefits of a UCC are reduction in the number of vehicle trips, reductions in the number of vehicle kilometers, and better utilization rates for vehicles (Huschebeck and Allen 2005). However, UCCs are generally considered to be unsuitable for perishable products such as fresh food (Browne et al. 2005). There are, however, some notable exceptions to this, such as Stockholm (SE) UCC which can handle cold foods, Heathrow airport UCC (UK) which has chilled and frozen facilities and one of the two UCCs in Siena (IT) which is specialized in food products) (Browne et al. 2005; Panero et al. 2011).

In the food sector, consolidation platforms are called “Food Hubs”, which are regional logistics distribution centers, offering logistic services (storage, administrative, transportation, marketing, etc. . . .) to producers at affordable prices (Barham et al. 2012). Based on the analysis of food hubs implemented in the United States, (Barham et al. 2012) has identified three types of food hubs (1) Farm-to-business which delivers mainly local food products to stores (2) Farm-to-consumer which provides local food directly to consumers, including consumer groups (CSA), and (3) Hybrid model which serves both stores and consumers directly. Morganti and Gonzalez-Feliu (2015) showed that a food hub has great potential in terms of optimization for the distribution of local food and particularly in urban areas. The authors compared a distribution network without a food hub to a distribution network with a food hub based in Parma. This comparison showed that the food hub improves logistics distribution. Moreover, these food hubs offer benefits to receivers; for example, collective restaurants may have only one interlocutor. It also allows receivers to have sufficient volumes and ensure respect for the cold chain (Siegenthaler and Estève 2014). Depending on their business model, there are different legal structures for the establishment of food hubs which necessitates distinguishing producers’ cooperatives (owned by farmers), privately held food hubs (owned by private investors), publicly held food hubs (owned by public), nonprofits and finally informal food hubs.

In Belgium, food hubs are generally “Farm-to-business” subsided by the public authority and they serve primarily supermarkets and groceries. CPL Promogest is one example which is a publicly held food hub that brings together 90 producers with over 1000 references. It offers producers a series of services such as order management, administrative tasks, kitting, and delivery. The main advantage of the non-profit food hubs is that they can receive public aid. However, this model is not sustainable and its status does not allow them to easily access private funding (Barham et al. 2012). Other food hubs have emerged and include Made in BW in the Walloon Brabant, Criée de Wepion and Distrikempen in Antwerp (RWDR 2014).

Transportation companies offer transport service to producers. Their expertise in transportation and logistics management and optimization allow to enhance logistics performance (cost, reliability, responsiveness . . .) especially in urban areas. In Belgium, several transportation companies (Heureux Nouveau, Sumy, Courier Monsain, etc....), specialized in the delivery of local products, have emerged recently. These transportation companies offer services that meet the needs of both producers and consumers regarding respect for the environment but also suit urban distribution needs. For this, they offer delivery through eco-friendly vehicles (bicycles and electric trucks), but also have the logistics platform close to consumers.

6 Modelling the Environmental and Economic Performance of Different Distribution Schemes for Short Food Supply Chains

Literature review presented in the previous section has led us to establish three major distribution schemes for short food supply chains: (1) direct distribution; (2) horizontal collaboration between producers and (3) distribution through a logistics service provider. However, it is still not clear which of those schemes represents an optimal solution from the environmental and economic point of view. Indeed, city logistics literature shows that solutions based on freight consolidation (such as Scheme 2 and Scheme 3) can bring significant environmental benefits, but also introduce an additional cost in the transport chain due to the additional transshipment (Allen et al. 2012; Gonzalez-Feliu 2011; Marcucci and Danielis 2008). Furthermore, the trade-offs between different types of freight consolidation solutions are not well known. Indeed there is a large body of literature relevant to consolidation schemes that involve setting-up of a physical infrastructure such as UCCs (Browne et al. 2005), but very few contributions address horizontal collaboration case studies in the urban freight transport literature.

To address this gap, we establish a model to evaluate the economic and environmental performance of different distribution models. The economic performance is assessed with regards to the total cost of transportation while environmental performance is assessed through the quantification of the greenhouse gas and air pollutant emissions of transportation activities.

In this section, we present a transportation cost and emission model for three distribution schemes. These models will be applied to a case of delivering community-supported agriculture (CSA) located in Brussels by local producers.

6.1 Overall Modeling Approach

To assess the economic and environmental impact of different schemes, we consider that each individual shipper and logistics provider aims at minimizing their distribution cost. The cost of a certain delivery route is therefore established by solving a classical Traveling Salesman Problem (TSP) for each producer.

Table 1 Emission factors for air pollutants (g/km) (EEA 2016)

Pollutants	CO	NOx	NMVOCs	NH_3	SO_2	$PM_{2,5}$	Pb	CO_2 lube	CH_4	NO_2
α (g/km)	0.075	0.221	0.035	0.019	6.384	9	4.17E-6	0.398	0	0.004

The transport costs are established based on the following elements: a distance-based factor and a time-based factor. A distance based factor accounts for the variable vehicles costs (e.g. fuel and tires). The time-based factor accounts for fixed vehicle costs (e.g. insurance, taxes, cost of ownership) and the cost of drivers. The costs of a route encompass both the costs linked to the driving as well as costs relevant to the loading and the unloading of the goods.

The transportation emissions are based on the methodology presented by the European Environment Agency in air pollutant Emission inventory guidebook and particularly the chapter related to Emission from road transportation (1.A.3.B.i-iv comprehensive Emission from road transportation) (EEA 2016). In this research, we evaluate greenhouse gases ($C0_2$, CH_4, and N_2O) and atmospheric pollutants (CO, NOx, NMVOCs, NH_3, SO_2, $PM_{2.5}$, Pb, CO_2, lube). We also consider only the emissions from combustion “tank to wheel”. The “well-to-tank” emissions related to energy production are excluded from this research. Following the recommendations of (EEA 2016), the Tier 2 methodology is chosen for quantifying emission of greenhouse gases and atmospheric pollutants. This methodology provides emission factors for each pollutant and for each vehicle technology (Table 1). For CO_2 emission, this factor is calculated based on the fuel consumption (FC) of vehicles considered and the CO_2 released by the combustion of this fuel.

After carrying out the quantification of transport emissions, we monetize these externalities based on their impacts on health, global warming, and soil and water quality. The monetization of transport emissions allows a better understanding of the impacts by the companies. The internalization of this transport external costs allows decision-makers to consider the potential impacts when they make a transport decision. In this research, we integrate the costs of these emissions into transport costs to have the true cost of transportation (Van Essen et al. 2008).

The monetization of greenhouse gases and atmospheric pollutants is based on the HEATCO research project (Maibach et al. 2008). The monetization of greenhouse gases is based on the equivalent carbon price. First of all, greenhouse gases are converted into CO2 equivalents following a conversion factor (β) which reflects its contribution to the greenhouse effect. ($\beta_{CO2} = 1$, $\beta_{N2O} = 1$, $\beta_{CH4} = 1$). The carbon price (γ) varies from 20 to 219€/ton of CO2-equivalent depending on the references. This research considers this price at 40$€_{2010}$/ton of CO2-equivalent as recommend by the Commissariat général à la stratégie et à la prospective (Now France Strategy). This value is based on the calculation method that will achieve in 2030, a carbon price of 100 by following a growth rate of 5.8% per year (CGSP 2013). The monetization of atmospheric pollutants is calculated based on cost/pollutant (δ). These costs are given depending on the type of vehicle and the area covered by it.

Let D be a set of nodes where customer demands are located and P a set of nodes where producers are located. Let L ⊂ P be a subset of producers that are considered as large producers and that can potentially consolidate goods from several small producers. All customer demands are known and fixed in advance and each demand node d is characterized by its demand q_d and a binary variable y_{dp} that indicates from which producer the customer demand is served. The node u represents the location of the urban consolidation center. The link set $A = \{(i, j) \mid i, j \in L\}$ represents the possible unidirectional movements using the road network. Two measures are associated to links (i, j) per transport service: an average travel distance dij and and average travel duration t_{ij}. The following notations express the model parameters:

6.2 Notations

Indices and sets

i, j node indices
I set of clients
P set of producers
L subset of large producers
E set of pollutants

Parametres

α_{qk} = specific emission for pollutant q of vehicle used by producer k
β_q = global warming potential (GWP) for pollutant q
γ = costs per unit of Equivalent CO_2 (€/t CO2-eq)
δ = Marginal external air pollution costs (€ct/vkm) with δ_u: urban, δ_s: suburban, δ_r: rural and δ_u: motorway
y = proportion of total distance traveled in urban area (y_u), in suburban area (y_s), rural area (y_r), motorway area (y_m).
q_d demand in produce of customer d
θ^p duration of delivery stop at customer location by the producers vehicles
θ^u duration of delivery stop at customer location by the urban consolidation centre vehicles
γ^p duration of unloading time at large producers location
γ^u duration of unloading time at urban consolidation centre
d_{ij} distance of arc (i, j)
t_{ij} travel duration of arc (i, j)
c_{ph} vehicle hourly cost of the producers
c^p_{km} vehicle kilometric cost of the producers
c^u_h vehicle hourly cost of the logistics service provider
c^u_{km} vehicle kilometric cost of the logistics service provider

We consider three different scenarios: direct distribution, co-loading and the use of a urban consolidation center. The following decision variables will be used in those scenarios:

x_{ij}^{p} indicates that the arc (i, j) is traveled by the vehicle of the producer p.
z_{lk} indicates that the customer demand of the producer k is allocated to the large producer l in a co-loading scheme.
w_k binary variable that equals to 1 if the producer delivers to the urban consolidation centre, 0 otherwise
r_{ij}^{m} indicates that the arc (i, j) is traveled by the vehicle m of the urban consolidation center

6.3 Scheme I: Direct Distribution from the Producers to the Customers

The first scheme concerns the direct distribution towards the customers by each producer. To lighten the model formulation, we define an auxiliary cost of travel on the arc (i, j) for the producers' vehicles:

$$c_{ij}^{p} = c_{km}^{p} d_{ij} + c_{h}^{p} t_{ij} \;\; \forall i, j \in D \cup P \tag{1}$$

The cost of the distribution is given by the objective function:

$$c_{dir} = \min \sum_{p \in P} \sum_{i \in D \cup P} \sum_{j \in D \cup P} x_{ij}^{p} c_{ij}^{p} + \sum_{p \in P} \sum_{i \in D \cup P} \sum_{j \in D \cup P} x_{ij}^{p} c_{h}^{p} \theta^{p} \tag{2}$$

Subject to

$$\sum_{i \in D \cup P} x_{dj}^{p} = y_{dp} \;\; \forall d \in D, p \in P \tag{3}$$

$$\sum_{i \in D \cup P} x_{ij}^{p} - \sum_{i \in D \cup P} x_{ji}^{p} = 0 \;\; \forall d \in D, p \in P \tag{4}$$

$$\sum_{j \in R} \sum_{j \in R} x_{ji}^{p} \leq | R | -1 \;\; \forall R \subseteq D, p \in P \tag{5}$$

$$\sum_{j \in D \cup P} x_{pj}^{p} = 1 \;\; \forall d \in D, p \in P \tag{6}$$

The objective function (2) contains two elements: cost of travel on the arc set and time-related cost linked to the duration of the delivery while servicing the customer demand. The constraint (3) indicates that if a customer's d demand is met by the producer p, the customer is visited exactly once by that producer's vehicle. The constraint (4) ensures the conservation of flow for all nodes of the network by forcing the equality between the number of arrivals and the number of departures at each node. The Eq. (5) reflects the subtour elimination. The Eq. (6) ensure that tour cannot be operated by multiple producers.

Equations (7 and 8) assess respectively GHG and air pollutant emissions. These transport emissions are evaluated on the basis of the total distance traveled by vehicles and emission factors (δ) per each pollutant. Then, the external costs of these pollutants are calculated based on the price of carbon equivalent (γ) for each pollutant.

$$E^{GHS}_{direct} = \gamma \left(\sum_{q \in E} \sum_{p \in P} \left(\sum_{i \in D \cup P} \sum_{j \in D \cup P} x^p_{ij} d_{ij} \right) \alpha_{qp} \beta_q \right) \tag{7}$$

$$E^{AirPol}_{direct} = (\delta_u y_u + \delta_s y_s + \delta_r y_r + \delta_M y_M) \sum_{p \in P} \left(\sum_{i \in D \cup P} \sum_{j \in D \cup P} x^p_{ij} d_{ij} \right) \tag{8}$$

6.4 Scheme II: Co-Loading Between Producers

This scheme represents horizontal collaboration in transport (i.e. co-loading). In this distribution scheme, small producers deliver to larger producers who in turn perform transport towards delivery locations in the city. In this scenario, we allocate small producers to large producers to minimize the overall cost of small producers.

The objective function (9) accounts for the cost of the round-trips between the small and large producers, the time-related costs linked to the unloading, the routing costs from large producers' locations and the time-related costs for the duration of the delivery at the customers location. The constraints (10 and 11) indicate that all small producers are allocated to exactly one large producer and that large producers are allocated to themselves. The constraint (12) indicates that every customer that is originally served by the large producer l or is served by a small producer p allocated to large producer l is served by exactly one route from the big producer l. The constraints (13) and (14) ensure the conservation of flow band the subtour elimination respectively for the routes performed from the large producers' locations. The Eq. (15) ensures that tour cannot be operated by multiple producers.

$$\begin{aligned} c_{CoLoad} = \min \sum_{k \in P} \sum_{l \in L} z_{kl} \left(c_{kl} + c_{lk} + c^p_h \gamma^p \right) + \sum_{l \in L} \sum_{i \in D \cup L} \sum_{j \in D \cup L} x^l_{ij} c_{ij} \\ + \sum_{l \in L} \sum_{i \in D \cup P} \sum_{j \in D} x^l_{ij} c^p_h \theta^p \end{aligned} \tag{9}$$

Subject to

$$z_{ll} = 1 \ \forall l \in L \tag{10}$$

$$\sum_{l \in L} z_{kl} = 1 \ \forall k \in P \tag{11}$$

$$\sum_{i \in D \cup P} x_{dj}^{l} = y_{dp} z_{lp} \ \forall d \in D, l \in L \tag{12}$$

$$\sum_{j \in D \cup L} x_{ij}^{l} \sum_{i \in D \cup L} x_{ji}^{l} = 0 \ \forall j \in D \cup L, l \in L \tag{13}$$

$$\sum_{j \in R} \sum_{j \in R} x_{ij}^{l} \leq\mid R \mid -1 \ \forall R \subseteq D, l \in L \tag{14}$$

$$\sum_{j \in D \cup P} x_{pj}^{p} = 1 \ \forall p \in L \tag{15}$$

Equations (16 and 15) represent the external costs of transport emissions for each distribution section.

$$E_{coload}^{GHS} = \gamma \left(\sum_{q \in E} \left(\sum_{k \in P} \sum_{l \in L} z_{kl} 2 d_{kl} \right) \alpha_{qk} \beta_m + \sum_{q \in E} \sum_{l \in L} \left(\sum_{i \in D \cup L} \sum_{j \in D \cup L} x_{ij}^{l} d_{ij} \right) \alpha_{ql} \beta_q \right) \tag{16}$$

$$E_{coload}^{AirPol} = (\delta_u y_u + \delta_s y_s + \delta_r y_r + \delta_M y_M) \left(\sum_{k \in P} \sum_{l \in L} z_{kl} 2 d_{kl} + \sum_{l \in L} \sum_{i \in D \cup L} \sum_{j \in D \cup L} x_{ij}^{l} d_{ij} \right) \tag{17}$$

6.5 Scenario III: Delivery Through a Logistics Service Provider

In this scenario, all producers have the possibility of delivering to a consolidation platform, from which the last mile transport is organized using the LSP's own vehicles. The allocation of the producers to the consolidation platform is based on minimizing their overall cost.

To lighten the model formulation, we define an auxiliary cost of travel on an arc (i, j) by the urban consolidation centre vehicle:

$$c_{ij}^{u} = c_{km}^{u} d_{ij} + c_{h}^{u} t_{ij} \ \forall i, j \in D \cup \{u\} \tag{18}$$

The objective function (19) accounts for the round-trips between the producers and the urban consolidation center and the routing and servicing costs for the final distribution using urban consolidation centre vehicles. This constraint (20) indicates that every customer is served by exactly one route. The constraints (21) and (22) ensure the conservation of flow and the subtour elimination for the UCC vehicles. The constraint (23) ensures that the capacity of the urban consolidation centre vehicles is respected.

$$c_{UCC} = \min \sum_{k\in P} \sum_{l\in L} w_k \left(c_{ku} + c_{uk} + c_h^u \gamma^u\right) + \sum_{m\in M} \sum_{i\in D\cup\{u\}} \sum_{j\in D\cup\{u\}} r_{ij}^m c_{ij}^u + \sum_{l\in L} \sum_{i\in D\cup P} \sum_{j\in D} r_{ij}^m c_{km}^u \theta^u \tag{19}$$

Subject to

$$\sum_{m\in M} \sum_{i\in D\cup\{u\}} r_{dj}^m = 1 \ \forall d \in D \tag{20}$$

$$\sum_{j\in D\cup\{u\}} r_{ij}^m - \sum_{i\in D\cup L} r_{ji}^m = 0 \ \forall j \in D \cup \{u\}, m \in M \tag{21}$$

$$\sum_{i\in R} \sum_{j\in R} r_{ji}^m \leq \mid R \mid -1 \ \forall R \subseteq D, m \in M \tag{22}$$

$$\sum_{i\in D} \sum_{j\in D\cup\{u\}} r_{ji}^m \leq a^m \ \forall m \in M \tag{23}$$

Equations (24 and 25) evaluate the external costs of transport emissions.

$$E_{UCC}^{GHG} = \gamma \left(\sum_{q\in E} \left(\sum_{k\in P} w_k 2 d_{ku} \right) \alpha_{qk} \beta_q + \sum_{q\in E} \sum_{m\in M} \left(\sum_{i\in D\cup\{u\}} \sum_{j\in D\cup\{u\}} r_{ij}^m d_{ij} \right) \alpha_{qs} \beta_q \right) \tag{24}$$

$$E_{UCC}^{AirPol} = (\delta_u y_u + \delta_s y_s + \delta_r y_r + \delta_M y_M) \left(\sum_{k\in V_p} w_k d_{ku} + \sum_{s\in M} \left(\sum_{i\in D\cup\{u\}} \sum_{j\in D\cup\{u\}} r_{ij}^m d_{ij} \right) \right) \tag{25}$$

7 Application to the Brussels Capital Region

The modeling framework that was described in the previous section was applied to a specific case of a network formed of 90 community-supported agriculture (CSA) delivery points in Brussels which were served by 30 local producers situated across Belgium (Volz et al. 2016). The description of this case is based on the data collected during the interviews conducted with the stakeholders of the short food supply chains.

Different types of stakeholders were interviewed. First, we asked local producers to describe their supply chain in terms of the number of CSA groups they serve, delivery frequency, volume, modes of transport, loading rates. In order to handle missing or incomplete data, we also conducted interviews with CSA groups and used online databases.

From these interviews, we have been able to describe the supply chain network of the distribution of local food in Brussels Capital Region. Moreover, it allows us to select the localization of the consolidation platform which could be located at the current location of the largest wholesale food market in Brussels, MABRU. Figure 2 provides the locations of the delivery points, small and large producers as well as the consolidation platform.

Regarding the physical flow, we extrapolated the collected data to the whole local food system by making hypothesis as described in the next section.

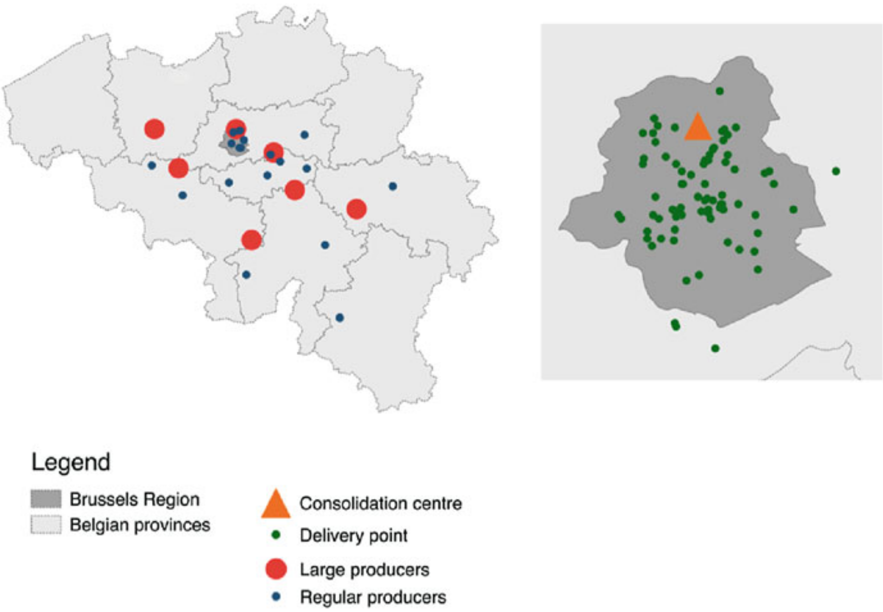


Fig. 2 Application to short food supply chains in Brussels - location of the delivery points, producers and consolidation centre

Table 2 Marginal external air pollution costs (€ct/vkm)

Vehicle	Urban	Suburban	Rural	Motorway
LCV Diesel Euro 6	0.929	0.495	0.333	0.319

Each delivery point supplies on average 30 families and each family purchases on average one crate of food per week with dimensions L40-l30-h20 and a volume of 0.2m^3, resulting in a total of 2700 crates per week. Each delivery point is independently organized and purchases on average from 3 local producers. 7 out of the 30 producers are considered "large producers", delivering an average of 18.9 delivery points per week and using large light commercial vehicles (LCVs) for the delivery of an average size of 12.5m^3 with an average load factor of 36.3% in volume. 23 out of the 30 producers are considered "small producers" delivering on average to 6 delivery points per week with small LCVs of an average size of 5.5 m3 with an average load factor of 26.0% in volume. The kilometric cost of vehicle is evaluated based on analysis of 6 different large LCV models in the Belgian market. This is 0.21€/km and 0.18€/km respectively for "large producers" and "small producers". The average time-based cost is 24.6€/hour (based on the estimations of drivers' salaries in Belgium). On average, producers spend 20 minutes per delivery location when delivering directly to customers. When delivering towards other producers or a consolidation platform, they are required to unload a larger amount of goods and therefore spend an average of 30 minutes.

The distances and time matrices were based on data provided by "openstreetmap" through "graphhopper" library. Finally, based on results of studies investigating the average operational cost of urban consolidation centres (e.g. (Boudouin 2006; Janjevic and Ndiaye 2016), it was considered that the cost of transshipment (including the cost of infrastructure, human resources and equipment) is 1€/crate.

Regarding the transport emissions, we consider light commercial vehicles with Diesel and Euro VI technology. Table 2 summarizes the costs of atmospheric pollutants adapted to Belgium. The fuel consumption of this type of vehicle is 80gFuel/km and CO2 emissions during combustion is 3.14 kg CO2 per kg of fuel (CGSP 2013).

8 Results

Figures 3, 4, 5, and 6 represent the analysis of the simulation of the three distribution schemes. Results suggest that the most favorable scenario for short food supply chain distribution in Brussels is Scheme II where small producers deliver towards large producers who in turn organize the last-mile delivery towards their customers. Indeed, compared to the direct delivery, this scenario allows decreasing the overall vehicle-km by 42%, the overall system costs by 28.1%, the GHG external costs by 42%, and air pollutants external costs by 41%. In comparison, the use of a

Fig. 3 Vehicles-km

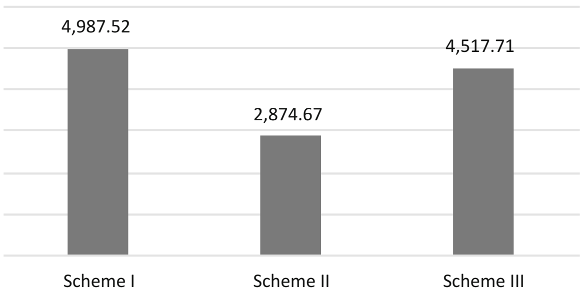


Fig. 4 Total cost of transport

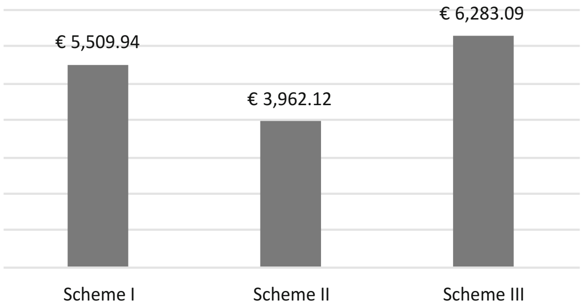


Fig. 5 Air pollutants External Cost

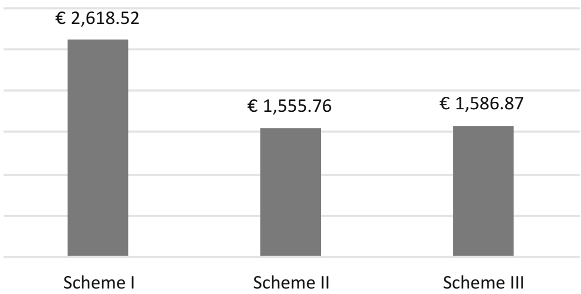
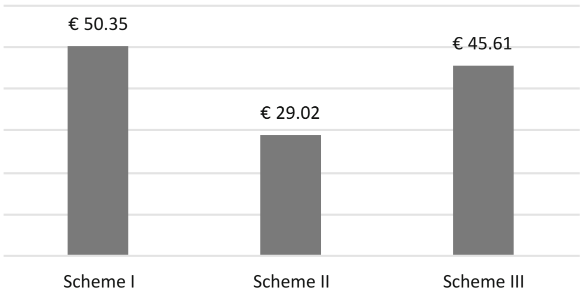


Fig. 6 GHG External costs



consolidation platform (UCC) located in Brussels decreases vehicle-km by 9.1%. Indeed, due to the location of the producers who tend to be situated far from the city, the major part of the vehicles-km is performed outside the urban area which results in a modest reduction of the overall vehicles-km using a local consolidation platform. Moreover, the urban consolidation center scheme increases the overall system costs by 14.0%. Indeed, although the vehicle-kms are decreased and therefore the overall transportation cost is decreased, the additional cost of the transshipment cancels the savings on transport and introduces additional costs. However, the Scheme II could be the most difficult to implement since it could face several barriers to collaboration cited in this article. Moreover, a reliable and effective framework for collaboration will be needed (IT systems, cost-sharing methods, legal framework, etc.).

9 Policy, Societal and Managerial Implications

This paper highlighted the fact that the short food supply chain in urban areas needs to adopt new and innovate logistic practices to provide a viable alternative to the traditional food supply chain. But some barriers must be addressed to ensure a successful deployment.

First of all, new and suitable policies must be developed by authorities to provide a favorable framework for the emergence of these new logistical solutions and to reduce the vagueness of current policies and regulations. For example, regulations regarding the transport for hire or reward must be clarified to enable the implementation of collaborative logistics solutions.

On the other hand, consumers must change their consumption behaviors. Indeed, consumers who buy local food also wanted to meet local producers when they deliver. This need didn't allow local producers to use logistics service providers to deliver their products.

Finally, the implementation of new logistics solutions requires the use of an information systems to ensure the management of information flows and their reliability. Nevertheless, stakeholders of local food systems, particularly small producers, are unaccustomed to using information systems to manage their logistics activities. It is therefore necessary to elaborate information systems that suit the local food system. The Choud'Brussels project (Nsamzinshuti 2016) aims to provide a solution to this challenge by co-creating, with the local food system stakeholders, a web platform that enables the exchange of information on logistics flows among actors who are involved in distributing local food in Brussels capital region.

10 Conclusion

In this paper, we investigated the potential of short supply chains to present a viable alternative for the distribution of food in urban areas. We highlighted main characteristics of these new forms of logistics organization and their benefits, and identified several distribution strategies. We then proposed a modeling framework that allows simulating the operational performance of these distribution strategies as well as their economic and environmental impacts. The application of this framework to the specific case of Brussels seems to suggest that the most cost-effective and environmentally-friendly alternative consists of a solution which aims at introducing horizontal collaboration between different producers to organize their deliveries. Regardless of these promising results, the implementation of this type of new logistics organization could bring additional challenges. Indeed, there are several business-related and organizational barriers for horizontal collaboration and consequently the transition towards new sustainable logistics schemes. Further research requires investigating more in depth these aspects and in particular governance models and cost sharing methodologies for collaborative transport networks in city logistics.

The main limitation of this research concerns data. Indeed, we have not been able to collect data from all stakeholders (producers, CSA groups). The data used in this research are based on a limited number of interviews that we conducted, which have been extrapolated to the entire local food system. Further research should be conducted to collect all data from all producers. In addition, the analysis should be extended to consider other aspects of performance such as the social impacts of distribution schemes.

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Sustainable Solutions for Urban Freight Transport and Logistics: An Analysis of Urban Consolidation Centers

Daniela Paddeu

Abstract Despite its key role for the economic vitality of a city, urban freight transport is responsible for negative externalities that affect our lives. In fact, it is a major contributor to climate change and global warming. Also, it causes increasing gas emissions, congestion, noise and traffic safety issues.

Drawing on the successful experience of the Bristol-Bath Freight Consolidation Center, which has been serving the city center of Bristol since 2002 and started covering Bath in 2012, this study analyses benefits provided by an Urban Consolidation Center (UCC). Based on a case study analysis, it aims to identify the key successes of a UCC scheme by focusing on the stakeholders' perspective. An analysis of the benefits coming from the sustainability scheme, such as polluting emissions reduction rates, is also provided.

Keywords City Logistics · Urban Consolidation Centres (UCCs) · Stakeholders' Commitment · Case Study

1 Introduction

Freight transport highly contributes to external costs related to road transport in urban areas; in fact, it is responsible for traffic congestion and accidents (economic impacts), polluting emissions and noise (environmental impacts) and for all the related 'social costs' that are due to diseases caused by pollution (Koehler 2004; Zhang et al. 2015; McKinnon 2010). Urban freight transport represents the so-called 'last mile' of the supply chain and are often the part of the supply chain with the highest costs (Chopra 2003). For this reason, measures and policies to define a more sustainable and efficient urban freight distribution system are needed.

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In the last years, the European Commission has been promoting implementation of city logistics policies all around Europe to reduce negative externalities related to urban freight mobility and improve the economic performance of urban areas. The most popular city logistics policy is, with any doubt, the Urban Freight Consolidation Center (UCC); it can contribute to reducing polluting emissions and congestion by collecting the goods addressed to a specific area in the city center and consolidating them into one large delivery made by a full-load and environmentally-friendly vehicle. UCC provides benefits not only for the citizens (because of the air quality improvement), but also for the stakeholders directly involved in the logistics process: the participating receivers and the suppliers (or carriers); specifically, participating receivers can benefit from cost reduction, because the just-in-time service allows to reduce the stock room space; also they can receive added services such as pre-retailing services and recycling of packaging. On the other hand, suppliers and carriers can avoid entering into the city center to make the deliveries, so they can save time and money.

However, due to the complexity of the multi-stakeholder environment, characterized by different actors with different needs and expectations, the number of successful UCC schemes in Europe is very low and most of them did not go beyond the experimental phase. This is also due to their economic sustainability. In fact, public funds during the launching phase are essential, but usually the scheme stops existing when funds finish and users have to pay for the service. To this reason, an analysis of the needs and expectations of the users ("*who pays what*") is needed to be able to understand how an economically sustainable scheme should be designed.

After providing a description of" Urban Freight Consolidation Center" and having established the general conditions necessary for collaborative economy solutions to be successful in the freight sector, this chapter provides an analysis of the pillar concepts of urban freight transport and logistics. In particular, benefits coming from sustainable urban freight measures are analyzed by considering the perspective of the direct users: the participating receivers. The study is presented by considering the case of the Urban Freight Consolidation Center that serves the cities of Bristol and Bath (UK). The point of view of the receivers participating in the scheme is analyzed.

2 Urban Freight Consolidation Centers (UCCs)

City logistics policies concern all the logistics and transportation activities performed in the last leg of the supply chain within the urban environment, the so called 'last mile deliveries'. They are managed by logistics providers who are in charge of the local distribution of goods, which have been consolidated previously in a shipping terminal. In this system, the corresponding logistics network consists of two transportation legs (Ehmke 2012); (1) From the hub to shipping terminals and (2) from the shipping terminals to individual customers. An example of last-mile deliveries performed in a hub and spoke network is provided in Fig. 1.

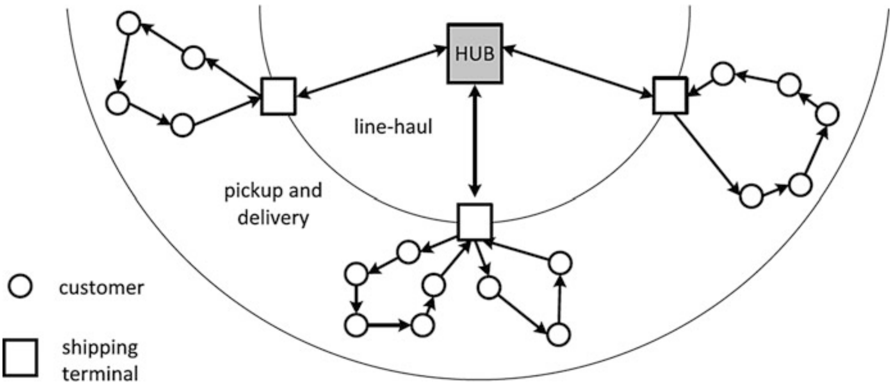

Fig. 1 Last-mile delivery in a hub-and-spoke network (Ehmke 2012)

- The first leg concerns the transportation of goods to shipping terminals by means of large trucks. Trans-shipment operations are performed at the terminals. Line-haul transports refer to long distance transportation from the sending depots to the hub and between the hub and the receiving depots.
- The second leg is related to city logistics services. Here, logistics providers pick up and deliver goods to customers, the last-mile delivery. It concerns short distance transportation by means of small trucks.

The literature pointed out that city logistics policies are usually implemented in medium-sized cities. In fact, due to the complexity and the size of the commercial areas in big cities, city logistics schemes are more difficult to be implemented and managed. Also, this type of system is more successful when other policies (i.e. access regulation, limited traffic zone, etc.) are applied.

The most famous example of city logistics intervention is the Urban Consolidation Center (UCC). Multiple shipment deliveries destined for a city center are unloaded to a depot usually located in the surrounding area of the city: the UCC. Here goods are *received,* consolidated by a third party logistics company and *subsequently* delivered to the receivers in the city center by means of environmentally friendly vehicles in full load, with the purpose of *optimizing deliveries and minimizing transport* (Nordtømme et al. 2015). Within the UCC scheme, resources such as warehouse infrastructure and vehicle space are shared with other potential competitors for the last mile, underpinning the logistics collaboration idea.

Different categories of UCCs exist (Browne et al. 2005). Type 1 (e.g. La Rochelle - France; Bristol - UK) makes deliveries to all or part of an urban area, and it is usually promoted by local authorities who want to benefit from the related traffic and environmental improvement. Type 2 (e.g. London Heathrow airport retail; Meadowhall shopping center in Sheffield) serves large sites with a single landlord, which include the airport, shopping centers and hospitals. Type 3 (e.g. London Heathrow airport during major development work) is used to make deliveries of construction materials to areas dedicated to this major building project.

Several studies recognized the potential benefits coming from the UCC. In fact, this type of scheme allows reducing the number of Heavy Goods Vehicles (HGV), thus avoiding a high level of polluting emissions in urban areas where the population is most exposed to poor air quality. System efficiency is also improved, because of the reduction in terms of vehicle-km and energy consumption (Paddeu et al. 2014). Additional services can be offered by the UCC to improve the overall quality of the supply chain (Verlinde et al. 2012), such as just-in-time stock holding for businesses with tight space constraints on their own premises. According to Janjevic and Ndiaye (2016), the use of UCC decreases time-based delivery costs while adding a service charge. They also pointed out that the size of the town plays an important role as the cost-attractiveness of UCC solutions increases with the town radius. However, this does not mean that UCCs are more suitable to large towns because larger towns imply higher distribution costs (Janjevic and Ndiaye 2016).

3 Benefits and Limitations of UCCs in Europe

3.1 UCCs Schemes in Europe: A Critical Review

Several trials and experimental research projects have been carried out in Europe to study the benefits and limitations related to the establishment of a UCC. This subsection analyses some significant examples of UCCs established in Europe in the last years. The review of the most significant and successful examples of multi-stakeholder collaborative schemes provided by Verlinde et al. (2012) highlights that both receivers and carriers are only inclined to change their way of receiving/delivering if they think their own organizations will directly benefit from it. For this reason, urban freight policies addressed to carriers are not likely to be effective, whereas policies addressed to the receivers lead to behavioral changes. This is due to the fact that receivers can impose their will on the carriers and they must be responsive to customers' demands if they want to stay in business (Holguín-Veras et al. 2008).

Holguín-Veras and Sánchez-Díaz (2016) highlighted that voluntary programs are more effective than regulation, due to the strong character of regulations, often perceived as an obligation to some participants to change their operations. On the other hand, voluntary programs encourage greater welfare because participants are aware of the benefit from it. The result is different if we consider a shopping area belonging to a single landlord/manager. In this case the landlord (e.g. UCC of Heathrow Airport) is able to strongly influence all the participants and to make the solution successful (Browne et al. 2007).

Opposition from shippers has been recognized by Doig (2001) as one of the key factors responsible for the end of the UCCs created by the Port Authority of New York and New Jersey as long ago as the 1940s. If the attention is focused on shippers, they could be reluctant to participate in a UCC scheme due to the losing control of their deliveries and of opportunity to increase brand recognition (because they cannot use their own trucks in the city center).

Thanks to the willingness to participate by the receivers, UCCs were successful in several cases. This is the case of SMILE project, carried out in the city of Malmö. The project involved 40–50 small food producers in the region with five buyers. All the stakeholders involved (producers and buyers) managed a common food logistics system to make orders and deliveries. SMILE allowed receivers and suppliers to work together with the aim to reduce the distance travelled by the fresh food. Another successful example is that of a Dutch project on demand-driven consolidation. In this case, deliveries were made by the same supplier or carrier agreeing on a mutual delivery day or time, avoiding to consider retailer's preferences to plan the deliveries. Also Binnenstadservice (BSS) represents a successful example of UCC that gives more importance to receivers rather than carriers (Van Rooijen and Quak 2009). Small and independent retailers are involved in BSS. Deliveries are performed by environmentally friendly delivery vehicles for free. A range of other extra services with fee are provided by BSS.

In fact, exactly as in the case of the UCC that serves the cities of Bristol and Bath, suppliers do not have any decisional power: receivers decide to join the scheme and suppliers have to make the deliveries to the UCC instead of to the receivers. A focus on two successful examples of UCCs in Europe is provided in the following sections.

3.2 The Nijmegen's Consolidation Center: Binnenstadservice.nl

Overview The UCC is Binnenstadservice.nl and it was established the 24th of April, 2008. According to Blom and van Nunen (2009), the difference with the others UCCs is that who initiated Binnenstadservice.nl is not the (local) government or a transport operator, but retailers. The UCC is located outside the city center and it is open 18 h a day. When the project started, only twenty clients joined the scheme. This number grew to 98 after only one year, with a corresponding growth of the delivered volume (Van Rooijen and Quak 2009). Binnenstadservice.nl provides not only transshipment, but also added services to the retailers, such as packaging, storage, and delivering to the end-customer. At the beginning these types of services were free of charge to encourage the retailers to use the UCC and the local government provided subsidies for the project. Retailers involved in Binnenstadservice.nl are the store-owners of independent stores only. The goods are ordered by the store owner to the shippers and the shippers make the deliveries to Binnenstadservice.nl. So the UCC, which receives goods from several suppliers, delivers in a single drop to the store-owner (Van Rooijen and Quak 2009). In this way, stores pay less to the shippers for the transport service and the money saved could be used to pay Binnenstadservice.nl for its services. By bundling the deliveries from multiple suppliers for the store-owner and delivering the goods at the time the retailer wishes, Binnenstadservice.nl offers a service that saves the time of the retailers of small stores. It only manages 'easy products' (i.e. no fresh food) and small deliveries. Environmentally friendly vehicles (such as electronic tricycles and natural gas trucks) are used to make the deliveries in the city center to reduce pollution.

Benefits and Limitations By paying an extra fee, retailers can receive extra services such as: storage, home-deliveries, value - added logistics including reverse logistics. Binnenstadservice.nl is innovative because it can perform deliveries also to other cities. It has been subject to a great deal of studies, which aimed at finding a solution of self-financing; in fact, during the first year it received a governmental subsidy. By the end of the trial period (first year), Van Rooijen and Quak (2009) highlighted positive impacts related to it (e.g. reduction in terms of number of goods vehicles and kilometers travelled in the city center), which increased in the period after. However, the improvement of local air quality and noise is limited due to the large number of cars and buses. The positive results of Binnenstadservice.nl in Nijmegen gave rise to some franchise initiatives in other Dutch cities (e.g. BSS already started business in Den Bosch, without subsidy). By expanding the Binnenstadservice.nl concept to other Dutch cities, BSS becomes a more interesting partner for carriers, which could result in new revenues for itself.

3.3 The Parma's Consolidation Center: Ecocity

Overview The Ecocity started working on March 2008, being the first one in Italy and Europe to deliver perishable food. It is located 5 km away from the city center, exactly as other efficient Italian urban freight consolidation centers such as Padua, Modena, and Vicenza. In Parma, 55% of the pollution produced by road vehicles is related to freight transport. Since 40% of goods are delivered to the city center, local authorities decided to establish the consolidation center. It is managed by a private company. However, to be successful, the scheme is supported by the implementation of access restriction policies by the public authority. Local authorities of Parma pursued three objectives (Morganti and Gonzalez-Feliu 2015):

- Reduction of air pollution, greenhouse gas emissions, waste and noise to avoid negative impacts on the health of citizens or nature;
- Improvement of resource and energy efficiency and cost effectiveness of goods transport, by considering external costs;
- Improvement of the attractiveness and the quality of the urban environment, by reducing the number of accidents and minimizing the road occupancy, without compromising the mobility of citizens.

The region of Emilia Romagna, the District of Parma, the Municipality of Parma and the publicly held company Infomobility invested 2M of Euros in the Ecocity project. This investment allowed paying the research work and pilot studies as well as the purchase of the vehicles and equipment.

Benefits and Limitations The case of Parma represents a successful example; it is probably one of the few cases of food consolidation center. Food deliveries are exigent both for delivery frequency and time. Morganti and Gonzalez-Feliu (2015) analyzed the consolidation center of Parma. They pointed out that food deliveries are usually daily and the average frequency is extremely varied: it ranges from 1 to 3 deliveries a day for small retailers (e.g. grocery stores) to 7–10 deliveries a day for large food outlets, depending on the size and the diversity of the supplied goods. Hypermarkets are the bigger receiver points, with about 20–30 commercial vehicle trips a day. Also, food deliveries are usually made by own account transport carried out by food suppliers, producers or shop-owners themselves. The analysis pointed out that the majority of the customers involved in Ecocity are small retailers related to the Ho.Re.Ca. (Hotels-Restaurants-Catering) sector, which is often seen as the most difficult segment to coordinate and change. On average, 40 tons of food products per day are delivered by Ecocity within the city center. Results show that after 3 years, there are 16 transport operators and carriers, 17 food manufacturers and suppliers (fresh and dry products), 7 corporate chain retailers and 10 produce wholesalers. The receivers are about 250 food businesses and food services, Ho.Re.Ca. establishments, grocery stores, corner shops, specialized stores, corporate retail points-of-sale (mostly superettes), which require daily deliveries of fresh and dry food products. Deliveries are performed by means of 3.5 tons vans powered by methane-fuel. Suppliers and transport operators have to deliver to the freight consolidation center and then 14 vehicles deliver the goods to the receivers in the city center. When needed, goods with temperature control constraints are managed by refrigerated warehouses and vehicles.

Deliveries of fresh food products represent a significant proportion of urban freight transport. However, probably because of the cold chain and of their quality preservation, costs related to the delivery of perishable goods are very high. This reason together with the shortage of available space for refrigerated platforms make such city logistics schemes extremely difficult to be implemented. Nevertheless, due to the low level of consolidation of fresh products with respect to the other types of goods delivery, the potential benefits of improved logistics can be high. According to Morganti and Gonzales-Feliu (2015), the main obstacles to the success of the application of these schemes to fresh products deliveries are:

- The delivery size (small) and frequency (high);
- The organization of the network (a good deal of receivers which are spread around the city);
- The complexity of logistics activities (carried out by wholesalers, suppliers and shopkeepers).

Third-party logistics and transport operators turned out not to be appropriate for last mile deliveries of food products. Moreover, in the case of Parma, light good vehicles (LGVs) used for fresh food deliveries use approximately 25% of their loading capacity and deliveries are of small size, due to the small storage space of the outlets (Morganti and Gonzalez-Feliu 2015).

4 Stakeholders' Commitment: Integration and Collaboration for a Successful Implementation of Sustainable Urban Freight Schemes

Due to the reasons explained above, city logistics policies can only be developed in a multi-stakeholder environment. All the stakeholders involved have different needs and expectations (Taniguchi and Tamagawa 2005; Tseng et al. 2005; Kiba and Cheba 2011), thus a coordinator is needed to manage and improve the urban system (Witkowski and Kiba-Janiak 2014). This role has generally been taken by local authorities, who represent one of the most important groups of urban freight transport stakeholders. A key reason why local authorities are normally involved as policy-entrepreneur in the context of city logistics is that participation is voluntary, so charges must be attractive, and hence revenues are low, which means subsidy must be provided by, or be procured by, the local authority (Fig. 2).

However, despite the potential to make a contribution to urban sustainability and economic vitality, many local authorities in EU countries still do not treat urban freight transport as a priority (Kiba-Janiak et al. 2015). Also, cost allocation and producer surpluses for the logistics companies, create a problem for the viability of UCCs as an effective policy idea and sustainable mobility practice.

Significant efficiency savings (e.g. amount to net social benefits) have been identified from the operation of the UCC of Bristol (UK), suggesting that the lack of a thriving UCC implementations is due to market failure (Paddeu et al. 2014), which can be considered as scenarios where individuals' pursuit of pure self-interest leads to inefficient results that can be improved upon from the societal point of view (Ledyard 2008; Krugman et al. 2007). The limited availability of subsidies do not allow subsidized UCC schemes for long periods, consequently the majority of them have a short lifespan (Browne et al. 2005; Van Duin 2009). Therefore, the identification of relevant stakeholders and their objectives is essential to designing a business model for a shared system that can be more permanent (Zenezini et al. 2015).

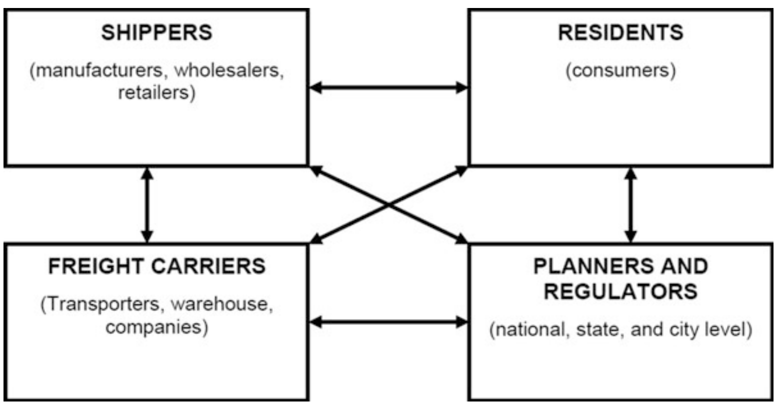

Fig. 2 Key stakeholders in urban freight transport (Taylor 2005)

Actors	Goals
Retailers, traders, manufacturers	• Fast deliveries and known schedules • Acceptable costs • High frequency of deliveries
Consumers	• Accessibility of shops • Affordable prices in urban centres
Transport operators (on own account)	• Freedom of self-provision • Freedom of hawking • Freedom of supply services in urban centers
Transport operators (3PL)	• Freedom of provision of efficient and effective distribution services, with minimum restrictions • Participation in the decision process for issuing restrictions for most polluting vehicles • Recognise the organisational effort to keep loading factors high.
Logistics, terminals, real estate operators	• Involvement in city logistics programming • Supply of areas for Urban Distribution Centres (inside and outside the city centre) • Supply of logistics services

Fig. 3 City logistics actors and goals (Vaghi and Percoco 2011)

Many potential receivers are reluctant to pay for the service because they do not perceive the added value of the UCC scheme. This is because the most tangible benefits in terms of cost savings arise to the logistics companies and also because not all potential participants in a UCC have a need for additional or different services (Zunder and Ibanez 2004; Marcucci and Danielis 2008). According to Janjevic and Ndiaye (2016) receivers that provide their own deliveries are most likely to benefit from the use of a UCC due to the inefficiency of their own delivery operations.

Access restriction policies (e.g. access restrictions for freight vehicles in terms of time-windows or routes, etc.) can represent an incentive for suppliers and receivers to join the scheme (Verlinde et al. 2012). However, despite such restrictions, many carriers prefer not to use the UCC and directly supply their customers because they perceive it as increasing their costs and reducing their profitability (Van Rooijen and Quak 2010). On the other hand, receivers need to be persuaded to participate because of additional costs and inferior service standards. On the contrary a high-potential opportunity is related to new shopping area developments (Triantafyllou et al. 2014). Suppliers and receivers should be convinced about the reason to change the current situation and to join a UCC scheme, because they usually are not fully aware of their responsibility for the environmental impacts associated with the deliveries they make/receive (Van Rooijen and Quak 2010). For this reason, stakeholders involved in the urban context should be informed about the reasons for implementing city logistics policies and freight traffic restrictions in urban areas (Koehler 2004; Patier 2006; Van der Poel 2000; Van Rooijen and Quak 2010) (Fig. 3).

Despite the benefits they receive by joining a UCC scheme, stakeholders would not be willing to participate because they do not want to change their delivery habits (Verlinde et al. 2012) and also because they do not want to share logistics and transport resources (e.g. warehouse, delivery vehicles, etc.) with competitors

(Fancello et al. 2017), or indeed to divulge confidential corporate information about competitive best practices (AECOM 2010). However, only the awareness of 'common interests and benefits for stakeholders' can allow effective cooperative schemes (Kiba-Janiak et al. 2015). For this reason, local authorities should know stakeholders' expectations and problems to design a system that is able to work within a long-term cooperation (Kiba-Janiak et al. 2015).

5 The Receivers and Their Key Role in the Urban Freight Context

In spite of the importance of both carriers and receivers, the latter are the most powerful agent for the success of a UCC implementation (Holguín-Veras et al. 2008). In fact, receivers decide the way they are delivered and suppliers and carriers conform as much as possible to the needs of their receivers, who are the main customers (Holguín-Veras et al. 2005). For this reason, changing the behaviour of receivers leads to upstream impacts on supply chains (Holguín-Veras and Sánchez-Díaz 2016). Receivers are usually more willing to join a UCC scheme because it improves the quality of the city environment (i.e. customers can enjoy more shopping if there are fewer motor vehicles in the area (Verlinde et al. 2012; Holguín-Veras and Sánchez-Díaz 2016). Also, they tend to accept city logistics policies if they receive monetary incentives or tax-reductions (Holguín-Veras et al. 2008).

The limited knowledge of the relevant factors influencing receivers' choice of delivery is still the main reason why appropriate policy instruments have not been put in place to effectively influence their behaviour (Holguín-Veras et al. 2008). Holguín-Veras and Sánchez-Díaz (2016) found a lack of knowledge about the roles played by the various economic agents involved in supply chains, which does not provide indications about the most effective ways to make a change. In general, adaptations on behalf of the receivers have resulted in UCCs being successful in several cases (Verlinde et al. 2012; Van Rooijen and Quak 2010). However, according to Stathopoulos et al. (2012) the policies aimed at receivers of goods are a much less studied issue and there are very few contributions considering city logistics policies explicitly focused on commercial receiver activities. Due to this and the key role assumed by receivers in the success of the implementation of sharing logistics systems highlighted in the previous sections, the next section focuses on a successful UCC implementation from the UK.

6 A Successful Example of UCC: The Bristol and Bath Urban Freight Consolidation Center (BBUCC)

6.1 Description of the BBUCC Scheme

Bristol is the largest city in South-West England. It was involved in three European projects that considered the use of a UCC:

1. CIVITAS VIVALDI (2002–2006);
2. START (2007–2008);
3. CIVITAS-RENAISSANCE (2008–2012 - demonstration project operated from January 2011 to June 2012).

The third project indirectly involved Bristol, because it concerned the neighboring city of Bath. However, due to the excellent results of the first and the second project, Bristol City Council decided to financially support the BBFCC to continue making deliveries to the receivers of Bristol. Also, with the aim of incentivizing new receivers to join the scheme, local authorities implemented traffic and access restrictions in Bristol. Due to its longevity, the BBUCC represents one of the most successful schemes in Europe. It is managed by DHL and deliveries are made by means of two Smith Newton 9-tonne-electric vans. It is located in Avonmouth, 20 min from Bristol city center. BBUCC is a cross dock center, where goods are unloaded by heavy goods vehicles coming from every part of the UK and then are loaded into full load electric vans and delivered to the city center.

BBUCC offers a wide range of added value services, such as just-in-time deliveries, storage, pre-retailing, crisis stock management, drip feed of stock, recycling of packaging – i.e. cardboard and plastics (Paddeu 2017). The receivers participating in the scheme are 81 in Bristol and 25 in Bath. They are part of big companies: 49 receivers translate into 106 outlets in total (Paddeu et al. 2017). The BBUCC periodically runs marketing campaigns to involve more receivers in the scheme. However, probably they are not effective because potential users do not see the need to change and join the scheme.

6.2 Costs

Unfortunately there is a limited availability of information on costs, benefits and subsidies received because they are commercially sensitive. However, it was possible to understand which cost items are the most impactful. Human resources represent the most significant cost. The BBUCC uses 2 electric vehicles to make the deliveries. They cost 90.000 £ each, whereas a diesel vehicle is £45.000 each. The electric vehicles cannot do a large route (120 km per charge), so are appropriate for the delivery route made to and from the BBUCC. Local authorities wanted to invest money for the use of the electric vehicles, so it was a good decision for the

BBUCC. The highest cost is represented for the drivers' wages, manager's wage and warehouse personnel's wages. It can be quantified as less than half a million pounds per year. The BBUCC pays a rent to DHL to be able to use the warehouse, which is property of DHL. All the money received by the BBUCC (public subsidies and receiver's fees) are used to cover costs.

6.3 Pricing Scheme

During the trial period within the European projects where the aim was to encourage receivers to join the scheme, the delivery service was free of charge thanks to the European subsidies. When the trial period ended, Bristol City Council (BCC) and Bath and North East Somerset Council (BNEC) contributed to finance the project. In fact, they pay a charge every month depending on the number of deliveries performed. At the moment they have a closed book contract with the BBUCC and so they pay a fixed price every month. Due to commercial confidentiality they normally do not publish the exactly amount. However, funds provided by Bristol City Council (BCC) and Bath & North East Somerset Council (BNESC) are not sufficient to cover all the costs of the BBUCC. For this reason, receivers started paying a fee for the service they receive from the BBUCC and they still pay for the service. It is possible to pay by pallet, by cage, or by box. The official charges for the RENAISSANCE project are £9 per cage and £12 per pallet, but they are not fixed.

In fact, charges depend on the commercial agreement signed between DHL and the receivers involved in the scheme, which is dependent on the amount of goods managed and delivered. Despite the charge introduced, no one left the scheme after the European projects ended, because they recognized the benefits from the service provided by the BBUCC (Paddeu 2017). To date, the BBUCC has been operating thanks to public subsidies. However, BCC and BNESC declared they want to stop providing subsidies to the BBUCC, thus the operation of the scheme could be compromised. This is mainly due to the "framework" of the users involved: receivers on the one side and suppliers/carriers on the other side. In fact, they all belong to big multiple chains, thus they pay only from one side (receivers pay, suppliers/carriers do not). When public subsidies stop existing, both sides (receivers and suppliers) must be required to pay for the BBUCC to be economically sustainable. However, being the same "entity" (same company), charges would be perceived as if they are paid twice. For this reason, it could represent the main cause responsible for the end of the BBUCC.

7 Estimation of the Sustainability Improvement Due to BBUCC

Paddeu et al. (2014) analyzed the environmental benefits provided by BBUCC. In fact, based on data of deliveries performed by BBUCC during a period of 17 months, they estimated polluting emissions and reductions in the number of vehicles. Also a Multiple Linear Regression model was developed to investigate the relationships between the number and the type of heavy goods vehicles delivering to the UCC and the number of deliveries. The evaluation pointed out a reduction in the number of deliveries by 74%. The most effective design for the BBUCC was a cross-dock approach (delivery in - delivery out). Emissions reductions in Bristol are identified as a result of sharing delivery vehicles for the final leg. Reductions of 28,677 kg of CO2, 122.29 kg of NOx, 2.31 kg of PM10, 20.32 kg of CO and 9854 kg of fuel were achieved thanks to BBUCC for the whole period considered. However, due to out-of service time of the electric vehicle, it was substituted by a diesel vehicle to make the deliveries and so reductions could have certainly been higher if the deliveries had been made by electric vehicles only. However, although the emissions reductions are potentially significant, they are currently limited by the small scale of the UCC. Also, a significant reduction in the number of HGVs in Bristol city center was calculated, with a mean of 75.5% with a peak value of 80.19% in April 2012.

8 Investigating the Point of View of the Receivers

Due to the key role of the receivers in the UCC scheme, this section provides a focus on the point of view of the receivers participating in the scheme in Bristol. A survey was carried out in 2013 with the aim to define the characteristics of the delivery service provided by BBUCC and investigate the perception of the receivers. To achieve more reliable results, the survey was addressed to the users who regularly use the service in Bristol, so it was limited to 21 receivers. The sample composition was as follows: 38% entertainment and technology stores; 24% clothing and footwear stores; 14% cosmetic stores; 10% food and drink stores; 10% household goods stores; and 5% jewelers.

All the goods delivered to the receivers surveyed have the same ‘delivery needs’ because perishable goods are not delivered by the BBUCC (Paddeu 2017). The receivers involved in the survey were asked to indicate their perception about the benefits they receive from the BBUCC. In general, the majority of the interviewees (95%) declared being highly satisfied with the overall delivery service provided by BBUCC. They perceive delivery to stock room and security of delivery as very important benefits for their businesses.

In fact, BBUCC directly delivers goods to the stock room, allowing receivers to save staff working time. Receivers perceive it as an economic advantage to their businesses, because they do not need a large space to stock the goods into the stock room due to the UCC; thanks to this, they can reduce the size of the stock room and use almost all the space available directly for sales activity.

They are very satisfied with the time and the frequency of the deliveries. However, Paddeu et al. (2017) found out some receivers complained about the impossibility to set the delivery time. This point was clarified with the BBUCC manager, who explained that they have the possibility to set delivery times by paying an extra fee. So, receivers who complained probably are not willing to pay more; on the other hand, receivers who did not complain (who represent the majority of the interviewees) recognized setting a delivery time as a benefit for their business, because they said they can receive goods at the time they want, during off-peak times. In this way, they can optimize their working time and improve the efficiency of their working staff. Receivers were also asked to indicate the importance to receive deliveries made by an electric vehicle. Receivers belonging to multiple retailer chains declared that this is in line with the ethical principles of their company and it provides a green image to their business. The other receivers (the smallest part of the sample) declared it is not important for their business, but they recognized it is important for the protection of the environment and for our wellbeing in general.

Finally, the results of the survey allowed identifying the key importance of human relationships. In fact, all the receivers interviewed expressed positive comments about the delivery staff. When they were asked to indicate positive and negative aspects of the service provided by the BBUCC, all of them recognized the professionalism and the helpfulness of the staff, who was considered always friendly and polite. Some receivers declared they will continue using the service also because they like and rely on BBUCC staff.

9 Conclusion

Thanks to the reduction in terms of polluting emissions and the number of delivery vehicles, UCC schemes can significantly improve the quality of life of urban areas. However, there is a limited number of analysis on the benefits available in the literature. This gap makes it difficult to determine the effectiveness of this types of schemes. The review of 67 UCC schemes, allows Browne et al. (2005) to conclude that in general the greatest potential for the success of a UCC scheme is to meet one or more of the following five criteria: (1) Strong public sector involvement in encouraging the use through a regulatory framework; (2) Significant transport problems in the area; (3) Bottom-up pressure from local interests; (4) The logistics problems that are solved should be associated with a site that has single manager or landlord; (5) The availability of funding. Then, they recognised four requirements to be economically viable (Browne et al. 2005): (1) Critical mass of users and volumes; (2) Stakeholders should be willing to use the UCC; (3) Additional services to gain extra revenues; (4) No dependence upon subsidies.

The urban freight environment involves different stakeholders with different needs and expectations. Broadly speaking, both receivers and suppliers benefit from the UCC; in fact, receivers can receive high quality deliveries and added value services, whereas suppliers can save time and money. However, the complexity of the stakeholders structure and the difficult collaboration is probably the main cause of the failure of these schemes, which are not overcome in the trial phase (Van Rooijen and Quak 2010).

Receivers have been widely recognized as the key stakeholders in the urban freight system. The analysis of the point of view of the receivers participating in the scheme in Bristol allowed identifying what kind of benefits they perceive. In general, they are highly satisfied with the overall delivery service provided by the BBUCC. They recognized the benefits from the BBUCC, in particular because they can receive deliveries directly to the stock room, so they can save time and improve their staff's work efficiency. They also recognized setting a delivery time as an important advantage, because they can decide to receive goods during off-peak times, when a low number of customers are at the store. A significant result of the survey is the importance of the relationship with the delivery staff. Receivers declared being very satisfied of the delivery staff and the satisfaction in this area represents an incentive to continue using the scheme. Drawing on the experience of Bristol, local authorities who want to successfully implement policies for sustainable urban freight mobility, should define a specific framework with the needs and expectations of all the stakeholders involved in the process. In fact, only the clear awareness of stakeholders' needs can provide the basis for designing a collaborative system that can be accepted by all the actors involved.

10 Direction of the Future Research

The paper highlighted the key role of the receivers for a successful implementation of a UCC. However, new innovative aspects such as transparency issues, governance models, new pricing models need to be considered in the future research in this field. In fact they could potentially increase the attractiveness of UCCs by receivers despite the cost induced by the end of subsidies. Business models of multi-stakeholder collaboration systems should be investigated and designed to explore the opportunity to make UCCs economically sustainable.

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Urban Vehicle Access Regulations

Osvaldo Navarro Lopez

Abstract Urban Vehicle Access Restrictions (UVARs) contribute to addressing several challenges that markets alone are not able to address. They are based on access time, allow certain types of vehicles or regulate access on emission levels of the vehicle, the loading factor, road use (size), parking capacity or loading and unloading operations. The chapter makes an in-depth analysis of the conditions and key success factors for several selected UVAR schemes and solutions. To this end, existing literature (scientific, sector-related and policy documents), best practices and interviews with relevant stakeholders are analyzed and useful conclusions are revealed.

Keywords City logistics · Low emission zones · Congestion charging · Urban Consolidation Centers · Cargo bikes · Carbon footprint

1 Introduction

An efficient urban transport system is essential for sustainable economic development in urban areas. Urban goods transport is now facing many difficult challenges due to:

- Increasing urbanisation;
- Increasing demand for frequent and just-in-time deliveries in urban areas, including at consumers' homes; new urban supply chains;
- Increasing competition for the use of limited urban infrastructure;
- Increasing complexity of the multidisciplinary problems both encountered and caused by urban goods transport.

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Policy-making for urban goods transport is particularly complex and difficult due to the following features:

- Conflicting and diverse requirements of a wide range of participants;
- Complex and diverse operations of urban goods transport and the various problems caused therefrom;
- Lack of expertise from urban practitioners and policy makers.

Therefore, a smooth urban freight distribution might increase the liveability of cities. Transport effectiveness and efficiency not only affect local and regional productivity rates, they also have an impact on citizens' quality of life (Albate and Bel 2009). In the optimal situation, cities are supplied with minimal negative freight transport effects.

There are many challenges to consider when developing long-term city planning, encompassing economic, social and environmental ones. A first one is emissions. A very important contribution to emissions from recurring congestion comes from urban freight distribution (Figliozzi 2011). Urban freight transport's fuel combustion contributes to exhaust emissions such as CO_2, SO_2, CO, volatile organic compound, non-methane organic compound, methane, NOx and particulate matter (PM). Approximately 40% of the CO_2 emissions in Europe comes from urban freight traffic (Bektas and Van Woensel 2015).

Emissions tend to vary per the vehicle speed, acceleration, number of deliveries, fuel type, distance driven, payload, road conditions and the vehicle's engine. Euro standards as defined by the European Union (EU) (Kirschstein and Meisel 2015; Paddeu et al. 2014; Teo et al. 2014), which were introduced in the EU as of 1993, define the acceptable limits for toxic exhaust emissions of all new motor vehicles sold in the EU Member States. At present, they cover emissions of NOx, hydrocarbons, CO and particulate matter. For each vehicle type, different standards apply. For light-duty vehicles (LDV) (cars and light vans), the emission standards currently in force are the Euro 5 and Euro 6, covered by Regulation 715/2007. For heavy duty vehicles (HDV) (lorries and buses), the standard in force is the Euro VI, covered by regulation 595/2009[1] (Unit 2015).

It has been widely documented that vehicle emissions may contribute to severe health and environmental problems (Fontes et al. 2014; Henschel et al. 2015; Popa et al. 2014). Thus, it is no longer acceptable to neglect these challenges locally when developing long-term city planning (Corburn 2015).

In addition to health and environmental challenges, urban logistics operations such as parking, loading and unloading can lead to other challenges such as road safety and compliance with traffic rules. Scholars have identified key reasons leading to increasing societal impacts (Alho et al. 2014; Marcucci et al. 2015; Vidal Vieira and Fransoo 2015):

[1]The following convention generally applies: standards for LDV use Arabic numerals (1, 2, 3 . . .), while standards for HDV use Roman numerals (I, II, III . . .). When a standard applies to both types of vehicles, we use Arabic numerals.

- Lack of collaboration, between logistics service operators and receivers, has contributed to problems such as traffic congestion and use of unsuitable unloading and parking areas.
- Pricing strategies, to foster a quicker turnover of vehicles to increase parking chances, can be enhanced by imposing a maximum parking limit or by adopting an escalating rate structure. For example, dynamic adjustment of on-street parking prices balanced demand and supply in different blocks within San Francisco, California.
- Parking enforcement becomes more important with articulated parking regulations, especially during peak-hours when violations are likely to concentrate. It requires monitoring, curb side management and physical barriers.

Other challenges, such as logistics sprawl should also be taken into consideration. Logistics sprawl may cause increased delivery distances, higher CO_2 emissions, and logistics staff having to move to a different location for work and, potentially, receive lower wages. On the other hand, local congestion may be more manageable as a result of the decentralisation of warehouses in suburban areas (Dablanc et al. 2014). These sets of problems tend to make citizens complain and request the elimination of freight from their neighbourhood. Yet harsh regulations on trucks would put businesses in urban areas at risk. Thus, the challenge is for policy makers to find the correct balance between freight traffic, liveability and people's safety in urban areas.

Balanced urban freight planning requires the engagement of all relevant stakeholders. However, meeting the conflicting and diverging interests of multiple stakeholders is a highly challenging goal (Cui et al. 2015). One main reason is that urban freight policies are usually not at the top of local policy makers' agendas nor are they taken into consideration by local businesses (Lindholm and Blinge 2014). Thus, it can be stated that whilst vehicle access regulation schemes can be used to control the access, time, size, or other characteristics of freight vehicles having access to or circulating within urban areas, to make these schemes successful requires policy makers to be engaged and other business stakeholders to disclose their needs, in order to jointly develop optimal city logistics solutions (Bhuiyan et al. 2015).

This chapter contributes by shedding light on the main characteristics of urban vehicle access restrictions (UVAR) applied to freight transportation from the point of view of economic, social and environmental sustainability. Furthermore, the chapter makes an in-depth analysis of the conditions and key success factors for several selected UVAR schemes and solutions. To that purpose, the chapter uses existing literature (scientific, sector-related and policy documents), best practices and interviews with relevant stakeholders.

2 Urban Vehicle Access Regulations

As defined in the European Commission Staff Working Document "A call for smarter urban vehicle access regulations (UVAR)[2]", are measures to regulate vehicle access to urban infrastructure. Access regulations for freight transport can differentiate on:

- Access time.
- Vehicle characteristics (tonnage, dimensions, age, Euro emission category).
- Load factors.

Access regulations can fall within three categories: prohibitions, which are command control measures; charging (pricing), where freight transport companies respond based on economic decisions; and prioritisation, providing incentives to use best practices (Comi et al. 2008). For example, in London, there is no charge for vehicles which emit 75 g/km or less of CO_2. Freight operators with more than six vehicles are eligible for a fleet discount. In Milan charges varies per the emission class of vehicles identified using the Euro class.

It is regarding these aspects that the policy maker can make choices when specifying the scheme (the UVAR characteristics), and make sure the scheme is optimally adjusted to the local circumstances and the nature and size of the problems. Moreover, a choice needs to be made on how to enforce the UVAR scheme.

2.1 Access Time

Access time regulation to urban areas is one measure that has become increasingly popular; especially in Europe. Access time regulations for delivering goods in urban areas, or so-called 'time windows' have become a somewhat common local phenomenon, especially in larger agglomerations. In some cities, the time windows have become gradually more strict following implementation (Quak and de Koster 2007).

For example, in Bucharest, freight vehicles over 5 tonnes can access the city centre only during a certain time window, and if granted a permit. The cost of this permit depends on the zone to access, and the weight of the vehicle. The Bucharest UVAR's main characteristics:

(continued)

[2]SWD (2013) 526 final.

– From 1 July to 31 August: between 20:00 and 07:00, vehicles over 5 tonnes can access and circulate the area only when possessing a permit; outside these hours, the vehicles cannot access the area.
– From 1 September to 30 June: between 19:00 and 08:00, vehicles over 5 tonnes can access and circulate the area only when possessing a permit; outside these hours, they cannot access the area.

2.2 Vehicle Characteristics

This scheme should specify very clearly how each individual freight vehicle is treated, based on transparent characteristics such as vehicle weight, size, age, and/or Euro norm emission class; However, there is a trade-off between the effectiveness of the vehicle characteristics scheme towards reducing negative societal impacts, and the overall logistics system efficiency.

For example, the logistics sector will react via changing behaviour. Businesses can invest in UVAR-exempted LDVs, for organising their last-mile deliveries.

Most of Europe's UVARs target larger freight vehicles only. Thus, when regarding the regional impacts, these UVARs are not always efficient. They often lead to an increase in the total amount of freight vehicles in cities, or in their surrounding region, thus increasing congestion. Therefore, the UVARs themselves may form an obstacle to better freight consolidation.

2.3 Load Factors

Less often, load factors are used as an UVAR criterion. UVARs with this criterion aim at reducing the number of LDVs and HDVs running below their maximal payload capacity increases consolidation of shipments. Consolidation increases logistics efficiency, reduces freight traffic and congestion, and improves overall environmental performance.

For instance, an UVAR in the city of Gothenburg allowed access in its first years (from 2007 on) to freight vehicles above 3.5 tonnes only if the driver

(continued)

could demonstrate the vehicle's payload exceeded 70% of its maximum payload capacity (Arvidsson 2013). This criterion was abandoned after 1 year, as enforcement proved to be too complex.

3 Preferred UVAR Schemes

In the Ecorys 2015 consultation (Maes 2015), stakeholders identified two preferred UVAR schemes for addressing local challenges related to urban logistics:

- Low Emission Zone (LEZ);
- Congestion Charging (CC);

3.1 Low Emission Zones

A LEZ defines an area with controlled access for certain vehicles. Specific access regulation criteria are based on vehicles emission levels and vehicle characteristics. Some LEZs only restrict access during certain hours of the day. LEZs have been implemented because of increased public health concerns, and supported by policymakers who do pay more attention to clean air policies. LEZ policies have typically targeted particulate matter (PM), starting with PM_{10}, which are significant contributors to pollution from vehicle emissions. Local policies follow European policy trends. EC Directive 2008/50/EC on ambient air quality and cleaner air for Europe included also air quality objectives for $PM_{2.5}$, including limit values and exposure objectives.

The implementation of LEZ schemes in Europe has followed different approaches, as can be seen from best practice cases in the UK, Sweden, Germany, Greece and Italy. These are briefly introduced below.

3.1.1 LEZ Best Practices

The implementation of the LEZ in London (United Kingdom) took place in four phases. In 2008, it applied to diesel vehicles weighing over 12 tonnes. Six months later, all vehicles with a gross vehicle weight (GVW) of over 3.5 tonnes had to comply with the Euro III PM standard which applied to

(continued)

HDVs only. In 2012, vans with an unloaded weight of over 1205 kg had to comply with the Euro 3 PM standard, which applies to LDVs while the standard for HDVs was raised to Euro IV PM. What defines the London LEZ, apart from its size and its inclusion of light goods vehicles, is its extensive use of Automatic Number Plate Recognition (ANPR) cameras (Dablanc and Montenon 2015). Today, the debate in London is centred around the Ultra-Low Emission Zone which is planned for 2020 and which intends to ban all diesel vehicles (including private vehicles such as passenger cars) which do not meet the Euro 6 standard in the zone currently covered by London's CC Zone (London T.f. 2014a).

In Gothenburg (Sweden), a LEZ was introduced in 1996, introducing emission controls for diesel PM and HC. In 2002, NOx control was added. Swedish LEZ are intended to prevent vehicles of more than 3.5 tonnes that do not comply with current emission standards from entering cities. The basic requirement for entering the LEZ was that all HDVs Euro II and III must not be older than 8 years. Vehicles certified for compliance with Euro IV classification could enter the environmental zone until 2016 (inclusive) (Trafikkontoret 2006). Vehicles certified for or complying with Euro V classification will enter the zone until 2020 (inclusive). The vehicle's year of registration is irrelevant for Euro IV and V vehicles. Adapted vehicles must meet all the emission standards of the set Euro standard. It is possible to upgrade a Euro II and Euro III vehicle to Euro V via retrofitting emission control devices such as particulate trap with Selective Catalytic Reduction, approved by the Swedish Transport Agency (SadlerConsultants 2015).

In Germany, the first LEZs were introduced in Berlin, Cologne and Hannover in 2008. The German government has categorised all vehicles into four mutually exclusive classes per PM_{10} emissions. Coloured stickers showing the emission group of a vehicle were introduced to identify low-emission vehicles. Every vehicle in an environmental zone in Germany must display the required sticker on the windscreen, making it easy to monitor the environmental zone. The stickers apply in every low emission zone in Germany. Each city specifies which sticker is required to drive in its environmental zone. As of 2015, 83 German cities had implemented LEZs, restricting access of vehicles to the LEZ based on the emission class, as indicated by the colour of the windscreen sticker. Only two out of the 83 LEZs did not require the green sticker equalling EURO 4.

The Athens LEZ in Greece is only effective from September to July each year, with different UVARs for the city centre and for the rest of Athens. Vehicles up to 2.2 tonnes can enter the city centre on alternating days depending on the last digit of the licence plate. In the whole of Athens, vehicles over 2.2 tonnes, and first registered before January 1991, were banned in 2013, when the LEZ was established. Each new calendar year, the banned vehicle registration date is increased by 1 year, gradually exempting only the newest vehicles.

In Italy, the air quality problems became primordial in the introduction of LEZs (Dablanc and Montenon 2015). Italian LEZ regulations are diverse, even within a city, because each municipality has the freedom to decide its own criteria. For example, in Rome, some LEZs require payments while others impose night-time regulations on certain types of vehicles. Moreover, zonal boundaries vary per the time of the day and to the day of the week. This diversity in regulations leads to overlaps and a large number of exceptions (Dablanc and Montenon 2015).

Milan LEZs include Area C (Circle of Bastions), Paolo Sarpi and Naviglia. Area C is delimited by openings with 43 cameras. From the 1st January 2016, freight vehicles Euro III can no longer access to Area C. In the LEZ Paolo Sarpi the transit and parking is forbidden of vehicles used for freight transport between 00.00 and 24.00 on all days of the week (Milan C.o. 2016).

3.1.2 LEZ Impacts

In general, determining the impact of local LEZs on air quality is difficult, due to (i) meteorological influences, and other factors such as (ii) the amount of traffic, (iii) the changing nature of the total vehicle fleets regardless of LEZs, (iv) other policies such as the introduction of vehicle scrappage schemes (i.e. stimulus schemes to seduce consumers to buy newer vehicles and shred the former ones), (v) the changed composition of traffic close to the monitoring stations as well as (vi) dynamic changes in vehicle flows.

Nevertheless, Table 1 describes some local impacts of LEZs.

In Gothenburg (Sweden), the LEZs had the greatest effect on HDVs with a total weight of under 16 tons: PM_{10} from these lorries reduced by 67% (Trafikkontoret 2006). In Germany the average LEZ-scheme led to a decrease of PM_{10} by

Table 1 Local impact of lezs

Impacts	European cases
CO_2	Milan (−22%. 2002/2008)
	London (−19%)
	Stockholm (−18%. 1996/2007)
PM	Berlin (−15%, 2005/2008)
	Stockholm (−60%. 1996/2000)
	London (−12%)
NO_x	Berlin (−20%. 2007/2010)
	Milan (−10%. 2002/2008)
	Stockholm (−10%. 1996/2000)
	London (−12%)

Navarro and Vanelslander (2015)

approximately 9% in traffic areas, ranging from 0% for smaller LEZs such as Tübingen to a significant 15% in the case of a more populated LEZ (Berlin, with 1.1 million inhabitants) (Wolff 2014). It can also be observed that the decrease in PM_{10} has been larger for traffic stations inside the LEZs than for those outside (Wolff 2014).

There is currently an ongoing debate about the necessity of measuring LEZs benefits through $PM_{2.5}$ emission reduction instead of PM_{10}, however the available data is not sufficient, as monitoring of $PM_{2.5}$ is only at an early stage (Broaddus et al. 2015). Some experts are even suggesting that it may be more appropriate to assess the impact of LEZs in terms of the reduction in elemental carbon, black carbon (a fine carbon powder produced by the incomplete combustion of hydrocarbons) or black smoke (a marker for diesel soot or the organic fraction of particles) rather than PM_{10}, $PM_{2.5}$ or even PM_1 (Borjesson and Kristoffersson 2015).

It is also necessary to point out that a LEZ might influence non-complying vehicles (in this case the most polluting vehicles) to drive around the zone, as such polluting more in the surrounding of the area.

With respect to economic impacts, Transport for London reports that negative impacts on shipping costs, organisation of business, or the transport industry are not yet known for the London case (Giuliano and Dablanc 2013).

There is a clear impact of introducing a different system of enforcement: when the city of Amsterdam put a system of ANPR cameras in place for its LEZ in 2009, the compliance rate rose from 66% (2008) to 97% (2010).

3.1.3 LEZ Enforcement

European solutions and techniques for the enforcement of LEZs vary considerably from city to city. The choice for specific enforcement techniques will impact the rate of compliance. Two dominant European LEZ enforcement models can be identified: (i) visual surveillance using windscreen stickers and (ii) cameras with ANPR technology.

The fine for – illegally – entering a LEZ depends on various criteria. Owners of non-permitted vehicles in London, for example, are allowed access upon payment of a charge which ranges from £100 to £200 per day. If a non-compliant vehicle is caught accessing the zone, a fine is levied which ranges from £250 to £1000 per day.

The specific access regulations when implementing LEZs can be specified in or encouraged by a country's national legislation (Tögel and Špička 2014). Countries such as Germany, The Netherlands and Sweden have developed national LEZ frameworks to ensure a consistent approach and to increase the ease of driving across their country. However, each municipality has the option of establishing a LEZ or not and of determining its scope. In other countries, such as Italy, no national framework exists and for that reason each municipality determines its own criteria. Comparing LEZ schemes between EU cities remains difficult as the regulations differ from city to city.

In France, national legislation was passed in 2010 allowing large urban communities to introduce LEZs. After failing to promote LEZs, the law was changed in 2015, with more options provided to municipalities to implement LEZs. In July 2015, a LEZ was introduced which covers the whole area inside Paris' ring road.

3.1.4 LEZ Stakeholder Involvement

To decide upon the implementation of an LEZ, it goes without saying that various stakeholders need to be consulted. The main stakeholders are illustrated in Table 2.

Some logistics providers in London admitted that the introduction of an LEZ benefitted them, as it forced them to improve their efficiency, optimise their vehicle routing, and become involved in projects to increase the size of their vehicle fleet (Dablanc and Montenon 2015).

Table 2 Stakeholder involvement when implementing a LEZ

Stakeholders	Involvement when implementing LEZ
Shippers/producers	Need to be consulted over existing shipments, and the related logistics procedures and routing.
Wholesalers	Idem
Logistics providers	Most directly affected by new schemes. They should be consulted on existing solutions for last mile deliveries, on existing use of transportation vehicles and of the feasibility of the proposed transition scheme (London T.f. 2008; Lutz and Rauterberg-Wulff 2009)
Retailers	To be consulted on flexibility in delivery times and delivery mechanisms
Consumers	To be consulted on possible impacts on shopping behaviour or other logistics related issues
Authorities	Fine-tuning of UVAR is the overall institutional framework
Citizens	Inhabitants and visitors. To be consulted on balancing possible negative impacts (in and outside the UVAR-area)

3.2 Congestion Charging

Congestion charging is the second preferred way to regulate freight flows in an urban area. Analysis shows that, in Europe, CC policy is less often implemented than LEZ schemes. Researchers have observed that especially low acceptance of road pricing is the main obstacle to its implementation, although its potential efficiency is generally appreciated.

3.2.1 CC Best Practices

An overview of CC schemes shows the different approaches which have been implemented across the EU for freight transport, illustrated by examples from London, Milan, Gothenburg and Rome.

In the UK, London introduced a CC since February 2003 covering London's central business district, over an area of eight square miles. All vehicles entering the zone are required to pay a daily fee during business hours (07:00–18:00). There is an exemption for vehicles which emit 75 g/km or less of CO_2. Freight operators with more than six vehicles are eligible for a fleet discount of £1 per vehicle per day (2015).

In Milan, a CC scheme – called ECOPASS – was introduced in January 2008. In 2012, ECOPASS was replaced with AREA C. The area under the scheme covers 8 km^2. Vehicles are granted access between 7.30 am and 7.30 pm if they have paid the daily charge. The latter varies per the emission class of the vehicle identified based on the Euro class. Charges apply to both passenger and freight vehicles.

In Gothenburg (Sweden), a CC was introduced in 2013. Its operating cost, including cost for maintaining the technical system, customer service and invoicing, was approximately €12 million for the first year of operation. This corresponds to 17% of the revenue generated by the scheme on a yearly basis.

Table 3 Local impact congestion charging

Impact	European cases
Road congestion	London (−39%. 2003 vs. 2007)
	Milan (−28.6%. 2015 vs. 2011)
	Stockholm (−29.1%. 2006 vs. 2011)

Navarro and Vanelslander (2015)

In Rome, there is a CC scheme in the inner area including the historic centre. The area covers 4 km^2 and is subject to access regulations between 6.30 am and 6.00 pm. Freight vehicles pay the same charge as passenger vehicles. To be granted a permit for goods delivery and/or maintenance work, operators must provide documentation which includes signed contracts with the customers located in the CC area.

3.2.2 CC Impacts

Table 3 illustrates the impact of currently existing CC schemes in some EU cities.

The first ex-post evaluations of the Milan CC scheme, requested by the city, have shown a decrease of approximately 18% in the number of freight vehicles entering a charged area compared to the pre-scheme period, probably mainly due to a reduction in transit traffic. There is also evidence that there has been a change in the composition of the circulating fleet with an increase in the number of vehicles in the less polluting classes. Since 2008, the share of freight vehicles and private buses exempted from payment (low emission types) in the total number of commercial vehicles has increased from 26.5% to 43.1% of. This indicates that the incentives created by the schemes for operators to use less polluting vehicles have been effective (Comi et al. 2008).

Freight traffic in London has however proven to be quite price-inelastic. Between 2005 to 2006, when there was a 60% increase in price, a 3–10% decrease in goods vehicle traffic was observed. This implies price changes do not have any effect on goods vehicle traffic. From 2010 to 2011, after a price increase by 25%, the number of LGVs declined slightly, but HDV traffic increased, implying that they are still inelastic to the price levels at that stage. Furthermore, average travel speeds inside the CC have fallen back to pre-CC levels over the decade since it was implemented, mainly due to road space reallocation to bicycles and signal timing changes prioritising pedestrian safety (Broaddus et al. 2015).

The London case, which reduced road congestion by over 30%, is an interesting example of how the freight industry negotiated with Transport for London regarding the fee for HDVs. The industry wanted to be exempted from paying, as there is no alternative mode of transport (goods cannot be carried by public transport). Transport for London argued that HDVs should pay more than cars because they damage roads. The final decision was a compromise where trucks pay the same fee as cars do. Nevertheless, this compromise clearly explains the observed price inelasticity afterwards.

As the London case demonstrated, it is not easy to set the effective prices in a CC scheme for HDVs. HDV charges are more difficult to set than charges for passenger cars because of the complexity of devising charging schemes which cover the cost of transporting freight in terms of time – also known as 'transport value of time' – as well as considering multiple externalities such as pollution, damage to infrastructure or potential costs of accidents.

3.2.3 CC Enforcement

Enforcement of CC schemes is generally attained by ANPR schemes. The enforcement of the charging schemes in Rome and Milan is automatic thanks to electronic checkpoints at the CC zone entrance points (Comi et al. 2008).

In Gothenburg, the accuracy of number plate recognition improved during the first year with the percentage of correctly identified passages increasing from 80% in January 2013 to 94% in the autumn of 2013 (Borjesson and Kristoffersson 2015). Stockholm uses the same APNR technology as in Gothenburg. Also, London uses ANPR technology.

3.2.4 CC Stakeholder Involvement

The initial absence of sufficient public and political support may explain why many cities have not introduced CC despite high congestion levels in their urban area.

Support can be created by offering incentive schemes. For example, one of the factors for receiving public and political support for CC in Stockholm was an agreement with the national government granting Stockholm a major infrastructure investment package. This package was funded by the CC revenue, and matched by a national grant of an equal amount. This agreement inspired Gothenburg politicians to strike a similar deal, co-funding a large infrastructure package with revenues from CC (Borjesson and Kristoffersson 2015).

In theory, CC is an effective way of limiting emissions. However, cities themselves cannot influence demand for pick-ups and deliveries, and consequently CC has demonstrated in some practical situations more limited effectiveness (Giuliano and Dablanc 2013). Two important reasons for this are:

- One concern amongst businesses in the CC area, particularly small ones, is that CC imposes additional direct and administrative burdens both on them and on their customers/clients who may choose to shop/eat or do business where transaction costs are lower (London T.f. 2014b).
- There is also concern among retailers that CC adds to their customers' household expenditure, thus reducing the customers' disposable income. However, CC is

beneficial in helping to reduce both delays and the unreliability of journey times caused by congestion, two factors that currently discourage customers/clients from travelling to the charging area (London T.f. 2014b).

Stakeholder involvement for implementing a CC system is like the involvement as described for LEZs (see Table 2). Two additional issues of attention are to be considered:

- To ascertain the necessary pre-CC scheme support from public and politicians. CC is to be demonstrated to be a tool beneficial to society, rather than an instrument to generate revenue for the municipality (Eliasson 2014). Hence, the vital role of communication, marketing and information dissemination in the implementation process of a CC must not be underestimated (Noordegraaf et al. 2014).
- To pay special attention to the impact of the scheme on transit-flows.

The key success factors of the implemented London CC scheme are (Ison and Rye 2005):

- A lengthy participatory process which involved continuous and extensive public consultation.
- Visible responsiveness where the views of stakeholders were considered and led to modifications in the scheme.
- The range of exemptions is limited, which further smoothed the introduction of CC in the eyes of the stakeholders.
- Willingness to adjust price levels when impacts deviated from the objectives.

In addition to the well-known successful example of London, there have also been failures. One example was the rejection of CC by the citizens of Edinburgh in 2005, 2 years after the London CC started. Lessons learned from the Edinburgh case suggest (Rye et al. 2008) the need of:

– Drafting clear enabling legislation.
– Appointing a political sponsor.[3]
– Establishing clear objectives.
– Keeping the CC scheme simple.
– Engaging stakeholders from the beginning.
– Maintaining the active promotion of congestion charging benefits.

[3]The sponsor is an individual or a group who acts at the senior level to be an advocate for the project and ensure that the project delivers the desired outcomes, under the allocated resources. The sponsor provides internal political support and ensures right prioritization of available funds and resources.

3.3 Combining Low Emission Zones and Congestion Charging

An important consideration is whether the city wants to combine the access regulation based on LEZ with CC.

The city of London for instance has both: A Low Emission Zone (LEZ), hence based on vehicle characteristics, combined by a Congestion Charging (CC) scheme. The former only applies to most of the Greater London area, and the latter applies only to the London central area.

In Milan, the "Area C" UVAR combines a LEZ with CC. The policies apply to both passenger and freight vehicles, and restrict less environment-friendly vehicles to enter the city's urban area. Access is free for electric and hybrid, bi-fuel and CNG-powered vehicles. Entrance is prohibited to Euro 0 petrol vehicles and diesel Euro 0, 1, 2 and 3. Access is also banned to vehicles longer than 7.5 m (valid prohibition from Monday to Friday from 7:30 to 19:30) (Milan C.o. 2016).

3.4 Choosing an UVAR Scheme

The individual choice of a city for a UVAR scheme, and the access regulations therein, depends on the size and nature of the problems, and the objectives of the scheme.

Table 4 structures the main questions to be answered before opting for a specific policy. For example: when the problem is congestion, and freight vehicles' share in the urban mobility is high and when these freight vehicles are on average new, a CC scheme is the better choice.

4 Preferred Solutions

Three preferred types of solutions have been identified to assist in mitigating unwanted side-effects of UVARs:

- Urban Consolidation Centres (UCCs)
- Cargo Bikes (CBs)
- Off-hour Deliveries (OHDs).

Table 4 Choosing the best UVAR policy for your local problem

	LEZ		CC
Enforcement	ANPR	Manual	ANPR
Main problem of the urban area: Congestion or emissions?	Emissions		Congestion
Number entry points to the UVAR zone	High	Low	High
Size of the UVAR zone	Small	Large	Small
Share of freight transport in the zone (% of vehicle flows)	Low		High
Population density within UVAR zone	High		Low
Characteristics of urban area: Commercial, housing, mixed	Housing/mixed		Commercial/mixed
Share transit in % freight vehicles in total vehicle flows	High		Low
Availability of alternatives (e.g. a ring road, other modes)	Yes		No
Characteristics of the freight fleet: Old, new, mixed	Old, mixed		New

These three solutions can mitigate the impact of UVARs on the logistics sector, while still reaching the objectives set for decreasing congestion and emissions. We explore some of the advantages and disadvantages of these solutions, as well as some key success factors, implementation issues and impacts to be expected.

4.1 Urban Consolidation Centres

A UCC is defined as a logistics facility situated in relatively proximity to the geographic area that it serves (be that a city centre, an entire town or a specific site such as a shopping centre complex). Many logistics companies deliver goods to the UCC, and from the UCC consolidated deliveries are carried out to businesses within that area. Within the UCC, a range of other value-added logistics and retail services can be provided (Allen et al. 2014; Allen et al. 2007).

Figure 1 illustrates the urban distribution systems using a UCC. The UCCs have become more professionally organised (as seen by the involvement of experienced logistics companies), and the legal framework used for setting up delivery consolidation activity is becoming more robust (Leonardi et al. 2015).

4.1.1 UCC Best Practices

Notable examples of UCCs are to be found in Utrecht (Degenkamp 2013), Padua (Danielis et al. 2010), Vicenza (Ville et al. 2013), La Rochelle, and Monaco (Dablanc 2007; SUGAR 2011) among others.

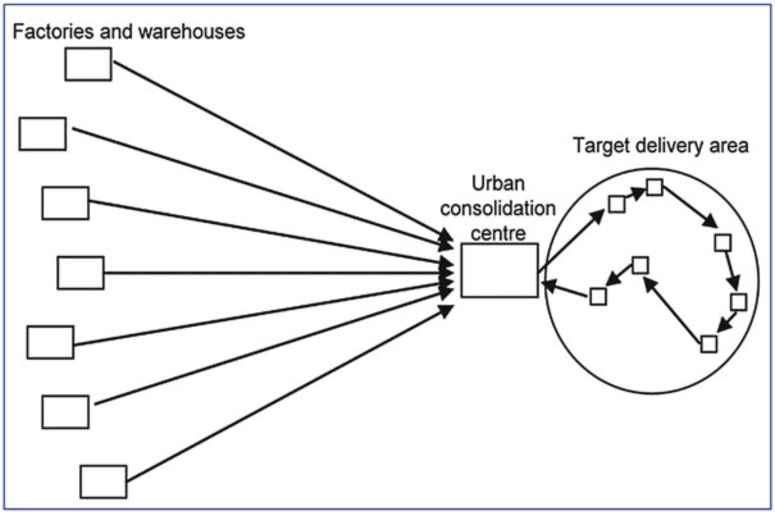

Fig. 1 Urban distribution systems with a UCC (Allen et al. 2014) (Source: Allen. et al. 2014)

In Italy, several active UCCs can be found. Among these, Padua's is one of interest. It is an example of EU good practice because it has been in operation since 2004 and has proven to be financially sustainable while being successful in reducing adverse environmental emissions.

An interesting legal case involving the city of Vicenza (Italy) and large parcel transport operators in 2008 demonstrated that there is a precedent for courts, at least in Italy, to accept cities' environmental justifications when imposing the use of a UCC on all external freight companies. A city that is actively considering implementing a scheme for consolidating urban deliveries must take additional financial and regulatory measures to guarantee a comparative advantage for the UCC. It is particularly important to accompany plans for a UCC with regulations favouring its use (Ville et al. 2013).

4.1.2 UCC Impacts

Table 5 describes some empirical impacts of European UCC projects.

Table 5 Local Impacts of UCCs

Impacts	European cases
CO_2	Brussels (−23%)
	London (−75%)
PM	Brussels (PM2.5–58%; PM10–22%)
Noise	Monaco (−30%)
Liveability	Monaco (−42% space used)
Road congestion / reliability	L'Hospitalet de Llobregat (load factors > from 68% to 73%)
	London (−70% freight journeys)
	Monaco (−38% congestion)
Commercial attractiveness	Bristol (100% on time delivery)
	London (delivery reliability 97%
Logistics costs	L'Hospitalet de Llobregat (−25%)

Navarro and Vanelslander (2015)

4.1.3 UCC Implementation

Two important factors which are critical to the success of a UCC scheme are:

- Level of demand. A sufficient UCC user and product delivery volume is required to drive down the costs per unit handled, thereby making the UCC competitive with traditional urban distribution systems.
- Fair cost and benefit sharing. UCC costs and benefits need to be shared between the various supply chain parties involved in the scheme.

In general terms, UCCs have the greatest prospect for success if they meet one or more of the following criteria (Browne et al. 2005):

- Availability of funding, since there is strong evidence to suggest that many UCCs without funding may fail.
- Strong public sector involvement in encouraging their use through the regulatory framework.
- Significant existing congestion / pollution problems within the area to be served.
- Bottom-up pressure from local stakeholders (e.g. retailers in a Street Association).
- Locations with a single manager/landlord.

4.1.4 UCC Stakeholder Involvement

However, many UCC case studies indicate that residents living close to a UCC are often the main opponents of UCC development for several rational reasons. The concentrated freight transportation may negatively impact the local community in terms of increased noise, reduced community vibrancy and safety despite the fact that a UCC creates employment in the local area (Ville et al. 2013). Addressing these issues and mitigating them as much as possible in the project development phase will enhance the support of this group of stakeholders.

4.2 Cargo Bikes

CB are used for final freight deliveries of smaller items. They can reduce congestion in cities and can be another solution for logistics operators to cope with UVARs. The vehicle characteristics range in payload from approximately 25 kg for conventional two-wheeled bicycles with a front basket or tray, to approximately 250 kg for three- and four wheeled cycles (equipped with rear-mounted boxes, cages or trailers). Electric bicycles can reach a speed of approximately 15 km per hour in free-flow traffic (Leonardi et al. 2012). The move towards shifting more goods by bicycle has led to a new range of different cargo bikes, some of which can carry up to 400–500 kg of goods and 2 m^3. Some are lengthened bicycles, so a large container can be fitted between the handle bars and the front wheel, while others have been fitted to take items that require refrigeration.

4.2.1 CB Best Practices

In Europe, examples of the use of CB for urban freight transport have, for example, been documented in France (especially in Paris), The Netherlands (Arnhem, Lochem, Nijmegen and Apeldoorn), Belgium (Antwerp and Brussels), Germany (Berlin), the UK (London, York, Nottingham, Cambridge) and Spain (Barcelona).

In Paris, over the past 10 years, 700 km of bicycle lanes have been constructed. After legal discussion, these lanes have now been officially opened to electrically-assisted tricycles and cargo bikes. Companies such as “La Petite Reine” or The Green Link estimate that this enhances the productivity of their delivery operations. La Petite Reine (a subsidiary of Groupe Star’s Service) operates approximately 100 cargo cycles, from several consolidation centres throughout the city.

4.2.2 CB Implementation

Given the advantages and disadvantages of cargo bikes, they are most suited for the distribution of products with a relatively low bulk density and size and which have simple storage or handling requirements.

4.2.3 CB Impacts

In 2010, an assessment study showed that, at that time, 30 cargo bikes in Paris were operating from a 600m^2 terminal, and this saved emissions equivalent to those produced by running diesel vehicles for 660,000 km (Melo et al. 2014).

DHL Netherlands replaced 33 trucks with 33 cargo bikes, thus saving 152 metric tons of CO_2 and €430,000 per year, while 10% of their vehicles are carbo bikes (Barner 2014). In Brussels, the example of Ecopostale can be noted, which began with four bicycles, seven cycles and one electric van, delivered 400 packages per day to banks, lawyers and other corporate customers and reached savings of 13 tonnes of CO_2.

In Central London, research shows that replacing diesel vans by electric vans and tricycles operating from a micro-consolidation centre would lead to a decrease in total distance travelled by 20%, and the CO_2-equivalent emissions per parcel delivered by 54%. The research is based on a trial experiment, like the Paris assessment, carried out by Office Depot between 2009 and 2010. This experiment tested six cargo bicycles, three electric vans and one truck and resulted in a total decrease of 62% in CO_2 emissions (kg/parcel) (Browne et al. 2011).

Barcelona has estimated savings of 912 kg CO_2/bike-year with the implementation of such a system (Melo et al. 2014).

4.3 Off-Hour Delivery

Another solution for the logistics operators to mitigate UVARs is the use of OHD. Retailers generally want to receive deliveries of goods during their normal work hours. Thus, most lorry traffic occurs during the most congested (daytime) traffic periods. If enough businesses can adjust their schedules to accept deliveries when there is less traffic congestion, it could enable transport companies to deliver goods quicker and at lower cost.

4.3.1 OHD Best Practices

Mercadona, a supermarket chain in Barcelona, has tested OHD and expanded its use to over 100 of its store locations throughout Spain. London began its OHD implementation in preparation for the 2012 Olympic Games and has continued since. In the Netherlands, silent vehicles and delivery equipment for OHD (PIEK technology) are promoted and the maximum noise level is regulated.

4.3.2 OHD Impacts

OHD could result in less traffic congestion, reduced cost of goods, economic benefits and would be better for the environment (Labelle et al. 2015). Many of the benefits of off-hour delivery, such as reduced congestion, improved air quality and safety, would serve the greater community, not just the carriers or customers. An OHD program steered and promoted by the city could switch more than 20% of the (currently congested) daytime freight traffic deliveries to off hours, and could achieve sizeable pollution reduction (Holguin-Veras et al. 2011).

The most recent large scale study on the benefits of PIEK silent equipment discusses main benefits: given a more stable engine use, the off-peak deliveries reduce the fuel consumption and so emissions. In the pilot, following decreases were realised: CO_2–23% to −67%, NO_X -41%, and PM_{10}–42%. In off-peak hours, an increase of the average speed per delivery round, due to less congestion towards the city, was noted. Also, organisational benefits are important. Vehicles and equipment can be used more efficiently. The last benefit for the company deploying silent equipment is the positive image, especially towards the citizens living close to the retail location, often the most frequent customers.

A study of OHD in New York City in 2009 and 2010 shows that implementing various OHD policies would generate total savings of between \$100 and \$200 million/year in travel time savings and pollution reduction (Holguin-Veras 2013). OHDs are estimated to be 30–40% cheaper for carriers than regular daytime deliveries (Holguin-Veras et al. 2014; Holguín-Veras and Aros-Vera 2014). Pedestrians and cyclists experience increased safety and an improved quality of life with less interference from deliveries; daytime non-freight travellers benefit from faster travel speeds; freight carriers see increased productivity; and customers enjoy increased reliability (Holguin-Veras et al. 2014).

4.3.3 OHD Implementation

Businesses that are most receptive to OHDs are those that are likely to be open during off hours, such as restaurants, bars, hotels, convenience stores, 24-h supermarkets, hypermarkets and medical facilities (Holguín-Veras and Aros-Vera 2014). “Unattended deliveries” (deliveries made in the absence of the customer’s staff, for example in buffer zones) are also a potential solution, although they require trust and a clear legal framework (Holguin-Veras 2013).

To make an OHD scheme a success, investments in silent equipment by retailers or the logistics sector are a necessity. In the Netherlands, silent vehicles and delivery equipment for OHD is developed (PIEK technology). The government promoted and organised an independent certification the equipment. The maximum noise level for the equipment is regulated by law, certification was organised by TNO. The PIEK technology is currently being exported to other European countries.[4]

4.3.4 OHD Stakeholder Involvement

Next to the benefits, OHDs feature some specific challenges. OHD is a simple concept, but it can be challenging to implement it because the benefits and costs are not always evenly distributed. The most significant negative social impact of OHD is the noise produced by unloading operations at night (Yannis et al. 2006). Transport providers favour OHD since it facilitates operations and the use of uncongested roads. Retailers (customers) would, on the contrary, prefer the goods delivered during regular opening hours, while citizens are interested in having a quiet environment during the night and fully re-stocked shelves when shopping. Policy interventions (Marcucci et al. 2015) then should aim to re-balance social costs and benefits.

The OHD scheme can perfectly fit into an UVAR zone, where the UVAR regulates access during day and off-peak times on different access criteria. Noise reduction can be attained using newer, quieter delivery vehicles and equipment. However, behavioural changes to reduce noise require training, especially for vehicle drivers and reception staff employed by the customer at the site (London T.f. 2015).

5 Conclusions

UVARs contribute to addressing several challenges that markets alone are not able to address. They are based on access time, allow certain types of vehicles or regulate access on emission levels of the vehicle, the load factor, road use (size), parking capacity or loading and unloading operations.

Each UVAR affects many stakeholders, and therefore requires specific stakeholders to be involved in the decision-making process. Moreover, the engagement of more than one authority level (i.e. local, regional, national) is usually necessary for successful UVAR implementation. The regulation scheme and the challenges determine the type of stakeholders that should be engaged.

It is very important to consider that the degree of impact of each measure not only varies from city to city but also depends on the presence of a mix of access regulations. However, in case of mixed measures, it is difficult to assess the extent to which each contributes to a given impact indicator.

As part of an overall approach, it is important not just to consider managing certain types of vehicles, but instead to manage the allocation of road space for all

[4]More information can be retrieved via: http://www.piek-international.com.

road users. For example, if only freight vehicles are targeted, then the road space they free up could fill with other vehicles, potentially making congestion and air quality worse. Given this fact, it is crucial that urban freight policy is considered together with other urban mobility policies, with policy makers seeking to strike a balance between all road users.

Since efforts and investments allocated by each stakeholder need to be evaluated against the performance of the UVAR scheme, a few tools and methods can be used to create the transparency and build trust for long term implementation.

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The Importance of Supplier Development for Sustainability

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Abstract Combining social responsibility, environmental consciousness, and economic performance in supply chain operations has led to sustainable supply chain management (SSCM) programs. In recent years, the growth and importance of sustainability in supply chains has increased due to an insurgence of interest in climate change, environmental pollution, energy price fluctuations, and basic consumer behavior. This trend is especially prevalent in supply chain management. Due to the highly competitive business environment, it is not only the performance of the firm that is critical, but also the performance of the suppliers of a firm. The sustainability of an organization depends on the relationship fostered with suppliers. Supplier development, defined as the activities organized by buyers to increase the performance of their suppliers, has originated from this concept. Thus, supplier development projects can play an important role in sustainability for the firm and for the supply chain. This chapter, using extant literature, gives a general framework for supplier development and the effects on sustainability.

Keywords Sustainable supply chain management · Supplier development

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1 Introduction

The most frequently cited definition of sustainability comes from the Brundtland Commission (1987). They defined sustainability as the "development that meets the needs of the present without compromising the ability of future generations to meet their needs." However, a major criticism of this macro-economic definition was that it was not clear enough to guide organizations to improvements within their supply chains. To give firms a better direction on how to evaluate and implement sustainability, the concept of the triple bottom line was developed. The triple bottom line considers all social, environmental, and economic performance of the firm when evaluating the impact and need for sustainability.

Since manufacturers may purchase many of their product components from several suppliers, it becomes very difficult for them to be sustainable without greening their supply chains. Therefore, to achieve sustainability, many suppliers and buying companies must also have sustainable operations. However, some suppliers find great difficulty in attempting to manage their operations effectively and efficiently.

Supplier selection and development is a crucial activity for firms to create sustainability across their supply base. Reuter et al. (2010) identified four benefits of a well-defined supplier development program. First, suppliers gain the ability to respond quickly to the changing expectations of buyers. Second, the image of the buying firm increases because of special standards. Third, the quality of products and components for both firms improves dramatically. Finally, the buyer benefits with a lower probability of supply disruption. Key sustainability performance indicators for buyers across a supply base include waste levels, transportation of hazardous materials, and carbon emissions. If issues arise with any of these key performance indicators, future purchases from these suppliers may be in significant jeopardy. Sustainable supplier development (SSD), therefore, plays an important role to avoid risks associates with a damage of reputation and environmental pollution.

Seuring and Muller (2008) state that "supplier developments were required before focal companies were even able to offer 'sustainable' products to their customers. This demands much deeper information flows along the supply chain, where suppliers have to gain detailed insights . . . " If organizations, especially original equipment manufacturers (OEM's), want to develop sustainability programs, they should not simply shift their environmentally polluting operations onto small and medium enterprises (SMEs). Using small and midsize suppliers that do not have sufficient capabilities for sustainable production can no longer used as an evasion to sustainable operations for large companies, as has been accepted practice in the past.

Today, the number of companies that consider social and environmental consciousness an important aspect of their business strategy is increasing. For instance, Sony works solely with suppliers that pass environmental regulatory requirements (Handfield et al. 2005). However, few manufacturing companies are applying sustainability criteria for their supplier selection process, a crucial process of sustainable supply chain management (SSCM). Leenders (1966) described the supplier development process as the effort of a buying firm to increase the capabilities of their suppliers (Ehrgott et al. 2013). Certainly, though, it can be difficult for the focal firm and suppliers to accomplish this because it requires a major commitment of time, money, and personnel. Due to the costs and risks involved in supplier development, it can be a challenging issue for many firms and their respective supply base (Monczka et al. 2009).

Organizations may choose to help their suppliers achieve success and market differentiation along the key competitive dimensions of cost, quality and the environment (Lin and Chai 2012). This chapter outlines the general framework of supplier development and informs on activities and barriers related to it.

2 Sustainable Supply Chain Management (SSCM)

In the literature, researchers have developed several perspectives on sustainability. In academia, however, it is the *triple bottom line* approach that is widely accepted (Seuring and Muller 2008). Elkington (1998) states that the environmental, social, and economic performance of a firm needs to examined in order for a firm to improve sustainability. Sustainable supply chain management (SSCM) aims to answer the question, "*What is it that we need to do, not just to survive, but to thrive and not just one year, three years, or five years from now, but in ten years, 20 years and beyond*" (Carter and Easton 2011). SSCM is defined as, according to the triple bottom line approach, "the strategic, transparent integration, and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic performance of the individual company and its supply chains" (Carter and Rogers 2008). Various activities of sustainability programs include reducing package material, recycling, redesigning, reducing disposal costs, and working with ISO 14000 qualified suppliers. Carter and Rogers (2008) define four different views of sustainability: strategy, risk management, organizational culture, and transparency. Strategy refers to outlining SSCM goals and objectives regarding overall sustainability issues of the firm. Risk management includes planning thunderbolts for the upstream and downstream supply chain. Organizational culture requires the firm embrace a common definition of well-defined ethical standards. Finally, transparency aims at traceability and controllability of the product and information flows within the supply chain.

Focal firms that organize the supply chain should attempt to achieve goal congruence with their suppliers regarding sustainability activities. This is especially true because mistakes of suppliers may negatively affect the buying firm with adverse publicity, reputational damage and costly legal obligations (Carter and Jennings 2004; Koplin et al. 2007). Therefore, the selection and development of suppliers are important issues for the efficiency of SSCM. Focal firms may choose to work with suppliers by using their own resources to help with improvement initiatives when facing problems about waste levels, transportation of hazardous materials, and carbon emissions. In more drastic situations, focal firms may even desire to change their supplier altogether.

SSCM further aims at minimizing disposal costs (Srivastava 2007). Costs incurred in the disposal process include those associated with disposal, reduction, recycling, redesign, and the implementation of environmental management systems (EMS's). If the disposal process is not managed appropriately, serious problems may occur. Problems such as the contamination of groundwater or streams, the leakage of toxic material, the pollution of air or water, and negative effects on flora and fauna (Qian et al. 2011).

The disposal process has relatively low operational costs; costs usually associated with programs intended to reduce the number of inputs required, such as raw materials, energy, and water. Srivastava (2007) defined source reduction as "focusing on preventing pollution at the source rather than removing it" (in products as well as in manufacturing process). Recycling is the "reuse of materials from returned products without conserving the product identity" (Kapetanopoulou and Tagaras 2011). Design for the environment means finding proactive solutions at the beginning of the product life cycle before the generation of waste. Design for the environment can lead to changes in production processes and item specifications. In addition, it also requires the need for an environmental management system so that the managerial operations that canalize a corporation can be used to strategically guide environmental initiatives (Lefebvre et al. 2003). Thus, an organization may be required to hire new employees (such as environmental managers and engineers) or set up environmental management or sustainability departments.

3 Supplier Development

Corporate social responsibility (CSR) cannot be more important, particularly in the face of corporate corruption that leads to economic crisis, worker rights and wage suppression around the world, and environmental degradation. Owners, corporate boards, and managers of all levels should clearly realize the consequences of ignoring CSR. Top and midlevel managers will play a major role in writing and instituting CSR policies and the code of conduct. CSR is a multifaceted concept, conceptualized as follows: responsibility to employees, responsibility to customers, responsibility to environment, and partnerships with NGO's (Agan et al. 2016; Türker 2009). Implementing CSR requires complete attention and overall efforts of all the employees of the firm.

One of the dimensions (sub-constructs) of CSR is a responsibility to the environment. Among many possibilities, one way firms may choose to implement environmental sustainability is to help suppliers develop environmentally safe products, processes, and technologies. Supplier development is a multi-faceted concept including supplier evaluation, incentives, and direct involvement. However, managers may choose between incentives, direct involvement, or a combination of both. The right choice depends on the parts, suppliers to be developed, and the current resources available to both the supplier and buyer partnership.

Supplier development is a long-term cooperative endeavor between the focal organization and its suppliers to improve the suppliers' skills (Watts and Hahn 1993). The focal companies can help their suppliers increase efficiency and find solutions for problems in their supply chains (Park et al. 2010; Lawson et al. 2015; Routroy et al. 2016). Many suppliers in Asia, Eastern Europe, and Latin America have neither the sufficient managerial and technological capabilities nor the environmental consciousness to make a successful supplier development program (Child and Tsai 2005; Zhu et al. 2011; Ehrgott et al. 2013). It is very possible that organizations in developed countries can face significant problems related to environmental damage and work conditions because of suppliers in developing countries (Ehrgott et al. 2013).

Arraiz et al. (2013) analyzed the Chilean Supplier Development Program conducted between 2003 and 2008. The Chilean government's initiative is worth praising. In return for support from the Chilean government, major buyers are required to help at least ten of their suppliers. The help provided to the suppliers by the buyers cut across a wide range of supply chain functions, but could include areas such as product development, quality control and assessment, identifying performance metrics, procurement transactions, and strategic sourcing initiatives. Both buyers and suppliers, because of the program, benefit from working together with a reduction in transaction costs and an improvement is customer service. Supplier development activities helped buyers improve their exporting processes, while at the same time helped suppliers increase their sales revenue, workforce retention, and sustainability. Although the buyers observed the benefits in 2 years, the suppliers experienced it in half that time. The governments of Mexico, Colombia and Uruguay then replicated the program within their respective countries.

3.1 Environmental Supplier Development (ESD)

Environmental Supplier Development (ESD) programs "encompass all activities through which the buying firm helps its suppliers reduce their negative environmental impact" (Ehrgott et al. 2013). Green supplier development is a crucial topic for the understanding and the implementation of best practices within supply chain management (Fu et al. 2012). Krause et al. (2000) categorized supplier development into four categories: competitive pressure, evaluation and certification, incentives, and direct involvement. Competitive pressure refers to working with many suppliers in their production processes to provide competitiveness between these suppliers in order to protect the environment. Regular evaluation and feedback activities drive suppliers to become more efficient and qualified. Direct involvement includes three different forms: capital and equipment investments to suppliers, partial or whole acquisition of the supplier firm, and operational knowledge transfer activities with investment in human and organizational resources (Modi and Mabert 2007).

ESD programs can also be classified as evaluative or collaborative activities (Krause 1999; Klassen and Vachon 2003). Evaluative activities imply the evaluating and monitoring of the environmental performance of suppliers. Collaborative activities refer to companies within a supply chain making an coordinated effort to succeed in specific improvements (Wee and Quazi 2005). Environmental collaboration requires knowledge sharing and a mutual objective to understand and improve related production systems with respect to environmental improvement (Vachon and Klassen 2008). Bai and Sarkis (2010) develop three classifications of green supplier development operations. These classifications are knowledge transfer, resource transfer, and organizational practices. Finally, Fu et al. (2012) categorized the environmental supplier development in three ways: green knowledge transfer and communications, investment and resource transfer, and management and organizational practices.

Several articles in the literature show that the evaluation of suppliers and their collaborative operations positively affects environmental performance (Agan et al. 2016; Ciliberti et al. 2009; Schliephake et al. 2009; Zhu and Sarkis 2007; Rao and Holt 2005; Gimenez and Tachizawa 2012). Moreover, some research also shows that environmental activities trigger a positive economic performance. For example, Rao (2002) indicates that there is a positive relationship between green SCM and economic performance with the mediating effect being environmental performance. To provide sustainability among suppliers, good performance evaluation procedures and collaboration are necessary (Lim and Phillips 2008; Strand 2009, Reuter et al. 2010). Lee and Klassen (2008) indicate that both evaluation and collaboration make for improved environmental performance for all organizations involved.

Several companies continue to work together with their suppliers to improve their environmental performance. Xerox developed a joint program with its suppliers to increase the amount of equipment reused in their processes (McIntyre et al. 1998). Ikea and Bosch are among the companies that stated in their websites that they are using ‘supplier development programs’ to work with selected suppliers to ensure future competitiveness and superior customer service. Castrol (a producer of lubricants to the automotive industry) and one of its customers organized a common project that resulted in lower lubricant consumption, lower costs, and a reduction in environmental impact (Reiskin et al. 2000). BASF, a chemical company, began a joint campaign to boost the environmental performance of suppliers in different geographical locations with the United Nations Global Compact, the United Nations Industrial Development Organization, and the United Nations Environment Program. With this program, BASF and its suppliers reduced energy consumption, reduced emissions, and decreased material consumption. Moreover, in order to reach their jointly developed goals, BASF provided technical support to suppliers in different operations (Bethke and Bluethner 2003; Ehrgott et al. 2013). Finally, Custom Print, a commercial printer in the USA, operated activities within its chemical suppliers. The result was a significant reduction in waste levels of harmful chemicals (www.epa.gov).

Collaboration cannot only lead to environmental improvements, but improvements in cost and quality across other supply chain processes (Klassen and Vachon 2003; Vachon and Klassen and 2008). Lorenzoni and Lipparini (1999) state that supplier development guides improvement to several organizational capabilities. ESD includes collaboration on product and process design, reduction, recycling, and waste management. At Eaton Corporation, for example, supplier development programs led to advancements in quality, delivery, capacity utilization, and productivity. They also realized a reduction in lead times and in supply costs (Modi and Mabert 2007).

ESD is often a source of competitive advantage for organizations. Firms that cherish environmental consciousness are more likely to persuade other partners within their supply chains to become environmentally responsible. When organizations manage common environmental projects with their suppliers, the brand image of the firm and public opinion will improve, particularly within niche market segments (Carter et al. 2000; Min and Galle 1997; Nestle 2017; Ikea 2017). Moreover, Blome et al. 2014 indicate there is a positive relationship between green supplier development and supplier performance, the result of which leads to higher innovativeness, lead-time reduction, enhancements to quality, and improved responsiveness.

3.2 Activities of Supplier Development

The literature identifies many activities that are included in the supplier development process. These activities include knowledge transfer, communication, bilateral management involvement, internal & external supplier integration, trust building, monetary aid, relational norms development, socialization mechanisms, supplier performance, training, exchanging personnel, and monitoring supplier progress (Narasimhan et al. 2008; Modi and Mabert 2007; Das et al. 2006; Bai and Sarkis 2010; Li et al. 2007; Govindan et al. 2010; Blome et al. 2014; Agan et al. 2016; Rodriguez et al. 2016).

The categorization of supplier development activities occurs in several different groupings. The most widely used and accepted categorization of supplier development activities is to divide them into direct or indirect activities. Indirect activities include monitoring, evaluation, communication, incentives and penalties, certifications, and setting targets. Some comprehensive and direct activities that are more difficult to assess include training and education, financial assistance, machinery grants, mutual visits, and locating employees at the supplier location (Wagner and Krauser 2009; Humphreys et al. 2011). These activities and their grouping are summarized in Table 1.

Wagner (2010) showed that indirect activities improve the performance of the product (with respect to quality and distribution) and the capabilities of the suppliers (with respect to activities related to management, production, logistics, and product development). He further showed that direct activities improve the capabilities of

Table 1 Direct and indirect activities

Indirect activities	Direct activities
Setting targets for suppliers	Giving advice on products and production
Monitoring suppliers	Training suppliers' employees
Giving feedback to suppliers on their performance	Employing technicians and engineers at the suppliers site
Deeply evaluating suppliers	Giving advice on quality and technology related issues
Using few (3 or less) reliable	Transferring implicit knowledge
Developing standards for all purchased items	Involving suppliers early in product development
Communicating effectively	Using MRPI and MRPII with suppliers
	Being able to access suppliers' information systems.
(Wagner and Krauser 2009; Ustasüleyman 2009; Agan et al. 2016; Blome et al. 2014)	Improving the performance goals of suppliers
	Teaching statistical process control
	Providing technological support
	Providing tools and machinery
	Providing financing for new investments
	Visiting supplier facilities regularly
	Inviting suppliers to buyer's facilities
	Eliminating non-value added activities
	Awarding supplier improvements
	Using single supplier
	(Wagner and Krause 2009; Ustasüleyman 2009; Humphreys et al. 2011; Agan et al. 2016; Blome et al. 2014; O'Charoen and Bispham 2015; Rodriguez et al. 2016)

the supplier only. A better management of direct actives improves the supplier capabilities more significantly than that of the improved management of indirect activities. However, Wagner (2010) also suggested that applying both types of activities at the same time could detrimentally affect target clarity and, therefore, lead to poor productivity and performance in the long-term. Thus, most studies recommend firms begin with improvements to indirect activities and then progress to improvements in direct activities. Finally, Ustasuleyman (2009) found that both types of development activities improve the purchasing performance (of the buyer firm), especially since indirect activities trigger direct activities.

Humphreys et al. (2011) analyzed the impact of several factors on the customer-supplier relationship while studying a group of electronic firms in Hong Kong. They found that effective communication, supplier evaluation, and strategic goals of the supplier significantly affected the customer-supplier performance. However, one must be careful in generalizing the result of this study to other industries and other geographical locations, particularly since the strategic priorities within the electronics industry revolve around speed, cost, and adaptation.

Table 2 Barriers of supplier development

Buyer originated barriers	Supplier-originated barriers
Lack of strategic focus	Lack of strategic planning
Unbalanced purchase or load volumes	Investment problems
Lack of cross-functional teams	Lack of qualified workforce
Lack of continuity	Out of date technology
Cost-oriented	Hesitation in sharing information
Not willing to share technology	Lack of project management skills
Organizational culture	Trust and dependence issues
Expecting benefits too soon	Non-structural and uniform information
Socio-economic differences	Spatial and linguistic distance

Mohanty et al. (2014) and Busse et al. (2016)

3.3 Barriers to Supplier Development

Although supplier development initiative show significant promise, a handful of known initiatives did not end successfully. In a study focusing on discrete manufacturing firms, Mohanty et al. (2014) and Busse et al. (2016) identified several barriers originating from supplier firm and the buyer firm (Table 2).

To improve the success of supplier development programs, certain Critical Success Factors (CSF's) are required. Busse et al. (2016) and Routroy and Pradhan (2013) identified several CSF's necessary to improve the probability of a successful supplier development program. By order of importance, the suggested CSF's are:

1. Long term strategic goals: both sides should understand each other's expectation
2. The geographic proximity of the supplier to the buyer
3. Top management support (from both sides)
4. Information sharing
5. Environmental proficiency: the ability of the supplier to be sustainable
6. Supplier's innovation capability
7. Supplier certification: to be certified by the buyer or third-party institutions
8. Incentives: systematically awarding suppliers based on performance measurement
9. Capabilities of tier 2 suppliers: financial, operational, and access to raw material
10. Direct involvement: direct supplier development activities
11. Business environment: technological and competitive environment
12. Project implementation experience
13. Overall maturity and capability levels of suppliers
14. Effective joint communications, an
15. Open organizational culture, and the fostering
16. Cross-contextual understanding.

The rankings could differ by country due to cultural difference and, thus, one should use caution when interpreting the results. In another study, Li et al. (2012) developed a comprehensive model to test the effects of critical success factors on the outcome of supplier development. With the exception of the strategic goals of the buyer (defined as developing long-term capability of the supplier) all other factors including top management support, long term dedication (loyalty), supplier evaluation, effective communication, supplier's strategic goals, and trust were found to be significant factor in the success of supplier development programs. By improved management of a strategic sub-set of the factors identified by partner firms, both the supplier and the buyer have benefited with a positive impact of performance.

4 Conclusion

Managing relationships with suppliers and customers is the very core of supply chain management. Because the majority of suppliers are small, they usually require aid in terms of sharing critical resources. These suppliers may turn to the development of strategic partnerships if appropriate resources are not available to them. According to Krause (1997), supplier development activities may eventually lead to cooperative, long-lasting, and strategic relationships. Seuring and Muller (2008) further conclude that focal companies should extend their supply chain scope for sustainability initiative and that supply chain partners need to cooperate much more than ever before. Major companies can be neither green nor socially responsible if they do not take actions that go beyond their first tier suppliers.

Currently, many OEM's have several SME's operating as suppliers that have insufficient resources or capabilities to produce environmentally safe goods. If OEM's are truly concerned with the environment, they should help their suppliers develop the necessary capabilities. The poor integration among supply chain partners with respect to sustainability initiatives indicates the urgent need to adopt, implement, and improve CSR. CSR requires a significant cultural change within the firm, a change that is impossible to achieve quickly. Therefore, shareholders, managers, and employees of the firm need to adopt a forward looking, long-term, and persistent view of CSR.

Managers should finally create a climate that is conducive to adopting, implementing, and improving CSR and SSCM initiatives. Equally important, as with any organizational activity, is the need to link and document supplier development to the core competencies of all firms involved along to their respective financial and stock performances.

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