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Transportation as a loosely coupled system: a fundamental challenge for sustainable freight transportation

Michael Browne[a], Anna Dubois[b], and Kajsa Hulthén[b]

[a]Department of Business Administration, University of Gothenburg, Gothenburg, Sweden; [b]Department of Technology Management and Economics, Chalmers University of Technology, Gothenburg, Sweden

ABSTRACT

In view of the pressing need to reduce the negative environmental impact of freight transportation we argue that it is essential to take account of the organization of the freight transportation system when considering how to address various individual activities and parts of the system. To support a transition to a more sustainable freight transportation system this paper examines the way in which different parts of the system interact and the way this can impact the scope for profound change. Taking loosely coupled systems (Weick, 1976) as a starting point, we scrutinize the couplings within and between three system layers of the freight transportation system: the supply chain layer, the transportation layer, and the infrastructure layer. In addition, we address two interfaces connecting these layers: the market for transportation services, and the traffic using the infrastructure. We find that tight couplings dominate in the supply chain and infrastructure layers and that these couplings depend on loose couplings in the transportation layer and the two interfaces. The pattern of couplings identified in the freight transportation system can explain several positive outcomes, such as flexibility and efficiency. But there are also major negative aspects of the loosely coupled nature of the system that create resistance to change and present a barrier in the drive for increased sustainability. The paper concludes that the identified couplings and system features have important implications for policies aiming to change the freight transportation system in ways that lead to significant reduction in the reliance on oil.

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1. Introduction

In an analysis of the education system, Weick (1976) drew on parallels between an unconventional soccer game and schooling. He conjured up a picture of apparently random movement, unpredictable behavior and a disordered playing field: "Imagine that you're either a referee, coach, player or spectator at an unconventional soccer match: the field for the game is round; there are several goals scattered haphazardly around the circular field; people can enter and leave the game whenever they want to; they can throw balls in whenever they want; they can say "that's my goal" whenever they want to, as many times as they want to, and for as many goals as they want to; the entire game takes place on a sloped field; and the game is played as if it makes sense." (Weick, 1976, p. 1)

In this paper we argue that this image that Weick went on to refer to as a loosely coupled system could apply equally well to the freight transportation system. Consider the trucks, vans, trains, and vessels in any urban (or other) area loading, unloading, and moving about in a seemingly uncoordinated fashion. Consider also all the effort to coordinate transportation services and make good use of the resources involved in the operations. While the current way of coordinating and organizing all these transportation activities seems to work, the need for change has become increasingly apparent.

According to Weick (1976), it is likely that a sense of efficacy may be greater in a loosely coupled system with autonomous units than it would be in a tightly coupled system, since there is room for self-determination by the actors. Therefore, loosely coupled systems are relatively inexpensive to run since loose couplings require little coordination and therefore generate low operational costs. However, this also implies that it may be a non-rational (and/or non-optimal) system for the allocation of resources and also un-modifiable and incapable of being used as a means of change.

The biggest driver of the need for change in and of the freight transportation system is the heavy reliance on fossil energy. As noted by the European Energy Agency (EEA, 2020) transportation remains highly dependent on oil with oil-derived fuels accounting for 95 percent of energy consumption in transportation. In this respect all transportation is problematic but freight transportation, in particular, has become an increasingly important polluter and contributor to climate change since it relies very heavily on fossil energy

CONTACT Kajsa Hulthén kajsa.hulthen@chalmers.se Department of Technology Management and Economics, Chalmers University of Technology, Gothenburg, SE-41296, Sweden

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sources (Lin, 2019). Energy use in the transportation sector is expected to continue to increase with oil comprising the largest share through 2050 (wri.org, 2019). Hence, the transportation sector's reliance on fossil fuels needs to be dramatically reduced:

> "To keep temperature rise within a range that averts the worst climate impacts, IEA modelling suggests that transportation emissions need to peak around 2020. Transitioning to zero-emission transport is a crucial step toward a livable future. Getting there requires a comprehensive suite of improvements, addressing clean fuels, vehicle efficiency, how we build cities, and how we move people and goods." (wri.org, 2019)

In terms of transportation modes, 72 percent of global transportation emissions are generated by road vehicles, which accounted for 80 percent of the rise in emissions from 1970-2010 (wri.org, 2019). Furthermore, the transportation sector is growing rapidly, with emissions projected to double by 2050 (Creutzig et al., 2015). As part of the challenge, freight transportation is considered an engine of growth and owing to the continuing specialization in industry it increases at a faster pace than the GDP in most countries. According to Sims et al. (2014, p. 603): "Reducing global transport greenhouse gas (GHG) emissions will be challenging since the continuing growth in passenger and freight activity could outweigh all mitigation measures unless transport emissions can be strongly decoupled from GDP growth." Figueroa et al. (2014) noted that the total amount of freight movements continues to rise steeply despite various regulations on exhaust emissions, green vehicle technologies, and efficiency measures taken by companies to save money at the same time as they yield environmental co-benefits. As McKinnon (2016, p. 16) noted: "Ever more radical options will have to be explored in an effort to meet the required reductions."

Hu et al. (2019) argued that transportation may be one of the more difficult sources of emissions to address. Focusing on freight transportation, they noted that the extent of the 'embodied' emissions can be exemplified by the situation in Sweden where these are nearly equivalent to all the private vehicle transportation of citizens (excluding package holidays and flights). The way in which consumption creates derived demand for transportation far away from the consumer entails particular challenges. Owing to specialization and globalization, materials can cross over the world multiple times before ending up with a final consumer, pointing to the importance of understanding the organizing of the freight transportation system. This, in turn, emphasizes the need for analytical frameworks that can be used to scrutinize different measures taken to tackle the many problems identified with transportation, without hampering the social and economic benefits.

Within the broader debate of climate change mitigation Creutzig et al. (2015) stressed the importance of transportation as a potential roadblock, because of both growth in demand and reliance on oil as the main energy source. Their analysis included both passenger and freight transportation considerations and the points they made are relevant to the issue of how to approach questions of change when looking at systems that exhibit inertia and apparent resistance to change.

Research applying system dynamics modeling to transportation problems emphasize the desirability of a holistics approach. For example, focusing on city logistics and urban freight transportation, Kunze et al. (2016) applied a partial system dynamics approach as one element in research with the goal of developing a holistic understanding of the potentials to reduce freight and service traffic in an urban context. The research had a strong focus on the "interdependencies of the different decision realms of the different stakeholders" (ibid., p. 695). Exploring the interrelationships between logistics and transportation operations, Aschauer et al. (2015) used a systems dynamics approach. They noted that interdependencies between logistics and transportation operations can occur in different ways and may influence the whole system in direct and indirect ways. The approach discussed in their research emphasized the need to consider systems and relationships in a comprehensive way to better understand opportunities to create positive changes.

Yet despite references to the need for a suite of improvements and the importance of a systems approach it is clear that the pace of change is slow and most initiatives only focus on small parts of the total freight transportation system. To enable a system level change a framework is needed to describe and understand the system and the organization and interactions within that system. In this paper we make an attempt to provide such a framework.

Analyzing the transportation system as a loosely coupled system means addressing the combination of loose and tight couplings between elements since this pattern of couplings determines the conditions for the dynamics within the system. Hence, certain changes may be relatively easy to make while others may be very difficult or even impossible if the pattern of couplings remains. Understanding the pattern of couplings may therefore help to frame more effective policy initiatives and other actions to reduce the climate change impacts of transportation activity, and thereby contribute to more sustainable transportation. We consider that oil plays a key role as an embedded resource in the transportation system. However, to change this reliance on oil it is not sufficient to have alternatives available - more fundamental understanding of the couplings and interfaces in the transportation systems is also required to identify possible paths supporting the transition to a sustainable transportation system.

A related approach dealing with 'low-carbon transitions' is the socio-technical analysis based on a multi-level perspective (MLP) introduced into transportation studies by Geels (2012) and Geels et al. (2012). According to Geels (2012, p. 472), transitions are non-linear processes resulting from the interplay of multiple developments at three levels: landscapes, regimes, and niches; "The MLP provides a way of addressing the core analytical puzzle of transitions, namely stability and change. On the one hand, existing systems are characterized by stability, lock-in, and path dependence, which give rise to incremental change along predictable trajectories. On the other hand, radical alternatives are being proposed, developed and tried by pioneers, entrepreneurs, social movements and other relative outsiders (to the existing regime). These alternatives typically face an uphill struggle against existing systems […]". Müller and Blanquart (2018) based their study of the conditions for radical innovation in freight transportation in France and Germany on MLP and identified several mechanisms protecting status quo. In particular, they found that: "[…] avoidance of radical new solutions and "unbreakable" linkages between policy and incumbents, resulting in negative lobbying" together with lack of capital, hindered innovation (ibid., p. 231).

In relation to the MLP approach, we focus mainly on the existing regimes in the freight transportation system, together with some examples of niches as attempts at 'radical innovation' to transform the system. Furthermore, Geels (2012) focused his analysis on auto-mobility which displays both differences and similarities with freight transportation (see Müller & Blanquart, 2018). Since transportation of people and goods to a large extent share the same infrastructures, the landscape level including e.g., spatial structures, political ideologies, and macro-economic trends, can be seen as shared between the two.

Inquiring into how the pattern of tight and loose couplings produces certain system outcomes is a way to improve the understanding of the conditions for change in a system. The aim of the paper is therefore to analyze the organizing of the freight transportation system regarding its pattern of loose and tight couplings and to inquire into the consequences of this pattern for change in and of the freight transportation system. We do not present new empirical data from surveys or case studies. Instead, we base our analysis and discussion on previous studies of different parts of the system.

The paper is structured as follows. In the next section, we present the framework which includes an overall description of the transportation system and of the main attributes of loosely coupled systems. This is followed by a section where we address the pattern of couplings in each system layer and the interfaces between them. Thereafter we discuss implications for policies directed at freight transportation sustainability, suggesting that some policies have failed because they conflict with the current pattern of couplings. The last section contains a concluding discussion.

2. Framework

The notion of a transportation system is often used in research as well as in policy documents as an implicitly 'known' system although the content of, and perspectives applied to, this system varies greatly. But what kind of system is the transportation system and what components does it contain? We have found inspiration in the literature on loosely coupled systems (Orton & Weick, 1990; Weick, 1976), originally developed to describe organizations such as the educational system. However, since we focus on an interorganizational system rather than on a formal organization we also draw on notions developed in the industrial network approach (Håkansson et al., 2009) which captures how activities, resources and actors belonging to different formal organizations are subject to interdependence across organizational boundaries (Håkansson & Snehota, 1995). Drawing on these ideas in combination enables scrutiny of the freight transportation system as an open system i.e., without starting out in a precise definition of all its elements or of any clear boundary in relation to other systems or contexts. The open nature of the system follows from how the freight transportation system is part of the broader transportation system that also includes personal and public transportation, and that these share some vital resources such as transportation infrastructure. In addition, many of the system elements that will be addressed in the paper have links to other contexts.

Orton and Weick (1990, p. 219) argue that that the concept of loosely coupled system should not be applied in a superficial way but that researchers should scrutinize the system: "What elements are loosely coupled? What domains are they coupled on?" Loosely coupled systems may contain elements that vary in the number and strength of their interdependencies. For example, every single industrial activity is to some extent interdependent with many other activities – they are coupled in various ways. Some of these couplings are tight while others are loose.

An important characteristic of loose couplings is that "coupled events are responsive but that each event also preserves its own identity and some evidence of its physical or logical separateness" (Weick, 1976, p. 3). The attachment between the events may be "circumscribed, infrequent, weak in its mutual effects, unimportant, and/or slow to respond" (ibid.). Loose couplings may occur in a number of dimensions: between individuals, sub-units, organizations, hierarchical levels, organizations and environments, ideas, activities, and between intentions and actions. Furthermore, Weick (1976) analyzed the potential effects of loose couplings, which may be functional and/or dysfunctional. Below we briefly describe the attributes associated with loose couplings and with loosely coupled systems.

A loosely coupled system may be a good system for localized adaptation where "any one element can adjust to and modify a local unique contingency without affecting the whole system" (Weick, p. 6-7). Hence, localized adaptations may be "swift, relatively economical and substantial" (ibid., p. 7). Weick furthermore suggested that the antithesis of localized adaptation is standardization. However, standardization of parts or tasks in a system may also work as a decoupling mechanism in that it can enable independence between (certain) elements and in that case foster loose couplings (Dubois & Gadde, 2002). Loose couplings also serve as a buffering mechanism against unfavorable conditions in the environment owing to the system as a whole not having to respond to every minor change that occurs in the environment.

Loosely coupled systems tend to preserve their identity, uniqueness, and separateness of elements. Therefore, the system can potentially retain a greater number of mutations and novel solutions than would be the case with a tightly coupled system. The greater freedom in a loosely coupled system requires the actors to deal with problems in a

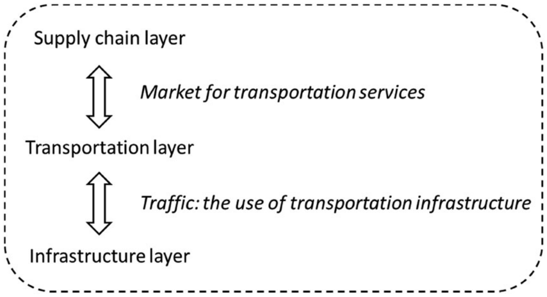

Figure 1. Layers and interfaces of the transportation system (Modified from Wandel et al., 1994).

multitude of ways. This, in turn, favors variety and experimentation which may, under the right conditions, result in innovation. However, such innovations are not easily spread due to the preservation mechanisms that also characterize loosely coupled systems.

The transportation system has been described as a complex open system consisting of a set of sub-systems or layers (ALICE, 2015; Manheim, 1967; Wandel et al., 1994). Drawing on these layered system descriptions we focus our analysis of the freight transportation system on three main system layers: first, the supply chain layer wherein the production, buying and selling of products take place; second, the transportation layer wherein the actual transportation activities are coordinated and carried out; and third, the transportation infrastructure layer containing roads, ports, railways, and other resources. In addition, we identify two interfaces connecting these system layers: the market for transportation services where the supply and demand meet, and the traffic as the use(s) of the transportation infrastructure (see Figure 1).

The framework for analysis of the pattern of couplings in the freight transportation system takes its starting point in this description of the system to enable scrutiny of the main couplings among activities, resources and actors in each layer as well as across the layers, i.e. in the interfaces between them. In the next section the couplings are analyzed for each layer and interface. Furthermore, initiatives to increase sustainability taken by private and public actors are brought up to exemplify how the couplings in the layers and interfaces impact on the possibilities to make substantial and long-lasting changes in the freight transportation system.

3. The pattern of couplings in the transportation system

The focus of our analysis of loose and tight couplings is the actors, activities, and resources that we define as the *elements* in the system. In this section we identify the main characteristics of the pattern of couplings following the five *domains* identified, i.e. the three freight transportation system layers and the two interfaces connecting these layers. Furthermore, we describe examples of sustainability initiatives in each domain. We end the section by summarizing the pattern of couplings identified in the freight transportation system.

3.1. The supply chain layer

Over time, the developments in supply chains have resulted in increasing integration of activities and resources within as well as across organizational boundaries. These general developments relate to overall industrial trends, for example increasing specialization, demands for customization, and globalization. Based on various kinds of adjustments in inter-organizational arrangements such as just-in-time solutions and make-to-order production, interdependencies between buyers and suppliers in supply chains have become strengthened over time (see e.g., Gadde et al., 2010; van Weele, 2010). However, these interdependencies do not only occur within but also across supply chains (Dubois et al., 2004) and, thus, supply networks have been suggested as a more suitable term to describe this system layer (Carter et al., 2015). Consequently, the couplings are typically tight in the supply chain layer for all three kinds of system elements: activities, resources, and actors. These tight couplings are associated with business relationships that are often characterized by collaboration rather than being of an arm's length 'market transaction' nature (Gadde et al., 2010). Collaborative relationships have been discussed in the supply chain literature as involving both vertical (within supply chains) and horizontal (across supply chains) collaboration (Barratt, 2004; Mason et al., 2007).

Sustainable supply chain management has attracted a lot of attention in recent years (Carter et al., 2015). For instance, efforts to create reverse logistics and closed-loop supply chains have become important means of creating circular business models (see e.g., Govindan et al., 2015). Sustainable supply chain initiatives, however, have mostly not concerned, or considered, freight emissions in supply chains (Ellram et al., 2022). Instead, efforts to create closed-loop supply chains may increase the need for transportation (van Loon & Van Wassenhove, 2020). Since transportation activities are integrated in supply chains (Eriksson et al., 2022; Hesse & Rodrigue, 2004) every supply network decision has an impact on freight emissions; "… supplier and distribution center locations, and choice of transportation modes and providers contribute to determining emissions in the supply chain" (Ellram et al., 2022, p. 19). Next, we address the transportation layer.

3.2. The transportation layer

The transportation layer includes actors that provide transportation services and resources such as trucks and ships. The layer is characterized by fragmentation and independence, especially where road freight transportation is concerned. The industry structure is featured by a few large companies operating in parallel with many small firms and by complex, varying and temporal business exchanges across tiers of actors in transportation and logistics networks (European Commission, 2014). The resources activated in the transportation layer are mostly of a standardized nature enabling use of the same equipment for many purposes. However, localized tighter couplings can be observed e.g., when vehicles are designed for special types of goods.

Clearly, road freight transportation is considered as the most flexible transportation mode. Blanquart and Burmeister (2009, p. 135) argued that the dominance of road transportation "is an important issue of public debate" since it "is often criticized for its negative external effects (pollution, accidents, congestion, …)". Furthermore, they concluded that despite "a clear political will (as well on the national as on the European level) to correct the modal split, the trend appears to be difficult to stop, given the difference in infrastructure costs and the difficulties of alternative modes to adapt to the current trends in production systems." (ibid., p. 135).

Moreover, there is a wide variety of business arrangements between transportation service providers in the transportation layer owing to the many different ways in which transportation service providers can specialize, e.g. in transportation modes and geographical scope (Sahay, 2003). Woxenius (2012, p. 65) pointed to the difficulty of defining actor roles in transportation chains: "the industrial organization differs significantly between different types of transport services depending on the character of demand, transport modes involved, regulations, levels of vertical and horizontal integration, etc." The fragmented and diffuse actor structure, the highly standardized resource constellation and the character of the business exchange structure imply that the transportation layer generally features loose couplings.

There are many examples of projects focusing on the transportation layer and aiming at making the use of transportation resources more efficient. For example, carrier associations have emerged that help independent carriers to exchange transportation requests to improve the utilization of their transportation resources (ASTRE, 2022). Such efforts, however, call for coordination between activities carried out by actors who do not normally collaborate but rather compete for orders. Furthermore, various initiatives are taken to promote multi-modal solutions which also require more coordination than what is required by relying on road freight alone.

3.3. The infrastructure layer

Investments in infrastructure such as roads, railways, ports, and airports are massive and planned for long-term use in view of expected future aggregate demand. The infrastructure layer is thus subject to governance at the system level which mostly concerns the national level but also regional and local/city levels. Transportation infrastructure is thus generally characterized by tight couplings, while adjustments to individual users and uses are rare. International (and national) standards provide the basis for the technical and organizational features of transportation infrastructure.

The vulnerability and lack of resilience of transportation network infrastructures have become growing concerns (Mattsson & Jenelius, 2015; Reggiani et al., 2015). As complex networks, their connectivity is considered both a reason and a solution to disturbances of various kinds. According to Mattsson and Jenelius (2015, p. 16):

> "To minimise the costs, infrastructure systems are often designed to work close to their capacity with small margins of reserve capacity and little redundancy. This renders them sensitive to various incidents, technical failures, disruptions, extreme weather, natural disasters, antagonistic actions and other threats. This, in addition to the interdependencies between and within the systems, could lead to serious consequences for society, should a critical component or sub-system fail or break down."

While the tight couplings between elements in the infrastructure layer are considered a concern of growing importance, initiatives to develop and integrate infrastructure across national boundaries, such as the Green Corridors initiatives in the EU (Psaraftis & Panagakos, 2012), intend to further strengthen the couplings within the infrastructure layer. A key issue for such 'corridors' to be successful is to adapt the infrastructure in a way that enables multi-modal and inter-modal transportation in an integrated way (UN, 2021). However, transportation infrastructure is long-lived and decisions "in the short run have long-term implications, and are typically hard to reverse" (ibid., p. 56). One challenge is that in many countries ministries are divided across modal lines and there are also different local, regional, and national ministries impacting on decisions of various geographical scopes, e.g. the rural and urban contexts (UN, 2021). Moreover, initiatives related to electrification of road infrastructure are taken by both public and private actors. An example of a private initiative is the collaboration between three large truck OEMs who have agreed to establish a public charging infrastructure in Europe for heavy-duty long-haul trucks (CCJ, 2021). This kind of initiative aims at accelerating the transition to fossil-free heavy-duty transportation and is an interesting example of how private actors take a lead in a domain otherwise dominated by public actors.

3.4. The market for transportation services: The interface between the supply chain and the transportation layers

The market for transportation services constitutes the interface between the supply chain layer and the transportation layer. For most companies, decisions regarding purchasing of transportation services are made last, and as a consequence of many other decisions relating to production and supply. Such decisions include outsourcing of manufacturing activities to far distant locations leading to an increased demand for transportation (Gurtu et al., 2017). In addition, environmental demands from buyers on transportation services are generally not frequent or well developed (Björklund, 2011; Ellram et al., 2022; Wolf & Seuring, 2010). Rogerson (2017) found that the specifications on transportation services made by buying firms, especially regarding time requirements, heavily influenced 'logistical variables' such as transportation mode used, length of haul, load factor, empty running, and fuel efficiency – all impacting on freight emissions.

Transportation can be viewed as the physical link connecting production and consumption units in the supply chain (Coyle et al., 2003). The provision of a product to a consumer in terms of the source of the raw material and components determines how the supply chain is divided into logistics and transportation chains (Woxenius, 2012). From a supply chain perspective, logistics and transportation activities are integrated in wider activity structures in which the division of labor changes as firms in- and outsource activities to improve their performance (Gadde & Hulthén, 2009). In a similar vein Blanquart and Burmeister (2009) argued that freight transportation needs to be viewed as intertwined in complex logistics and production processes and that it not should be regarded as a simple movement from A to B. Also, Hesse and Rodrigue (2004) emphasized the need to consider transportation as an integrated rather than a derived demand.

Böge's (1995) example of the 'well-travelled yoghurt pot' illustrated how the manufacturing company's focus on its operations and exchanges with its suppliers of goods does not include particular attention to the transportation distances to which these operations and exchanges give rise. This relates to Sanchez Rodrigues et al. (2008, p. 389) arguing that "there appears to have been a failure to properly integrate transport into supply chains". The same authors argued that since changing conditions in the supply chain layer often result in uncertainty for carriers (i.e. transportation providers), it leads to situations in which "carriers may build considerable amounts of flexibility into their service offerings, perhaps in terms of volume, route, fleet mix, and time, with cost implications" (ibid., p. 393). Furthermore, there appears to be "low levels of understanding" of how the actions on one system level impact another, e.g. how actions on the supply chain layer impact the operations of actors on the transportation layer and vice versa (ibid., p. 393).

The loose couplings in road freight (and road transportation in general) permit high degrees of flexibility (Dong, 2018) but also, combined with the fragmentation and independence characterizing the actors in the transportation layer, a risk of inefficient capacity utilization of both vehicles and road infrastructure. Such over-capacity, however, contributes to the buffering attributes of the overall transportation system. Hence, the flexibility of the system comes at a cost that the actors seem willing to pay.

All these examples of studies point at how loose couplings feature the interface between the supply chain layer and the transportation layer. However, there are exceptions to this general pattern. Supply chains characterized by large relative transportation costs (e.g., in mining or steel production) are often subject to extensive transportation-related investments adjusted to very specific purposes and are thus subject to tighter couplings. In addition, the development of business relationships between transportation service buyers and suppliers, encompassing special arrangements such as third- and fourth party logistics, wherein logistics service providers work closely together with their customers, may strengthen the couplings (Andersson & Norrman, 2002). However, while such business arrangements may be subject to local adjustments, the technical (transportation resource) interdependencies between firms are most often limited, and thus loose couplings dominate this interface. To counteract the negative effects of such loose couplings there are calls for a "closer link to be organized" between the transportation system and industrial supply chains since "transport sustainability measures need support and leadership of all supply chain actors, in order to avoid suboptimal environmental measures in the transport system" (ALICE, 2015, p. 21). As part of this, so called horizontal collaboration between supply chain actors has been promoted through initiatives to increase the resource utilization across supply chains to improve efficiency in logistics and transportation. For example, within the European CO3 consortium, the mission of CO3 "was to encourage a mind change in the competitiveness and sustainability of European logistics by stimulating horizontal collaboration between European shippers" (CO3,3, 2022). In one of the projects within CO3, a major retail company together with some of its suppliers and a joint 3PL launched an initiative to increase fill rates by sharing transportation capacity that would otherwise run empty. The project showed that such initiatives could result in a reduction of CO2 emissions per pallet, wasted vehicle capacity, and traffic.

3.5. Traffic: The interface between transportation and infrastructure

Traffic is the interface between the transportation infrastructure and the physical resources activated in transportation, e.g. the vehicles using it. Both loose and tight couplings can be identified in the traffic interface. The variety mainly relates to the modes of transportation, i.e. road, rail, sea and air, and the degree of special adjustments required between the infrastructures and the vehicles using them. Modes that operate on fixed routes and specific schedules (e.g. rail services carrying containers to and from a port) will be charaterised by tight couplings. Although road freight transportation also operates to fixed schedules and specific routes there is generally more flexibility than is the case for rail transportation resulting typically in looser couplings. Carriers in road freight transportation have also been developing more dynamic approaches to routing and scheduling i.e. being able to respond to changes such as congestion in real time.

Policy-level planning of infrastructures with regard to long-term traffic demands relies on macro level models. Tiwari (2000), for one, criticized current traffic models for their assumptions of 'homogeneous' traffic conditions, i.e. road traffic consisting primarily of cars or motorized vehicles with similar characteristics. According to Tiwari these models have led to the development of a range of analytical techniques for traffic management such as demand-supply analysis, capacity and level of service analysis and simulation modeling (ibid., p. 73).

For rail, sea and air traffic, the couplings between vehicles/vessels and infrastructure are typically tighter than for road traffic, i.e. ships in relation to ports, trains in relation to tracks and planes in relation to airports. This hence requires more coordination of activities and adjustments between resources among the transportation and

Table 1. The pattern of couplings in the transportation system.

Domain: System layer/*Interface*	Elements	Couplings
Supply chain layer	Activities and resources of the buyers and suppliers of goods	Tight: integrated supply chains subject to interdependence between elements
Market for transportation services	*Activities and resources of the buyers and suppliers of transportation services*	*Loose: transactional and independent (but tighter when subject to special arrangements)*
Transportation layer	Activation of resources (e.g. vehicles) for goods transportation	Loose: (but tighter when vehicles are adjusted to special types of goods)
Traffic	*Connections between technical resources (vehicles and physical infrastructures)*	*Loose: for road transportation* *Tight: for rail, sea and air*
Infrastructure layer	Physical transportation infrastructure resources	Tight: subject to standards and long-term investments

infrastructure actors involved. Intermodal transportation solutions, e.g. sea and rail, entail large investments and require adaptations to both modes of transportation (Roso et al., 2009). Woxenius and Behrends (2010) analyzed the drivers and barriers in rail-based intermodal freight transportation (IFT) and concluded that it is "evident that commercial implementation of new IFT concepts requires a significant element of system innovation" and that the process requires concurrent changes of many types of technological resources in addition to organizational challenges (ibid., p. 734). In general, rail based IFT has often been described as a disappointment in the European transportation market, and it represents a complicated system encompassing a wide variety of relationships between actors, activities and technical resources, which in turn implies inertia to change (Woxenius & Behrends, 2010). Dong (2018, p. 339), argued that firms often interpret intermodal solutions based on rail and sea transportation to lack "flexibility in delivery quantity, frequency, schedule, etc., and result in larger inventory and/or longer periods between deliveries."

Consequently, firms are reluctant to implement such solutions even though they would be more sustainable from an environmental point of view. This was also noted by Blanquart and Burmeister (2009, p. 143) who observed that the dominance of road freight could partly be explained by this mode's "superior ability to adjust to flexible production systems" and by Islam and Blinge (2017) who pointed out that rail as a transportation mode has been slow to adapt to the current door-to-door, rather than terminal-to-terminal, solutions.

To conclude, both loose and tight couplings can be identified in the interface between the transportation and the infrastructure layers. Loose couplings feature road transportation while rail, sea and air transportation are characterized by tighter couplings.

However, initiatives such as introduction of wireless communications technology in connected vehicles may tighten the couplings between infrastructure and other elements of the transportation system. This kind of technology enables real-time communications and the data generated from such solutions can help improve traffic safety and be used to analyze real-time traffic data enabling redirections and re-planning of traffic to improve the use of infrastructure. Furthermore, so called platooning initiatives where several trucks are wirelessly connected in a convoy reduces CO2 emissions due to a reduction of air resistance and thereby fuel savings (UN, 2021). Also, geofencing enabling for instance speed control in pre-defined geo-fence zones are subject to a lot of interest and projects (see e.g. Foss et al., 2019; Lindkvist et al., 2022).

4. General patterns of couplings within and between system layers

The overall identified pattern of loose and tight couplings suggests that tight couplings mainly prevail in the supply chain and the infrastructure layers, while loose couplings are dominant in the transportation layer and the two interfaces. Table 1 summarizes the general pattern of couplings between elements within each domain: the system layers and the interfaces connecting the layers (the latter in italics).

The loose couplings in the transportation layer and in the interfaces between the layers can be seen as setting the terms for the overall system functions that are described for loosely coupled systems. Loosely coupled systems promote short-term efficiency while preserving their structure and characteristics, meaning that they resist change when the pattern of couplings is challenged. Therefore, the success or failure of various measures depend on the fit with the current pattern of couplings. However, considering the extensive need for change in and to the transportation system, it can be suggested that very few, if any, measures to address the sustainability issues can be taken without challenging the current pattern of couplings within this system. In particular, oil, as a key resource on which a substantial part of the loose couplings in the transportation layer relies, cannot simply be replaced by a similar resource with regard to the current pattern of couplings.

In the next section we discuss policy implications following from the identified pattern of couplings in the freight transportation system with particular focus on sustainability.

5. Examples of implications for policies directed at freight transportation sustainability

The transportation system has no central leadership or governance structure to rely on where change is concerned. According to Geels (2012, p. 481): "Policy makers have no privileged position outside the system (the 'cockpit') from which they can pull levers and change the transport system." Geels also observed that most transportation policies prioritize congestion over environmental sustainability at national and local levels, while European policy makers are more active in this regard. These 'landscape' aspects affect the whole transportation system. Moreover, in their analysis of mechanisms that preserve the system, Müller and Blanquart (2018) concluded that national innovation cluster policies are essential, but not enough for radical innovation. Referring to the MLP framework, they also concluded that governments are not supporting destabilization of the prevailing regimes. Considered as a loosely coupled system, the freight transportation system seems to be stabilized mainly through its loose couplings; (1) between the supply chain and the transportation layers, to cope with the tight couplings within supply chains (Ellram et al., 2022; Eriksson et al., 2022), and (2) between the transportation and the infrastructure layers which can be seen as a prerequisite for all kinds of vehicles (used for transportation of both people and goods) to share the same road infrastructures, and to provide a high level of flexibility for all users.

In general terms, it can be argued that the transportation system has evolved as a loosely coupled system largely due to oil being a key resource. Adjustments of various elements in the wider system have been made over time in accordance with the pattern of loose couplings stemming from the heavy reliance on this specific resource. However, the main challenge today, to replace oil with other sources of energy, does not seem possible to enforce without major changes in and to the transportation system. In particular, the energy system needs to become more integrated with the transportation system and may thus require tighter couplings within and across system layers than that which prevails with oil as the dominating resource in the transportation system. The loose coupling between the transportation layer and the two interfaces, especially the one between the transportation layer and the infrastructure layer, are problematic in this regard. However, in parallel with efforts to reduce the dependence on oil, emerging digital infrastructure elements, broadly referred to as Intelligent Transport Systems (ITS), may affect certain couplings within the system. Geels (2012) analyzed ITS as a niche with a potential to crack the current regime since "it is pushed by powerful companies and embraced by transport professionals" (ibid., p. 479). For one thing, Geels predicts that ITS may facilitate congestion charging and road pricing, which may transform roads (or the use of roads) from public goods into payable services. That is, such developments could have an impact on the interface between the transportation layer and the infrastructure layer.

Electrification of road transportation requires adjustments and investments of different kinds that entail increasing interdependence between actors and resources within and across transportation system layers which challenges the current pattern of couplings. Azar and Sandén (2011) argued that for private companies to dare to make huge investments in, e.g. infrastructure for new fuels or electric vehicles, strong government commitment, broad agreements and long-term visions are critical. The authors suggested that technology-specific market-oriented policies are needed to bridge the gap between invention and large-scale diffusion of new technologies with low or zero carbon emissions. In terms of the pattern of couplings, this suggests tighter couplings enforced by stronger policies – and thus what Geels (2012) refered to as changing the regimes of the system.

In view of the overall sustainability challenge and the many efforts to change parts of the transportation system, we argue that it may be fruitful to analyze and address freight transportation as a loosely coupled system since this may provide insights into the difficulty in formulating policies that lead to changes that are scalable and can be repeated in different contexts. Policies are developed at various levels – at the local/city level, the regional level (a county or state within a country), the national level, and the international level, while the transportation system spans all these boundaries. Considering the pattern of couplings in the transportation system it seems particularly problematic to change the prevailing regime by tightening some of the loose couplings without also addressing the effects on other parts of the system. The weak links between different policy levels entail additional challenges in this regard since these policy levels relate to business actors in different ways e.g., truck OEMs operating at a global scale are not willing to make significant investments to accommodate local policies.

Achieving urban freight operations with low or zero emission is a policy goal for many cities (see e.g., Quak et al., 2016). However, increasing the use of electric vehicles for urban delivery has so far been largely unsuccessful despite more suitable vehicles becoming available. Transportation companies (carriers) may be willing to change to electric delivery vehicles but fear that they will not be able to achieve any benefits from such a change and that their customers will make decisions based largely on the price for transportation and flexible services being offered. As a result, widespread system level change is inhibited because no organization has the power to drive the change due to the complicated interlocking relationships that currently exist. Some urban freight policies at a local level may also have unintended consequences. For example, when the city of Sao Paulo in Brazil introduced urban access restrictions, based on vehicle size, many operators changed from using one large vehicle to using two or more smaller vehicles (Zambuzi et al., 2016) which, in turn, made congestion worse.

At a regional, national, or international level, policies may be formulated to encourage mode shift from road to rail or water to make transportation more sustainable. Yet the loosely coupled nature of the transportation system tends to weaken such initiatives and limit the level of take-up and the potential benefits. There is also scope for companies to work together to achieve higher levels of vehicle utilization and to consolidate flows, in turn leading to a reduction in fossil fuel use. Yet such horizontal collaboration efforts remain rather limited and thus freight capacity will continue to be greater than required (i.e. services are duplicated) with no single organization having the power to change this. The problems and weaknesses stemming from this inefficient use of transportation resources, e.g. low vehicle fill rates and too many vehicle trips, are accommodated by the freight transportation system but at the expense of more efficient and sustainable operations. The loose coupling featuring the interface between the supply chain layer and the transportation layer is particularly problematic in this regard. Policies at various levels, e.g. taxes on fossil fuel, have an impact on the market for transportation services, but since the value of transportation from the perspectives of supply chain actors are heterogenous, the consequences of such policies are manifold and difficult to predict. For most firms selling highly refined products the share of transportation on total costs is insignificant in contrast with other supply chain costs, while for companies selling heavy input materials such as timber, transportation cost increases are critical. The latter category has typically made a lot of adjustments to make the best possible use of the most cost-effective transportation resources e.g., by developing specific sea or rail freight solutions.

While many policies aim at being 'technology neutral' (Azar & Sandén, 2011) there are examples of experimentation with specific technologies engaging both private and public actors. For instance, in Sweden and Germany there are efforts to establish the feasibility of 'E-highways' where large trucks can operate using electricity possibly by means of a catenary system and thus avoid the problems of trying to change large trucks to battery power i.e. loss of payload and range related issues (The Swedish Transport Administration, 2017). Such a development needs to be supported by a national policy and would also require the commitment of transportation companies and their customers. The consequence of making such investments would be to replace loose with tight couplings between the transportation layer and the infrastructure layer in some parts of the infrastructure.

As we have noted, policies need to be framed in ways that take the pattern of couplings into account. In the case of transportation this suggests that policy makers must recognize that many elements and aspects of transportation are characterized by loose couplings either by developing policies that fit with the current pattern of couplings or by considering what it would take to change the pattern of couplings in the system. Within the European Union, examples of policies that fit with the pattern of couplings are those that, through regulations and standards, have resulted in a steady improvement in the environmental performance of vehicles. However, this has not led to a fundamental change away from the reliance on oil as a fuel nor to stimulate more efficient use of transportation resources. Beside policies and regulations directed at influencing the development and sales of vehicles, some policy agendas seem to be oriented to tighten certain couplings in favor of increasing transportation efficiency, energy efficiency and the replacement of fossil fuels with bio-based fuels and electricity. Considering Weick's (2009) notion on how loosely coupled systems resist change, it seems problematic that policy makers at the same time are 'maintaining' instead of 'expanding' their role – for example by strengthening the links between different policy levels - in efforts to change the loosely coupled nature of the system. Müller and Blanquart (2018) arrived at a similar conclusion and recommended that neo-classical thinking and acting need to be abandoned and that introducing new principles in policy is a huge future challenge.

Based on the framework outlined in the paper we propose that further research is needed to identify policies that work and those that do not. This research could start with a focus on freight transportation and develop comparisons at various levels - local, national, and international. Research initiatives within the EU are interesting in this regard. In its research and innovation roadmap, ALICE (2015) suggested integrating transportation services and supply chains, as well as transportation services and infrastructures, thus corresponding to tightening the couplings in the two interfaces or markets for transport services and traffic, by investments in corridors, hubs and synchromodality. However, the following quote illustrates some of the challenges involved in these endeavors:

> "So far, network integration has been focused on interconnectivity and interoperability of transport processes and equipment. Integration has been achieved only partially at the TEN-T core network level, without alignment of hubs and corridors specifically for freight transport. There is a poor match between requirements of door-to-door freight services within Europe and the supporting pan-European infrastructure. In addition, important dynamic qualities of the transport system such as flexibility, resilience and responsiveness are still underdeveloped. Thirdly, integration has not been achieved in the vertical sense, aligning transport services with supply chain requirements of manufacturers, distributors and the wholesale sector. Freight services are, therefore, insufficiently customer-oriented to serve increasingly diverse client's needs."(ALICE, 2015) (https://www.etp-logistics.eu/wp-content/uploads/2015/08/W26mayo-kopie.pdf).

Hence, the problems identified while tightening important couplings within the system to make it more sustainable correspond with the positive features of the loosely coupled nature of the system (such as flexibility, resilience and responsiveness) discussed in this paper. In view of how research addressing sustainable transformation of the transportation system most often focuses on individual layers or elements of the system we suggest that further research to a larger extent takes system level characteristics and impacts into account. If not, large investments in new elements or sub-systems to make the transportation system more sustainable may not result in the intended system level effects.

6. Concluding discussion

Based on analysis of the couplings within and between the identified transportation system layers, we suggest that it may be instrumental to address the freight transportation system as a loosely coupled system. We conclude that the identified pattern of couplings favors short-term efficiency in transportation operations while the possibility of bringing about changes that challenge the current pattern of couplings are circumscribed. This is critically important in view of the need to reduce or eliminate the oil dependent nature of the transportation system. Policies and actions to make the transportation system more sustainable need to take account of the interactions and interdependencies in the transportation system and the nature of couplings within and across the layers and interfaces. This conclusion is in line with Müller and Blanquart (2018) that argued for a stronger focus on processes and interdependencies in further studies of innovation in freight transportation.

Current policies focusing on supporting alternative energy sources do not seem to result in rapid change in behavior that transforms the system, and efforts to make better use of transportation resources seem far less frequent than those focusing on replacing fossil fuels – while both are needed.

The complexity of the transportation system implies difficulties in identifying who needs to act and who needs to interact to achieve different outcomes. The loose couplings in the transportation system mean that many current activities and resources in the system work without coordination or interaction between the actors relying on them. Hence, when these loose couplings need to be replaced by solutions that require resource adaptations carried out in interaction between specific actors (e.g. in the development of electric roads), or activity adjustments (e.g. other principles for supply chain planning), this becomes very difficult to put in place. A special category of challenging changes concerns the boundary between public authority and markets for various system elements, such as vehicles, transportation services, road use, etc., and the new forms of interaction between public and private actors that may become necessary to make the transportation system sustainable.

We began the paper with a reference to Weick's (1976) engaging analogy about watching a soccer game. Importantly, as Weick noted, despite the apparent chaos "the game is played as if it makes sense". Everyone knows the rules (well enough) and everyone seems comfortable with the game as it is played. As we have argued, this is a problem for transportation - we can all agree that things need to change if transportation is to make the contribution to climate change mitigation but too many people and organizations remain comfortable with the way things are and the perception that the transportation system works. An unconventional soccer match may thus have important lessons for policy formulation that can really lead to changes that contribute to a sustainable freight transportation system.

ORCID

Michael Browne http://orcid.org/0000-0003-1900-5189
Anna Dubois http://orcid.org/0000-0002-5248-3687
Kajsa Hulthén http://orcid.org/0000-0002-8455-0389

References

ALICE. (2015). *Corridors, Hubs and synchromodality: Research & innovation roadmap*. www.etp-alice.eu.

Andersson, D., & Norrman, A. (2002). Procurement of logistics services – A minute's work or a multi-year project? *European Journal of Purchasing & Supply Management*, *8*(1), 3–14. https://doi.org/10.1016/S0969-7012(01)00018-1

Aschauer, G., Gronalt, M., & Mandl, C. (2015). Modelling interrelationships between logistics and transportation operations – a system dynamics approach. *Management Research Review*, *38*(5), 505–539. https://doi.org/10.1108/MRR-11-2013-0271

ASTRE. (2022). ASTRE - Association des transporteurs européens [Online]. Retreived May 16, 2022, from https://www.astre.fr/en. .

Azar, C., & Sandén, B. (2011). The elusive quest for technology-neutral policies. *Environmental Innovation and Societal Transitions*, *1*(1), 135–139. https://doi.org/10.1016/j.eist.2011.03.003

Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. *Supply Chain Management: An International Journal*, *9*(1), 30–42. https://doi.org/10.1108/13598540410517566

Björklund, M. (2011). Influence from the business environment on environmental purchasing – Drivers and hinders of purchasing green transportation services. *Journal of Purchasing and Supply Management*, *17*(1), 11–22. https://doi.org/10.1016/j.pursup.2010.04.002

Blanquart, C., & Burmeister, A. (2009). Evaluating the performance of freight transport: a service approach. *European Transport Research Review*, *1*(3), 135–145. https://doi.org/10.1007/s12544-009-0014-5

Böge, S. (1995). The well-travelled yoghurt pot: lessons for new freight transport policies and regional production. *World Transport Policy and Practice*, *1*(1), 7–11. https://doi.org/10.1108/EUM0000000004024

Carter, C. R., Rogers, D. S., & Choi, T. Y. (2015). Toward the theory of the supply chain. *Journal of Supply Chain Management*, *51*(2), 89–97. https://doi.org/10.1111/jscm.12073

CCJ. (2021). Major truck OEMs partner to build out EV charging infrastructure in Europe. *Trucking news and briefs for Friday, Dec. 17, 2021*. Retrieved May 31, 2022, from https://www.ccjdigital.com/alternative-power/article/15286520/major-truck-oems-partner-to-build-out-ev-charging-infrastructure-in-europe.

CO3. (2022). CO3: Collaboration, concepts for co-modality.(Web page). Retrieved May 31, 2022, from http://www.co3-project.eu/.

Coyle, J. J., Edward, J. B., & Langley, C. J. (2003). *The management of business logistics: A supply chain perspective* (7th ed.). Western/Thompson Learning.

Creutzig, F., Jochem, P., Edelenbosch, O. Y., Mattauch, L., van Vuuren, D. P., McCollum, D., & Minx, J. (2015). Transport: A roadblock to climate change mitigation. *Science (New York, NY)*, *350*(6263), 911–912.

Dong, C. (2018). A supply chain perspective of synchromodality to increase the sustainability of freight transportation. *4OR*, *16*(3), 339–340. https://doi.org/10.1007/s10288-017-0367-x

Dubois, A., & Gadde, L.-E. (2002). The construction industry as a loosely coupled system: implications for productivity and innovation. *Construction Management and Economics*, *20*(7), 621–631. https://doi.org/10.1080/01446190210163543

Dubois, A., Hulthén, K., & Pedersen, A.-C. (2004). Supply chains and interdependence: A theoretical analysis. *Journal of Purchasing and Supply Management*, *10*(1), 3–9. https://doi.org/10.1016/j.pursup.2003.11.003

EEA. (2020). *Transport: increasing oil consumption and greenhouse gas emissions hamper EU progress towards environment and climate objectives*. Briefing no. 15/2019. https://doi.org/10.2800/433449

Ellram, L. M., Tate, W. L., & Saunders, L. W. (2022). A legitimacy theory perspective on Scope 3 freight transportation emissions. *Journal of Business Logistics*, *00*, 1–27.

Eriksson, V., Dubois, A., & Hulthén, K. (2022). Transport in supply networks. *The International Journal of Logistics Management*, *33*(5), 85–106. https://doi.org/10.1108/IJLM-06-2021-0350

European Commission. (2014). *Report on the State of the EU Road Haulage Market. Task B: Analyse the State of the European Road Haulage Market, Including an Evaluation of the Effectiveness of Controls and the Degree of Harmonisation*. *Aecom* February 5.

Figueroa, M., Lah, O., Fulton, L., McKinnon, A., & Tiwari, G. (2014). Energy for transport. *Annual Review of Environment and Resources*, *39*(1), 295–325. https://doi.org/10.1146/annurev-environ-031913-100450

Foss, T., Seter, H., & Arnesen, P. (2019). *Geofencing for smart urban mobility*. SINTEF Report 2019:00123.

Gadde, L.-E., Håkansson, H., & Persson, G. (2010). *Supply network strategies*. Wiley and Sons.

Gadde, L.-E., & Hulthén, K. (2009). Improving logistics outsourcing through increasing buyer-provider interaction. *Industrial Marketing Management*, *38*(6), 633–640. https://doi.org/10.1016/j.indmarman.2009.05.010

Geels, F. (2012). A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. *Journal of Transport Geography*, *24*, 471–482. https://doi.org/10.1016/j.jtrangeo.2012.01.021

Geels, F., Kemp, R., Dudley, G., & Lyons, G. (2012). *Automobility in transition?: A socio-technical analysis of sustainable transport*. Taylor & Francis Group; Routledge. ISBN13: 978-0-415-88505-8..

Govindan, K., Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research*, *240*(3), 603–626. https://doi.org/10.1016/j.ejor.2014.07.012

Gurtu, A., Searcy, C., & Jaber, M. Y. (2017). Emissions from international transport in global supply chains. *Management Research Review*, *40*(1), 53–74. https://doi.org/10.1108/MRR-09-2015-0208

Håkansson, H., Ford, D., Gadde, L.-E., Snehota, I., & Waluszewski, A. (2009). *Business in networks*. Wiley.

Håkansson, H., & Snehota, I. (1995). *Developing relationships in business networks*. Routledge.

Hesse, M., & Rodrigue, J.-P. (2004). The transport geography of logistics and freight distribution. *Journal of Transport Geography*, *12*(3), 171–184. https://doi.org/10.1016/j.jtrangeo.2003.12.004

Hu, J., Wood, R., Tukker, A., Boonman, H., & de Boer, B. (2019). Global transport emissions in the Swedish carbon footprint. *Journal of Cleaner Production*, *226*, 210–220. https://doi.org/10.1016/j.jclepro.2019.03.263

Islam, D., & Blinge, M. (2017). The future of European rail freight transport and logistics. *European Transport Research Review*, *9*(1), 11. https://doi.org/10.1007/s12544-017-0227-y

Kunze, O., Wulfhorst, G., & Minner, S. (2016). Applying systems thinking to city logistics: A qualitative (and quantitative) approach to model interdependencies of decisions by various stakeholders and their impact on city logistics. *Transportation Research Procedia*, *12*, 692–706. https://doi.org/10.1016/j.trpro.2016.02.022

Lin, N. (2019). CO2 emissions mitigation potential of buyer consolidation and rail-based intermodal transport in the China-Europe container supply chains. *Journal of Cleaner Production*, *240*, 118121–118121. https://doi.org/10.1016/j.jclepro.2019.118121

Lindkvist, H., Dubois, A., Lind, F., & Melander, L. (2022). *Managing freight transport in cities–User perspectives on geofencing* [Paper presentation]. To be Presented at the 9th Transport Research Arena Conference, Lisbon, Portugal, November

Manheim, M. (1967). *Principle of transport systems analysis. Transportation system analysis and evaluation of alternate plans. Serial: Highway Research Record, Issue Number: 180*. Highway Research Board.

Mason, R., Lalwani, C., & Boughton, R. (2007). Combining vertical and horizontal collaboration for transport optimisation. *Supply Chain Management: An International Journal*, *12*(3), 187–199. https://doi.org/10.1108/13598540710742509

Mattsson, L.-G., & Jenelius, E. (2015). Vulnerability and resilience of transport systems–A discussion of recent research. *Transportation Research Part A*, *81*, 16–34.

McKinnon, A. (2016). Freight transport deceleration: Its possible contribution to the decarbonisation of logistics. *Transport Reviews*, *36*(4), 418–426. https://doi.org/10.1080/01441647.2015.1137992

Müller, S., & Blanquart, C. (2018). The inventor's perspective on conditions for radical innovations in freight transportation: Case studies from France and Germany. *Journal of Innovation Economics & Management*, *25*, 211–238.

Orton, J. D., & Weick, K. E. (1990). Loosely coupled systems: A reconceptualization. *Academy of Management Review*, *15*(2), 203–223. https://doi.org/10.5465/amr.1990.4308154

Psaraftis, H. R., & Panagakos, G. (2012). Green corridors in European surface freight logistics and the SuperGreen project. *Procedia - Social and Behavioral Sciences*, *48*, 1723–1732. https://doi.org/10.1016/j.sbspro.2012.06.1147

Quak, H., Nesterova, N., van Rooijen, T., & Dong, Y. (2016). Zero emission city logistics: current practices in freight electromobility and feasibility in the near future. *Transportation Research Procedia*, *14*, 1506–1515. https://doi.org/10.1016/j.trpro.2016.05.115

Reggiani, A., Nijkamp, P., & Lanzi, D. (2015). Transport resilience and vulnerability: The role of connectivity. *Transportation Research Part A*, *81*, 4–15.

Rogerson, S. (2017). Influence of freight transport purchasing processes on logistical variables related to CO2 emissions: A case study in Sweden. *International Journal of Logistics Research and Applications*, *20*(6), 604–623. https://doi.org/10.1080/13675567.2017.1308472

Roso, V., Woxenius, J., & Lumsden, K. (2009). The dry port concept: Connecting container seaports with the hinterland. *Journal of Transport Geography*, *17*(5), 338–345. https://doi.org/10.1016/j.jtrangeo.2008.10.008

Sahay, B. (2003). Supply chain collaboration: the key to value creation. *Work Study*, *52*(2), 76–83. https://doi.org/10.1108/00438020310462872

Sanchez Rodrigues, V., Stantchev, D., Potter, A., Naim, M., & Whiteing, A. (2008). Establishing a transport operation focused uncertainty model for the supply chain. *International Journal of Physical Distribution & Logistics Management*, *38*(5), 388–411. https://doi.org/10.1108/09600030810882807

Sims, R., Schaeffer, R., Creutzig, F., Cruz-Nunez, X., S'Agosto, M., Dimitriu, M., … , … Tiwari, G. (2014). Transport. In O. Edenhofer, R. Pich-Madruga, Y. Sokona, E. Farahani, S. Kafner, K. Seyboth, … J. C. Minx (Eds.), *Climate change 2014: Mitigation of climate change. Contribution of working group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

The Swedish Transport Administration. (2017). *National roadmap for electric road systems*. Retrieve April 3, 2020, from https://www.trafikverket.se/contentassets/445611d179bf44938793269fe58376b6/dokument/national_roadmap_for_electric_road_systems_20171129_eng.pdf.

Tiwari, G. (2000). Traffic flow and safety: Need for new models of heterogeneous traffic. In D. Mohan & G. Tiwari (Eds.), *Injury prevention and control* (pp. 73–91). Taylor and Frances.

UN. (2021). Sustainable transport, Sustainable development. *Interagency Report, Second Global Sustainable Transport Conference*. United Nations publication issued by the Department of Economic and Social Affairs, Reprinted 2021.

van Loon, P., & Van Wassenhove, L. (2020). Transition to the circular economy: the story of four case companies. *International Journal of Production Research*, *58*(11), 3415–3422. https://doi.org/10.1080/00207543.2020.1748907

van Weele, A. J. (2010). *Purchasing and supply chain management*. Cengage Learning.

Wandel, S., Ruijgrok, C., & Nemoto, T. (1994). Relationships among shifts in logistics, transport, traffic and informatics. In *Logistiska framsteg*. Studentlitteratur.

Weick, K. E. (1976). Educational organizations as loosely coupled systems. *Administrative Science Quarterly*, *21*(1), 1–19. https://doi.org/10.2307/2391875

Weick, K. E. (2009). *Making sense of the organization: the impermanent organization* (Vol. *2*). John Wiley and Sons.

Wolf, C., & Seuring, S. (2010). Environmental impacts as buying criteria for third party logistical services. *International Journal of Physical Distribution & Logistics Management*, *40*(1/2), 84–102. https://doi.org/10.1108/09600031011020377

Woxenius, J. (2012). Directness as a key performance indicator for freight transport chains. *Research in Transportation Economics*, *36*(1), 63–72. https://doi.org/10.1016/j.retrec.2012.03.007

Woxenius, J., & Behrends, S. (2010). Innovation drivers and barriers in intermodal freight transport. In T. Whiteing (Ed.), *Towards the Sustainable Supply Chain: Balancing the needs of business, economy and the environment*. The Chartered Institute of Logistics and Transport.

wri.org. (2019). Blogpost by Wang, S., & Ge, M., October 16, 2019.

Zambuzi, N., Cunha, C., Blanco, E., Yoshizaki, H., & Carvalho, C. (2016). *An evaluation of environmental impacts of different truck sizes in last mile distribution in the city of São Paulo, Brazil* [Paper presentation]. Paper Presented at the ILS 2016 Conference, Bordeaux.