ASSESSING ACTIONS TOWARDS SUSTAINABLE LOGISTICS: A FRAMEWORK

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Abstract: Sustainability includes a variety of aspects, e.g., environment, economy and society, related to each other in different ways. Most studies concerning sustainable logistics do not reflect these relations, since they deal with one issue at a time (e.g., CO_2 – emissions or congestion), have a short- and medium time perspective, and seldom take into account impacts on other systems, e.g., energy or land-use systems. In order to develop long-term strategies towards sustainable logistics, actors in the logistics system require knowledge about the complexity of the problem and the interdependencies of their actions. Hence, there is a need for a holistic framework for sustainable logistics including all aspects of sustainability, the relevant logistics actions as well as their interdependencies. This paper takes a first step towards developing such a holistic framework. The suggested framework includes the relations between decision areas in material and transport level at one hand and the logistical and environmental sustainability goals at the other. The authors argue that decisions in the transport level have a direct affect to both logistical and environmental goals, while material flow decisions are of major concern for logistical goals. Furthermore, logistics systems that integrate material flow and transport flow decision making will be more successful in meeting logistical and environmental goals, thus leading to more sustainable logistics. In order to identify more sustainable logistics solutions, there must be a raised awareness about the key factors linking decision areas and performances.

Keywords: *sustainable logistics; holistic view; framework.*

INTRODUCTION

Sustainability is most commonly defined as combining economic development with environmental concerns as well as social responsibility, also called the triple bottom line (Norman and MacDonald, 2004). One difficulty in the issue of sustainable logistics is how to simultaneously strive toward economic benefits, a reduced impact on the eco-system and social responsibility. Decreasing product life cycles and increasing product values have led to innovative logistics approaches like JIT with less storage and more frequent deliveries (Chopra, 2003) in order to increase service levels and reduce tied-up capital. The implications for freight transport are a rising demand for the shipping and delivery of smaller units in a higher frequency, an increasing importance of time, reliability and speed. As a consequence, many industries have increased their reliance on

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road transport leading to higher unsustainable impacts.

Since transport is the most important source of environmental impacts in the logistics system (Wu and Dunn, 1995) 'green logistics' measures have been introduced in the transport sector, i.e., cutting externalities of vehicle movements (McKinnon, 2003). However, the benefits of more efficient and clean vehicle movements have been offset by decisions on superior levels, e.g., centralisation of warehouses, sourcing from more distant suppliers, JIT production, etc., which often increase the demand for vehicle movement in absolute terms. Approaches for reducing the environmental impact focusing on more energy efficient technology have therefore proven to be insufficient (Aronsson and Brodin, 2006). Freight transport demand is the result of complex interaction between decisions made at different levels. These decisions form a hierarchy, i.e., the decisions at a higher strategic level on logistics structures and trading links between the company and its suppliers and customers establish the framework for transport decisions (McKinnon, 2003). Hence, it is difficult to isolate transport as an independent activity (Drewes Nielsen et al., 2003). On the other hand, transportation and logistics can also be seen as complementary systems and there seems to be a growing acceptance to analyse transport as an activity embedded in its own systemic logic in transport chains. It is the location of the logistics activities in relation to transport infrastructure that determines the nature, the origin, the destination, the distance and even the possibility of movements to be realised (Rodrigue et al., 2006). Hence, transport cannot be solely considered as a derived demand, but as an integrated demand where physical distribution and materials management are interdependent (Hesse and Rodrigue, 2004).

When developing strategies for sustainability, a holistic view, a large enough system perspective, needs to be taken (Holmberg and Robért, 2000). In logistics, this is especially important, since the complexity of logistics and freight transport decision making may lead to sub-optimisations; actions improving one part of the logistics system create problems in another part. Furthermore, sustainable logistics strategies need to take a long-term approach, since scope of time of actions corresponds to the actions' improvement potentials (Jansen, 2003). The short-term approach aiming at an optimal use of the current system offer immediate improvements which are, however, limited. Jump-like changes can only be achieved by a radical system renewal and require long-term changes in system structures.

Earlier studies show that there is a need for developing methods that takes a holistic system approach on sustainability and logistics (Santén and Blinge, 2010). Most studies concerning sustainable logistics focus at environment as well as one issue at a time, e.g., CO_2 – emissions or congestion (e.g., Piecyk and McKinnon, 2009). Furthermore, they have a short- and medium time perspective and seldom take into account effects on the system as a whole. Also, actors in the logistics system require knowledge about the interdependencies of their actions.

The purpose of this paper is to take a first step towards developing a framework, having a holistic approach on sustainable logistics. The aim of the framework is to highlight the interdependencies in between decisions in different parts of the logistics system and the sustainability goals.

The composition of the paper is as follows. The following section explains the research approach and the methods used. The next coming two sections present the development of the components included in the framework. After that, the relations between the components in the framework are discussed. The final section contains the conclusions and outlines further research.

RESEARCH APPROACH AND METHOD

In this paper we take a first step towards developing a conceptual framework for sustainable logistics. According to Meredith (1993) a conceptual framework is a collection of interrelated propositions which are accomplished by an integration of a number of different works summarising common elements, contrasting the differences and extending the work in some fashion. A framework explains an event, provide understanding or suggest testable hypotheses.

The general structure of our holistic framework is based on the hierarchical model presented by Wandel et al. (1992) that consists of the three layers material flow, transport flow and infrastructure. The freight flow is the top layer, which represents supply chains consisting of nodes and links. It determines the demand for freight transport in terms of shipment size, frequency, lead time, delivery precision and flexibility. The second layer is the transport network, which translates the freight transport demand into traffic. It provides transport services, resulting in actual load unit flows that generate demand for vehicle flows. The traffic is realised in an infrastructure layer that consists of, e.g., roads and rail tracks on which vehicle movements take place. The layers are connected by markets where supply and demand of the different layers are matched. Later development of the model introduced information infrastructure and information flow layers, but these layers are beyond the scope of this research.

The research approach for developing the framework is shown in Figure 1. It consists of three steps. In the first step the goals of sustainable logistics are identified (depicted as circles in the figure). At this stage, the research is limited to the economic and environmental goals; the social dimension of sustainability is beyond the scope of this study. The second step reviews the decision

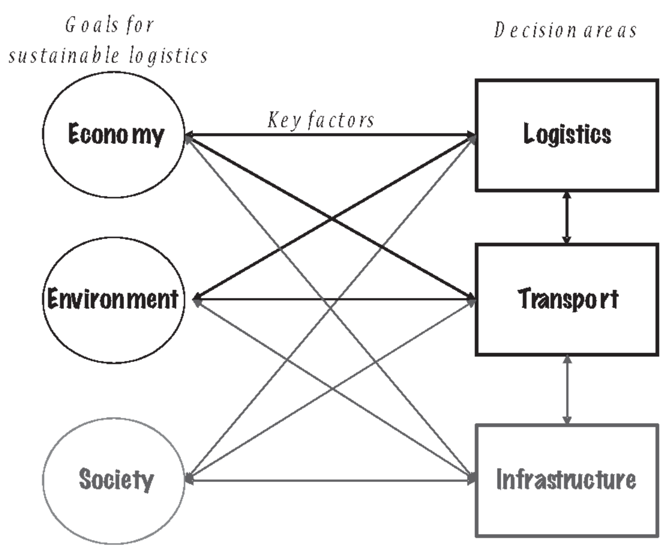

Figure 1 Framework for sustainable logistics

areas in logistics and transport which are relevant for the goals of sustainable logistics (boxes). Here, the analysis is limited to logistics and transportation and excludes infrastructure decisions. The third and final step indentifies the key factors which link the sustainability goals with the decision areas (arrows).

This article takes the form of desk research and conceptual work based on a review of previous research on sustainability and logistics frameworks; both on a general level and more specific logistics and transportation. The literature review includes scientific articles published in top journals in the logistics, transportation and sustainability area. As a complement to scientific articles, books were used as a source for identifying the traditional goals of logistics. An expert panel consisting of logistics researchers was providing the study with valuable input to the development process.

GOALS OF SUSTAINABLE LOGISTICS – LOGISTICS AND ENVIRONMENT

To affect the profit positively, i.e., improve the economic performance, by improving companies' efficiency and effectiveness is one of the main purposes of logistics (Jonsson, 2008). The performance areas that are crucial in logistics have been summarised from commonly used definitions of logistics as explained by Shapiro and Heskett (1985) and Jonsson (2008), see Table 1. These definitions describe the areas often included in logistics performance measures.

To deliver the right commodity at the right place, in right quantity, in right quality, at right price, in right condition and at the right customer (Shapiro and Heskett, 1985) concern the customer service as fulfilling the demands from the customer being one major purpose of logistics. Jonsson (2008) identifies logistics main performance variables being customer service, costs, tied-up capital, flexibility, time and environment. These variables are related to each other where flexibility and time serves as indirect variables linked to service, costs and tied-up capital. Therefore these latter three performance variables serve as the major areas of logistics goals in our framework.

The environmental impacts of freight transport mentioned in the literature usually are air pollution; climate change; disturbance to nature, the landscape and water; reduction in natural visibility and additional effects from upstream/downstream processes (Schreyer et al., 2004). In our

Table 1 Summary of areas included in logistical goals

Customer service	Costs	Tied-up capital
Product quality (right commodity, condition, quantity, time, etc.)	Low transport cost	Buildings, plants, warehouses and equipment
Supply goods flow information	Low cost for warehouse handling, buildings, personnel, equipment	
Availability of products – delivery time	Low administration cost; personnel and information systems	Products
Flexibility	Low packaging cost	

framework, environmental goals are developed by focusing upstream in cause–effect chains, and by that removing the underlying sources of problems rather than to 'fixing' problems once they have occurred (Robèrt, 2000).

The three ecological system conditions developed by Holmberg and Robèrt (2000) define the favourable outcome for a sustainable society and direct problem-solving upstream towards problem sources by using these conditions as an overall goal, a plan for sustainability can be identified that avoids 'dead-ends' in the future and thus includes favourable outcomes and activities that are to be further measured by different tools.

The first two conditions concern the flows of substances, first substances that naturally exist in the ecosystem and second substances that are produced by society. In order to reach a sustainable society it must be a balance in the flow, i.e., the substances extracted from earth crust (system condition one) as well as the substances produced by the society (system condition two) must not increase in the eco-system systematically. In the logistics system, the use of resources extracted from the earth crust is mostly concerned with the fossil fuels used for energy in the different production activities and facilities in the logistics system and in the transport system. There are also materials used in the logistics system based on substances from earth crust, e.g., material for buildings, infrastructure, equipment and vehicles. All these activities affect the sustainability with regards to condition one. The use of material within the logistics system based on substances produced by society affects condition two. Furthermore, the combustion of fossil resources in either power plants or vehicles increase the emissions of greenhouse gases and pollutants.

System condition three concerns how the ecosystem gets manipulated by e.g., overharvesting and land use. In order to reach a sustainable society these kinds of manipulations cannot systematically increase. In the logistics system the land use from different facilities and the use of infrastructure contribute to barrier effects which manipulate the eco system. Furthermore, waste ending up in landfills as well as ballast water from ships is also of negative effect for the sustainability of the system contradicting condition three. The environmental goals are summarised in Table 2.

RELEVANT DECISION AREAS FOR SUSTAINABLE LOGISTICS

Since transport is the most important source of environmental impact in the logistics system (Wu and Dunn, 1995) it is central to emphasise the transport system as a separate system when including environmental considerations into logistics. Using transport and material flow levels as a base for structuring logistics decisions the relations in between the layers of logistics get underlined. Furthermore, different actors operate within these two levels; e.g., transport buying companies among suppliers

Table 2 Summary of areas included in environmental goals for logistics

Material	Energy source	Pollutants	Eco-system	Waste
Reduce use of scarce and non-healthy resources (by e.g., dematerialisation or substitution)	Renewable resource use	Reduce air pollutants (NO_x, SO_x, particles, etc.) Reduce water pollutants	Limited land use and barrier effects	Reduce waste

in supply chain in material flow level and transport operators in the transport flow level. To distinguish in between these two levels facilitate to understand other actors systems as well as to see the interface in between them.

Decision making in logistics can further be classified into three time perspectives: strategic, tactical and operational (Jonsson, 2008). The strategic perspective broadly shapes the logistics structure and sets the general guidelines for decisions taken at the tactical level, which determines goals, rules and limits for the operational level (Crainic and Laporte, 1997). In the remainder of this section the relevant decision areas concerning material flow and transport flow are indentified and categorised according their time perspective, i.e., strategic, tactical and operational.

Material flow

The logistics decisions on this level are shaping the demand for transportation, between and within companies or organisations and from suppliers to customers (Wandel et al., 1992). It is about how these companies and organisations are located, what markets to serve from each company and what suppliers to choose set the overall amount of transport needed. Furthermore, how to manage the planning of material within each company, what inventory level to have, etc. set the characteristics of what kind of transports needed.

Three type of decisions can be included in the strategic perspective; decisions about sourcing, production and distribution. Firstly, *sourcing network* is about choices regarding which suppliers to use and also about choices regarding if some production units should be outsourced externally or not. Secondly, *production network* regards the production such as location and capacity of production units. Thirdly, *distribution network* is about number of markets and choices about warehouses and its location. All three network decision areas regard the structure of the different types of nodes in the network; its location, its capacity and the number of each type of node (Aronsson and Brodin, 2006; Jonsson, 2008; McKinnon, 2003; Schmidt and Wilhelm, 2000). *Management of material flow* is about production level in the plant, assembly policy, inventory level, shipment sizes (Schmidt and Wilhelm, 2000) and order quantities (Jonsson, 2008). The operational perspective concerns decisions such as *scheduling deliveries* of the final products to customers (Schmidt and Wilhelm, 2000), *placing purchasing orders* to suppliers (Jonsson, 2008) and *selecting carriers* for performing the actual transport (Wu and Dunn, 1995).

Transport flow

Strategic perspective concerns *transport network design* including decisions about location, capacity and type of nodes for transhipments. Woxenius (2007) defines six significantly different theoretical designs from the perspective of transport system operator: direct link, corridor, hub-and-spoke, connected hubs, static routes and dynamic routes. The networks differ in logistical requirements for their operation and in transport efficiency (Hesse and Rodrigue, 2004). Direct links between sender and receiver are easy to operate, but at the expense of efficiency since they often create less-than-full-load as well as empty return problems. Consolidation of freight in hub-and-spoke and corridor networks increases efficiency through scale economies but the logistical requirements for consolidating shipments belonging to different origins and destinations are extensive. Tactical perspective concerns *management of vehicle flow* which concerns scheduling of vehicles and choice of transport mode. There are five basic transport modes for carrying out the movement of goods: road, rail, air, water and pipeline. Because the modes vary in economic service characteristics (e.g., speed, availability and flexibility), capacity and cost structure, each mode is the predominant option for a certain type of transport flow (Stock and Lambert, 2001). If freight flows are not large enough to fill larger transport units such as trains and ships, consolidation networks are a necessity which increases the logistical complexity. An additional tactical decision concerns *vehicle technology and fuel choices.* Finally, decisions regarding operational perspective include *route planning choices*, what kind of telematics to be used, vehicle routing and scheduling systems to be used and if collaboration between companies can be made in order to make the final transport more efficient (Piecyk and McKinnon, 2009).

The decision areas in material flow and transport flow are summarised in Figure 2. In the next section the relation between these decision areas and the logistics goals are analysed.

RELATIONS BETWEEN GOALS AND DECISION AREAS

Environmental goals are often related to the very final activity that contributes to the effect, such as exhaust emissions from the driven truck. However, the efficiency improvements often rely on e.g., both the transport operator's network and ability to perform effective shipping as well as on e.g., how the transport buyer plan their orders or pack the shipment. Therefore it is especially important to be aware of the relation between environmental goals and performances within all decision levels. In order to also reach environmental sustainability goals, it is important to identify the key factors determining the relations

1 between decision areas in material and transport flow level and
2 between decision areas and sustainability goals.

Thus, some decisions are directly connected to the different set of goals while others indirectly are.

Decision areas direct relations to goals

Our suggestion for the direct relations between decisions areas and logistical and environmental goals are shown in Table 3. What seem obvious is that decisions in both material and transport flow level affect the logistical goals. However, the relations to the environmental goals are most apparent in the transport flow level. Some of the relations are exemplified below.

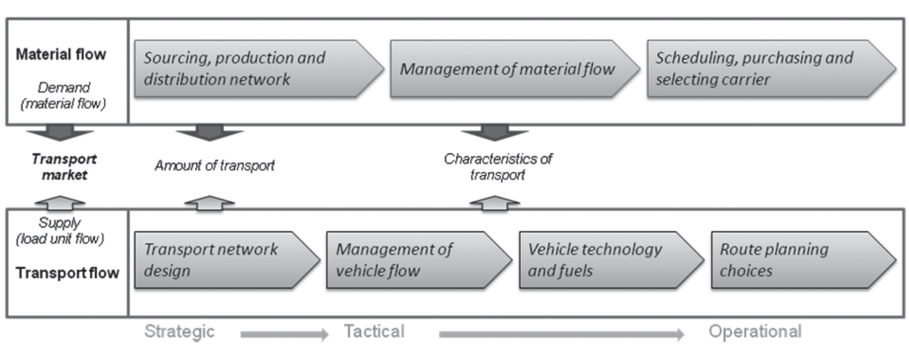

Figure 2 Decision areas in material flow and transport flow level

Table 3 Direct relations between decision areas and logistical and environmental goals

	Sustainability goals	Logistical			Environmental				
	Decision areas	Customer service	Costs	Tied-up capital	Material	Energy	Pollutants	Eco-System	Waste
Material flow	Sourcing, production and distribution network		x	x				x	
	Management of material flow	x	x	x					x
	Scheduling, purchasing and selecting carrier	x	x						
	Transport network design		x	x				x	
Transport flow	Management of vehicle flow	x	x			x	x	x	
	Vehicle technology and fuels		x		x	x	x		
	Route planning choices	x	x			x	x		

The nodes and geographical distances in between the sourcing, production and distribution networks from suppliers to markets are shaping the general structure of the network. An example of logistical goals to be affected by these decisions is the amount of tied up capital that is strongly related to the number of nodes chosen in the network, such as warehouses and plants. Furthermore, management of material flow affect the customer service directly, e.g., delivery frequency and lead time relates to availability of products – a shorter lead time and a higher frequency of deliveries to warehouses will make the availability of products higher for the customer.

In the transport level, management of vehicle flow determines the actual mode usage and its load factor. The mode usage has a strong influence on the environmental goals, differing from their type; e.g., air transport having most energy usage and rail least. Also each transport mode serves the logistical goals in terms of contributing to the customer service and influences the tied-up capital; dependent on e.g., speed of the transport and its flexibility. By consolidating goods flow a transport operator can reach higher customer service by more frequent shipping, more destinations from each origin and possibly also the smoothening of handling peaks at terminals (Kreutzberger, 2001). Naturally, an increased load factor can reduce the amount of vehicles used, using smaller amount of fossil fuels in total and emitting fewer pollutants on a general level. The disadvantages of consolidation can be additional transhipments and detours, which may result in increasing chain transit time and costs (Bontekoning, 2000).

There are wide variations in the amounts of pollutants per vehicle kilometre driven in a freight transport operation both within and between modes, depending on the vehicle technology applied and the energy source used. A reduction of the use of non-renewable energy sources can be achieved by a shift to low fossil carbon fuels; however, these fuels are generally less energy efficient. Furthermore, doubts have been raised about the benefits of these fuels because of the energy consumption and

GHG emissions tied to fuel production and changes in land use to accommodate the growing of crops for biofuels, which is putting pressure on land, biodiversity, water resources and global food prices (European Environmental Agency, 2008). To gain a full appreciation of the environmental benefits of alternative fuels, however, one must conduct a detailed Life Cycle Analysis (LCA). This leads to the first proposition:

Proposition 1: *Decisions in the transport level have a direct affect to both logistical and environmental goals, while material flow decisions are of major concern for logistical goals.*

Decision areas indirect relation to goals

Table 3 shows that decisions concerning material flow determine directly the logistical goals while there is no direct relation to the environmental goals. Meeting environmental goals are mainly directly dependent of decisions concerning transport flow. However, since there are strong interactions and interdependencies between material flow and transport flow, decisions concerning material flow indirectly also influence the environmental goals. At the same time transport decisions influence the logistical goals. These indirect relations are depicted in including goals, decision areas and the key factors determining the goals in two separate examples. Example A, shows how decisions to increase the customer service lead to more environmental impacts from transport. Increasing the flexibility of orders for the customers require shorter lead times. This change in the management of the material flow increases the quality requirements for the transport service that is used for the transport. This can have negative consequences on the ability to fulfill the environmental goals on the transport flow level, since changes of the vehicle flow are needed in order to meet the required lead time demands. Instead of rail or sea transport which may be too slow for the demanded lead time, faster modes like road and air transport have to be used. Furthermore, the possibilities for consolidating the shipment with other transports decrease, since the lead time demands require a direct transport, resulting in more traffic. Both cases lead to increased environmental impacts (Figure 3).

On the other hand, actions to fulfill the environmental goals on the transport level indirectly influence the possibilities to meet the logistical goals on the material flow level (Example B). A modal shift from road and air to the large-scale transport modes such as sea or rail reduces pollutants and energy use. However, this change requires bigger shipment sizes and consequently influences the management of the material flow. To achieve shipment sizes which are large enough to use large-scale transport modes, a shift towards fewer shipments is needed. This change in shipment frequency reduces customer service levels and increases the tied-up capital and hence decreases the possibilities to achieve the economic goals of sustainable logistics.

Meeting environmental goals are crucial for being more sustainable in the logistical system, above examples are describing some trade-offs in between the logistical and environmental goals, but also the contribution to the different set of goals by acting in different levels and by different actors in the logistics system. The following proposition are suggested based on the previous discussion:

Proposition 2: *Logistics systems that integrate material flow and transport flow decision making will be more successful in meeting logistical and environmental goals, thus leading to more sustainable logistics.*

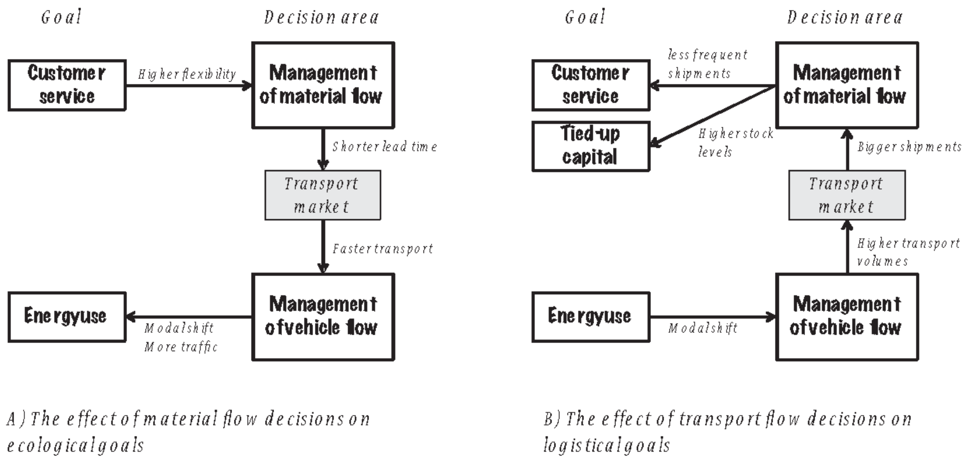

Figure 3 Examples of key factors determining the relations between decisions and goals (A) the effect of material flow decisions on ecological goals and (B) the effect of transport flow decisions on logistical goals

CONCLUSION

This paper suggests a holistic framework for decision making towards sustainable logistics. In order to identify more sustainable logistics solutions, there must be a raised awareness about the relation between material flow and transport flow decision areas and performances. Actions need to be taken on all levels to improve the logistics as well as to contribute to the environmental goals. By increasing knowledge about how organisations' logistics strategies affect the outcome in terms of environmental impact and logistical performances a larger step can be taken toward sustainability. This may be done through increased understanding and co-operation in between actor's environment, having a longer time perspective and a more holistic way of thinking. The suggested framework includes the relations between decision areas in material and transport flow level at one hand and the logistical and environmental sustainability goals at the other.

The framework should be seen as a first step in a research project being further developed having the aim of specifying the criteria of sustainable logistics and furthermore facilitating potential choices of sustainability actions within the freight transport and logistics system; how to understand the interaction between different sets of actions and how to identify actions aiming at sustainability. There is a need for identifying key factors that determines the relations

1 between decision areas in material and transport flow level and
2 between decision areas and sustainability goals.

These key factors linking goals and decision areas can be seen as indicators or criteria for sustainable logistics.

Further research aims at adding the social aspects of sustainability as well as infrastructure decisions to the framework. Furthermore, testing and developing the model in a company context will be of importance, both at material and transport flow level. Examples of questions to be raised are: Is the framework useful in order to identify possible actions to be taken at different areas of decisions? What key factors determine the effects from actions taken? Are these key factors possible to measure and follow up? What data are available in practice?

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