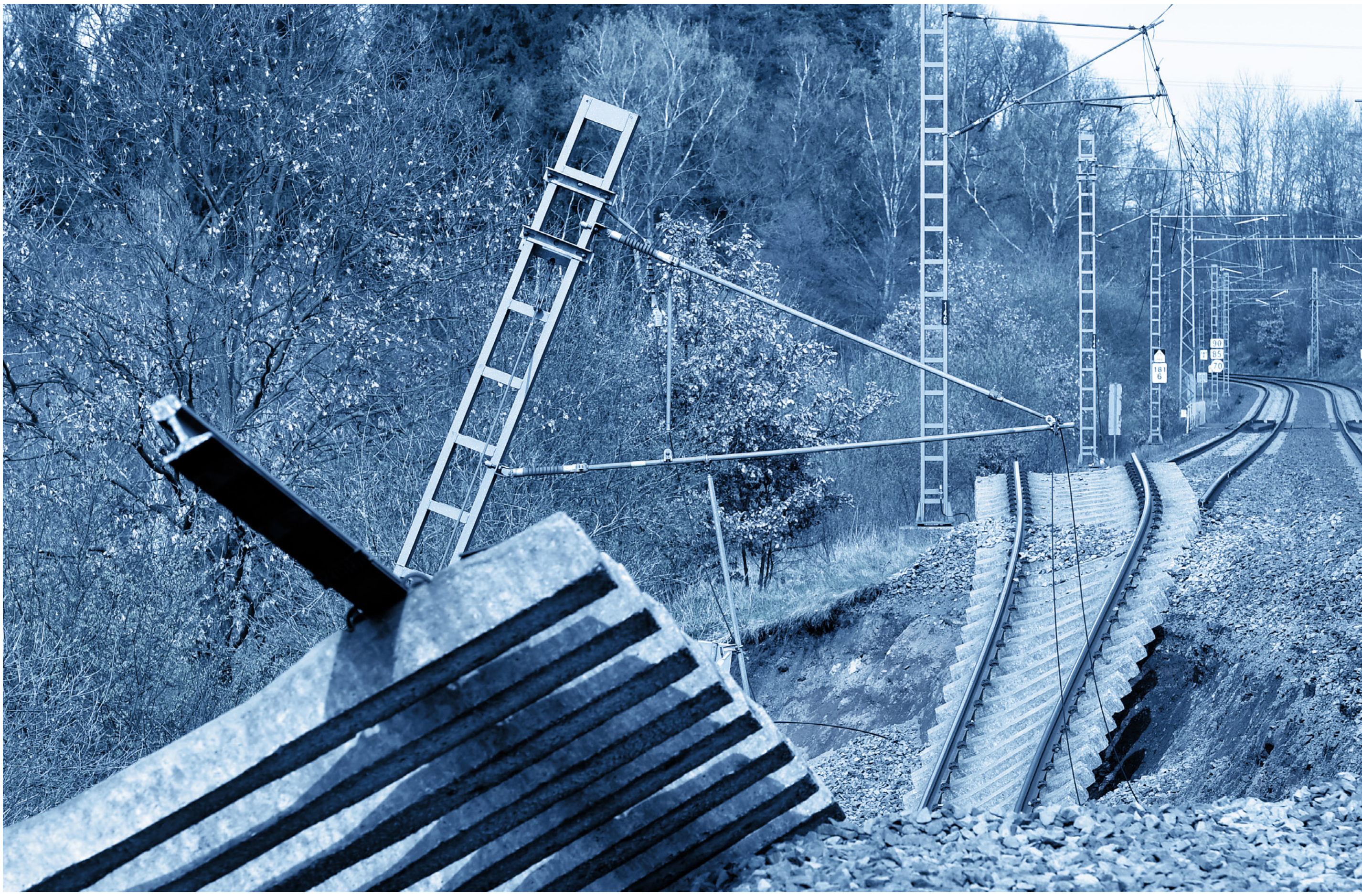
International Transport Forum



Innovation and Technology in Multimodal Supply Chains

Discussion Paper

171

Roundtable

Lóránt Tavasszy

Delft University of Technology

Innovation and Technology in Multimodal Supply Chains

Discussion Paper

171

Roundtable

Lóránt Tavasszy

Delft University of Technology

The International Transport Forum

The International Transport Forum is an intergovernmental organisation with 59 member countries. It acts as a think tank for transport policy and organises the Annual Summit of transport ministers. ITF is the only global body that covers all transport modes. The ITF is politically autonomous and administratively integrated with the OECD.

The ITF works for transport policies that improve peoples' lives. Our mission is to foster a deeper understanding of the role of transport in economic growth, environmental sustainability and social inclusion and to raise the public profile of transport policy.

The ITF organises global dialogue for better transport. We act as a platform for discussion and pre-negotiation of policy issues across all transport modes. We analyse trends, share knowledge and promote exchange among transport decision-makers and civil society. The ITF's Annual Summit is the world's largest gathering of transport ministers and the leading global platform for dialogue on transport policy.

The Members of the Forum are: Albania, Armenia, Argentina, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Canada, Chile, China (People's Republic of), Croatia, Czech Republic, Denmark, Estonia, Finland, France, Former Yugoslav Republic of Macedonia, Georgia, Germany, Greece, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Kazakhstan, Korea, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Mexico, Republic of Moldova, Montenegro, Morocco, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Arab Emirates, the United Kingdom and the United States.

International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
contact@itf-oecd.org
www.itf-oecd.org

ITF Discussion Papers

Cite this work as: Tavasszy, L (2018) "Innovation and Technology in Multimodal Supply Chains", *International Transport Forum Discussion Papers*, OECD Publishing, Paris.

Acknowledgements

The author is grateful for comments given on earlier versions of the paper by Alan McKinnon and Ricardo Sanchez.

Table of contents

Introduction

The aim of this paper is to discuss the impacts that various technological and organisational innovations in logistics could have on multimodal transport. Our emphasis in terms of impact assessment is on the use of multiple modes of transport by companies, in an effort to increase the efficiency, quality, resilience and sustainability of their services. We will roughly follow a technology assessment (TA) approach: a "systematic attempt to foresee the consequences of introducing a particular technology in all spheres it is likely to interact with" (Braun, 1998). Basic elements of TA include: (1) definition of the topic, (2) describing the technology, (3) establish the expected benefits of the technology, (4) describing potential hazards or side effects and (5) identifying supportive measures or policies for the technology. Given the specific context of our paper, we will:

- Interpret the term "technology" broadly, encompassing technological and organisational innovations that are expected to impact multimodal transport.
- Discuss a vision for the convergence of all innovations for the future freight transport system in the form of the physical internet.
- Look at the impact of individual innovations and also their interdependencies and combined effect on multimodal transport.
- Discuss impacts on efficiency, sustainability and resilience[1].

The paper is structured along the lines of a technology assessment. The first section reviews the main current innovations in logistics, from different angles. This is followed by discussing the expected impacts and barriers for deployment in more detail. The paper concludes with a brief summary of the main propositions and recommendations for policy and research.

Megatrends in logistics innovation

There is a growing knowledge base on long term logistic outlooks, radars, roadmaps, hype cycles and knowledge maps. Although this material is not necessarily science-based and hardly used in the scientific literature, they contain a rich source of information to grasp the main trends and possible trend breaches for the coming decades (WEF, 2016; WEF, 2018; DHL, 2016).

Below we present innovations as individual changes but note that there has been relatively little exploration of the interdependences between innovations within a single logistics system or, system-of-systems. Innovations may be causally linked, one being a prerequisite for the other, may be competing, incompatible or synergetic. Eventually some kind of convergence process will emerge which will allow these innovations to work together in the same supply chain. We have not encountered visions of future logistics systems that combine all these innovations in one coherent picture. Perhaps the most far reaching attempt at an all-inclusive view is the vision of the Physical Internet (PI). The PI term was first introduced in the Economist in 2006 (Markillie, 2006) and later framed as a scientific design challenge in the "Physical Internet Manifesto" (Montreuil, 2011a and 2011b). The term is derived from an analogy to the digital internet, where transport operations would equally be based on system-wide optimisation, albeit for physical products instead of information. Its design entails the summation of a number of innovative concepts:

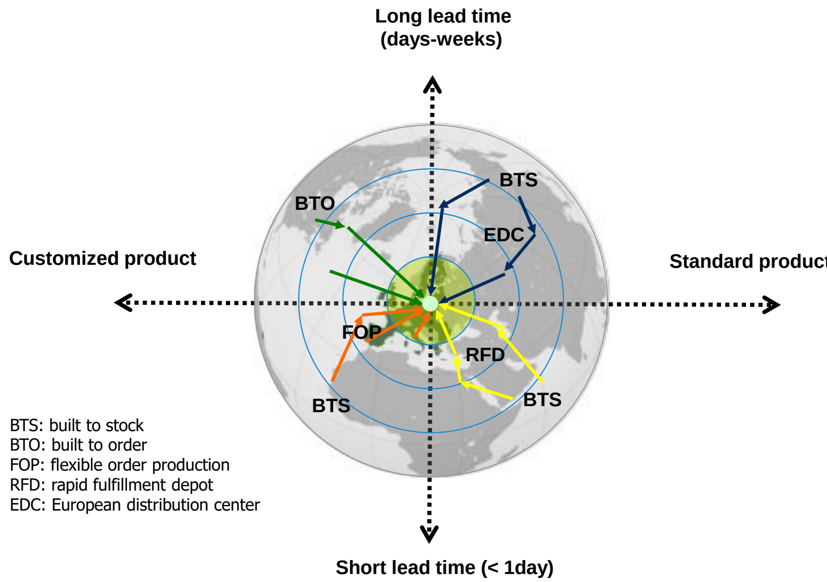
- A very high level of standardisation of equipment and of automation of transport and transshipment processes.
- An open access to physical networks.
- A continuous system-wide exchange of information and a strong collaboration between logistics actors.

Together, these innovations create a self-organising system and provide a step change in performance, including a reduced use of transport assets, improved utilisation of transport infrastructure and shorter distances to transport products. Although the current freight and logistics system is evolving in this direction, its evolution is very slow, suffering from a lack of, or poor governance and subject to many economic, political and ecological threats. In the past few years, the PI vision has gained wide endorsement and has become the basis for international R&D roadmaps such as those proposed by the European Technology Platform (ETP) ALICE (ALICE, 2015). Nevertheless, it still needs further operationalisation into technical designs, closer scientific scrutiny and a critical view of its sustainability (Sternberg and Norman, 2017). Components of the PI have been identified, yet the consistent system-level design has not yet been elaborated. Below we will discuss four megatrends in logistics innovation separately, with relations between them where appropriate.

Mass-individualised logistic services

The growth of mass-individualised consumption around the world has changed the nature of products ordered by consumers. Manufacturers put effort into so-called "servitisation" of their products and are moving towards product-service systems (Tukker, 2004). Product customisation has progressed to an extent that 3D printing allows instant production with a flexible specification, near to the consumer (Durach et al., 2017). Globalisation has allowed the creation of these fulfilment structures at neutral total costs, and facilitates consumer markets being reached worldwide. The new technologies have fuelled new service propositions and is stretching the capabilities of manufacturers and their service providers considerably, requiring them to continuously review and redesign their supply chains (Bonev et al., 2017). The impact on freight flows is expected to be high, but is still uncertain and depends on the product or service being traded (Fisher, 2003; Birtchnell and Urry, 2013). Combined, these changes are leading to a new global supply chain configuration being introduced with, as a common feature, a growing emphasis on customer orientation through postponed production and storage. Figure 1 below illustrates the increasing variety of supply chain configurations.

Figure 1. **A supply chain evolution compass**



Source: modified from Vermunt (2000)

The figure collapses a functional (quadrants in a 2x2 matrix) and a geographical dimension (concentric circles from global to local) into one scheme and shows distribution structures that are typical for the four quadrants. Over the decades, product offerings have evolved from standard products with long lead times (top, right hand side quadrant, e.g. the T-Ford), to customised products with extremely short lead times (left bottom quadrant, e.g. pizza delivery). Each of these offerings has its own characteristic spatial and functional supply chain structure, from long distance chains where production is done a long time in advance of orders, up to extremely short local chains, with flexible production within the region, or 3D printing at home. As markets are moving more towards customised and responsive products and services (top right to bottom left, in the figure), spatial configurations of supply chains are becoming more diverse.

Clearly, new technologies for manufacturing, storage, transportation and communication have been important preconditions for creating and maintaining these structures. Also, globalisation has been an integral part of this development. Increasing wages in former low-wage countries and changes in trade agreements have stimulated firms to move their production or storage sites to the next low-cost location, or choose a place closer to the market. These changes create new spatial dynamics of trade as manufacturing is re-locating in search for low wages. The phenomenon of so-called "reshoring" of activities is under constant debate. The latest research results indicate that reshoring is real, but is mostly prominent for short distance trade relations (<2000 km), strongly influenced by economic cycles and, surprisingly, also happens in reverse wage relations e.g. China re shoring its own manufacturing base from abroad from 10% imports of intermediate goods in 2004 to 5% in 2014 (see Delis et al., 2017 and Marin et al., 2017). Globalisation has spurred the emergence of a global freight transport system. Volatility and spatial dynamics of trade require a certain degree of redundancy in global physical infrastructures, like maritime ports or global corridors. Given the structural oversupply in ships, ports, roads and rails, this redundancy appears to be present, possibly at the cost of efficiency under regular conditions (OECD, 2017; NDRC, 2015).

Interestingly, a significant new market has developed for global business-to-consumer (B2C) shipments of standard products, with a long lead time (upper right quadrant in Figure 1). B2C e-commerce has allowed a disintermediation of supply chains for consumer products from China to the West. The AliExpress offerings typically exploit the wage differential bypass of wholesale and retail trade. Prices are also kept low by choosing slow modes of transport, leading to delivery times of several weeks, up to 60 days (www.aliexpress.com). A large variety of products is traded this way, including those that typically have a short lead time, like high-tech products.

Network integration and synchronisation

An important organisational innovation (termed a "transformational" and a "short term" innovation by Gartner in 2010) is horizontal collaboration between manufacturers and service providers, in bundling their flows to allow the use of shared transport assets and services.

This collaboration can take different forms. Carriers can decide to use each other's trucks, shippers might source transport services together or service providers (as they often do) may decide to bundle flows of their clients, with or without their consent.

How great is the potential of horizontal collaboration for reducing logistic costs? Transport statistics indicate that there is still room for improvement, as capacity utilisation is still well below 100%. Average utilisation of capacity in terms of weight was measured in Europe to lie around 43%, with around 20% of trips being empty and the remaining 80% being almost half-utilised (see Eurostat, 2016). Although utilisation in terms of volume (cubic meters or pallet spaces) is not measured in transport statistics, local surveys indicate that this utilisation is considerably higher, up to 87% of capacity (Combes, 2010; Davydenko et al., 2016). Moreover, it varies significantly between sectors of industry. Table 1 shows the utilisation rates obtained from a representative survey of trips from the 80 largest carriers in the Netherlands (Davydenko et al., 2016).

Table 1. **Different utilisation rates of loaded truck trips across sectors of industry**

NSTR-1 Code	Commodity	Utilisation in m^3 (%)	Utilisation in m^2 (%)	Utilisation in kg (%)
0	Agricultural products and live animals	47	82	31
1	Foodstuffs and animal fodder	79	87	61
2	Solid mineral fuels	-	-	-
3	Petroleum products	-	-	37
4	Ores and metal waste	-	87	66
5	Metal products	58	67	75
6	Crude and manufactured minerals, building materials	87	-	46
7	Fertilizers	-	-	33
8	Chemicals	80	94	73
9	Machinery, manufactured and miscellaneous	93	72	69

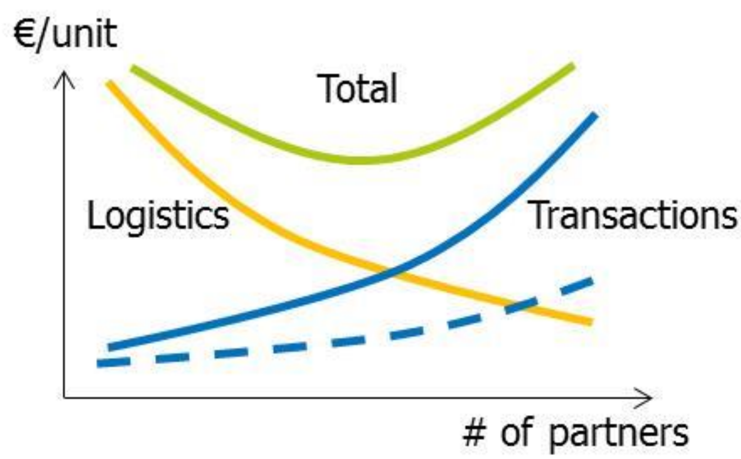
Note: "-" indicates data not being able to arrive at representative or publishable results

Source: Davydenko et al. (2016)

Obviously, there are several practical logistics constraints to optimisation, implying that utilisation rates will never be 100%. Nevertheless, studies of the past decade show that the impacts of consolidation in a fast moving consumer goods environment can be significant. Groothedde (2006) came to logistics cost reductions of 10%-20%, similar to the more recent CO3 project (CO3, 2014). Simulations in the broader context of the Physical Internet (PI) resulted in savings of up to 26% (Ballot et al., 2012).

An important precondition for horizontal collaboration, as described in the PI vision, is the creation of shared and open networks. Shared, in the sense that not one player has the power or prerogative to reserve capacity for itself. Open in the sense that access to the market is available for everyone. Although transaction cost economics dictate that the optimal number of partners in a network is finite (constrained as it is by the costs of communication to the point at which marginal benefits equal the marginal costs of adding one more partner), with the ICT revolution ongoing, marginal communication costs are nearing zero and, theoretically, the number of partners could be infinitely large. Figure 2 illustrates this trade-off.

Figure 2: **Network growth through decreased transaction costs**



Source: Author

Next to horizontal collaboration, vertical integration of supply chains is needed to effectively respond to changing consumer needs. A recent development is the increased demand orientation of production flow planning and sourcing (demand based MRP coupled with MRP based ordering from main suppliers), to reduce working inventory, improve internal alignment between demand forecasting and production, and allow a faster response to changing client demands. Many innovative business models are now emerging that exploit the possibilities to provide better customer service and turn these into revenue generation mechanisms. Typical services that emerged in the last decade include for example instant fulfilment and local pick-up and delivery services at homes, shops or offices. Many of these services have been introduced by logistics start-ups in competition with large retailers or service providers. The understanding of the demand side of the market is often only rudimentary and not research based. Revenue generation and optimization, however, require an advanced understanding of demand patterns and willingness to pay for different services. Currently these insights from research are scarce, especially for these new markets with flexible, individualized services and auxiliary or value added logistics.

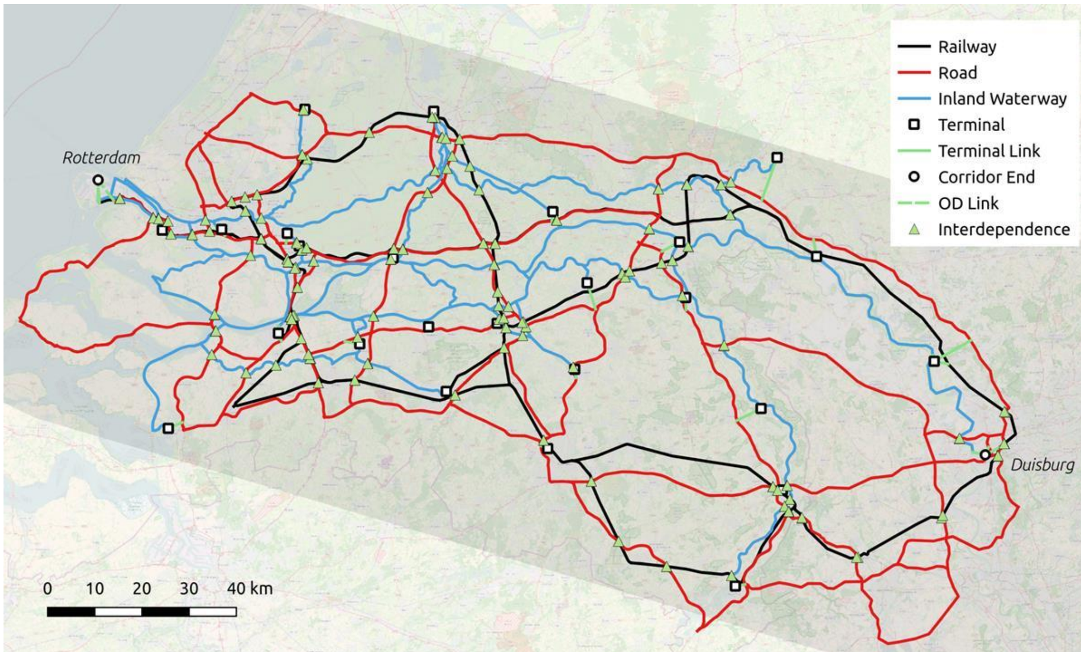
Interesting innovations also lie in the formation of new outbound service networks across geographical corridors, visible in strategic investment schemes such as the One Belt, One Road (OBOR) initiative, as well as in innovative operational practices in intermodal transport chains. Whereas multimodality denotes the general availability of multiple modes as options for transport, the term intermodal denotes a specific transport option where multiple modes are used in a door-to-door transport chain. Loads are transferred between the transport legs of single modes at transhipment terminals. The term synchromodality, also translated as synchronised intermodality, was recently introduced in the Netherlands, following the initiative by the terminal operator ECT in the port of Rotterdam, to create an innovative hinterland planning and booking service, allowing the synchronisation of demand and supply schedules by smart planning and booking (Tavasszy et al., 2017). This is a more specific service within the intermodal transport option. Instead of pre-specifying the mode(s) and routes of transport, the choice of mode in the door-to-door chain is postponed until as late as possible, to allow maximal consolidation and resilience benefits. This has allowed shippers and carriers to optimise the use of hinterland modes and to be more responsive to maritime schedule delays, hinterland disturbances and changing needs in the supply chain. In Europe, the synchromodality concept has been adopted as an essential part of the vision of the Physical Internet (ALICE, 2015) and several Research and Development (R&D) projects on the topic have been launched since.

Horizontal and vertical collaboration are intimately related. The creation of networks for horizontal alignment of services to transport demand also requires changes in vertical collaboration through a re-alignment of supply activities. For example, if two carriers decide to pool capacity, they will need to work together to produce one and the same service to the customer. This may affect other companies within supply chains as well. As all partners will have obligations up- and downstream in their supply chain, horizontal alignment may force them to reconsider the vertical arrangements as well. Lighter forms of collaboration through alignment of activities may eventually lead to full integration, including shared management, business models and strategy. At all times, however, efficiency gains of collaboration will be weighed against loss of autonomy of individual companies or agility of the supply chain.

Depending on the extent to which investments and revenues need to be shared, different organisational structures will emerge. Companies might decide to extend their business model, as in the example of ECT, the stevedore who effectively added a hinterland forwarding service to its business model. Information intermediaries (the ICT technology connected to this will be discussed in the next section) can connect actors for a fee, which may be sufficient to create a win-win situation. In other cases, more complex revenue sharing arrangements or joint-ventures will be needed (see Groothedde, 2006). A transformative business model includes services of the crowd of business providers and consumers - who effectively become carriers - as they offer transport services through business-to-business (B2B), consumer-to-business (C2B) or consumer-to-consumer (C2C) crowdsourcing platforms.

It is important to stress that, although network integration and synchronisation may be efficiency focused, an important positive effect is also the increased quality and resilience of transport services. In contrast to efficiency improvements which keep the network as it is, the expansion of a network across several modes or companies, including the improved communication, will render a network which is more capable of providing customised services (Tavasszy et al., 2017) and of dealing with disruptions. Networks that absorb more demand without capacity extension *and* without an increased possibility to shift demand between partners, will end up being less resilient. A recent study for the Dutch intermodal transport network (Van Dam, 2017) established a measure for intermodal resilience. This measure expresses the number of random attacks that a network can undergo before its connectivity is reduced to a pre-specified level (e.g., major centres becoming inaccessible). Intermodal terminals are found to significantly increase the resilience of a freight network. In the case of the hinterland corridor of the port of Rotterdam, Van Dam finds that the existing terminals double the resilience of the network, compared to a situation without these terminals. Such an improvement could only be achieved within a single mode network if investments would be made of several orders of magnitude higher than with the realisation and connection of a handful of terminals. Figure 3 illustrates the density of the multimodal network for the Rotterdam-Duisburg corridor, including its intermodal facilities.

Figure 3. **Dense and connected multimodal corridor connecting Rotterdam and the German hinterland**



Source: Van Dam (2017)

On the corridor roughly measuring 1 000 km^2 the three main modes of transport are connected by more than 20 intermodal terminals, which together cater for increased resilience. At the same time, it notes interdependencies (crossings, bridges, tunnels) between networks which make the network vulnerable. The economic importance of these facilities also depends on the characteristics of users and their valuation of risk, flexibility and resilience. Despite the intuitive appeal of intermodal connectivity and interoperability, we are not aware of any other study on the potential resilience benefits of intermodal networks.

Digitalisation in logistics planning and execution

Information and communications technology (ICT) plays a major role in the planning and management of supply chains. There is a myriad of software applications that, roughly, provide supply chain managers with support for three functions: (1) business intelligence for the positioning of logistics within the firm's business, (2) supply chain planning for strategic and tactical questions where investments are involved with a return period of a year or longer and (3) supply chain execution, which supports the actual storage and movement of products.

Table 2. **Commonly used Information and Communications Technology systems in logistics**

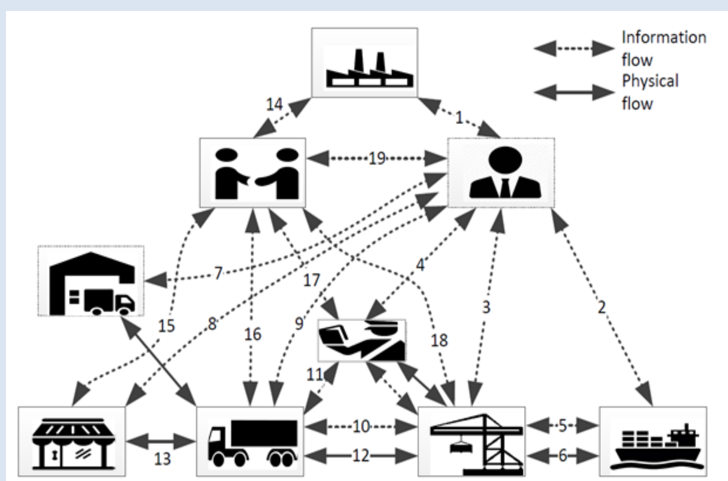
Business intelligence	ECM - Enterprise Commerce Management
	PPM - Performance & Profitability Management
Supply chain planning	SND – Strategic Network Design
	DPS – Demand Planning Systems
	APS – Advanced Planning / Scheduling Systems
	MRP – Material Requirements Planning
Supply chain execution	GTMV – Global Trade Management & Visibility
	MES – Manufacturing Execution System
	WM/CS – Warehouse Management/Control Systems
	FMS – Fleet Management Systems
	(M)TMS – (Multimodal) Transport Management Systems

Enterprise Resource Planning systems (ERP) have a wider scope at company level and are connected to most of these. Above the company level, or between company divisions or plants, shared web-based (inter- or intranet based) platforms may be used to allow inter- or intracompany communication. In practice, much information exchange in logistics is paper based and exchanged by hand or in a non-automated way (e.g. fax, mail). A concrete example of a typical situation is in the box below where the information flow and the physical flow related to a port call for a container transport is showed. Already in the current situation, information flows are much more complex than the physical flows. Very little of these flows are exchanged in digital form or in an automated fashion, most of it is on paper. One can imagine the magnitude and complexity of the change that digitalisation implies, with these flows and actors involved.

Box 1: The complexity of information exchange at ports

Using Figure 4 below as reference, clients can work either with the shipping line agent (arrow 1) or the forwarder. In case of the shipping line agent (SLA), SLA books the needed capacity for the containers in the most convenient sea-vessel (2). Documents must be provided to the sea terminals (3) and to the Customs (4). The shipping line contacts the terminal constantly before the departure and during the (un-)loading (5, 6). SLA makes an appointment with the container depot (7) and the place where the goods physically are or must be delivered to (8). He arranges the inland transport (9). Inland carriers check the status of the sea vessel at the container terminal (10), they also need to know the Customs status (11) of the container to transport the container from the terminal (12) to the Goods location (13) or in the reverse direction. Thus, the carriers contact the Customs (mostly indirectly via port services but we make a simplification in this example). Instead of shipping the line agent, the forwarder can execute the organisation of the transport (14), the forwarder needs to contact all the parties mentioned above (15-18). The interaction with the shipping line and the depot goes through the shipping line agent (19). However, the inland carriers still need to communicate with the SLA (9) to check the status of the container at the shipping line.

Figure 4. **Example of information exchange situation in a port**



Source: Delawari (2013)

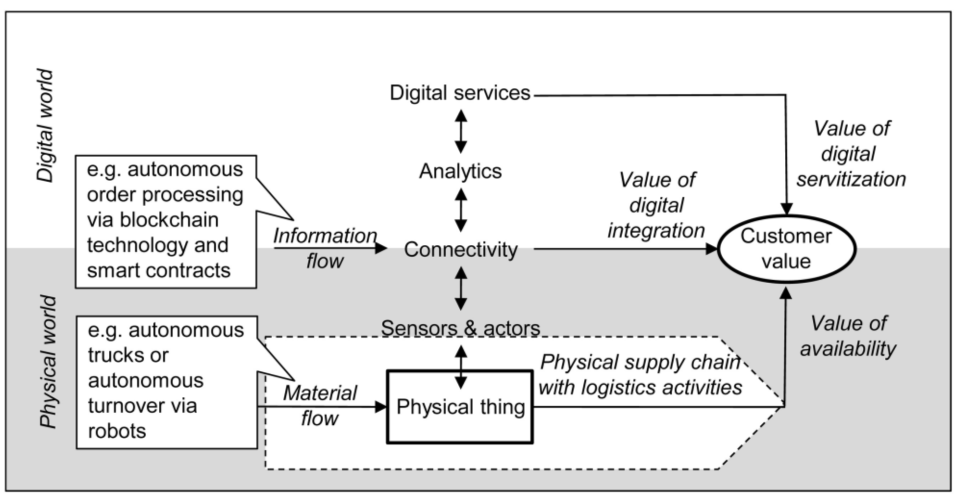
ICT is probably the strongest force transforming the logistics industry today. Ubiquitous ICT systems are being made possible by several concurrent developments that have been evolving since the middle of the 20th century:

- The exponential increase in computing power of processors (as predicted by Moore in 1965, a doubling in processor capacity each 18 months).
- A reduction in size of computers from the mainframes in the 1950’s to the devices (wearables, smartphones, smart things, sensors) of today.
- The widespread implementation of computing power, connectivity and communication/actuation capabilities into autonomous objects, creating the IoT.

- The massive increase in our information processing capabilities and analytics due to artificial intelligence (neural networks, machine learning, deep learning etc.).
- Collective mobilisation and shared use of computing resources across the planet to create practically limitless storage and calculation capacity (cloud and fog[2] computing).
- Digitalisation of administrative and paper-based communication systems, leading to instantaneously exchangeable data and increased adaptability of systems.
- A growing availability of data about logistics operations, and an opportunity to use contextual data (big data) to interpret this data and optimise processes situationally.
- Awareness of the potential of exchanging data between actors in the chain, to an extent that new data markets are created, shared systems are developed (blockchain) and investments are pooled.

The main impact of digitalisation of logistic services is twofold. Firstly, the conventional services in the physical logistics world are enhanced and improved, due to improved information availability. Secondly, the dimension of information based services is extended, providing additional added value to the physical product and its delivery, which could not be provided before, such as, for example, prediction of product quality. Figure 5 below shows this dual innovation.

Figure 5. **Digitalised world business models**



Source: Hofmann and Rüsch (2017); Fleisch et al. (2014)

The opportunities and challenges for traditional business models are enormous (see Fleisch et al., 2014; Strandhagen et al., 2017) and go well beyond the transfer from analogous to digital flows:

- New product propositions have to address global, digital services for local, physical assets that seem unconnected and inaccessible.
- New languages have to be developed to allow systems and people to communicate.
- Firms need to make adaptions from hierarchical, to decentralised, to distributed systems.
- Trust needs to be built between supply chain partners to exchange and protect sensitive data for mutual benefit.

- The independent and autonomous behaviour of objects has to be factored in.

New architectures for such cyber-physical systems are needed that systematically connect the physical and digital systems to help tackle the above business and technology challenges in a consistent way. The manufacturing industry, within its Industry 4.0 paradigm, has already started working on such architectures (see Zezulka et al, 2016). However, these are still lacking for logistics, as are the roadmaps for development and transformation of information systems in logistics. Architectures and ontologies upon which the newly emerging multi-agent systems can be based are growing in silos and not shared worldwide. Mapping and road mapping initiatives such as the WEF Mapping Global Transport program (see WEF, 2016) and the European ETP-ALICE Digitalisation in Logistics roadmap (ALICE, 2015) may be cornerstones of such a program. Projects like iCargo (Dalmolen et al., 2015) and Cassandra (Van Stijn et al., 2011) have paved the way for initiatives like the EU's Digital Transport and Logistics Forum (DTLF) (www.dtlf.eu) which can oversee the development of the mentioned architectures and roadmaps. Below we summarise some of the main ICT technologies that are being discussed today. We highlight the main characteristics of the innovation, its intended impact and areas of implementation with regards to logistics. We also include the Technology Readiness Level (TRL) 1-9 of these innovations (see Appendix for explanation). Note that a high TRL only implies that the technology is available for the market and does not imply market uptake or widespread application.

Summarising the impact column of the table below, we arrive at the following main impacts of transformational ICT innovations:

- A move towards collective and shared software and data, first on a smaller scale (bilateral systems), later moving towards larger groups; these support end-to-end supply chain integration, including transport and storage systems as well as security.
- An increase in data analytics capabilities for all areas of supply chain execution from descriptive, to diagnostic, predictive to prescriptive information.
- Growing autonomy of movable assets, including the product itself, in a series of steps starting with automation and situational awareness, to autonomous movement. Remote monitoring and control of assets and products facilitates reliable operations.
- Knock-on effects of low communication costs and fast communication on the number of partners in a network and on supply chain deadweight losses due to cash-to-cash cycle time reduction,

It will be clear that the below technologies have many more applications than listed here and that the situation is highly dynamic. Rather than from research publications, regular status updates are better obtained from fast-cycle websites such as (itsubwaymap.com) or consulting companies like Gartner who provide yearly updates of supply chain management innovations.

Table 3. **Key Information and Communication Technology innovations and their implementation in logistics**

ICT Innovation	Nature of innovation	Intended effects	Final impact	Technology Readiness Level
Analytics as a Service, including: - machine learning - deep learning	Deriving meaning from very large amounts of heterogeneous data for operational control. Includes descriptive, diagnostic, predictive and prescriptive analytics.	Obviates complex modelling and gives a rapid turnaround of measurements to situation analysis and advice for sense-and-respond systems.	Tactical and operational control of transport and logistics systems (FMS, WMS, Transportation forecasting). Possibly also strategic business intelligence.	8
Cloud/Fog Computing	Computing power and databases made available as a service.	Access to high quality and capacity services for all.	Necessary to host platforms for data exchange and software for analytics, such as crowdshipping, shared data or business process-as-a-service platforms.	9
Internet of Things (IoT)	Objects can sense, actuate and communicate over the Internet.	Global autonomous sensing and actuation networks.	All areas where intelligent objects are useful (Robotisation, Mobile Asset Optimisation, Warehouse Control Systems, Temperature Control etc.).	5
Blockchain	Securely shared, collectively governed database of all transactions ("distributed ledger").	Zero time lag between action and information; no intermediary; installs trust for trade and cooperation in large groups.	Smart contracts for service delivery, product traceability, e-compliance, supply chain finance, supply chain visibility.	5
Big Open Data	Access to pooled data for purposes of visibility and analysis.	Pre-condition for analytics.	E-governance, Supply chain visibility, statistics, research, analytics.	8
Augmented Reality/Virtual Reality	Context visualization trough screens or wearables for higher situational awareness.	Increase of performance for operational tasks in regular and disturbance conditions.	Complex operational environments in transport, warehousing, production.	8
Traffic Control Towers and Intelligent Transport Systems	Merger of Fleet Management System (FMS) and Transport Management Software (TMS) navigation apps with traffic management ICT applications.	Improved responsiveness of logistics to traffic conditions.	Shorter and more reliable travel times for all modes.	9

Transport technology: flexibility and scale economies

The maritime container, as a box to combine and move shipment-level cargo in an efficient way across long distances, has been the most transformative change in the logistics industry in the past century. It has achieved its position through efficiencies of unitisation, scale and standardisation (see e.g. Levinson, 2013 or Martin, 2014 for an understanding of the genealogy of containerisation). The next frontier in containerisation is the so-called “grey container”, where maritime carriers would use each other’s containers, without keeping separate pools with the carrier’s logos. Although the harsh competition is still preventing carriers from co-operating in the use of their assets, slowly the situation is improving, through an entirely different mechanism. The global economic crisis of 2008-2016 has accelerated the pace at which mergers and acquisitions in the maritime shipping industry take place, leading to a reduction from nine major alliances before the crisis and 4 now (Global Shippers Forum, 2016). The consolidation benefits of this shared use of assets will not only occur because of the reduced container stock or maritime fleet that has to be maintained. Aligned schedules and exchange of information will lead to improved service schedules and opportunities to consolidate freight in the hinterland.

With our supply chain reconfiguration compass (Figure 1) in mind, we can infer the new needs for transportation that will occur inside supply chains. These should respond to changes brought about in supply chains while products and services are moving from the upper right quadrant, around the circle, to the lower left quadrant. Products with a shorter order lead time will not always require faster modes of transport globally; as distribution structures will develop that rely on distribution centres closer to the consumer. At the continental level (say, Europe), faster modes will be needed to satisfy customer requirements. Instant fulfilment (i.e. delivery within 2 hours) is only possible if products are brought directly to the consumer from nearby the last-mile border, preferably into the back yard or office. Other important (perhaps slowly more important) features of transport services are reliability and flexibility. Road transport appears to hold the best cards for continental distribution, with service being fast, reliable and, due to the wide variety of vehicles available, flexible as well. Competition for road transport from rail and waterways is modest and mostly existing within niches of the freight transport market (Tavasszy et al., 2017), including markets for special commodities, port hinterland connections or corridors across natural barriers in transport. New technologies are mostly geared towards automating existing modes. Below we summarise the latest main modal innovations that have appeared in the last century and, as in the case of ICT, we discuss its intended and expected final impact. As in table 3, TRL levels relate to practical technology availability and not to widespread use of the technology.

Table 4. **Key transport technology innovations**

Technology Innovation	Nature of innovation	Intended effects	Final impact on logistics	Technology Readiness Level
Hyperloop	Surface mode with airline speeds: fast magnetic levitation train inside a vacuum tube.	High speed between terminals.	May reduce travel times for interregional transport.	4
Drones	Unmanned transport of smaller shipments reachable for the masses.	Automating home delivery, warehouse towers, remote area deliveries.	Fast deliveries of single shipments. Efficient if no personnel needed. Low DC floor space.	7
Platooning	Connected driving for trucks, combined with partial automation of driver tasks (up to SAE level 4).	Savings in fuel costs, increased driver productivity and reduced terminal or warehouse costs, increased safety.	Cost reductions of up to 25% for road transport.	6
Space freight transport	Freight rockets via space for very long distance.	Faster transport alternative.	Only feasible for very time sensitive small products across long distance.	5
Sail ships	Sails on freight ships.	Can take over propulsion from diesel engine.	Reduced non-renewable energy use.	7
Underground transport	Tube systems for unit loads.	Adds new infrastructure.	Faster access for urban freight and reduced congestion on roads.	9
Electrified highway and trolley truck	Pantograph system on trucks similar to trolley busses with electric trucks.	Extends the action range of electric vehicles.	Depending on the energy source, potentially carbon free.	8
Robotised warehouses and terminals	Automated order picking, container transshipment and/or movement.	Labour cost reduction, higher reliability, increased capacity.	Reduced unit costs.	9
Autonomous trucks	Truck without a driver (automation level 5).	Labour cost reduction, higher reliability.	Strong reduction of road transport costs, no driving time limitations.	7
Autonomous rail wagons (rail AGV)	Individual rail wagon equipped with automatic route control system.	Increased flexibility, higher utilization of rail.	Flexible container transport by rail at costs below road transport.	6
Autonomous vessels	Vessel without a captain.	Smaller, flexible vessels become economically viable.	Possible competition for road transport.	6
Foldable container	Containers with flexible sides that can be folded and stacked.	Improved use of space for empty containers.	Reduced costs of transport.	9
Flexible chassis systems	Interface chassis for continental containers.	Fast transshipment from trucks to rail.	Mostly: increased speed of intermodal transport.	9
Modularisation	Rationalization of load unit and container dimensions.	Reduced loss of space and improved exchangeability between carriers.	Increased utilization of space, support to shared networks.	6
Advanced inland transshipment	New terminal designs.	Lower costs, increased speed, reduced land use.	Mostly: increased speed of intermodal transport.	9

Impacts on multimodal transport

In this section we first discuss the expected aggregate impacts of the innovations discussed above, illustrating the transformative nature of innovations. Next, the significant hazards and barriers to innovation that have to be conquered or circumvented are discussed. Finally, we explore the possible trade-offs between the efficiency-driven innovations in logistics with two other, possibly contradicting, objectives: resilience and sustainability.

Economic impacts

Benefits of new technology reach well beyond the logistics system and propagate through the supply chain, up to the primary resources and down to the final consumers. Wider economic effects include backward (or upstream) and forward (or downstream) effects. Backward effects relate to the inputs to transport and logistics processes, such as labour and materials. Forward effects relate to improvements in productivity, allowing to produce better services at lower prices, from which clients then benefit. In order to understand the full benefits of an innovation, total productivity effects should be measured in a way double counting is avoided. Propagation of effects through the supply chain result often in transfer of benefits, and not new ones – double counting should be avoided in that case.

Digitalisation allows automation of administrative processes, services and manufacturing. The direct benefits include a much higher speed of processing, higher responsiveness and improved reliability. Backward effects mainly involve savings in labour costs due to reduction of personnel (note that according to economists this is a benefit, as jobs are a cost driver in the system). Similarly, transport technology innovations also can result in lower costs (due to economies of scale, or energy savings) or improved service levels. Forward indirect effects include reduced inventories, improved service quality, lower financing costs of services and improved resilience.

Literature that assesses the benefits of logistics innovations is scarce. A qualitative evaluation of logistics innovations was part of the preparation of the European Commission’s Strategic Transport Technology Plan (STTP) in 2012 (JRC, 2012). Besides the above mentioned standard problems in benefit accounting, often other issues complicate evaluation:

- Specifications of innovations in their eventual operational environment, including their performance, are often hard to predict.
- Insight is lacking in the propagation of primary impacts in logistics processes, as well as on how these processes respond to innovations.
- Innovations can seldom be evaluated in isolation, as their application requires a redesign of business processes.
- Innovations are often interdependent or deployed together.

The World Economic Forum and Accenture (WEF, 2016) provide estimates of the likely benefits of logistics innovations. Benefits from digitalisation and associated new services typically results in total logistics cost savings in the order of magnitude of 10%-40%. The value at stake in the logistics industry that is influenced by digitalisation amounts to about USD 1.5 trillion, while the societal impact until 2025 is estimated at USD 2.4 trillion. The part of this value that could be apportioned to specific innovations (about 90%) is distributed as in Table 5. It categorises impacts as either internal impacts on the service quality side (business value) and the cost side (cost reduction) of logistics services; or as an external effect of logistics services (emission and congestion reduction). Almost two-thirds of the impacts originate from horizontal collaboration (crowd sourcing, control towers, shared warehousing) and over 1/3 from digitalisation (analytics, trade facilitation, autonomous transport). Also, two-thirds of the benefits work through cost reductions. External benefits are small.

Table 5. **Expected benefits of logistics innovations in 2025 (USD bn).**

Logistical Innovations	New business value	Logistics cost reduction	Emission and congestion
Data analytics	600		
Control Towers	210		
Trade Facilitation	170	600	-55
Crowdsourcing	310	800	180
Autonomous Transport		50	
Shared Warehousing		500	70
Total	1 290	1 950	195

Source: WEF (2016)

Note that care must be taken in giving a detailed interpretation of these numbers. For example, the numbers are not independent, i.e. innovations overlap and effects cannot be added without double counting. Despite such interpretation problems and the limited reporting on the background of these data, the study does provide a first idea of the order of magnitude of impacts and the relative impact of the different innovations.

Network efficiency vs. resilience and sustainability

These factors will not only play a role in accelerating the adoption of innovations, but also in minimising any negative effects or avoiding hazards, as discussed in the previous section. Containing these risks (e.g. relating to negative sustainability or resilience impacts) is equally, or perhaps even more relevant to our future than making innovations work as intended. Interestingly, a self-organising and extremely efficient system with high customer oriented services may have drawbacks. Optimisation of processes according to efficiency principles could probably go at the cost of other objectives. We name two challenges:

Efficiency vs. Resilience

Innovations, especially in grand visions like the PI, are now mainly geared towards asset sharing and utilisation optimisation. This will have both alleviating effects and pressuring effects on the physical network. Collaboration between logistics service providers in the use of their distribution centres increases the reach of a single company to that of neighbouring networks, thereby allowing new and additional options in case of disturbances. On the other hand, collaboration also increases the utilisation of single links, reducing the reserve capacity and thus allowing congestion to occur more quickly. How the balance between these two will emerge is not yet known.

Efficiency vs. Environmental and Social Sustainability

A key challenge for an advanced and autonomous logistics system is that it should be controllable in a way that it achieves objectives set by humans. This control challenge is not trivial and particularly relevant for objectives that may conflict with efficiency such as resilience against disruptions, or environmental and social responsibility. To a certain extent, efficiency and sustainability gains will be achieved together: a better utilisation translates directly into fewer vehicles on the road. The targets for sustainability improvements are much higher, however, than the expected efficiency improvement that the logistics system alone can provide. Additional measures will be needed to achieve these targets, such as technological measures (e.g. electric power trains). If these do not allow targets to be reached, the logistics system will have to be conditioned to work more sustainably. This implies that additional incentives, resources and control mechanisms must be put in place. Measurement systems need to be in place to understand the performance of the system in various directions, such as carbon footprint. Traceability of all goods and services should be facilitated for full accountability. Allocation mechanisms should be developed to know who is responsible for which impacts of the system. Eventually, compensation mechanisms should be implemented to allow balancing between objectives or actors (e.g. gainsharing).

Impacts of innovations on multimodality

In Europe and in many other regions in the world, the truck is by far the dominant mode in freight transport (EU: 49% of freight performance in tonne-kilometres; without considering maritime transport, more than 70%; Eurostat, 2015). Over the last decades the share of truck transport has increased. A decline of the share of road transport has only been witnessed in niche markets where intermodal transport services are operating. In these markets, the share of intermodal transport in the total freight market has been significant, often exceeding the share of road transport (see box below for more detail).

The European Commission's ambition is still to have more than 30% of all freight transport above the distance of 300km to be moved by non-road modes by 2030, growing to 50% by 2050 (European Commission, 2011). Next to the concern whether this goal is attainable at all, the current rail and waterways networks would probably be unable to accommodate this growth (Tavasszy and Van Meijeren, 2011). A positive noteworthy aspect of this ambition is that, due to the distribution of freight volumes across transport distances, a strong impact could be achieved at a relatively low effort. Above 300 km, only 11% of all freight is moved (measured in tons). At the same time, however, this volume is responsible for 56% of the tonne-kilometres. This latter indicator is more representative for the environmental impact of freight transport.

Box 2: Intermodal transport: success story or failure?

In general, intermodal transport is considered as one of the most promising techniques for train and barge to regain market share, as it combines advantages of barge or train with those of truck transport. How can we assess the performance of intermodal transport?

- Volumes transported by intermodal rail and barge services in Europe have increased considerably over the last decade. Intermodal rail volumes have grown with 43% since 2005. In the hinterland of the port of Rotterdam, barges and rail account for almost 50% of hinterland container movements (port of Rotterdam, 2014).
- Although these volumes are impressive, intermodal (rail and barge) transport still account for less than 5% of the total surface traffic (in tonne-km) of goods in Europe as a whole. Intermodal transport has mostly been successful in situations where transport costs could be kept extremely low (e.g., over very long distances or with double-stack container movements in the United States), where natural or regulatory barriers were present against road transport (e.g., the regulations limiting permits for road transport across the Alps) or where transshipment costs had to be incurred anyway (e.g. at major seaports).
- In the future, this technology might become more important as road transport is facing increasing congestion and risks higher tariffs due to rising wages, fuel prices and environmental costs. Rail and inland waterways could become a more strategic alternative to road transport. In addition, rail and waterways as well may become complements, rather than competitors. Especially in case of major traffic incidents that block an entire corridor, these larger-scale modes could act as alternatives for each other and created a more robust freight network. Examples from the recent past on the North-South axis through Europe include the capsized barge Waldorf in the Rhine and the collapse of a rail foundation in Bavaria in 2017.
- Policy support is an enormous challenge. Decades of attention from policy makers to modal shift have resulted in (amongst others) deregulation, decentralisation and privatisation of railways, improved interconnectivity and interoperability of networks and EU operational subsidy schemes. This has not resulted in a visible increase of rail and inland waterways shares. The European Court of Auditors has recently concluded that the financial stimulation measures for new enterprises in the Marco Polo programme have not had the desired effect (ECA, 2013). Nevertheless, it is difficult to know what would have happened without these policies.

In summary, the development of intermodal transport has been a success in niche markets, but does not appear to have changed the longer term picture of modal split in Europe.

Source: Adapted from Tavasszy et al. (2017)

Undoubtedly, the logistics innovations discussed above will have an impact on how multimodal transport will perform. In the above, the focus has been on the supply side: the design and management of these chains. Below we focus on the expected impact on the demand for the various modes of transport.

Logistics innovations determine the demand for transport via many different logistics decisions. Table 7 below illustrates the considerations that companies go through, which shapes their eventual demand. An early conclusion from this table may be that supply chain considerations should be leading in the design of a transport system in which intermodal or synchromodal services are in demand. Recent research into synchromodal systems appears to confirm the potential of supply chain driven measures (see. Dong, 2017).

Table 7. **Supply chains decisions and transport demand**

Functional area of decision making	Freight generation (total volume moved)	Spatial Distribution (distances covered)	Network Usage (technology, routes)
Sales	Sales volume Number of varieties.	Distances to markets.	Service requirements and scale for outbound flows.
Production planning	Transport intensity of products (water and air).	Distances within the supply chain.	Service requirements for in- and outbound flows
Sourcing	Volumes, service levels and excess flow due to uncertainty.	Distances to suppliers.	Service requirements and scale for inbound flows
Distribution structures	Locations of intermediate inventories.	Degree of centralisation determines detours.	Service requirements towards modes and vehicles.
Inventory	Network/channel inventory policy.	Access to main networks from warehouses.	Service requirements towards modes and vehicles.
Transportation	Limited influence.	Access to main networks.	Direct influence.

Source: Adapted from McKinnon (2001)

Mass-individualised consumption will imply that an increasing variation in types of supply chain and hence, specifications of transport demand. The fragmentation of flows, combined with an overall higher service quality level demanded by consumers, will put considerable pressure on supply chains to further reduce their transport costs. More and more, companies will seek horizontal collaboration or outsourcing of transport activities to reduce their costs. This creates a bundling of flows that is beneficial for slower, high scale modes of transport (Groothedde, 2005; CO3, 2014). This bundling will only be feasible up to a certain point downstream, where the products are split up to be distributed towards the individual consumer. In the final stage of the supply chain, we expect that as part of the broader movement of customised services, individual products will increasingly be shipped to the consumer. The distances for transport from shop to consumer will shrink as the demand for immediate or instant (within-day, within 2 hours, flexible location) deliveries increases. In summary, products will be moving more together over longer distances and, on the final stretch, more separately.

Digitalisation will have a profound impact on multimodal transport as it will accelerate the changes described above. An additional question is how it might influence freight transport demand. Possibly, the new offering of service flexibility may, for some products, create a market for switching between services, to cater for shippers who make en-route changes to shipment destinations or volumes, or carriers who want to deal quickly with transport system disruptions.

Automation will benefit all modes of transport; the biggest impact is expected in labour intensive modes, like road transport. Research to date has indicated that efficiency increases in road transport may have mild effects of innovations with mild cost reductions (up to about 15%, (see JRC, 2009)). Higher levels of automation that remove the driver altogether, could lead to significant cost reductions and subsequent modal shift, as driver wages can make up about 50% of transport costs[3]. Adapting the legal framework for partial or full automation is needed to unlock these benefits (see Tavasszy, 2016). The impact of exotic, new modes of transport like drones or the Hyperloop, is difficult to forecast. The projections of the costs of these modes vary widely, but so far they are too expensive to change the landscape, and impacts are mostly felt in high-end product niche markets.

Logistics innovation and multimodality: barriers

It is not uncommon in the logistics sector that innovations with a high potential benefit at system level are not adopted within supply chains. The main reason is that individual actors have to make investments or will reap the benefits, and the balance is not always right for every player in the supply chain. A review of hundreds of city logistics initiatives in Europe (BESTUFS, 2007) found that largely for this reason, most new urban distribution concepts introduced around the turn of the century had failed. In a detailed review of ten major innovations in intermodal transport technology in Europe, van Binsbergen et al. (2014) observed eight barriers for adoption of innovations in large, complex transport systems. It is difficult to tell which of these barriers are most pronounced in the logistics sector as little research has been done on the above factors in the context of supply chain innovations of the future, as discussed here. We discuss these factors and their interpretation below.

Table 6. **Barriers in logistics innovation and their latest development**

Barrier factors	Latest development in logistics sector
High investment costs, surpassing the capacity of SME's in the transport sector.	Business models around digitalisation do not necessarily involve large initial investment costs. However, many start-ups struggle to make a profit in the first years.
Unequal distribution of costs and benefits of innovations between supply chain partners leading to rearrangement of business models.	Collaboration in logistics is becoming exceedingly more common, as companies are depleting opportunities to save logistics costs internally, but are continuously pressured to provide better services. Experience with investment and gain sharing arrangements is improving.
Changes in power relations in the supply chain will be avoided by those in power.	The advent of ubiquity of data and information systems may appear to weaken supply chain power relations
Starting small will only be possible for companies with sufficient capital to spend on operational losses.	New, advanced production systems such as 3D fabbing require a small scale of operations to break even.
Government actions to support innovations are lacking, badly designed or not understood.	The dialogue between governments and industry seems to be improving as CSR and climate change is increasingly on the agenda, and industry is publicly challenging government to provide clear policies and guidelines.
Unexpected changes in external conditions, such as the global economic crisis, may affect all investments.	An accumulation of crises has re-emphasised the importance of resilience. Nevertheless, dealing with highly uncertain, high impact risks is still a major challenge for decision makers.
Overreliance on technological hardware (neglect of behavioural factors, political optimism bias, locked-in governance and inflexible business models).	There is ample evidence that this is a major barrier for logistics innovation. Challenges like information asymmetries in supply chains are non-technical and can be driven by power imbalances inherent in supply chains.
Innovation project management is missing, or lacking a multi-actor approach, foresight, road mapping, resources or room for failure.	Lately, logistics innovation practices have moved towards more pragmatic approaches, characterised by collaborative structures and an incremental, minimum viable product approach.

Source: Binsbergen et al. (2014)

Specifically for multimodal transport, the latest developments towards synchromodal transport systems, four barriers (or, put positively, enablers) can be identified which are specific cases of the barriers mentioned above (Tavasszy et al., 2017):

Legal/administrative issues: The most elementary change in terms of transactions is that shippers, when they book transport services, do not yet fix the mode of transport (a-modal booking). This change has a cascade effect on all contracts needed for realising the services, including the second- and third-order services, administrative handling of the shipping, the conditions of shipping, the division of responsibilities, the contracting of insurance services and so forth. Barriers for these changes in transactions primarily lie around the change of business models and the adoption of practices and instruments for data access, processing and sharing.

Trust based collaboration: The reliance of transport contracting on service quality preferences instead of a fixed mode of transport introduces the possibility for shippers and service providers to collectively optimise their systems. This requires stronger collaboration between service providers and shippers, compared to the (still dominant) situation when shippers seek only low prices. For these arrangements to become reality, collaboration structures need to develop that are not yet customary. Competing service providers are not used to work together, and often are not allowed to, given antitrust policies and regulations. Data availability is hampered by the absence of proper data standards, incompatibility of company information systems and a lack of sharing agreements.

Market structure: Shortcomings in current and governance arrangements concerning liability include the lack of incentives to disclose and share information about contents and the absence of an agreed approach to transparency of data in global trade lanes (Klievink et al., 2012). These shortcomings are deeply rooted in current institutions. Currently, one of the main barriers is the fragmentation of the service market into a large number of small-scale companies, typically owning few assets and serving local markets. The SME approach with respect to innovation is very different from the approach of leading large forwarders and service providers. Due to their low capability to adopt technology and set standards, many SME firms are lagging behind in their use of information.

Cultural issues: A-modal booking requires a specific mindset of shippers. The second aspect is the shift from a "mode-based" to a "service-based" hinterland transport. Without this mental shift, the modalities can be simply seen as competitors; the complementary nature of them cannot be explored and the integration cannot happen. Finally, there is a need to go from a (dominated) "predict and prepare" hinterland operation towards a (complementary) "sense and respond" mind set. In fact, the performance of hinterland transport is less defined by our "prediction capabilities" than by our "control-room capabilities" and how to react to sudden changes.

An important barrier not mentioned in the above concerns the dynamics of adoption. Typically, around the introduction of new technology, technology prices are still high, which discourage firms to acquire the new technology. These prices will only drop when sufficient demand is available. This chicken-and-egg problem especially frustrates the development of markets for electric vehicles. Governments can step in with subsidies for consumers and producers, as launching customer or a provider of (e.g. charging) infrastructure.

Conclusions and recommendations

This paper summarises a large number of innovative developments in logistics that will influence multimodal supply chains. We discuss innovations in logistics organisation, in information systems and in transport technology. Three megatrends in innovations emerge. *Mass-individualisation* of products and services leads to an increasing pressure on supply chains in terms of service quality requirements. The resulting higher costs can be balanced by increased horizontal cooperation across company boundaries. *Digitalisation* is the main autonomous force that accelerates the above patterns. Ubiquitous information systems, resources and services will create a sense-and-respond logistics system where planning becomes less relevant and significant gains result from reduced capital stocks through smart contracts. *Technological innovation* is spurred by digitalisation, reducing the labour input to logistics processes through autonomous vehicles and, on the long term, equipment may enter a new phase of modularisation in the physical internet (PI).

At a system level, the "physical internet" is the only comprehensive vision about how these innovations could converge into a single logistics system. As such it is also a compelling vision, leading researchers to discuss the whole system, rather than the parts of the system, or the sum of the parts. However, the R&D to develop physical internet ideas has only started recently and much work towards its design and implementation still needs to be done. The current ideas about when this would start to become reality vary between 2030 and 2050. On one hand this seems too far away to plan any investment; on the other hand, given the transformational nature of this vision, it allows us time to install necessary long term framework conditions like physical infrastructure and governance structures.

Rather than evaluating all these innovations in detail, our focus was on providing an overview and to discuss the overall impacts and barriers. Estimates of the impacts of logistics innovation are still based on studies of partial innovations or very crude aggregate analyses. The consensus about benefits seems to be, however, that their order of magnitude is large enough to disturb existing business models within the logistics market. Benefits could run into trillions, which justifies their treatment as transformational innovations. Costs include not just investment and operational costs but also broader transition costs (e.g. accommodating a changing labour force and skills). Benefits lie also in improving the resilience of systems due to increased flexibility. These benefits may be interesting for the logistics sector as operations keep requiring higher service at lower costs. More importantly perhaps, they may prove to become critical for mitigating external threats related to climate change or cybercrime. A possible risk of the main line of innovation towards autonomous, self-organising and mass-individualised services also includes an overreliance on short term efficiency benefits, at the cost of sustainability and resilience.

Barriers to the implementation of innovation are generally non-technical. Supply chains are complex systems, where innovations usually require a re-design of business models and re-alignment of relations between stakeholders. These processes take much more time than the process of introduction of innovations into the technical environment. The gradual implementation of innovations requires many different contributions from all supply chain stakeholders, including government. This results in a complex process that is difficult to manage. Roadmaps for R&D and implementation can provide support. Currently, such roadmaps are virtually non-existent, with the ALICE technology platform roadmaps in Europe being a notable exception.

Concerning resilience, we find that the complexity and speed of change, combined with the very diverse state of governance and professional competences amongst the transport actors (from very advanced to severely lagging), is a risky combination in the face of the global sustainability challenges ahead. The direction of change promoted by the major innovations does not necessarily reduce this risk. Possibly, the reduction of asset intensity of the system due to collaboration will make it easier to respond to these challenges, which in essence require the system to be adaptive and agile. Also, the slow change away from centralised, planning based systems to distributed, flexible transport should increase system resilience. At the same time, the reduction of redundant capacity, combined with the increase of scale in transport modes, also imply a higher probability (less slack) and a higher impact (larger volumes at once) of failures, together implying higher risk. The net outcome of all these factors is unclear.

In this paper we have explored the interrelations between innovation in multimodal supply chains and the performance of the transport system. The challenge to keep the transport system efficient, sustainable and resilient is becoming increasingly visible. Challenge comes from the outside in the form of environmental pressure, technological and service innovations and increasing global market powers. Intelligence in system governance is needed to steer Research and Design (R&D), logistics management and policy making in the right direction. A shared, solid vision is needed of the way in which all these innovations should converge; research could contribute to filling the initial knowledge gaps. Financial resources need to be mobilized beyond the typically public infrastructure capacity investments and private technological innovations, to overcome market barriers to increase the sustainability and resilience of the system. Despite the general recognition of existing market and government failures, there is no consensus on how this could be achieved.

Notes

1 We define sustainability as the ability of a system to meet the needs of the present without compromising the ability of future generations to meet their own needs (cf. Brundtland) and resilience as the ability of a system to return to its original state after disruption, while maintain its function during a disruption.

2 Fog computing, fog networking or fogging relies on distributed computing resources rather than single data centres, creating a more resilient and efficient infrastructure.

3 These shares vary widely by country, being around 30% in the UK (RHA), 40% in the USA (ATRI) and China (Forbes) and 50% in the Netherlands (TLN).

References

ALICE (2015), Roadmap for Hubs, Corridors and Syhromodality (http://www.etp-logistics.eu/; accessed 30-1-2018)

Global Shippers Forum (2016), The Implications of Mega-Ships and Alliances for Competition and Total Supply Chain Efficiency: An Economic Perspective, Accessed 31/8/2018, https://www.globalshippersforum.com/media/1267/gsf-mega-ships.pdf

Baines, T. S., H. W. Lightfoot, O. Benedettini, and J. M. Kay (2009). The servitization of manufacturing: A review of literature and reflection on future challenges. *Journal of Manufacturing Technology Management*, 20(5), 547-567.

Ballot É., B. Montreuil, R. Glardon (2012), Simulation de l'Internet Physique: contribution à la mesure des enjeux et à sa définition, PREDIT Research Report, Mines Paris Tech, Paris

BESTUFS (2007), Good practice guide on urban freight. BESTUFS Consortium, www.bestufs.net/results.html (accessed 3-5-2018)

Birtchnell, T. and J. Urry (2013). Fabricating futures and the movement of objects. Mobilities, 8(3), 388-405.

Bonev, M., A. Myrodia, and L. Hvam (2017). Reconfiguring Variety, Profitability, and Postponement for Product Customization with Global Supply Chains. In Managing Complexity (pp. 13-26). Springer International Publishing.

Braun, E. (1998). Technology in context: Technology assessment for managers. Taylor & Francis US.

Christidis, P. and G. Leduc (2009). Longer and Heavier Vehicles for freight transport. JRC European Commission, 1-40.

Ciccullo, F., M. Pero, M. Caridi, J. Gosling and L. Purvis (2017). Integrating the environmental and social sustainability pillars into the lean and agile supply chain management paradigms: A literature review and future research directions. *Journal of Cleaner Production*.

CO3 Project Deliverables, see http://www.co3-project.eu/ (accessed 5-1-2017)

Combes, F. (2010), The Choice of Shipment Size in Freight Transport, PhD Thesis, Université Paris-Est, Paris

Commission of the European Communities – CEC (2001). White Paper. European transport policy for 2020: time to decide [COM(2001)370]. Luxembourg: Publications Office of the European Union

Dalmolen, S., H. M. Moonen, J. van Hillegersberg, A. J. R. Stoter and E.Cornelisse (2015, May). Supply chain orchestration and choreography: Programmable logistics using semantics. In Advanced Logistics and Transport (ICALT), 2015 4th International Conference on (pp. 76-81). IEEE.

Davydenko, I., M. Jacobs, L.A.Tavasszy (2015), Trucks are better utilized (in Dutch), Proceedings of Vervoerslogistieke Werkdagen, HAN, Nijmegen

Delawari, A. A. (2013). Shared Situational Awareness Between Inland Actors at Port of Rotterdam, MSc Thesis TU Delft

Delis, A., N. Driffield and Y. Temouri (2017). The global recession and the shift to reshoring: Myth or reality?. *Journal of Business Research.*

DHL (2013), Logistics Trend Radar.

Dong, C., R. Boute, A. McKinnon and M. Verelst (2017). Investigating synchromodality from a supply chain perspective, Transportation Res. Part D: Transport and Environment.

Durach, C. F., S. Kurpjuweit and S.M. Wagner (2017). The impact of additive manufacturing on supply chains. *International Journal of Physical Distribution & Logistics Management*, 47(10), 954-971.

ECA (European Court of Auditors) (2013), Have the Marco Polo programmes been effective in shifting traffic off the road? Special report no. 3, Luxembourg: Publications Office of the European Union

Fisher, M. L. (2003). What is the right supply chain for your product. Operations management: critical perspectives on business and management, 4, 73.Fleisch et al., 2014;

Fleisch, E., M. Weinberger and F. Wortmann (2014). Business models and the internet of things, Bosch IoT Lab Whitepaper. University of St. Gallen.

Groothedde B., (2005), Collaborative Logistics and Transportation Networks, a modelling approach to network design, PhD Thesis T2005/15, Delft: TU Delft

Hofman, W., M. Punter, H. Bastiaansen, E. Cornelisse and S. Dalmolen (2016). Semantic technology for enabling logistics innovations–towards Intelligent Cargo in the Physical Internet. *International Journal of Advanced Logistics*, 5(2), 58-69.

Hofmann, E. and M. Rüsch (2017). Industry 4.0 and the current status as well as future prospects on logistics. Computers in Industry, 89, 23-34.

ITF (2017), "The impact of mega-ships: The case of Jakarta", International Transport Forum Policy Papers, No. 42, OECD Publishing, Paris, https://doi.org/10.1787/d66339af-en.

JRC (2012), Scientific Assessment of Strategic Transport Technologies, Brussels: European Commission

Levinson, M. (2016). The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger, Princeton University Press.

Marin, D., R. Veugelers, and J. Feliu (2017). 5 A revival of manufacturing in Europe? Recent evidence about reshoring. Remaking Europe: The New Manufacturing As An Engine For Growth, 103.

Markillie, P. (2006), The physical internet: A survey of logistics, The Economist

Martin, C. (2014). The packaging of efficiency in the development of the intermodal shipping container. Mobilities, 9(3), 432-451.

McKinnon, A. (2001). Integrated logistics strategies. Handbook of Logistics and Supply Chain Management. A. M. Brewer, et al., Elsevier Science Ltd.: 157-170.

Montreuil, B. (2011). Toward a Physical Internet: meeting the global logistics sustainability grand challenge. Logistics Research, 3(2-3), 71-87.

NDRC (2015), Vision and Actions on Jointly Building the Silk Road Economic Belt and 21st Century Maritime Silk Road, National Development and Reform Commission, http://en.ndrc.gov.cn/newsrelease/201503/t20150330_669367.html (accessed 30-1-2018)

Sanchez, R.J. and L. Mouftier (2017), The puzzle of shipping alliances in April 2017, available at http://www.porteconomics.eu/2017/04/20/the-puzzle-of-shipping-alliances-in-july-2016/, accessed 18-01-2018

Smit, J., S.Kreutzer, C.Moeller and M.Carlberg (2016), Industry 4.0, Brussels: European Parliament

Sternberg, H. and A. Norrman (2017). The Physical Internet–review, analysis and future research agenda. International Journal of Physical Distribution & Logistics Management, 47(8), 736-762.

Strandhagen, J. O., L.R. Vallandingham, G. Fragapane, J.W. Strandhagen, A.B.H. Stangeland and N. Sharma (2017). Logistics 4.0 and emerging sustainable business models. Advances in Manufacturing, 1-11.

Tavasszy, L. A., B. Behdani and R. Konings (2017). Intermodality and Synchromodality, in: Geerlings, H., B. Kuipers and R. Zuidwijk (Eds.). Ports and Networks: Strategies, Operations and Perspectives. Routledge.

Tavasszy, L., and J. Van Meijeren (2011, October). Modal shift target for freight transport above 300 km: an assessment. In Proceedings of the 17th ACEA SAG meeting.

'Technology Readiness Level' (last updated 2018)) *Wikipedia*. Available at https://en.wikipedia.org/wiki/Technology_readiness_level https://en.wikipedia.org/?title=Rush_(band)(Accessed: 10 January 2017).

Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Business strategy and the environment, 13(4), 246-260.

Ugarte, G. M., J. S. Golden and K.J. Dooley (2016). Lean versus green: The impact of lean logistics on greenhouse gas emissions in consumer goods supply chains. *Journal of Purchasing and Supply Management*, 22(2), 98-109.

United States Department of Defense (2011) "Technology Readiness Assessment (TRA) Guidance" (PDF). United States Department of Defense. April.

van Binsbergen, A., R. Konings, L. Tavasszy and R. van Duin (2013), Mega-projects in intermodal freight transport: innovation adoption. In: Priemus, H. and B. van Wee (eds.), International handbook on mega-projects, Cheltenham: Edward Elgar Publishers.

Van Dam, W. (2017), Robustness Analysis of the Dutch Synchromodal Freight Transport Network, MSc Thesis TU Delft

Van Riessen, B., R.R. Negenborn, R. Dekker and G. Lodewijks (2015). Service network design for an intermodal container network with flexible transit times and the possibility of using subcontracted transport. *International Journal of Shipping and Transport Logistics*, 7(4), 457-478.

Van Stijn, E., A.J. Klievink and Y.H. Tan (2011). Innovative ICT solutions for monitoring and facilitating international trade. Network Industries Quarterly, 13 (3), 2011.

Vermunt, J., F. Binnekade (2000), European Logistics, The Hague: Holland International Distribution Council

WEF (2016), Digital Transformation of Logistics, White paper, World Economic Forum

WEF (2018), Transformation map for supply chains and transport, available at https://toplink.weforum.org/knowledge/explore, accessed 18-1-2018

Zezulka, F., P. Marcon, I. Vesely, and O. Sajdl (2016). Industry 4.0–An Introduction in the phenomenon. IFAC-PapersOnLine, 49(25), 8-12.

Appendix – TRL levels

Technology readiness levels (TRL) are a method of estimating technology maturity of Critical Technology Elements (CTE) of a program during the acquisition process. TRL are based on a scale from 1 to 9 with 9 being the most mature technology. The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technology ('Technology readiness level', 2018).

Table 7. **Technology readiness levels in the United States Department of Defense**

Technology readiness level	Description
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).
8. Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.

Source: United States Department of Defense, 2011

Innovation and Technology in Multimodal Supply Chains

This paper investigates innovations in multimodal supply chains. It covers innovations in technology and IT, physical hardware and how supply chains are organised. It outlines direct and indirect impacts of these innovations, showing the ramifications for multimodality, the broader logistics system and sustainability challenges.

International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
+33 (0)1 45 24 97 10
contact@itf-oecd.org
www.itf-oecd.org

Published: 10/2018 | Photo credit: Slavomir Kubes/CTK Photo