

Chapter 2

Broad Developments Impacting Supply Chain Collaboration



Supply chain collaboration is not a topic that is relevant in isolation. It is impacted by some larger global developments that change the logistics industry. In this chapter we discuss four major developments that impact supply chains and call for collaborative approaches: (1) Sustainability, (2) Digitization, (3) Increased optimization power, and (4) Globalization.

2.1 Sustainability

Following the alarming reports of the International Panel of Climate Change (IPCC), most of the world leaders now are taking actions to significantly reduce greenhouse gas emissions and to ensure a livable planet also in the second half of the twenty-first century and onwards. Several climate conferences have been organized by the United Nations, with a provisional highlight written down in the Paris Agreement of 2016. As a short summary, the undersigning countries¹ vow to do everything in their ability to limit the average global temperature rise by 1.5–2 °C.

The European Union is one of the main promoters of the Paris Agreement. As the EU website² states:

¹All countries in the world except for four OPEC countries (Iran, Iraq, Angola, and Libya), two countries torn by conflicts (South Sudan and Yemen). Sadly, the USA joined this list by withdrawing from the accord in 2019.

²https://ec.europa.eu/commission/presscorner/detail/en/IP_19_5534

“The EU has the most comprehensive and ambitious legislative framework on climate action in place and it is successfully transitioning towards a low emissions economy, aiming at climate neutrality by 2050 – between 1990 and 2017 its greenhouse gas emissions were reduced by 23% while the economy grew by 58%. The EU has already overachieved its 2020 greenhouse gas emissions reduction target and has completed its unique binding legislative framework that will allow us to over-deliver on our climate targets for 2030. At the same time, the EU Adaptation Strategy has encouraged national, regional, and local adaptation action since 2013. Conscious that our emissions make up only around 9% of the global total, the EU is continuing its outreach and collaboration, financial and technical, to all partner countries. The EU remains the world's leading donor of development assistance and the world's biggest climate finance donor. Providing over 40% of the world's public climate finance, the EU and its Member States' contributions have more than doubled since 2013, exceeding EUR 20 billion annually.”

It almost goes without saying that sustainability has become the most important driver for transport efficiency. In Sect. 7.1 we will discuss in more detail the available empirical research on the motivations that companies have for engaging in collaboration, but it is fair to say that recently the importance of sustainability in this decision has become more and more prominent and that will only become more apparent in the years to come.

The transport industry is considered a growing contributor to global climate change. According to the International Transport Forum (ITF) freight transport accounts for about 39% of transport CO₂ emissions and around 8% of CO₂ emissions worldwide. It is also a major contributor to air pollution. Road constitutes 62% (50% non-urban, 12% urban) of emissions, while sea contributes 27%, air 6%, rail 3%, and inland waterways 2%. In Europe, freight constitutes 6% of total CO₂ emissions and 30% of transport CO₂ emissions. As it stands, the total emissions from freight need to be almost fully decarbonized by 2050 compared to the 2015 levels if we are to meet the climate ambitions set out in the Paris Agreement. However, the real challenge facing us is that demand for freight transport is predicted to triple and associated CO₂ emissions to more than double over the same period, according to the ITF. This means that nothing short of a transformational shift towards the decarbonization of global freight transport is necessary to meet global climate targets (ALICE 2019).

Given the massive task, it is good to see that following up on the Paris Agreement of 2016, more and more governments, associations, and businesses are setting bold climate targets. The ambition is for Europe to be the first climate-neutral continent

in the world by 2050.³ This will be achieved with a two-step approach, designed to reduce CO₂ emissions by 50%, if not 55%, by no later than 2030. In addition, more than 600 companies have committed to these targets, with some even pledging to reach zero emissions by 2050. The deployment of greener and cleaner vehicles, trains, barges, ships, and airplanes as well as other technologies for a more efficient transport network is forecasted to be too slow to reach our climate change targets. The short-term focus therefore is on finding new opportunities for efficiency gains in freight transport and logistics.

In this section we explain that CO₂ emissions can not only be reduced by technological advances (lower fuel consumption, electrification, etc.), but that also significant savings can be achieved through innovative supply chain concepts such as collaboration. Large efficiency gains and benefits to all logistics stakeholders are possible by doing more with less. The existing idle capacity of assets and infrastructure in all modes of transport could be better used, and flows could be managed in a more integrated way. Open logistics services and connecting networks can improve capacity utilization. It is difficult to see how we can reduce transport emissions in the short run without increased supply chain collaboration. In other words: *Given the eminent threat of global warming, transport inefficiency is a luxury that belongs to the past*

Fortunately, there is a quickly developing body of research that is available to logistics decision makers to reduce the carbon footprint of their logistics operations. A comprehensive review of the literature on “green SCM” is offered by Tseng et al. (2019). The study finds a consistent growth in the evaluation of green SCM practices and performance. Although the concept of green SCM already started gaining popularity among academicians from the beginning of the twentieth century, they find a sharp growth of publications on the topic after 2010, resulting in a body of literature of at least 880 papers until September 2010 when their paper was submitted for publication.

Another overview is provided by McKinnon (2018). He shows that there is no shortage of strategies or carbon-reducing initiatives. Policymakers and business leaders who are committed to bringing emissions down to levels consistent with the COP21 Paris Climate Change Agreement can use it to come up with regulation, design programs, and action plans. In addition, ALICE (2019) provides some detailed actions that can be taken by the industry to reduce overall emissions. Some of them relate to supply chain collaboration and these are summarized in Table 2.1.

In the Netherlands, following up on the COP21 in Paris and realizing the massive task it meant for the Dutch logistics industry, a work program was started called “Factor 6.” By 2050, the Netherlands must have reduced its greenhouse gas emissions by 60% compared to the 1990 base year. Since 1990, the Dutch economy obviously has grown significantly, resulting in an increase of 150% in the demand for

³The new president of the European Commission, Ursula von der Leyen said in her first statement to the European Parliament plenary session: “I want Europe to become the first climate-neutral continent in the world by 2050. To make this happen, we must take bold steps together. Our current goal of reducing our emissions by 40% by 2030 is not enough. We must go further. We must strive for more. A two-step approach is needed to reduce CO₂ emissions by 2030 by 50, if not 55%.”

Table 2.1 Link between collaboration and proposed sustainability measures (ALICE 2019)

Measure	Description	Link to collaboration
Adjust truck size to load	The fuller the load compartment, the better the overall efficiency. Matching the size of the vehicle with the load (volume or weight) contributes to efficiency	By combining LTL shipments of various shippers or LSPs trucks can be filled to (almost) their exact capacity
Optimizing use of vehicle space	Optimize the loading of vehicles taking the vehicle and freight dimensions into account. Improvements of the load factor of the vehicle through efficient unit loads and a combination of mechanical and manual loading may be necessary	Combining loads from shippers from various supply chains makes it possible to better use the multidimensional capacity of trucks, by, for example, combining heavy with voluminous products in a truck
Bundling shipments across product categories with similar shipment characteristics	This can be realized through (1) horizontal collaboration, (2) freight exchange platforms, (3) open cross docks, (4) mixed load and weight volume, (5) urban consolidation centers, (6) crowd shipping, (7) high capacity vehicles, (8) use of public transport modes	On the short-term, these bundling measures are only possible if they are somehow coordinated through a control center such as a 4C
Modular packaging	Redesign of product packaging and load carriers for optimal fit to products	Modular packaging (see also Sect. 3.1) strongly facilitates horizontal collaboration as loads can be better combined physically
Backhauling	Picking up or delivering cargo on return or round trips as compared to returning with empty vehicles or vessels	To increase backhauling and reduce empty repositioning it is important to oversee as many supply chains and movements as possible. A 4C or other forms of horizontal collaboration strongly increases the possibility of finding backhauls
Open warehouses	This solution looks for a systemic load consolidation and optimization in which the capacity in logistics sites and transport networks are made available for use in an optimized way for multi-supplier and multi-retailer groups	Multi-supplier or multi-retailer warehouses have an important effect that either starting points or destinations of multiple transport are the same. This is especially profitable if the warehouses host companies from the same industry

Note that once a Physical Internet (see Sect. 3.7) is in place, these bundling measures can occur decentrally, so without an overarching control tower. In a way, the Physical Internet is then an automation of a 4C

transport. *Ceteris paribus* this means more transport movement and more CO₂ emissions by a factor of 2.5. In addition, the agreed 60% reduction in absolute emission levels requires another reduction by a factor 2.5. Together, this challenge is summarized as Factor 6: to reach the COP21 goals, the logistics industry must improve its efficiency by roughly a factor 6.

This can be achieved in three high-level ways:

1. Reduce emission per ton-km (Cleaner vehicles, modal shift, driver trainings, etc.).
2. Reduce the number of transported tons (by producing smaller products, reducing packaging, 3D printing, etc.).
3. Reduce the number of kilometers travelled (local sourcing, load factor optimization, improved network design, collaboration, etc.).

To achieve Factor 6, most likely all three approaches must be followed in parallel. In this document, we focus on the third approach.

It is estimated that in Europe vehicles are empty 25% of the time that they are moving (Eurostat 2019). In this regard, sharing available and idle capacity is key to overcome the increase in freight transport fragmentation with smaller but much more frequent shipments (due to e-commerce, for example, see Sect. 3.5). It is estimated that better freight matching (for which smart algorithms are available) could reduce empty running by 15–40% overall. Horizontal collaboration or coordination through a 4C seems a prerequisite to accomplish any of this.

In a European stakeholder consultation, ALICE (2019) arrived at the following ranking for transport measures to fulfill the Paris agreement decarbonization strategy (based on both impact and feasibility):

1. Renewable energy in combination with electrification, hybrids, and hydrogen.
2. Multimodal optimization.
3. Load consolidation and optimization.
4. Use of efficient vehicles, vessels, and fleets.
5. Synchromodality and flows synchronization.
6. Improve fleet operation.
7. Supply chain restructuring.
8. Consumer behavior.

At least three measures (number 2, 3, and 5) will be difficult to achieve without coordination, which highlights the importance of 4Cs to decarbonize transport.

Sustainability was also one of the motivations for Van Laarhoven (2008) to propose the 4C concept. This is because cross-chain control aims at more efficient coordination of production and orchestration of physical movement of goods. This should automatically lead to fewer negative environmental impacts from the so-called supply chain waste. Improved coordination of transport modes leads to reduced empty running and as a result also to smaller CO₂ and NO_x emissions.

Supply chain waste is also referred to as the “hidden costs of transport.” Van Breedam and Vannieuwenhuysse (2018) argue that without strongly improved coordination of transport, the share of hidden costs in the total logistics cost is likely to increase much faster than the actual direct cost for logistics as is illustrated in Fig. 2.1.

Ferrell et al. (2019) add to this that transport inefficiency is harmful as obviously it brings no added value to society or consumers and because of the contribution that freight movement has on the growth of CO₂ emissions. Even if we accept that fossil

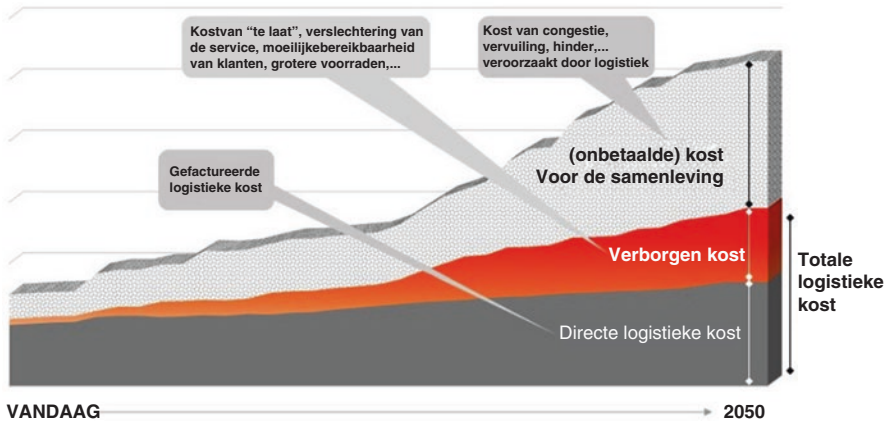


Fig. 2.1 Ceteris paribus development of logistics cost (Van Breedam and Vannieuwenhuysse 2018) (In Dutch)

fuel combustion will be the predominate propulsion mechanism to move freight for the foreseeable future, the amount of CO₂ associated with empty miles to reposition assets is problematic at best and approaching being unacceptable to some. In the USA transport generates about 29% of CO₂ emissions with the freight transport sector alone (which is defined as trucks, ships, and trains used to deliver freight), contributing approximately 10% of the CO₂ emissions annually (USEPA 2019). Simply reducing unproductive trips by means of a 4C can make an important difference.

2.2 Digitization

In its essence, digitization means transforming analog information into zeroes and ones so that computers can work with it. There are many examples of digitization in businesses. Converting handwritten or typewritten text into digital form is an example of digitization, which, for example, still applies today to some shipping documents.

Digitization is a prerequisite for logistics control towers of any considerable size. Fortunately, digitization has been developing at a fast pace over the last couple of years, taking away a huge impediment for the dynamic coordination of multiple supply chains from a single physical (or virtual) location.

This digital transformation has received enormous attention in recent years. There are many recommendable books on the topic, but a good overview is given by Raskino and Waller (2015). For the purpose of this report, we limit ourselves to only a few subtopics of digitization that are of special relevance to 4Cs: (1) Big data analytics, (2) Industry 4.0 and the Internet of Things, and (3) Robotics and artificial intelligence.

2.2.1 Big Data Analytics

A serious amount data is available. Until 2010 most of the digital data available was (more or less) structured company data from dedicated systems for the management certain company processes. The steep growth that can be seen from Fig. 2.2 is primarily caused by the rise of social media that generates enormous amounts of data every second. And in principle these data can be used for better decision making. This is called *big data analytics*.

In recent years, also the amount of data produced from end-to-end SCM practices has increased exponentially. And often supply chain professionals are struggling to handle these huge datasets. Supply chain analysts are using new techniques to investigate how data are produced, captured, organized, and analyzed to give valuable insights to industries.

Tiwari et al. (2018) investigate big data analytics research and applications in SCM between 2010 and 2016. They define big data as huge or complex sets of data that consist of exabytes and more. See Fig. 2.3 to interpret the size of an exabyte.

With big data analytics it is not possible anymore to store all available data locally and process, interpret, and visualize it. The size of the global datasphere is increasing exponentially (see Fig. 2.2) and this is predicted to continue to do so in the next couple of years. Academia and practitioners agree that this flood of data creates ample new opportunities, therefore many organizations try to develop and enhance their big data analytics capability. The topic of big data is continuously evolving and expanding, and the main attributes of big data are now captured in into the *5V concept*, which refers to volume, velocity, variety, verification/veracity, and value. Zhong et al. (2016) provide a comprehensive discussion on the current big data technologies including storage, data processing, and data visualization

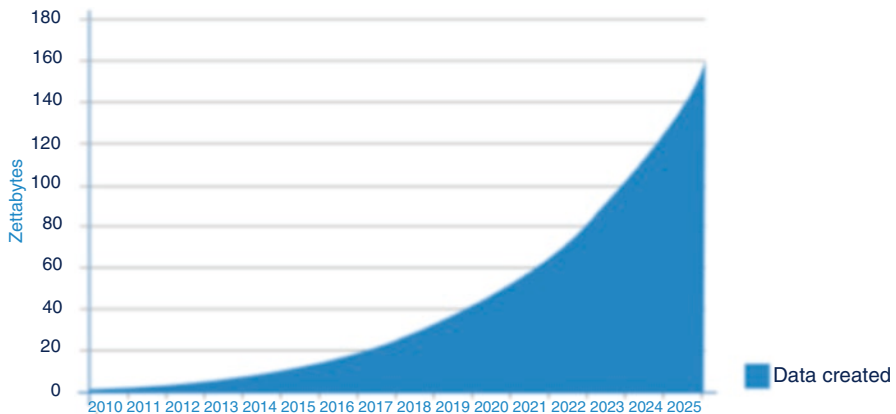


Fig. 2.2 Annual size of the global datasphere (Source: Ellis et al. (2015))

yotta [Y]	$10^{24} = 1\,000\,000\,000\,000\,000\,000\,000\,000$
zetta [Z]	$10^{21} = 1\,000\,000\,000\,000\,000\,000\,000$
exa [E]	$10^{18} = 1\,000\,000\,000\,000\,000\,000$
peta [P]	$10^{15} = 1\,000\,000\,000\,000\,000$
tera [T]	$10^{12} = 1\,000\,000\,000\,000$
giga [G]	$10^9 = 1\,000\,000\,000$
mega [M]	$10^6 = 1\,000\,000$
kilo [k]	$10^3 = 1\,000$
hecto [h]	$10^2 = 100$
deca [da]	$10^1 = 10$

Fig. 2.3 Digital information metrics

technology. They reviewed more than 100 recent publications on big data applications in SCM and were able to categorize them into the following topics:

1. Strategic sourcing.
2. Supply chain network design.
3. Product design and development.
4. Demand planning.
5. Procurement.
6. Production.
7. Inventory.
8. Logistics and distribution.
9. Supply chain agility and sustainability.

Tiwari et al. (2018) define the term *big data analytics* as the application of advanced analytic techniques including data mining, statistical analysis, predictive analytics, etc. on big datasets. It refers to the processes of examining and analyzing huge amounts of usually unstructured data to draw conclusions by uncovering hidden patterns and correlations, trends, and other business valuable information and knowledge, to increase business benefits, increase operational efficiency, and explore new market and opportunities. Figure 2.4 shows the big data analytics model by Mayo (2017)

Nguyen et al. (2018) have produced another review of recent research in the field of big data analytics. This review explains where and how big data analytics has been applied within the SCM context. It addresses four specific research questions: (1) in what areas of SCM is BDA being applied? (2) At what level of analytics is BDA used in these SCM areas? (3) What types of BDA models are used in SCM? (4) What BDA techniques are employed to develop these models?

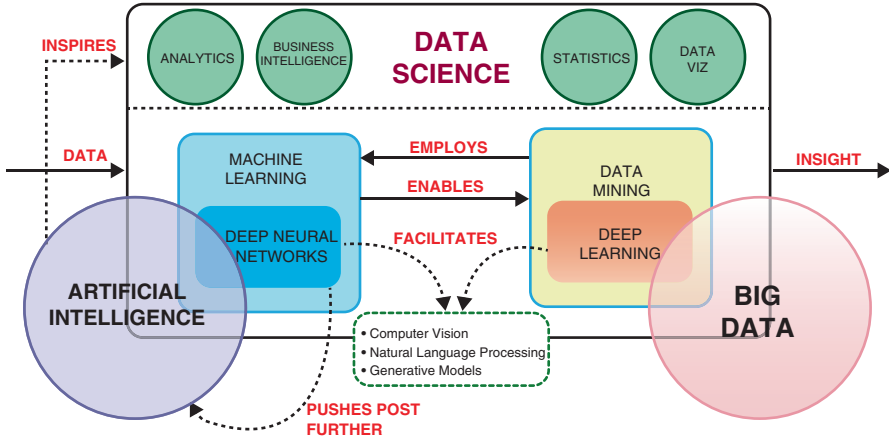


Fig. 2.4 Big data analytics model (Mayo 2017)

2.2.2 Industry 4.0 and the Internet of Things

Erboz (2017) introduces Industry 4.0 by listing some examples of the diverse technologies that belong to Industry 4.0:

- Mobile devices.
- Internet of Things (IoT) platforms.
- Location detection technologies.
- Advanced human–machine interfaces.
- Authentication and fraud detection.
- 3D printing.
- Smart sensors.
- Big data analytics and advanced algorithms.
- Multilevel customer interaction and customer profiling.
- Augmented reality/wearables.
- Fog, Edge, and Cloud computing.
- Data visualization and triggered “real-time” training.

Most of these technologies can be summarized into four major components:

- Cyber-physical systems.
- Internet of Things.
- Cloud computing.
- Cognitive computing.

For the purpose of this report, and for SCM at large, the development referred to as the *Internet of Things* (IoT) is the most relevant component of Industry 4.0. Ben-Daya et al. (2019) have reviewed the logistics literature on the IoT. They define IoT in the context of SCM as follows:

“The Internet of Things is a network of physical objects that are digitally connected to sense, monitor and interact within a company and between the company and its supply chain enabling agility, visibility, tracking and information sharing to facilitate timely planning, control and coordination of the supply chain processes.”

The IoT takes supply chain communications to another level: the possibility of human to things communication (“Hey Google...”) and autonomous communication among things while being stored in a facility or being transported between different supply chain entities. These new capabilities offer exciting opportunities to deal more effectively with SCM challenges through improved visibility, agility, and adaptability (Ellis et al. 2015). The data emitted by smart objects, when effectively collected, analyzed, and turned into useful information, can offer unprecedented visibility into all aspects of the supply chain, providing early warnings of situations that require remediation. Responding to these signals in time can create new levels of supply chain efficiency. What was lacking so far is not the availability of information but rather the technologies for collecting and processing big data and the time lag between data collection and action. IoT will allow the reduction in the time between data capture and decision making that enables supply chains to react to changes in real-time (Ellis et al. 2015).

Furthermore, according to Ferrell et al. (2019) IoT supports operational efficiency by providing information about networks and asset utilization. IoT can connect different parts of a supply chain, and thus can provide large amounts of information and data to facilitate detailed analysis. IoT can also be beneficial in last-mile delivery, which causes challenges for the logistics provider as consumer demands become more sophisticated and the number of delivery points continues to grow. IoT can connect the logistics provider with the end consumer by cost-effective solutions that provide value for the end customer and operational efficiency for the logistics provider. It can also help the LSPs with asset tracking, which gives companies a way to make better decisions and save time and money. Together, these benefits can also have the potential to facilitate horizontal collaboration through 4C concepts.

IoT will also enable remote management of supply chain operations, better coordination with partners and can provide more accurate information for more effective decision making, thereby strongly enabling 4C concepts.

2.2.3 Robotics and Artificial Intelligence

The Oxford Dictionary defines Artificial Intelligence (AI) as *the theory and development of computer systems that are able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision making, and translation between languages*. AI applications are appearing extremely fast and are expected to become ubiquitous very soon. This also has far-reaching consequences and opportunities for SCM.

DHL Trend Research (2019) confirms that AI is rapidly transforming the way LSPs operate as a result of the ongoing trend towards automation and continued

Table 2.2 Four main areas of AI applications in supply chains

<p><i>Back-office AI</i> presents a significant opportunity to streamline the internal functions of logistics corporations such as accounting, finance, human resources, and IT. Here, cognitive automation can be applied to critical logistics tasks such as ensuring the most updated customer addresses to bolster successful deliveries</p>	<p><i>Predictive logistics</i> can be enhanced by AI to shift the logistics industry from operating reactively with planning forecasts to proactive operations with predictive intelligence. An example is predictive demand planning using data from online shops and forums to predict unexpected volume spikes for trending products. LSPs and suppliers can then avoid costly overstocks or out-of-stock situations that result in lost sales for both the supplier and the consumer</p>
<p><i>Seeing, speaking, and thinking logistics assets</i> empowered by AI can greatly relieve the physical demands of modern logistics work. Applications include the use of AI-powered robotics solutions and AI-based computer vision systems which can augment much of today’s logistics operations such as material sorting, handling, and inspections</p>	<p><i>AI-powered customer experiences</i> can further personalize customer touch points, drive shipment volumes, and increase customer loyalty and retention. For example, the use of conversational AI interfaces (e.g., Amazon Alexa) can enable LSPs to streamline interactions and be more attuned to their customers’ needs and developments</p>

improvements in computing (see Table 2.2). AI will augment human expertise through systems that help generate novel insights from big data and eliminate difficult tasks for humans. In logistics AI will in the next years enable back-office automation, predictive operations, intelligent logistics assets, and new customer experience models. Performance, accessibility, and costs of AI continue to improve thanks to major advances in big data, algorithmic development, connectivity, cloud computing, and processing power. With AI, logistics networks can be orchestrated to an unparalleled degree of efficiency, redefining industry behaviors and practices. As such, AI will be instrumental to help 4Cs to process the enormous datasets that will become available once they go live on a large scale. All decisions that currently are made by humans (usually assisted by customized planning software) are now to be made in a single control center, see Sect. 2.3. It is expected that this will only be possible with the help of AI.

TNO (2020a) recently issued a position paper on the role of AI in logistics systems. They subdivide AI application in the categories “Sensing,” “Thinking,” and “Acting.” Then they discuss AI innovations such as traffic behavior, intelligent emission management, maintenance planning, and smart loading. The authors conclude that AI can contribute to the development of an integrated mobility and transport system that will strengthen the Dutch economy using new technologies.

Schniederjans et al. (2020) have also produced an overview of supply chain digitization trends, with special attention to AI. They analyzed that the external communication between human beings averages approximately 10 bits per second, whereas robots can communicate at rates over one gigabyte per second.

Facets like *machine learning* (ML) and artificial intelligence are further enhancing the use of robotics. ML is a subset of artificial intelligence where computers are given the ability to progressively improve their performance on a task with data but

without the need for explicit programming. However, individuals are still needed to optimize the use of these technologies for supply chain network performance. This confirms the need for effective organizational and business models around these technologies.

Although digitization developments including AI seek to automate learning and optimization in organizations, the proliferation of these technologies have not yet reached the more strategic areas of SCM, such as network design and cross supply chain orchestration. This makes it even more important to think about how 4Cs should be organized, staffed, and made scalable by leveraging AI and ML techniques. Once that is ensured, AI technologies will enable 4Cs to create efficiency levels that are completely unattainable for supply chains that are managed individually.

2.3 Optimization Capability

The fruits of the increased possibilities offered by the digitization progress in supply chains can only be reaped if the huge data that becomes available can be effectively translated into improved decision making. In other words, do we have the optimization potential in a 4C to work with the immense data coming from multiple individual supply chains with their own definitions, execution, contracts, legal obligations, etc.? This question is of course broad and has many aspects that can be discussed. To focus ourselves to the application of optimization capabilities in supply chain orchestration, we briefly discuss the following four subtopics: (1) Computing power, (2) Real-time optimization, (3) Digital twins and simulation, and (4) Optimization software developments.

2.3.1 Computing Power

The 4C concept assumes that multiple supply chains are coordinated and optimized as if they were a single supply chain, while still satisfying company-specific restrictions. Logically, this brings a great challenge to solve bigger and bigger optimization problems. Since most supply chain planning and optimization problems are NP-hard, the computation time to reach the global optimum increases exponentially with the problem size. Next to the possibility to use heuristics to strongly reduce calculation time through sacrificing some of the solution quality, fortunately there is also the development of powerful (cloud) computers that can solve bigger and bigger optimization problems within a given allowed calculation time. As Karaenke et al. (2019) put it, recent advances in optimization potential and computing power allow for more coordination and provide new and promising approaches to solve daunting orchestration problems in (retail) logistics and possibly other applications in SCM that have not been available only a few years ago.

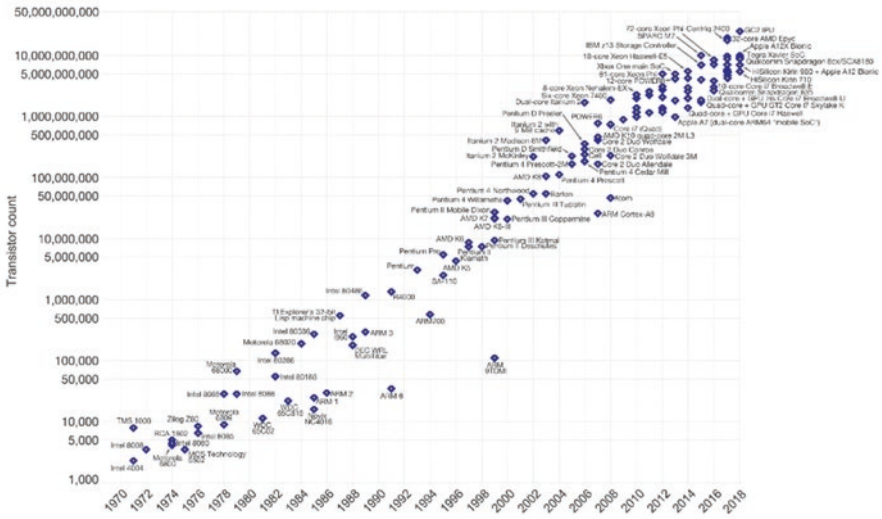


Fig. 2.5 Moore's law. Source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)

Basic optimization problems in operation research such as the Travelling Salesman Problem that were impossible to solve top optimality ten years ago are now solved in a matter of seconds or minutes. The driving force behind this is Moore's law (see Fig. 2.5) which states that computing power measured in the number of transistors on integrated circuit chips of the same size grows exponentially, roughly doubling every two years.

2.3.2 Real-Time Optimization

Until recently a lack of real-time information of logistics resources was common in the logistics industry (Liu et al. 2019). Historically, this resulted in increased logistics cost, energy consumption, logistics resources consumption, and low load factors. In the absence of real-time information, it is difficult to achieve efficient, high-quality, and sustainable logistics services, especially given the increasing logistics service requirements. To deal with such challenges, real-time dynamic optimization strategies for logistics optimization and coordination are proposed in literature and developed by commercial software houses. Using IoT enabled real-time status of vehicles and carriers a 4C can make optimal planning decisions combined with the actual status on the road, rail, or water. In addition, such real-time information can be shared with other stakeholders in the supply chain. There is ample evidence from literature (e.g., Liu et al. 2019) that including real-time information contributes to reduced logistics cost and fuel consumption, and improved vehicle utilization rates.

2.3.3 Digital Twins and Simulation

Giusti et al. (2019) define a digital twin as an information entity that mimics the features of a physical entity. These features concern the properties, state, evolution, and operations carried out by the physical entity. A recent review of digital twins and their applications is conducted by Tao et al. (2018). Historically used in industrial settings, digital twins can be applied to supply chains as well. This is especially important for 4Cs where combinations of supply chains are dynamic and cannot depend on historical knowledge like is common in traditional supply chain planning. For example, shipments can be represented by digital twins that provide up-to-date information on their state. Moreover, digital twins can be used for simulation purposes to test critical decisions, such as modal shift or bundling of shipments.

Simulation is a technology that uses offline systems to show the potential benefits of alternative solutions. It can be used in a model or digital twin of the real world and to then add or modify some characteristics in a safe testing environment. In this way it is possible to better understand the benefits of applying new concepts such as supply chain collaboration or to take more conscious operational decisions in the real world.

Digital twins are not quite common in logistics analysis yet. But there are some interesting initiatives in this field that are worth mentioning. The LEAD project sponsored by the EU (starting in 2020) will apply the digital twin concept in the area of urban logistics, which is a very suitable area given the many stakeholders and decision makers that all interact in a complex and small geographical area. A digital twin will be used to model the current and future behavior of an urban network in a variety of conditions and configurations, anticipate failures and optimal schedules for operation, and simulate possible policy effects. The digital twin evolves with the city by bringing together relevant data from a variety of sources and by receiving real-time city data through sensors (i.e., big data from urban platforms and real-time traffic data). Given the complexity of combining the planning of multiple supply chains together, also 4Cs provide a very suitable environment for making use of digital twins, especially for companies considering joining a 4C or not. Without the risk of making a drastic change to their current supply chain setup, a digital twin can help to test the risks and benefits of joining a 4C.

2.3.4 Optimization Software

A final optimization capability development that is useful to mention in the context of horizontal collaboration and 4C is the increased availability of dedicated software tools aimed at large scale supply chain optimization. Gansterer and Hartl (2018) mention that especially centralized entities (such as a 4C) typically face huge and complex optimization problems, since they must plan operations for several

individual, but interconnected fleets. Thus, sophisticated solution techniques are required. There is a vast field of problems and methods that have not been investigated so far from a collaborative perspective. In their directions for further research Gansterer and Hartl (2018) propose to investigate how a 4C exchanges requests among collaborators, while trying not to redistribute more than necessary. This would lead to a 2-objective problem, which minimizes (1) total cost and (2) the deviation from the decentralized solution. A related question is how the 4C can motivate participants to reveal their data. These incentives might be provided by using smart profit sharing mechanisms or, e.g. side payments. Finally, since central decision makers face huge optimization problems, the application of solution methods for large scale VRPs is supposed to further improve the success of supply chain orchestration. For this purpose, advanced processing methods like parallel computing should be considered.

Fortunately, also many powerful algorithms and tools from the commercial area and academia have become available in recent years. Figure 2.6 shows the typical subdivision of supply chain analytics tooling into four areas: descriptive analytics, diagnostics analytics, predictive analytics, and prescriptive analytics.

In each of these categories more and more (usually licensed) software tools become available. An overview from 2018 by Gartner can be found in Fig. 2.7. And looking at data science a bit broader than the pure supply chain optimization tooling, Fig. 2.8 shows a number of software categories that are supportive to supply chain optimization, i.e. programming languages, data platforms, deep learning, machine learning, data exploration, data ingestion, and general development tools. All these tools are valuable pieces of the data analytics jigsaw puzzle that comes

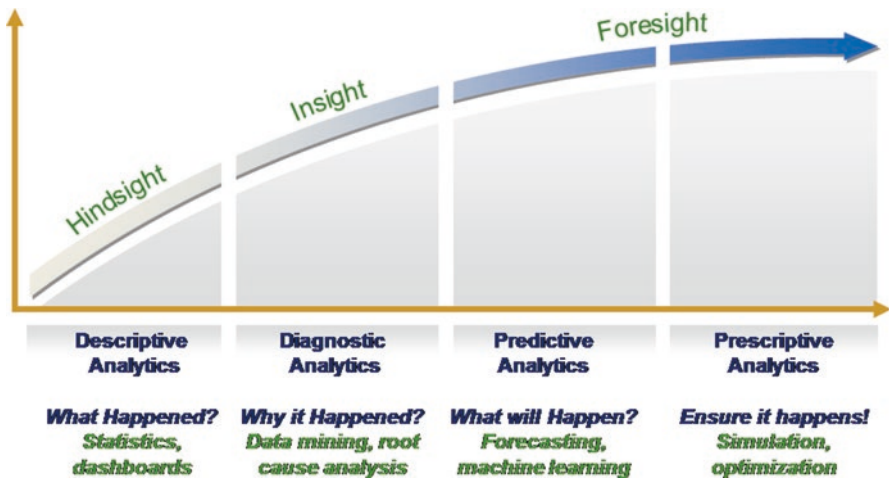


Fig. 2.6 The four areas of (supply chain) analytics

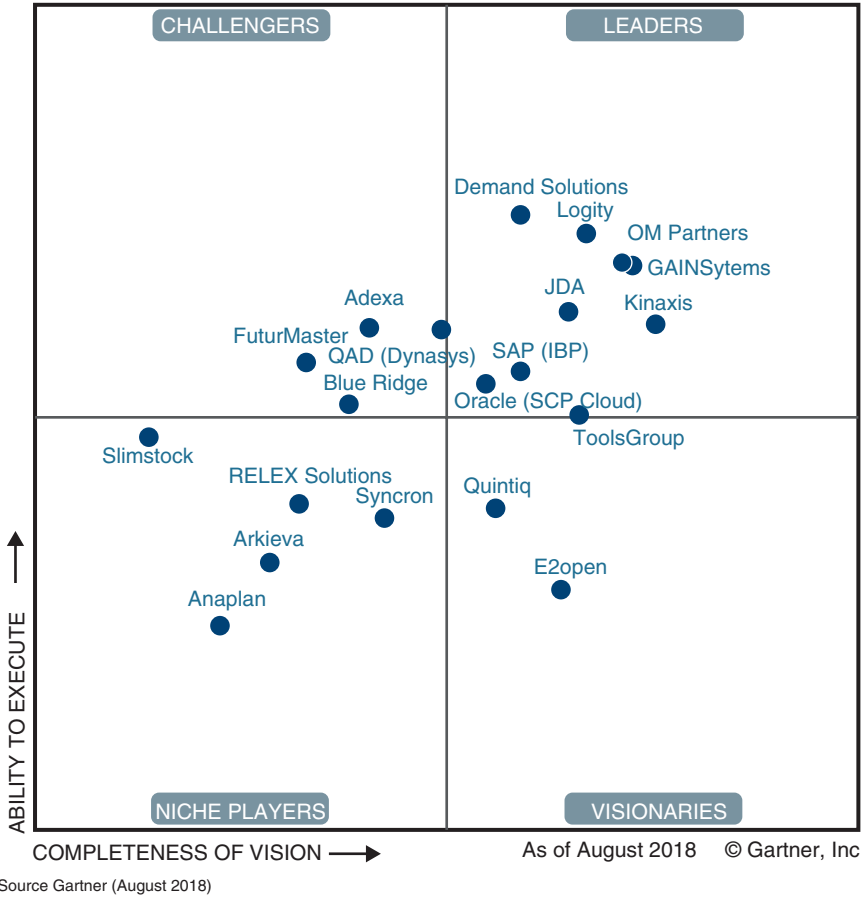


Fig. 2.7 Gartner supply chain optimization magic quadrant

with the 4C concept. In the Dutch 4C program these topics were covered by the projects ICCOS⁴ and Autonomous Logistics Miners⁵.

From a more academic perspective, Arunachalam et al. (2018) provide a comprehensive literature review on “big data analytics” in supply chains. Figure 2.9 shows how big data analytics developed out of pure statistical techniques on the wave of strongly increased availability of data. Figure 2.10 illustrates the importance of the topic of big data analytics in recent academic supply chain literature.

Based on this vast body of literature, the authors categorize the data analytics capability of companies or supply chains by enriching the descriptive, diagnostic,

⁴ See www.dinalog.nl/project/industry-4-0-driven-supply-chain-coordination-for-small-medium-sized-enterprises-iccoss/ (In Dutch)

⁵ See www.dinalog.nl/project/autonomous-logistics-miners-for-small-medium-businesses/ (In Dutch)

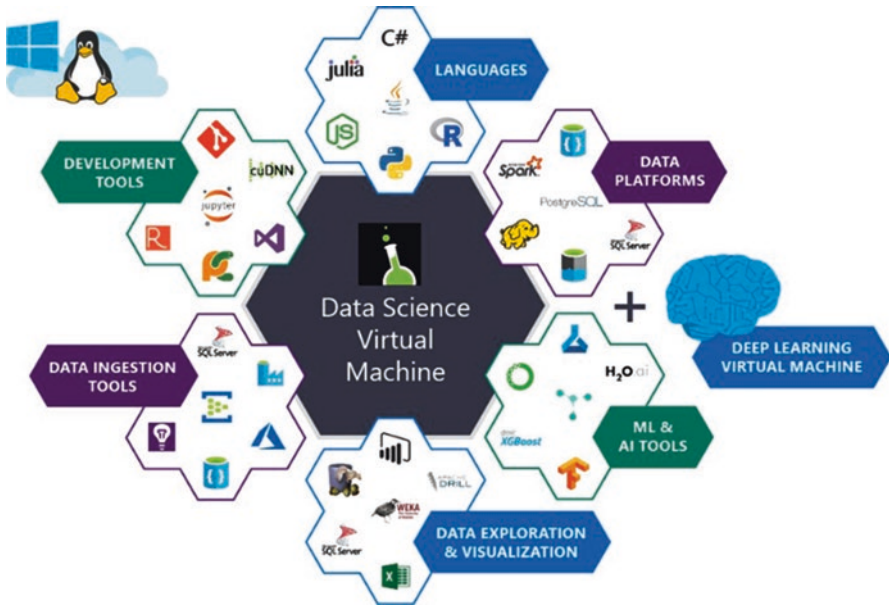


Fig. 2.8 The Data Science toolkit. Source: radacad.com/data-science-virtual-machine

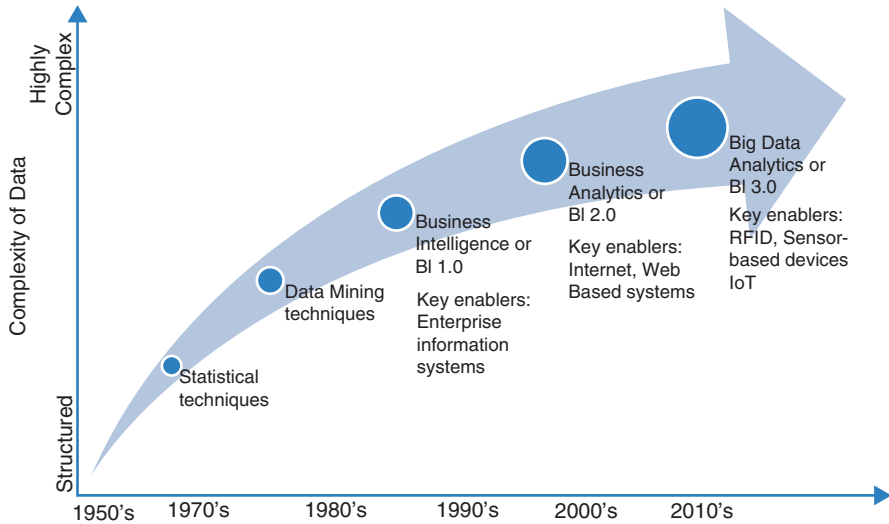


Fig. 2.9 Complexity of data over the last 70 years (Arunachalam et al. 2018)

predictive, and prescriptive categories with a dimension of how strongly these analytics capabilities are embedded in the organization. Using these two axes, companies can be positioned in the adoption stage, initiation stage, or the routinization stage, as can be seen from Fig. 2.11.

Search terms	SCOPUS	WoS
“Big Data” and “Supply chain”	104	65
“Big Data” and “logistics”	101	30
“Big Data” and “operations management”	15	8
“Big Data” and “operations performance”	1	1
“Big Data” and “operations research”	6	3
“Business Analytics” and “supply chain”	10	13
“Business Analytics” and “logistics”	6	4
“Business Analytics” and “operational performance”	2	2
“Business Analytics” and “operations management”	3	3
“Business Analytics” and “operations research”	4	5
“Business Intelligence” and “supply chain”	64	35
“Business Intelligence” and “logistics”	39	17
“Business Intelligence” and “operational performance”	7	4
“Business Intelligence” and “operations management”	3	3
“Business Intelligence” and “operations research”	6	3
“Business Intelligence” and “operational performance”	7	4
“Supply chain analytics”	8	4
“Supply chain” and “predictive analytics”	16	13

Fig. 2.10 Peer-reviewed papers on supply chain analytics and related topics between 2008 and 2016

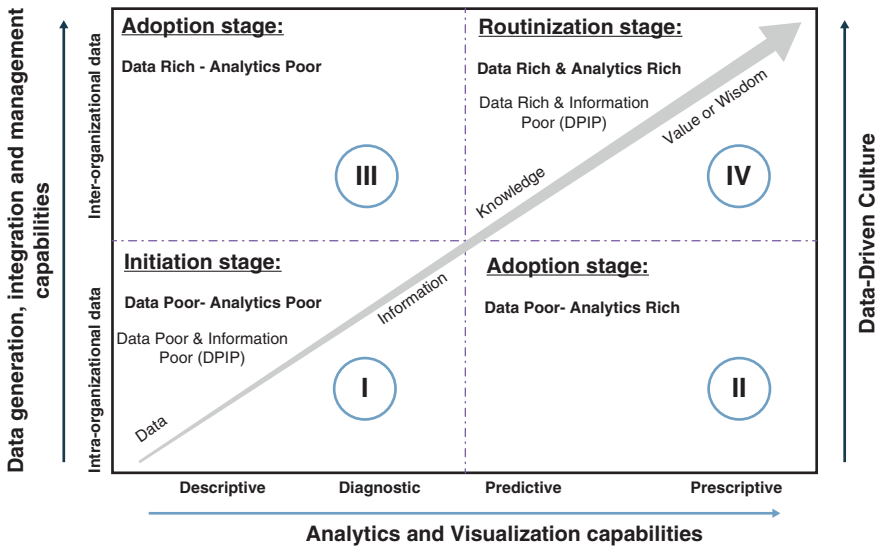


Fig. 2.11 Big Data Analytics capability framework for supply chains

2.4 Globalization, (Political) Instability, and the Corona Pandemic

A final general topic that impacts the applicability of supply chain collaboration and 4C are the international developments such as globalization, political instability, and the Corona pandemic.

Historically, the EU is the world's largest exporter and biggest trader in goods. Moreover, it is estimated that in the next 10–15 years, 90% of the world's growth will come from outside the EU (ALICE 2015), so the EU has every interest in making sure that its companies remain competitive and are able to access new markets and benefit from these sources of growth. Globalization entails joining global value chains and delivering products, services, and technologies that no individual country would be able to produce on its own. In this context, logistics is a key enabler for global trade.

Regarding globalizing trade, Veenstra and Zuidwijk⁶ note that the Dutch (and European) distribution logistics show a problem. The current logistics system is designed for very precisely planned delivery of stores, a tight utilization of truck capacity, and a strict regulation by (local) authorities. Such a setting does not lend itself very easily to scale up in a response to demand peaks. Especially in the last mile, trucks are already planned and to their full capacity, and the number of trucks is optimized to reach the most cost-effective distribution execution. But the Corona crisis brings forward the question whether this is really the best setup for logistics processes. It would probably be better to also prepare for abnormal circumstances and major disruptions. The Corona crisis might be a “Black Swan event,” but in recent years society and the logistics industry have been confronted with things like Brexit, international terrorism, natural disasters, climate change, etc. These phenomena and the countermeasures that are taken by governments and companies hugely impact supply chains. For individual companies it is almost impossible to prepare for such scenarios. Extensive collaboration through a 4C can bring a solution. In the Netherlands, for example, in the early phase of the Corona Crisis the logistics industry has already started redistributing logistics capacities between industries that see deep troughs in their volumes (for example, restaurant deliveries) to industries that see high peaks (for example, supermarket deliveries). This example shows how vital collaboration is in the dynamic world we live in.

This report is being written in the three months directly after the first confirmed Corona patient in Europe, late January 2020. With developments are still well underway, currently all layers of governments, from municipal to EU level, are imposing fierce regulations on citizens and companies as to how to behave to fight the pandemic. Obviously, this is necessary for public health, but it comes at a high cost for the economy and will have a big effect in the years to come. It is encouraging to see how firmly governments can act when faced with an eminent crisis, in this

⁶Dinalog Blog. <https://www.dinalog.nl/blog-albert-veenstra-en-rob-zuidwijk-logistiek-en-corona-virus/>

case the Corona virus. They take the leading role in combatting the crisis as it surpasses every other layer of decision making. Suddenly, active government intervention is not objected against as has been done in the mostly liberally oriented European governments, but instead there is an outcry for fierce government intervention. This rehabilitation of a strong and active government to fight company-, sector-, and even nation-surpassing challenges is a phenomenon that might be encouraging for other global challenges such as global warming and, in the context of this report, the impact of transport efficiency on sustainability. Once the worst part of the Corona pandemic will have died out, there will most likely be a new economic landscape and governments can guide their rebuilding programs by their firm sustainability ambitions. The pandemic was able to spread quickly partly because of massive long-distance travelling and long global supply chains. This might be reviewed once the pandemic is over. Adding to this, citizens will notice the “collateral benefits” of the Corona crisis such as cleaner air in metropolises, reduced CO₂ emissions, and higher working day efficiency in certain industries due to conference calling instead of daily commutes and business travel. In the end, the pandemic might show that there is a limit to economic growth under our contemporary circumstances, and we should focus more on making our current economic activities more efficient, rather than on increasing the size of our economies.