Transportation Research Part E 129 (2019) 1–11

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

The strategic role of logistics in the industry 4.0 era

Christopher S. Tang[a,*], Lucas P. Veelenturf[b]

[a] UCLA, United States
[b] Eindhoven University of Technology, the Netherlands

ARTICLE INFO

Keywords:
Industry 4.0
Additive manufacturing
Blockchain
Drones
Artificial intelligence
Logistics
Transportation

ABSTRACT

By leveraging new technologies (Additive Manufacturing, Advanced Robotics, Artificial Intelligence, Autonomous Vehicles, Blockchain, Drones, Internet of Things, etc.), many companies are developing cyber-physical systems that can change the competition landscape. In the midst of this exciting development, we examine the strategic role of logistics and transportation services for creating economic, environmental and social values. Also, we discuss some new research directions.

1. Introduction

Industry 4.0 is a term that originates from a German government project that promotes the computerized manufacturing in 2011. Industry 4.0 is also referred to as the "fourth industrial revolution" since the industrial revolution that took place in the 18th century. The first industrial revolution improved the productivity of the iron and textile industries by using steam power; and the second industrial revolution took place just before WWI and created reduced manufacturing cost by using electric power to create mass production. With the development of personal computers and the internet in the 1980s, the third industrial revolution transformed the economic landscape (Rifkin, 2011). After the term Industry 4.0 was revived in 2011 by the German economic development agency, the fourth industrial revolution builds on the third, leveraging emerging technologies (or Industry 4.0 technologies) such as Additive Manufacturing, Advanced Robotics, Artificial Intelligence, Autonomous Vehicles, Blockchain, Drones, Internet of Things, etc.

Unlike the previous three, Schwab (2016) argues that the fourth industrial revolution is fundamentally different because it leverages *connectivity* and *communication* among billions of devices. These emerging technologies along with voluminous real-time data will transform the manufacturing and service operations along a global supply chain, and change the interactions between humans (consumers and supply chain partners) and machines. Currently, many companies are exploring ways to create value by exploiting these Industry 4.0 technologies. According the McKinsey Global Institute, operations and equipment optimization in the factory setting can generate up to $3.7 Trillion of value by 2025 (Manyika et al., 2015). More recently, Frank et al. (2019) examine different economic and technological drivers for companies to adopt various Industry 4.0 technologies. Based on a survey of 92 manufacturing companies, they find that computerized (or smart) manufacturing is a key driver.

The notion of Industry 4.0 or the Fourth Industrial Revolution has kindled public interest. For instance, according to the data obtained from Google Trends, the number of google searches (worldwide) that contained the term "Industry 4.0" or "Fourth Industrial Revolution" began in 2012 and 2015; respectively, and the number of searches continued to increase as of March 2019 (Fig. 1). Most of the searches took place since 2016. It is interesting to note that most of the related queries are: "what is industry 4.0",

* Corresponding author.
E-mail address: chris.tang@anderson.ucla.edu (C.S. Tang).

https://doi.org/10.1016/j.tre.2019.06.004
Received 6 June 2019
Available online 01 July 2019

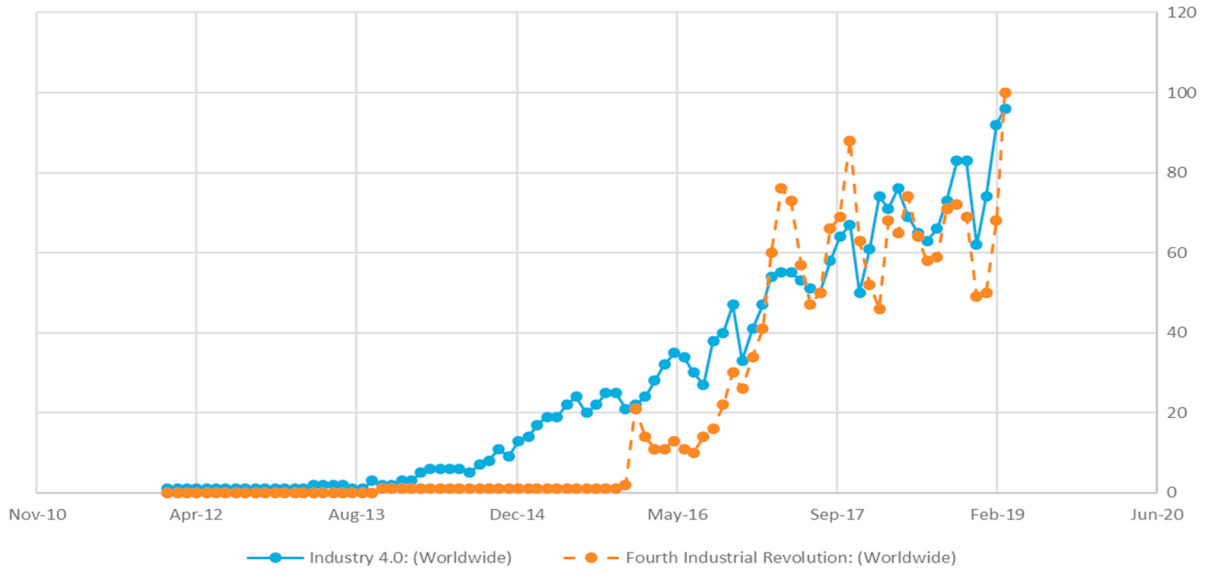

Fig. 1. Number of Google Searches conducted between January 2011 to March 2019 that contains the keywords "Industry 4.0" or "Fourth Industrial Revolution". The vertical scale is normalized to 100.

"internet of things," or "what is the fourth industrial revolution?" Based on these queries, it appears that Industry 4.0 is a relatively new topic that deserves a better understanding. Currently, consulting firms such as IBM, McKinsey, and Deloitte are issuing different reports to explain the term Industry 4.0 and its impact (Zhang, 2017; Baur and Wee, 2015; and Deloitte Insights, 2018).

We also searched through Scopus citation database by using the keywords "Industry 4.0" or "Fourth Industrial Revolution" that appear in the title, abstract, or keywords of academic articles published between 2012 and 2018. As shown in Fig. 2, there were 2320 published articles that contain the keywords "Industry 4.0" (and 329 articles that contain the keyword "Fourth Industrial Revolution"). Also, most of the research articles that contain the keywords "Industry 4.0" appeared in engineering journals (25%), computer science journals (11%) and business journals (8%). We obtain a similar result for those articles that contain the keywords "Fourth Industrial Revolution".

In summary, Figs. 1 and 2 reveal that Industry 4.0 is an emerging topic and the research in this area is nascent. Hence, there is a golden opportunity for the operations management (OM) research community to understand the implications of this new revolution, to identity novel research questions, and to examine the conditions under which these emerging technologies can create economic, environmental, and/or social value.

1.1. A brief description of technologies associated with Industry 4.0

We now provide a brief description of different technologies associated with Industry 4.0. The reader is referred to Berman (2012) for a detailed description about 3D printing, Babich and Hilary (2019) for an extensive discussion about the strengths and weaknesses of Blockchain, and Olsen and Tomlin (2019) for more discussion on other technologies.

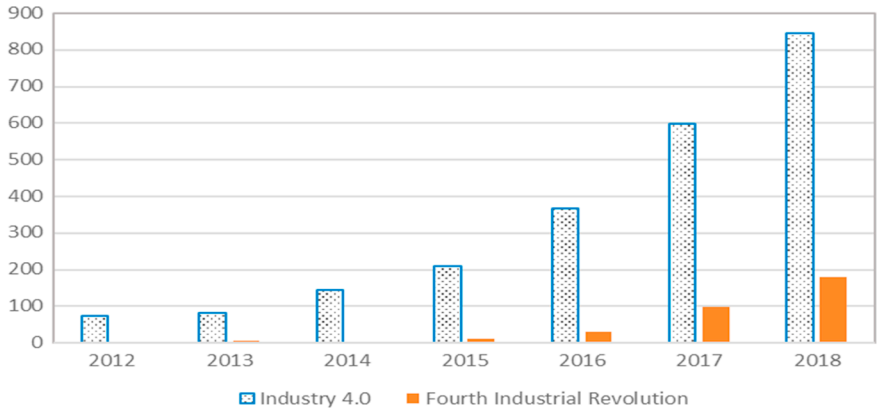

Fig. 2. Number of academic articles published between 2012 and 2018 that contains the keywords "Industry 4.0" or "Fourth Industrial Revolution".

- **Additive manufacturing (also known as 3D printing).** This is a technology that uses a digital 3D representation of an object and produces the physical object by depositing layers of materials (plastic, resin, stainless steel, ceramics, etc.). Additive manufacturing can enable firms to develop prototypes (product prototypes) and personalized products (hearing aids, knee replacements, and even toys) faster, cheaper and better (Berman, 2012; Sodhi and Tang, 2017). In the context of spare parts, Song and Zhang (2018) find that additive manufacturing creates more value to the firm as the number of parts increases. For the design of components, Westerweel et al. (2018) found that the higher design cost of additive manufacturing can be overcome with reduced logistical cost and reduced lead-time. From the strategic perspective, Dong et al. (2018) show that a firm that adopts additive manufacturing will offer more product variety to compete. Motivated by RepRap, a company that produces 3D printers that can *replicate themselves*, Hu and Sun (2019) study the tradeoff between production and sales of these self-replicable 3D printers. The reader is referred to Rogers et al. (2016) for a comprehensive discussion of different research questions arising from 3D printing services. More recently, Hedenstierna et al. (2019) examine the role of 3D printing in the context of outsourcing.
- **Advanced robotics.** The advancements of the communication technologies, sensor capabilities, and artificial intelligence are making robots smarter so that they can work safely alongside human workers. For example, BMW has robots and human workers work alongside on its assembly line in its plant in South Carolina. Also, wearable robotics with exoskeletons can aid human workers to reduce repeated motion injuries due to lifting heavy boxes in the warehouse or harvesting fruits in the field. Companies such as Caterpillar and GE are exploring the adoption of wearable robotics to improve worker safety. JD.com, the largest online retailer in China, has adopted various advanced robots to stack products on shelves and pack merchandise in 500 warehouses (Marr, 2018). By 2019, JD.com implemented the world's first automated warehouse in Shanghai equipped with Mujin robots (Hornyak, 2019).
- **Drones.** Drones are unmanned aerial vehicles that can be controlled remotely. These drones can carry different sensors to record data (visual and audio) for monitoring and surveying operations, to carry certain devices including robotic arms for pick up and drop off operations, or automated sprays for farming operations. Drones can be viewed as an element of the internet of things. More recently, drones have been used for search and rescue operations.
- **Internet of Things (IoT).** The internet of things refers to a system of devices (e.g., sensors) that can communicate and interact with others over the internet, and this system can be remotely monitored and controlled. With drastic reduction in cost and increase in processing speed for these sensors and significant improvements in measurement and communication technologies, the adoption rate of internet of things is growing exponentially in recent years. Columbus (2018) reported that, by 2020, Discrete Manufacturing, Transportation & Logistics and Utilities industries are projected to spend $40B each on IoT platforms, systems, and services.
- **Blockchain.** A Blockchain is a distributed and secure ledger. As articulated by Olsen and Tomlin (2019), it is distributed because it can be written and accessed by different (possibly authorized) entities and its data is stored on a peer-to-peer network. Also, it is secure because once a "block" has been added to the chain (i.e., information written by an entity), it cannot be altered unilaterally. Despite these promises, Babich and Hilary (2019) identified several weaknesses of blockchain ranging from lack of privacy, garbage-in-garbage-out, inefficient, etc. Wang et al. (2019) conducted in-depth interviews with 14 supply chain experts to explore how blockchain technology may transform supply chain operations in the future.
- **Artificial Intelligence (AI).** In contrast to the "natural intelligence" possessed by humans, AI mimics natural intelligence using computers to interpret external data, to learn from such data, and use those learnings to conduct descriptive, predictive, or prescriptive analysis. For example, IBM Watson is an AI system that is capable of answering questions posed in natural language. Also, GE uses sensors to collect data from its gas turbines or windmills via its Predix Cloud (an online platform), and then use machine learning and deep learning algorithms to conduct preventive maintenance before a breakdown.

As the above technologies are being developing, many firms are exploring different ways to exploit these exciting Industry 4.0 technologies. At the same time, OM researchers are establishing different research agendas.

1.2. Logistics: a diamond in the rough

Within the context of Industry 4.0, OM research has been focusing on the manufacturing applications of these exciting technologies (Olsen and Tomlin, 2019). This trend is understandable because the term Industry 4.0 was originally intended to promote the computerization of manufacturing by the German government since 2011. The manufacturing focus is reflected from a recent survey of 1600 C-level executives across 19 countries conducted by Deloitte: 73% of the respondents reported that they are currently developing Industry 4.0 based technology initiatives that focus on improving operations (mostly in manufacturing), and yet only 6% focus on logistics (Deloitte Insights, 2018). This observation implies that many firms undervalue of the strategic role of the logistics function as a competitive lever or as a business model[1].

The minor role that logistics plays in the mind of company executives motivated us to examine the strategic role of logistics in the Industry 4.0 era in this paper. Specifically, we shall argue how companies can leverage Industry 4.0 technologies to create economic,

[1] Besides the fact that logistics originated from military operations, we define logistics more "broadly" and it includes transportation of humans and goods. Specifically, in our view, the logistics function deals with the detailed coordination of a complex operation involving human, materials, equipment, information and finance. In many instances, this coordination entails the movements of materials, humans, and/or equipment, the exchanges of information among humans and or devices, and the transactions of finance among entities.

environmental and social value by transforming the logistics function as:

1. A competitive lever;
2. A social value creator; and
3. An enabler for sustainability.

In the remaining of this paper, we use some real examples to illustrate how different Industry 4.0 technologies can enable a firm, a government, or an NGO to do good and do well at the same time. Also, we pose some research questions for OM researchers to explore further.

2. Logistics service as a competitive lever

Despite logistics is an important function that gets the right product to the right customer at the right time, many executives tend to view logistics as a *cost* to be managed and often overlook the fact that logistics can cause a company to make or break. Consider the downfall of Blockbuster in 2010. Being the world's largest video rental company in 2004 with over 9000 stores world-wide, Blockbuster allowed each customer to rent a video from a store for a fixed fee, but the customer must return the video tape or DVD back to the same store within a 2-day time window (to avoid penalty). As the *de facto* monopoly, customers tolerated this business model even when they have to pay the penalty for being later or for returning the video to a different store. However, when Netflix came along in the late 90 s and allowed each customer to return his DVD in a pre-paid postage envelope at their own convenience and to receive the next DVD in his queue automatically by mail afterwards, Blockbuster lost the patronage and filed for bankruptcy in 2010. This example highlights the importance of the logistics function from the customer perspective. Another case in point, the demise of online grocery store Webvan and online furniture store furniture.com was partly due to poor logistics performance: customers complained about late deliveries and missing items, and the firm faced high "last mile" delivery cost.

The above examples suggest that, to compete successfully in the retail sector, logistics is key. This may explain why largest online retailers such as Amazon and Alibaba's Tmall invest heavily in logistics. To compete in the e-tailing sector, fast (and even free) and reliable delivery services become a competitive lever for an online store to differentiate itself from other online stores selling similar products at similar prices. By leveraging Amazon's Whole Foods stores[2], Amazon offers 2-hour home grocery delivery services (Amazon Prime Now) to its prime members at selected locations in the United States. Also, instead of relying on UPS and FedEx, Amazon created "Amazon Logistics" delivery service in 2018 to gain better control of the last mile delivery performance (speed, reliability, and cost). In 2018, the company's fulfillment and shipping expenses amounted to $34.0 billion and $27.7 billion respectively, up from just over $1 billion each in 2007. The total logistics cost $61.7 billon accounts for 27.5% of its net revenue (Richter, 2019). Buchman (2018) reported that Amazon operates 258 distribution and fulfillment centers in the United States and additional 486 such centers around the world by using thousands of trucks and 32 Boeing 767 aircraft. In China, to compete in online retailing, Alibaba took majority ownership of its subsidiary logistics unit Cainiao[3] in 2017, and pledged to invest $15 billion over five years to build out a global logistics network.

Based on the recent focus of Amazon and Alibaba on logistics, it is evident that logistics should not be viewed as a cost center. Instead, logistics service is a weapon that enables firms to compete on speed, reliability and cost. The advent of new technologies can affect the logistics function in several fundamental ways:

1. **Faster Speed: delivery services conducted by drones or delivery robots.** To speed up the delivery service, Amazon is exploring the use of drones for delivering small packages. In China, Alibaba's food delivery unit Ele.me[4] started delivering foods by drones in 2018 on 17 different routes from over 100 local restaurants in Shanghai's Jinshan Industrial Park covering an area of 58 square kilometers (Tao and Yang, 2018). In 2019, Google got approval to use its Wing drones for home deliveries in Australia. In the meantime, researchers started to focus on the required operational models to route the drones to different customer (e.g. Carlsson and Song (2018), Agatz et al. (2018)). Also on the ground, unmanned vehicles are tested for faster deliveries, like the delivery robots of Domino's pizza. To speed things up even further, Amazon filed a patent called "anticipatory shipping" in 2014. The key idea is to use predictive analytic tools to analyze a customer's shopping history along with other customers' shopping history to predict what she may need. In theory, anticipatory shipping would enable Amazon to ship products (possibly by drones) to consumers even "before" they even order them (Kopalle, 2014).
2. **Higher Reliability: storage and retrieval systems using robots**. To automate the storage and retrieval operations at Amazon's fulfillment centers, Amazon spent $775 million in 2012 to acquire Kiva robotic system. The Kiva system improves productivity by

[2] Amazon acquired Whole Foods for $13.7 billion in 2017 so that it can expand its home grocery deliver service Amazon Fresh in selected locations within the United States.

[3] Cainiao Logistics is an internet technology company that specializes in "platform services" for logistics networks. It offers logistics services to different vendors who sell products on Alibaba's Tmall by using an online platform to coordinate the logistics functions provided by different delivery service providers.

[4] Ele.me is an online platform that offers online food delivery service by coordinating customers, restaurants, and meal delivery service providers in China. It was acquired by Alibaba in 2018.

recording and tracking items within the fulfillment center and by bringing the products directly to employees to pick, pack, and ship. These systems require careful design choices and operating strategies, for example Roy et al. (2019) analyzes the effects of different robot storage zone assignment and queue allocation strategies. The development of robotics exoskeletons (as wearable robotics along with sensors) can help the employees to improve the speed and reliability of their pick and pack operations and reduce repeated motion injury at the workplace (Ashley, 2017).

3. **Lower Operating Cost: inventory monitor and replenishment systems using smart sensors.** In physical stores, real time information about inventory on the shelves is often inaccurate and costly to obtain (DeHoratius et al. 2008). The reduction in cost and the improvement in capability of different sensors offer a new opportunity for stores to develop "smart shelves" using weight sensors that can monitor the existing quantity of items on the shelves, notify stock room staff to refill inventory before the item gets depleted from the shelf, and inform warehouse or vendor for immediate replenishment. Besides smart shelves, start-up company Wasteless.co is running different pilots with supermarket chains (e.g. with Ahold-Delhaize) using electronic tags to implement dynamic pricing. In the shelves of fresh products (e.g., meat, cheese, etc.), different items of the same product may have different expiration dates, and savvy customers will purchase the freshest item that has the longest expiration date. The new price tags of Wasteless show different prices depending on the expiration date: items with a short expiration date is sold at a discount defined by a smart algorithm considering multiple factors like weather (on a rainy day almost expired BBQ meat needs more discount than on a sunny day). Some pilot runs conducted in Italy suggest a reduction of 89% in food waste, according to Wasteless (Pieters, 2019). In a related development, AWM Smart Shelf offers additional value beyond logistics: it uses cameras mounted on its smart shelves to gather data on shopper behavior and demographics. By using various Artificial Intelligence tools to analyze a massive data, AWM can develop personalized videos to display on its smart shelves according to age, gender, or ethnicity (Horowitz, 2019). One step further, the inventory of a final end consumer in its house can also be measured. Think of Samsung's smart fridges with cameras with which the owners get full information about inventory, expiration dates etc. Finally, with real time inventory information at different warehouses, an online retailer can make real time decisions about product price and the warehouse from which an incoming order is filled (Lei et al., 2018).
4. **Improve Efficiency: Container shipping enabled by blockchain.** Because ocean freight operations involve many organizations (exporters, terminal operators, trucking companies, customs officers, freight forwarders, ocean carriers, insurance companies, banks, importers, etc.) and lots of paper work (bill of lading, invoice, certificate of origin, freight shipping forms, inspection certificate, export packing list, insurance certificate, etc.) and because many processes are done manually, long and uncertain delays are commonly observed. Djankov et al. (2010) reported that the average export time in Asia is 25 days with a standard deviation of 12 days. When in early 2019 container ship MSC Zoe lost containers in front of the Dutch and German coast it took them weeks before the exact number (more than 340) of lost containers was known. To improve the efficiency of this archaic process of a $200 billion ocean freight industry, IBM and Maersk (the largest container carrier in the world) formed a partnership in 2017 to develop a blockchain platform to automate the process so that documents for shipping containers can be digitalized and containers can be tracked. By leveraging the distributed and secure capability of blockchain technology, all updated information and documentation can be verified and reconciled by all involved parties without duplication errors, and more importantly, without delay (Groenfeldt, 2017). In April 2019, China Shipbuilding Industry Company Limited (CSICL), a subsidiary of shipping giant China Shipbuilding Industry Corporation, signed an agreement with Shanghai Bank, under which it will explore the use of blockchain technology to financing its upstream suppliers. Besides ocean freight, Choi et al. (2019) examine the potential benefits of using blockchain technology on implementing the mean–variance (MV) theory for risk analysis in the context of air logistics.

As these Industry 4.0 technologies are helping firms to transform their logistics functions as competitive weapons instead of cost centers, we propose a few research questions for further studies.

1. How should a firm redesign its supply chain structure to align with the transformed logistics services in the Industry 4.0 era?
2. How would these emerging technologies affect the way supply chain partners communicate, coordinate and collaborate? For example, should a retailer (customer) share its smart shelf (fridge) data with vendors so that vendors can offer "anticipatory replenishment" services?
3. How would 3D-printing affect the logistics industry? For instance, instead of purchasing a physical product (e.g., a toy), customers can download a digital file and print the product at home, by passing the entire physical supply chain (except for the transport of the raw materials).
4. Will the economic value created by blockchain outweigh its implementation cost? For example, Will the economic benefit created by the operational efficiency in container shipping through blockchain far exceed its implementation cost?
5. What is the impact of advanced robotics on job design of human workers? Will advanced robotics become a complement or substitute of a human worker?
6. How would drones and robots take over the home deliveries? Will there be drones and delivery robots everywhere? How to organize and regulate these unmanned delivery services without crating chaos?

3. Logistics as a social value creator

Besides transforming the logistics arm of a firm into a competitive weapon, various emerging technologies can improve the

logistics operations by creating social value. Consider the challenges that the World Food Program[5] (WFP) faces when distributing food and cash to refugees in war-torn countries or beneficiaries in disaster zones. Putting aside the challenges of getting the supplies, the distribution of food and cash is even more challenging because the distribution infrastructure is usually non-existent and the information record about legitimate recipients is either incomplete or inaccurate. Consequently, fraudulent claims are common and many legitimate recipients end up not getting the aid. With the advancements of blockchain technology, WFP worked with Parity Technologies, a startup led by ethereum co-founder Gavin Wood to develop a blockchain platform called "World Food Programme Building Blocks" in 2017 that uses a distributed ledger to record the iris image of each refugee[6]. In doing so, the authentication process is only a simple iris scan that is efficient and accurate. This way, each legitimate refugee in Jordan can get their rationed food supply, and even cash for women who participate in the UN Women's Cash for Work Programme in Jordan (Judkslian, 2018). We now provide a few examples in this section and conclude with a few research questions.

1. **Faster and safer response and recovery operations using drones.** After a natural disaster such as hurricane or forest fire, the traditional use of helicopters for response and recovery mission can be costly and even dangerous for the responders when the mission takes place at difficult terrain and at night. For example, one week after the landfall of Hurricane Harvey in 2017, FAA (Federal Aviation Administration) authorized 43 small drones to fly below 400 feet and away from large crowds of people to enable local authorities, and local transportation and utility companies to assess damage to homes, roads, bridges, power lines, etc. Also, Allstate insurance deployed drones to collect visual images of homes and send footage to Allstate's claim adjusters so that they can evaluate different insurance claims (Marshall, 2017). In the same vein, search and rescue missions along rivers and coastlines are labor and resource intensive and inefficient. By using a drone equipped with a heat-sensitive infrared camera, it can quickly search a given search area and scan for images that fits the outline of a human being. In doing so, rescue forces can be sent directly to the exact location to perform the rescue function. Finally, on smaller scale accidents, drones can be life savers. In several countries such as US and the Netherland, some cities are equipped with automated external defibrillator (AED) drones that can be dispatched quickly to save patients who suffer from sudden heart attacks.
2. **Improve accessibility to diagnostic care and drug administration by using wearable medical devices.** In rural areas of many developing countries, the access of diagnostic care and pharmacy services is limited for two key reasons: (a) rural clinics are either not available or over-crowded; or (b) rural clinics are perceived as low quality. Quite often, many rural patients travel long distance to seek health services in cities. With the advancements of different wearable medical devices, patients can share their medical data with their online doctors via telemedicine. A wearable medical device can be defined as a biosensor that collects physiological data (heart rate, body temperature, blood pressure, blood oxygen, glucose level, etc.) in real time. For example, Apple Watch Series 2 can monitor most data, Dexcom G6 is a continuous glucose wearable device that can sync its data with iOS and Android smart devices. With wearable medical devices that can sync with various smart devices, many Chinese patients are sharing their medical data with their online doctors via various telemedicine platforms that are more accessible and affordable (Liu, 2018). Besides monitoring various physiological data of a user, Covestgro (formerly Bayer MaterialSience LLC) launched a new wearable medical device Makroblend M525 in 2015 that can monitor vital signs during physical activity or administer drugs. Backed by Sanofi, Enable Injections is developing a wearable device that can deliver IV drugs that may connect to smartphones via Bluetooth (Muoio, 2018).
3. **Improve farmer productivity by using drones and smart sensors.** As the world population continues to grow and as the size of arable land continues to shrink, there is a need to develop ways to improve farmer productivity for growing more food in a cost-effective and time-efficient manner. This need has motivated some startup companies to create innovative business services in agriculture (also known as Agriculture 4.0) by developing drones with special sensors and cameras that can interact with smartphones and computers. In France, a startup company Delair-Tech is developing a drone that can enable farmers to monitor crops for diseases, assess yield and identity where fertilizer is needed as in "precision farming". This service is based on a subscription, and the Economist reported that it plans to charge 15 Euros per hectare.
4. **Improve provenance by using blockchain.** After a series of food and drug adulteration incidents (milk formula scandal in China, Heparin adulterated with melamine, counterfeit drugs) in recent years (Babich and Tang, 2012) many companies are under pressure to disclose provenance information about names of suppliers, materials used and produced by suppliers, etc. The logistics for identifying, monitoring and tracking the operations along a supply chain is very costly and time consuming. For this reason, many firms are using blockchain technology to track the provenance of products such as fish, pork, coffee, etc. Also, Walmart and nine other firms (Nestle, Dole, Tyson Foods, Unilever, etc.) partnered with IBM to use blockchain to track and trace provenance so that they can improve food safety and be more responsive to food recalls. Besides food, Luxury brand conglomerate LVMH, launched a blockchain platform in 2019 to track provenance so that it can authenticate certain luxury goods (Allison, 2019).
5. **Improve mobility via smart transportation.** The underlying challenges for the poor, the sick, and the elderly to get around result in "social exclusion". Therefore, to improve social inclusion, easy access to affordable mobility is essential. With the advent of Internet of Things and the massive adoption of smartphones, Mobility as a Service (MaaS) initiatives are popping up at many cities with Helsinki in Finland as the leading example (Goodall et al. 2017). The underlying concept of MaaS is to provide all mobility options, which include public (trains, busses, etc.) and private (taxi, Uber, car/bike sharing) services as an "integrated"

[5] The World Food Program is the food-assistance branch of the United Nations. It is the world's largest humanitarian organization addressing hunger and promoting food security by providing food assistance to over 90 million people in over 80 countries in each year.

[6] This biometric data (e.g., iris image) is based on the refugee registration data collected by the UN Refugee Agency.

service provided by a single app (e.g., Whim in Helsinki). This app offers travel suggestions to customers based on their personal travel preferences in terms of modes, costs and travel time. Once a customer selected a multi-modal travel plan, he can pay for this travel plan via mobile payment through this app. As different cities are developing different MaaS app, there is hope that these apps can offer accessible and affordable mobility options to city dwellers[7].

6. Currently, many firms are developing autonomous cars/taxis for transporting people; however, due to safety concerns, it will still take a long time before autonomous cars are able to drive everywhere under all circumstances (especially the interaction with bikers and pedestrians and severe weather conditions are challenging). However, autonomous buses on dedicated lanes are already employed and NEXT Future Transportation Inc.[8] is even testing autonomous vehicles in Dubai where people can transfer inside from one vehicle to another vehicle. It has the potential to make the cost of mobility even lower to improve affordable and accessible. There is an on-going research stream that examines the impact of the implementation of autonomous vehicles on the movement of people (e.g., Gkartzonikas and Gkritza, 2019; Olsen and Parker, 2019).
7. Finally, in the Industry 4.0 era, traditional public transportation systems such as railways are going through different transformations. For example, in the Netherlands, Netherlands Railways is using smart sensors to monitor the weights of different railcars and to predict the future capacity (sitting and standing) of each railcar before the train arrives at the next station. Then Netherlands Railways can use its mobile app to notify passengers waiting on the platform at the next station about available space on different railcars. This real time information can lead to faster dwell times, fewer delays, and better customer service quality. To shorten dwell times and reduce unnecessary delays even further, Netherlands Railways has equipped all conductors with smart watches informing them the exact second at which the train should depart.
8. In the grand scheme of things, Industry 4.0 technologies enable a smart city to create new social values derived from the interconnectivity of smart buildings, smart grid, smart mobility and smart retail. Qi and Shen (2019) discuss several research opportunities arising from the increasing integration of smart systems and business models at the urban scale.

The above examples illustrate how Industry 4.0 technologies can create social value. At the same time, it raises several research questions.

1. By leveraging the data collected by different wearable medical devices, how should the government (or an insurance company) develop incentive mechanisms to encourage users to improve their health conditions?
2. Precision farming based on drones can certainly provide value to farmers. However, to monetize this type of service when farmers are unsure about its value, how should a service provider determine its pricing strategies? Should it be subscription based? Should the firm consider a risk-sharing pricing strategy?
3. As different firms form partnership using blockchain technology to track and trace the operations along the supply chain, there is a concern about privacy. How can this issue be dealt with? To ensure that the virtual copy corresponds to the physical copy of the supply chain operations, who should audit the records and how often should the record be audited?
4. Mobility as a Service requires synchronization between many stakeholders (municipalities, transportation operators, data providers etc.) and the passengers. Which pricing mechanism should one use to coordinate supply and demand? How to organize monthly mobility subscriptions with a fixed/unlimited amount of miles per month? How to share the profit amongst different transportation operators?

4. Logistics as a sustainability enabler

Besides economic and social values, there is a rising concern about “sustainability” and a clarion call for renewable energy, carbon footprint reduction, endanger species protection, and ecosystem sustainability. This concern is legitimate because the growing demand generated from the world’s growing and ageing population (from 7 billion in 2017 to over 9 billion by 2050) far exceeds the shrinking supply of natural resources (arable land, natural water sources, oil and gas, etc.)[9]. This concern has caused the public to become more aware about environmental issues (e.g., climate change, deforestation, and water and air pollution) and social issues (e.g., poverty, hunger, income inequality, gender equity, population growth) over the last two decades, and this public concern is also reflected in the Millennium Development Goals (United Nation 2000)[10]. For example, by analyzing global data on fisheries and ocean temperature maps between 1930 and 2010, scientists from Rutgers University in New Jersey discover that global warming has significantly affected fish stocks worldwide by 4% (Gerretsen, 2019). To make things worse, the ecosystem is damaged even further as fishing trawlers are catching all sea foods by pulling huge fishing nets along the bottom of the sea or in midwater at a specified

[7] In many cities buses are still operated with fixed timetables and routes. With GPS in each bus and widespread adaptation of smart phones, this can be organized (especially outside peak hours) in a more flexible way, similar as the ride sharing systems (e.g. Quadrifoglio et al., 2006, 2008 and Qui et al., 2015), resulting in more people taking the bus and less empty mileage outside rush-hours.

[8] https://www.next-future-mobility.com/.

[9] In 2012, WWF reported that human “used the equivalence of 1.5 planets to support their activities.” http://wwf.panda.org/about_our_earth/all_publications/living_planet_report_timeline/lpr_2012/demands_on_our_planet/.

[10] In 2000, all United Nations members declared their commitments to help achieve the following eight Millennium Development Goals by 2015: (1) Eradicate extreme poverty and hunger; (2) Achieve universal primary education; (3) Promote gender equality and empower women; (4) Reduce child mortality; (5) Improve maternal health; (6) Combat HIV/AIDS and other diseases; (7) Ensure environmental sustainability; and (8) Develop a global partnership for development.

depth in West Africa (Adams, 2019). Without immediate interventions and strict law enforcements around the world, the planet's ecosystem is collapsing at an alarming rate. As the supply of natural resource is shrinking quickly, many firms are concerned about sustainable supply of raw materials in developing countries (e.g., coffee beans, cocoa beans, etc.) for their production. Currently, firms and governments are exploring ways to apply different emerging technologies to address some of the sustainability issues.

1. Protect endangered species from extinction by using drones and AI. Across Africa and Asia, illegal trades of endangered species that worth $7 to $10 billion annually are threatening the survivals of elephants, rhinoceros, tigers, etc. Just between 2007 and 2017, over 7245 African Rhinos have been lost to poaching and they will be extinct without immediate human interventions. Over the last decade, many organizations such as World Wildlife Fund (WWF) and Save the Rhino collected donations and contributed funds to recruit more rangers to safe guard these Rhinos. However, this approach is very costly and inefficient. Currently, scientists are developing innovative methods to save these animals. First, through direct observations obtained from various recording from drones, scientists from IBM learned that Zebras normally move along-side Rhinos. When facing a predator (e.g., a lion), a herd of zebra will scatter. However, when encountering a poacher with a gun, these animals will move in opposite direction. Anticipating this behavior, these scientists put radio collars on zebras so that they can monitor the location and movement of these zebras. This way, they can alert the rangers when the zebras move in opposite direction to reduce poaching. Second, by using machine learning and deep learning to analyze historical data on poaching incidents, computer scientists can predict when and where Rhinos were likely to be poached so that rangers and drones can patrol these target areas to prevent poaching. In 2012, Google offered $5 million to support WWF to expand its conservation-drone program in Africa and Asia to protect these animals from harm's way (Tang, 2018).

2. Reduce water waste in farming by using drones and data analytics. In Chile, researchers are developing drones with spectral sensors and cameras that can allow farmers to monitor the condition of their crops from their smartphones. By analyzing the data captured by camera using spectral analysis, farmers can monitor moisture content, ground water, plant health, and pest infestation as well as growth rate of the plant. This way, farmers can "localize" water and pest control, saving water and improving yield (Scandella, 2015). Finally, a Spanish startup BrioAgro installs underground sensors to collect data on the moisture and light levels and the soil nutrients. By analyzing the data transmitted from these sensors to BrioAgro, the startup company prescribes "localized" water and fertilizer solutions via farmers' mobile phone. In doing so, farmers can reduce water waste via precision farming.

3. Reduce emission via smart transportation. By leveraging the ridesharing information technology that enables a platform (e.g., Uber, Didi) to track and trace all vehicles and all customers in the system in real time, pooling services such as Uber (Pool), VIA and BlaBlaCar are becoming more popular. Also, autonomous vehicles can increase the number of shared rides even more in the future: a study in Switzerland indicates that 61% of the respondents prefer a pooled shared autonomous vehicle over a private autonomous vehicle (Stoiber et al., 2019). In addition to pooling rides among passengers, pooling between parcels and drivers (so called "crowd shipping") is gaining traction. A crowd shipping platform assigns drivers (ordinary persons who registered with the platform) to parcels for them to deliver to their neighbors on their way back home from the office or from a shop. Therefore, by piggybacking the rides that the drivers would have taken anyway, this crowd shipping platform reduces the number of deliveries via traditional delivery vans and thereby reduces emissions. To push this crowd shipping idea further, it is possible for the platform to facilitate transfers of goods between crowd shippers reduces the system wide required travel distances even further (Sampaio et al. 2018). For a more detailed overview of crowd sourced logistics systems, the reader is referred to Sampaio et al. (2019b) for details.

Crowd shipping is one of the initiatives to better utilize the space in individual's cars. Another initiative is "trunk delivery service" under which a Logistics Service Provider (LSP) such as DHL can gain temporary access to the trunk of the customer's car (Volvo, GM, Ford, or Lincoln) so that the LSP can deliver the goods even when the customer is not home. Doing so can reduce emissions because it reduces the need for the LSP to visiting the customer again or for the customer to pick up the goods at a designated collection point (Liu et al, 2019). However, the potential is even higher if customers can share their full itinerary with the LSP so that the LSP can choose the most convenient time slot and location for their deliveries (Reyes et al. 2017, Ozbaygin et al. 2017, and Sampaio et al. 2019a).

4. Sustain supply of high quality agricultural products by using blockchain. Many well sought after agricultural products (e.g., coffee beans, cocoa beans, shea nuts) are produced by smallholder farmers in developing countries. Because the supply chain operations is complex and often opaque and the market price of these products tend to fluctuate significantly, farmers get low and unstable wages (or prices) for their efforts. In many cases, they may abandon one crop and switch to a different crop, making the supply even more unstable. To sustain the supply of high quality coffee beans, Starbucks launched the C.A.F.E. program that is intended to help farmers to develop sustainable farming practices (e.g., organic farming, drip irrigation, etc.) and donated millions of disease-resistant trees (100 millions by 2025) to help farmers fight different threats such as coffee leaf rust. At the same time, Starbucks worked with various NGOs (e.g., Rainforest Alliance) to ensure farmers are compensated fairly for their sustainable farming practices. However, such effort is labor intensive and often inaccurate. To overcome this challenge, Denver's Coda Coffee partnered with a startup bext360 to develop the world's first blockchain-traced coffee that integrates machine vision, blockchain, cloud computing, and AI to trace every step: coffee bean collection, washing, drying, milling, export, roasting and retail operations (Philips, 2018). For instance, smallholder farmers in Uganda can deposit their collected beans into a "bextmachine" that uses 3D scanners, machine vision, and AI (machine learning) to determine the quantity and quality of the coffee beans. Then the bextmachine will issue a receipt to farmers so that they can collect fair payments.

The above examples illustrate how these emerging technologies can be used to improve sustainability. As firms and government are applying these emerging technologies to improve sustainability, there are some research questions that deserve our attention:

1. Various technologies can be applied to reduce poaching of endangered species. However, as supply decreases, some ethical buyers may be willing to offer an even higher price. As such, more poachers will enter the market and create a potentially bigger problem.

Table1
Some key research questions arising from the logistics function in the Industry 4.0 era.

Technology\Strategic role of logistics	Competitive lever	Social value creator	Sustainability enabler
Internet of Things (IoTs)/ Drones	How would IoTs transform the way supply chain partners communicate, coordinate, and collaborate?	How would IoTs facilitate the development of "Mobility as a Service"?	How would IoTs (drones) protect endanger species?
3-D printing/Advanced Robotics/Autonomous Vehicles	How would 3D-printing transform the logistics industry? How would advanced robotics affect job design of human workers?	How should a firm leverage the personalization capability of 3D-printing to create social value? How would advanced robotics improve mobility and social activities for those who are in need?	How would ride sharing enabled by autonomous vehicles reduce emissions?
Data Analytics/Artificial Intelligence	How would data analytics and artificial intelligence improve logistics efficiency?	How should multiple transportation service providers develop an integrated service that benefits different stakeholders?	How would big data analytics improve the productivity of sustainable farming?
Blockchain	How would blockchain affect the competitiveness of a logistics service provider?	How should the government regulate blockchain technology that can balance conflicting objectives associated with different stakeholders?	How would supply chain transparency facilitated by blockchain technology improve ethical supply chain practice?

If one examines the supply and demand dynamics, how should the government develop programs to curb the demand instead of the supply of endangered species?

2. It is well known that approximately 80% of the fresh water withdrawn from rivers and groundwater is used to produce food and other agricultural products, what kind of incentive programs that the government should use to provide economic incentive for farmers to adopt water conservation solutions willingly?
3. Trunk deliveries and crowd shipping appear to be promising; however, the issues of trust and safety are two obstacles for these innovative ideas to take hold. What are the mechanisms that crowd shipping and truck deliveries should develop to ensure trust and safety for all involved parties?
4. While blockchain technology appears to be promising, there are potential weaknesses that can undermine the good intentions of different entities (Babich and Hilary, 2019). Also, because the adoption of blockchain technology requires participation and commitment of different entities, conflicts ensue. Saberi et al. (2019) propose four blockchain technology adoption barriers and future research directions. Therefore, a natural question is: what are the mechanisms that can facilitate commitments and self-enforcements for different entities to adopt blockchain technology?

5. Conclusion

We have discussed the potential use of emerging technologies (drones, smart sensors, robotics, blockchain, artificial intelligence, etc.,) for transforming the logistics function from being mundane to exciting, and for enabling the logistics function as a competitive lever, a social value creator, and a sustainability enabler. Table 1 characterizes some of the research questions raised in this paper.

We have also raised some concerns about the applications of these technologies. Besides many technologies are not proven, they may create other problems including: social unrests due to job losses to automation (e.g., autonomous vehicles, robots, drones, etc.), social inequality due to the fact that these technologies often involve smart phones and smart devices that are still inaccessible by the poor, and even more severe income inequality especially when the technologies often create more benefits for the educated class. Given all these challenges, researchers should also examine the impact of these emerging technologies on the welfare of different socio-economic classes of citizens (Sodhi and Tang, 2014).

Also, despite recent advances of different technologies that support the Industry 4.0 movement, companies must take measures to mitigate several underlying risks:

- **Cyberattacks.** As supply chains are becoming more digitalized and rely on real time communication and coordination of many different devices (sensors, robots, drones, etc.), there is a heightened concern about cybersecurity. For instance, because industry 4.0 involves many devices communicating via different operating systems and different information systems, digitalized supply chains can be vulnerable to cyberattacks. These attacks can include industrial espionage, IP leakage, or even production sabotage. In some cases, cyberattacks can bring an entire logistics/transportation system to its knees.
- **Faulty data.** Smart devices are capable of sensing, collecting, sharing, analyzing data, etc. so that they can facilitate many supply chain operations smoothly. However, if the system is being hacked or if the system is not functioned properly, disasters ensue as we witnessed two crashed of Boeing's 737 Max in 2019 due to faulty readings of a key sensor. It is simply too risky to rely on smart devices to manage a supply chain; hence, companies must develop a fool-proof protocol with human interventions.
- **Safety regulations.** Many firms are exploring the use of advance robotics and automated guided vehicles in manufacturing, robotic systems in automated storage and retrieval warehouse operations, and autonomous trucks and drones in delivery operations. Some standard safety guidelines and regulations must be developed to ensure worker and public safety. For instance, the operations of Heathrow and Gatwick airports in London airports were disrupted after unauthorized drones were flying within the restricted airspace in 2018.

- **Privacy issues.** Many sensors record visuals and sounds of different movements of different people in many places. For example, many smart shelves record shopper's demographic data and their shopping habits within a shop. As such, there is a legitimate concern over privacy issues about this massive data collection. The government must develop regulatory measures to ensure companies collect and store this data properly for public safety.

In summary, the emerging technologies that support the Industry 4.0 movement create excitement because they are disruptive so that many new business models can emerge. At the same time, they create concerns over employment and safety. However, if the private and public sectors can collaborate with the government to establish mutually beneficial plans, these technologies can create value for companies and the society at large.

Acknowledgment

We thank Professor T.M. Choi for inviting us to prepare this article.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tre.2019.06.004.

References

Adams, P. 2019. Is China's fishing fleet taking all of West Africa's fish? BBC world news. March 25, 2019. https://www.bbc.com/news/av/world-africa-47698314/is-china-s-fishing-fleet-taking-all-of-west-africa-s-fish.
Agatz, Niels, Bouman, Paul, Schmidt, Marie, 2018. Optimization approaches for the traveling salesman problem with drone. Transport. Sci. 52 (4), 965–981.
Allison, I. 2019. Louis Vuitton owner LVMH is launching a Blockchain to track luxury goods. Coindesk. March 26, 2019.
Ashley, S. 2017. Robotics Exoskeletons are Changing Lives in Surprising Ways. NBCnews.com. February 21, 2017.
Babich, V., Hilary, G., 2019. Distributed ledgers and operations: what operations management researchers should know about blockchain technology. Manuf. Serv. Operat. Manage forthcoming.
Babich, V., Tang, C.S., 2012. Managing opportunistic supplier product adulteration: Deferred payments, inspection, and combined mechanisms. Manuf. Serv. Operat. Manage. 14 (2), 301–314.
Baur, C., Wee, D., 2015. Manufacturing's Next. Act. McKinsey Report.
Berman, B., 2012. 3-D printing: the new industrial revolution. Business Horizon. 55, 155–162.
Buchman, E., 2018. The Rise of Amazon Logistics. Transport. Top. August 20, 2018.
Carlsson, J.G., Song, S., 2018. Coordinated logistics with a truck and a drone. Manage. Sci. 64 (9), 4052–4069.
Choi, T.M., Wen, X., Sun, X., Chung, S.H., 2019. The mean-variance approach for global supply chain risk analysis with air logistics in the blockchain technology era. Transport. Res. Part E: Logist. Transport. Rev. 127, 178–191.
Columbus, L. (2018) 10 Charts that will challenge your perspective of IoT's growth. Forbes. June 6, 2018.
DeHoratius, N., Mersereau, A.J., Schrage, L., 2008. Retail inventory management when records are inaccurate. Manuf. Serv. Operat. Manage. 10 (2), 257–277.
Deloitte Insights, 2018. The fourth industrial revolution is here: are you ready? Deloitte Insights Rep. https://www2.deloitte.com/content/dam/Deloitte/tr/Documents/manufacturing/Industry4-0_Are-you-ready_Report.pdf.
Djankov, S., Freund, C., Pham, C.S., 2010. Trading on time. Rev. Econ. Stat. 92 (1), 166–173.
Dong, L., Shi, D., Zhang, F. 2018. 3D printing vs. traditional Flexible technology: Implications for manufacturing strategy. Working Paper. Washington University in St. Louis.
Frank, A.G., Dalenogare, L., Ayala, N.F., 2019. Industry 4.0 technologies: Implementation patterns in manufacturing companies. Int. J. Prod. Econom. https://doi.org/10.1016/j.ijpe.2019.01.004.
Lei, Y., Jasin, S., Sinha, A., 2018. Joint dynamic pricing and order fulfillment for E-commerce retailers. Manuf. Serv. Operat. Manage. 20 (2), 285–301.
Gerretsen, I., Earth's fish are disappearing because of climate change, study says. CNN world news. February 28, 2019.
Gkartzonikas, C., Gkritza, K., 2019. What have we learned? A review of stated preference and choice studies on autonomous vehicles. Transport. Res. Part C: Emerg. Technol. 98, 323–337.
Goodall, W., Dovey Fishman, T., Bornstein, J., Bonthron, B., 2017. The rise of mobility as a service. Deloitte Rev. 20, 111–129.
Groenfeldt, T. 2017. IBM and Maersk Apply Blockchain to Container Shipping. Forbes. March 5, 2017.
Hedenstierna, C.P., Disney, S.M., Eyers, D., Holmstrom, J., 2019. Economies of collaboration in build-to-model operations. J. Oper. Manage. https://doi.org/10.1002/joom.1014.
Hornyak, T. 2019. The world's first humanless warehouse is run only by robots and is a model for the future. CNBC. Feb 17, 2019. https://www.cnbc.com/2018/10/30/the-worlds-first-humanless-warehouse-is-run-only-by-robots.html.
Horowitz, B. 2019. 8 Ways Artificial Intelligence is Revolutionizing Retail. PC Magazine. February 7, 2019. https://www.pcmag.com/feature/366279/8-ways-artificial-intelligence-is-revolutionizing-retail.
Hu, B., Sun, Z., 2019. Managing Self-Replicating Innovative Goods. Working Paper. University of Texas at Dallas.
Judkslian, R. 2018. Inside the Jordan refugee camp that runs on blockchain. MIT Technology Review, April 12, 2018.
Kopalle, P. 2014. Why Amazon's Anticipatory Shipping is Pure Genius. Forbes. January 218, 2014.
Liu, C. 2018. China embraces telemedicine. HSBC Insights. July 26, 2018.
Liu, C., Wang, Q., Susilo, Y.O., 2019. Assessing the impacts of collection-delivery points to individual's activity-travel patterns: a greener last mile alternative? Transport. Res. Part E: Logist. Transport. Rev. 121, 84–99.
Manyika, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R. Bughin, J., Aharaon, D. 2015. Unlocking the Potential of Internet of Things. McKinsey Global Institute Report. June 2015.
Marr, J., 2018. How Chinese Retailer JD.com Uses AI, Big Data & Robotics To Take On Amazon. Forbes, Aug 3, 2018.
Marshall, A. 2017. Above devastated Houston, armies of drones prove their worth. Wired. September 4, 2017.
Muoio, D. 2018. Enable Injections brings in $50 M for wearable subcutaneous therapeutic delivery devices. Mobihealth News. October 25, 2018.
Olsen, T.L., Tomlin, B., 2019. Industry 4.0: opportunities and challenges for operations management. Manuf. Serv. Operat. Manage forthcoming.
Olsen, T.L., Parker, R. 2019. Autonomous Vehicles: A research agenda for operations management. Working paper. University of Auckland.
Ozbaygin, G., Karasan, O.E., Savelsbergh, M., Yaman, H., 2017. A branch-and-price algorithm for the vehicle routing problem with roaming delivery locations. Transport. Res. Part B: Methodol. 100, 115–137.
Philips, E. 2018. Bringing Blockchain to the Coffee Cup. Wall Street Journal. April 15, 2018.
Pieters, J. 2019. Albert Heijn to combat food waste with "Dynamic Discounts". NL Times. May 21, 2019 https://nltimes.nl/2019/05/21/albert-heijn-combat-food-

waste-dynamic-discounts.
Qi, W., Shen, Z.J.M., 2019. A smart-city scope of operations management. Prod. Operat. Manage. 28 (2), 393–406.
Quadrifoglio, L., Dessouky, M.M., Ordóñez, 2008. A simulation study of demand responsive transit system design. Transport. Res. Part A: Policy Pract. 42 (4), 718–727.
Quadrifoglio, L., Hall, R.W., Dessouky, M.M., 2006. Performance and design of mobility allowance shuttle transit services: bounds on the maximum longitudinal velocity. Transport. Sci. 40 (3), 351–363.
Qui, F., Shen, J., Zhang, X., An, C., 2015. Demi-flexible operating policies to promote the performance of public transit in low-demand areas. Transport. Res. Part A: Policy Pract. 80, 215–230.
Reyes, D., Savelsbergh, M., Toriello, A., 2017. Vehicle routing with roaming delivery locations. Transport. Res. Part C: Emerg. Technol. 80, 71–91.
Richter, F. 2019. The Growing Weight of Amazon's Logistics Costs. Statista. March 1, 2019.
Rifkin, J., 2011. The Third Industrial Revolution. Palgrave MacMillan Publishers.
Rogers, H., Baricz, N., Pawar, K., 2016. 3D printing services: classification, supply chain implications and research agenda. Int. J. Phys. Distribut. Logistics Manage. 46 (10), 886–907.
Roy, D., Nigam, S., de Koster, R., Adan, I., Resing, J., 2019. Robot-storage zone assignment strategies in mobile fulfillment systems. Transport. Res. Part E: Logistics Transport. Rev. 122, 119–142.
Saberi, S., Kouhizadeh, M., Sarkis, J., Shen, L., 2019. Blockchain technology and its relationships to sustainable supply chain management. Int. J. Prod. Res. 47 (7), 2117–2135.
Sampaio, A., Savelsbergh, M., Veelenturf, L., Van Woensel, T., 2018. The Benefits of Transfers in Crowdsourced Pickup-and-Delivery Systems, working paper Eindhoven. University of Technology.
Sampaio, A., Kinable, J., Veelenturf, L., Van Woensel, T., 2019a. A Scenario-Based Approach for the Vehicle Routing Problem with Roaming Delivery Locations under Stochastic Travel Times, working paper. Eindhoven University of Technology.
Sampaio, A., Savelsbergh, M., Veelenturf, L., Van Woensel, T., 2019b. Crowd-based city logistics. In: Faulin, J., Grasman, S.E., Juan, A.A., Hirsch, P. (Eds.), Sustainable Transportation and Smart Logistics. Elsevier, pp. 381–400.
Scandella, A. 2015. Drones in precision farming. IoT Telefonica. November 19, 2015. https://iot.telefonica.com/blog/drones-in-precision-farming.
Schwab, K., 2016. The Fourth Industrial Revolution. World Economic Forum.
Sodhi, M., Tang, C.S., 2014. Supply chain research opportunities with the poor as suppliers of distributors in developing countries. Prod. Operat. Manage. 23 (9), 1483–1494.
Sodhi, M., Tang, C.S. 2017. Supply Chains Built for Speed and Customization. Sloan Management Review, Summer Issue.
Song, J., Zhang, Y. 2018. Stock or Print? Impact of 3D Printing on Spare Parts Logistics. Working Paper, Duke University.
Stoiber, T., Schubert, I., Hoerler, R., Burger, P., 2019. Will consumers prefer shared and pooled-use autonomous vehicles? A stated choice experiment with Swiss households. Transport. Res. Part D: Transport Environ. 71, 265–282.
Tang, C.S. 2018. Saving Rhinos from Extinction in an Intelligent Way. UCLA Anderson Supply Chain Blog. June 11, 2018. https://blogs.anderson.ucla.edu/global-supply-chain/2018/06/saving-rhinos-from-extinction-in-an-intelligent-way.html.
Tao, L., Yang, Y. 2018. Your Chinese takeaway is ready to be delivered by drone. South China Morning Post. May 30, 2018.
Wang, Y., Singghih, M., Wang, J., Mihaela, Rit, 2019. Making sense of blockchain technology: how will it transform supply chains? Int. J. Prod. Econ. https://doi.org/10.1016/j.ijpe.2019.02.002.
Westerweel, B., Basten, R.J.I., van Houtum, G.-J., 2018. Traditional or additive manufacturing? : assessing component design options through lifecycle cost analysis. Eur. J. Oper. Res. 270 (2), 570–585.
Zhang, J. 2017. Cognitive Manufacturing and Industry 4.0. IBM Blog. March 17, 2017.