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A peer-to-peer platform for decentralized logistics

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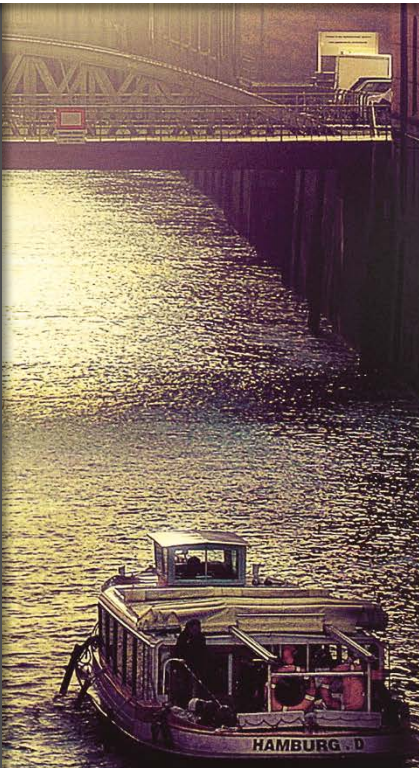
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A Peer-To-Peer Platform for Decentralized Logistics

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We introduce a novel platform for decentralized logistics, the aim of which is to magnify and accelerate the impact offered by the integration of the most recent advances in Information and Communication Technologies (ICTs) to multi-modal freight operations. The essence of our peer-to-peer (P2P) framework distributes the management of the logistics operations to the multiple actors according to their available computational resources. As a result, this new approach prevents the dominant players from capturing the market, ensures equal opportunities for different size actors, and avoids vendor lock-in. The latest ICTs such as Industrial Data Space (IDS), Blockchain, and Internet-of-Things (IoT) are used as basic building blocks which, together, enable the creation of a trusted and integrated platform to manage logistics operations in a fully decentralized way. While IDS technology allows for secured data exchange between the different parties in the logistics chain, Blockchain technology handles transaction history and agreements between parties in a decentralized way. IoT enables the gathering of real-time data over the logistics network, which can be securely exchanged between the different parties and used for managing the decision-making related to the control of the freight transportation activities. The practicability and the potential of the proposed platform is demonstrated with two use cases, involving various actors in the logistics chains.

Keywords: Peer-to-Peer Logistics; Blockchain; Industrial Data Space; Internet-of-Things

1 Introduction

Digitized logistics integration, beside drastically decreasing manual work, opens the door for novel ways of optimizing the logistics processes and transport routes. It also enables real-time monitoring of transportation flows in order to react dynamically to unexpected circumstances. As a result, the integration of the newest Information and Communication Technologies (ICT) offers great potential to improve cost-effectiveness in logistics and enables new business models based on real-time economics. Today, 70% of companies lack operational performance data along the entire value chain, (World Economic Forum, 2016). To face this issue within the European Union (EU), the long-term goals and the related roadmaps of the European Technology Platform ALICE (c.f. etp-logistics.eu) aim at a 10%–30% increase of efficiency in the EU logistics sector, which means EUR 100–300 billion cost relief for the European industry. A true “people, planet and profit” oriented logistics and supply chain sector contributes not only in industry competitiveness but also in meeting environmental policy targets.

One of the main challenges in logistics is that various independent parties are involved (freight forwarders, 3rd party logistic service providers, multimodal transport operators, carriers, etc.). Communication between these parties needs to be accurate, and the associated necessity is to create a common platform where all parties share the necessary relevant information. Several attempts towards the implementation of such a platform were carried out in several past EU-funded research projects (such as CONTAIN, FREIGHTWISE, e-FREIGHT, or iCargo, c.f. containproject.com, freightwise.tec-hh.net, eutravelproject.eu), and recently by commercial products such as Uber Freight. The problem when adopting such approaches is that some organization needs to run the common platform. While having platform dominance often represents a good business opportunity for the company running the platform, other actors have to pay fees and follow the whims of the platform owner. Furthermore, a single gatekeeper poses a risk for diversity and fairness in the market. Multiple competing platform companies, on the other hand, create the risk of a splintered market resulting into non-optimal logistics decisions in separate silos.

An alternative solution – and the focus of this contribution – is to handle logistics management in a peer-to-peer (P2P) fashion. While P2P logistics is sometimes understood as crowd-sourced transportation, we concentrate here on the conventional transportation industry. The essence of our P2P approach is that the logistics management system is fully distributed to the computational resources

of the actors. The outcome is a distributed system with a network of interactions between parties. The proposed framework aims at using and integrating two recent P2P technologies: Industrial Data Space (IDS), developed at Fraunhofer Institute in Germany, and Blockchain, which was initially a key part of cryptocurrencies (Mukhopadhyay et al., 2016), but is now a separate technology on its own.

The proposed P2P approach blocks dominant players from capturing the market, ensures equal opportunities for different size actors, and avoids vendor lock-in. The essence of the introduced P2P platform is that the cloud-enabled transport management system is distributed over multiple actors according to their computational capabilities. The result is a distributed system with a network of interactions between actors and entities, which enables smart and innovative data based services.

Ultimately, we present a framework that goes beyond the paradigm of a centralized platform, and we propose a fully P2P architecture for logistics management. The platform combines three novel technologies: IDS, Blockchain, and IoT. All these technologies have been tested and used in their specific fields but never been combined in the present way. Therefore, the proposed system provides the logistics field with a totally new management approach, and open possibilities for new innovations and businesses utilizing this platform.

2 Related Work

The key question raised in this paper is how can a logistics management system based on P2P ideas help and provide new value in the digitized supply chain, and solve the contradiction between interoperability and data sovereignty. While the technical components we are introducing in the present contribution have already been investigated in various contexts including logistics, they have never been applied in an integrated fashion to logistics as an enabler for smart and innovative data based services. Some companies are already marketing P2P logistics services (e.g. p2plogistics.co.uk), however it is important to note that they are simply using a centralized client-server architecture platform to match the transport needs and crowd-sourced providers. Ideas towards a P2P approach have first been envisioned on a general level in a Hewlett-Packard patent (Chen and Hsu, 2007), but application of such ideas to logistics has not been systematically studied nor experimented so far.

A recent survey by Sternberg and Andersson (2014) gives an exhaustive overview of the existing scientific research contributions on distributed freight management. In particular, the authors observe that “decentralized intelligence in logistics can be viewed as a disruptive architectural innovation operating on an IT-infrastructure level, displaying massive network effects that has not yet materialized”. Sternberg and Andersson see the problem of reaching the critical mass of adopters as a key challenge, and highlight the importance of industrial experiments.

Industrial Data Space (IDS) reference architecture and technology have been created by the Fraunhofer Institute and the Industrial Data Space Association (c.f. industrialdataspace.org). The association has currently 50+ members ranging from manufacturing, production, logistics, ICT to services, such as DB Schenker, ThyssenKrupp, Schaeffler, FESTO, Bosch, SICK, Salzgitter and SMEs like Setlog and Quinscape. Experiments on IDS technology are ongoing in 10+ European IDS hubs. The IDS Connector software component (Otto, 2017), which allows for secured data sharing and processing, is currently standardized in a fast track procedure by DIN, the leading German standardization institution, and by ISO in parallel. IDS is recognized as a key enabler for future industry platforms by the EU’s Digitising European Industry initiative (European Commission, 2016; Jarke, 2017; Jesse, 2017).

Yuan et al. (2016) claim in a recent contribution that Blockchain can revolutionize intelligent transport systems, and as a result the use of Blockchain in various industrial and logistics applications is currently widely investigated. Blockchain has already been applied to logistics in several R&D projects and academic research. For instance, Apte and Petrovsky (2016) discuss the implementation of Blockchain within pharmaceutical supply chains, and Zhang et al. (2017) combine Internet-of-Things (IoT) and Blockchain in order to propose a novel business model for IoT services. Tian (2016) combines RFID and Blockchain for building a traceable agri-food supply chain. A recent contribution by Korpela, Hallikas, and Dahlberg (2017) studies the challenges raised by the integration of Blockchain in supply chain frameworks. Blockchain design functionalities are shown to support good integration for ledger and smart contracting, however for a global integration within a supply chain context, a common standardized data model is additionally required to secure the interoperability, which is performed by the IDS technology in the platform proposed in this contribution. Blockchain technology and various associated industrial business cases are currently analyzed in a national project in Finland (BOND - Blockchains bOosting FiNnish InDustry, c.f. vtt.fi/sites/BOND). A Scandinavian consortium (DBE Core, c.f. dbecore.com/portfolio/what-next),

including IBM, is working on the integration of Blockchain open logistics APIs, as well as on associated new business models for open transportation ecosystems. SmartLog ([c.f. kinno.fi/en/smartlog](http://c.f.kinno.fi/en/smartlog)), a EU-funded research project, is currently investigating the first Proof-of-Concept implementation for a solution involving Blockchain and IoT in the logistics industry.

The business opportunities raised by the appearance of IoT have been acknowledged by Gartner to represent a major market prospect in the next decade (Rivera, 2014). Papert and Pflaum (2017) give recommendations on how IoT could be implemented by logistics companies. One of their key findings is that the IoT platform should be based on open interfaces and open source software to support communication among different applications. There exist several recent studies on various ways to apply IoT to logistics, transportation, and vehicles (Da Xu, He, and Li, 2014; Guerrero-Ibanez, Zeadally, and Contreras-Castillo, 2015; Guo et al., 2017; Contreras, Zeadally, and Guerrero-Ibanez, 2017).

In terms of Technology Readiness Level (TRL), the Blockchain technology is already in massive use in digital currencies, but for other use cases it is still under development (TRL5). IDS Connector technology is used in industrial pilots (TRL5). Positioning and other IoT sensing technologies have been in production use for a long time (TRL9). The integration of IDS, Blockchain, and IoT has not been fully demonstrated in industrial use (TRL5) for logistics system management.

3 A smart platform for decentralized value chain operations

3.1 Concept

The ultimate objective of this contribution is to take advantage of novel P2P technologies, in order to enable the creation of a trusted, decentralized logistics platform. Figure 1 gives a general sketch of the proposed platform. IDS technology allows for data exchange between the different actors in the logistics chain. Its key feature is data governance, in the sense that it enables parties to work together without releasing confidential information to each other. IDS Connectors can implement in a decentralized fashion any type of tailored algorithms, e.g. for calculating transportation options matching the customers' needs, or for merging procurement systems. Since these algorithms are embedded inside

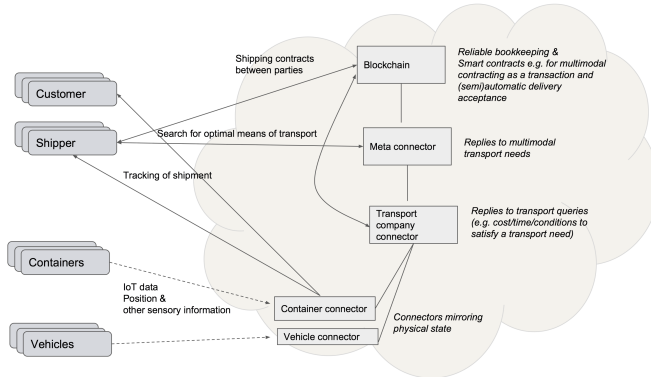


Figure 1: High-level system architecture with example data flows.

IDS Connectors, proprietary business logic does not need to be disclosed. In a similar way, the customer company can work privately with the IDS Connector using sensitive data without disclosing it to anyone. Trust is further enhanced by the option to have IDS Connectors certified by 3rd parties.

Like IDS, Blockchain technology works in a P2P fashion, managing transaction history and verifying agreements between parties in a decentralized way. The distributed trust, which Blockchain enables, is a perfect match to the distributed IDS technology. Indeed, Blockchain technology allows for the establishment of Smart Contracts, which, once agreed, can be run by autonomous programs without any human intervention.

IoT is the third key building block needed in order to allow timely information in a dynamic environment (Al-Fuqaha et al., 2015). This consists in a large collection of networked sensors or other devices communicating with each other and delivering data to higher level applications using a suitable middleware (Razzaque et al., 2016). The data collected by IoT sensors can be stored, processed, and shared by applying cloud-computing (Botta et al., 2016).

In Figure 1, IDS Connectors represent containers (or other transport units), vehicles, and transport companies. The meta-connector is a virtual entity searching, optimizing, and managing end-to-end transport routes and processes, which

can span multiple means of transportation and multiple transport companies. A brokering service maintains a directory of available IDS Connectors. IDS allows for standardization of the data transfers and the data formats used. As a result, IDS provides all actors of the logistics chain with an easy access to the platform, and to the services it offers. IDS Connectors communicate with each other, and with the IDS broker. For instance, when a company needs a transport service, it uses a dedicated meta-connector, which performs route optimization by combining the best transport means and service providers to form a single transport chain.

The transport unit IDS Connector also collects and manages information from IoT sensors installed in the containers or in other transport units. The essential events in IoT data, such as crossing national borders or sensory readings of changed freight conditions (e.g. location, temperature, humidity level, etc.), can also be stored into the Blockchain. In this way, e.g. automatic payment can be authorized after the transport unit has been delivered to the final customer and the merchandises in it have been stored in agreed conditions (e.g. temperature). The transport unit IDS Connector can also offer real-time information on the location and other sensor data to the company that ordered the transport service.

Let us now focus on one of the most natural process to be handled, where optimal transport routes have to be negotiated. Thanks to the present P2P platform, a multi-modal routing algorithm can be implemented within the IDS Connectors in order to determine the best transportation means and schedule for each freight request arising in the logistics system. In addition to monetary objectives, the algorithms could use, e.g. environmental factors as an optimization goal. Since any user can create new IDS Connectors, adding new specific routing algorithms is possible, depending on the customers' needs. The route planning of the transport units might typically consist of:

- An offline algorithm, which first determines an ideal multi-modal routing schedule, based on the data available at the time of the transportation request.
- The initial schedule may thereafter be modified and adapted via the execution of an online algorithm, which determines dynamic recourse actions in case of perturbations to the original schedule (delays, disruptions).

For the latter online algorithm above, there are many events which have an impact on the time of arrival of a transport unit: traffic perturbations, rest periods of the driver, as well as breakdowns. For these reasons, IoT is implemented in order to

constantly track freight units and vehicles along their journey. Real-time data is collected from the numerous IoT sensors deployed over the logistics network as well as from the freight units and vehicles measured via GPS-tracking. Open data, including real-time traffic information, can also be considered by the online routing module. The estimated time of arrival can be automatically calculated with the help of GPS coordinates that are sent automatically to the IDS Connector. Time consuming events can also be manually sent (e.g. in the GS1 EDI XML format) to the customer via the IDS platform, which will re-optimize the route and recalculate the estimated time of arrival. The driver himself can negotiate new time slots through a smartphone-based platform. Hence, the online algorithm is able to help in bringing more reliability to the logistics network and allows for a substantial reduction of transportation times. When it comes to multi-modal transportation networks, it allows to react to random perturbations during the shipment by dynamically and automatically managing mode changes using the IDS Connectors, and to manage the related contracting with the involved carriers by using the Blockchain feature. Through the IDS technology, the routing module can provide users emitting a freight request not only with the best option (in terms of transportation costs, route, and combination of modes), but also with possible routing alternatives and associated costs. This allows the users to autonomously plan on the online platform their freight request based on their particular needs.

Blockchain technology is used to confirm and store contracts negotiated by IDS Connectors. Also, transactions associated with the routing decision-making processes, which involve the selection of various transport carriers and operators, are recorded by the IDS platform on the Blockchain to ensure future traceability, visibility, and transparency. As Smart Contracts are shared programs inside Blockchains, they do not need any 3rd party validators, and can be executed automatically, when all definitions in the contract have been fulfilled, e.g. when IoT readings satisfy agreed conditions.

Such a decentralized logistics platform will have to be first implemented in smaller use cases, as the ones presented in Section 4 below. This will allow hence to investigate in parallel the role and potential of new service and product innovations by identifying service gaps. This is done by analyzing how companies and the business ecosystem increase revenues and cut costs by using real-time business processes, and identifying opportunities for cost-cutting through the elimination of manual work.

3.2 Impact

The essence of the present decentralized P2P platform is to show the potential for high interoperability through distributed Blockchain and IDS technologies. In the following, we discuss the benefits of the proposed platform, grouped by the enabling technologies.

Peer-To-Peer

The proposed platform, based on P2P technologies, allows for a flexible integration of ICT and operational processes of the different involved parties. It offers a complete real-time mapping between physical freight and digital information flows. Applying P2P technologies and cloud-based service architecture ensures easy access to the system with user devices ranging from sensor platforms, mobile phones/tablets, and PC computers. The P2P concept provides hence the different supply chain partners with equal opportunities, no matter their size and importance. Another key benefit of the P2P approach is scalability, as the workload is divided, and there is hence no bottleneck in the system.

IDS and Data Sharing

The data sovereignty of IDS technology has been designed in order to enable data exchange while keeping control of the data. Horizontal collaboration is implemented via the effective information and data exchange that is achieved through the IDS Connector technology. As only the IDS Connector APIs are fixed, new ICT players can start introducing new functionalities by creating their own IDS Connectors. The system is therefore open to both logistics and ICT parties to easily join in. The APIs enable the integration of IDS Connectors to company internal data systems, and thus to their specific operational processes. IDS Connectors ensure data privacy and confidentiality of sensitive business data.

Blockchain

Blockchain technology provides the different supply chain partners with the technical basis for trust while the data governance mechanisms of IDS will handle information sharing. As a result, Blockchain technology is used to build a reliable

general electronic bookkeeping solution, as the Blockchain approach is highly successful in guaranteeing the truthfulness of the data.

Internet-Of-Things

IoT technologies are used to monitor the location and state of freight units and vehicles. As a result, real-time data, such as location and other IoT sensor data, can be used in managing the logistics decision-making, which is directly used to control the freight transportation activities. In this way, tailored real-time optimization algorithms can be implemented in order to allow for reacting dynamically to deviations. Ease of deployment is a key design goal for IoT data collection mechanisms.

Multi-Modal Routing Algorithms

The proposed platform allows for the development of novel static and dynamic algorithms for optimal multi-modal transport decisions. Indeed, the above ICT technologies facilitate the data and information sharing between the different parties, and hence using them opens the door for smarter decision-making. More efficient logistics will focus on shortening transportation routes, increasing vehicle load factor, reducing empty runs by improved route planning, as well as shortening the lead time and consequently reducing inventories. This will result in creating savings in transportation costs. The resulting financial savings arise as a result of both better combinations of loads and higher load factors, and better selections among multiple routes and the specific advantages offered by the different transportation modes (flexibility of trucks, smaller environmental footprint of railways, lower costs of maritime transport, etc.), which helps to shorten the freight delivery routes, as well as to reduce CO₂ emissions. All these aspects will hence also have a positive impact on the ecological footprint of the logistics system.

As highlighted in (Korpela, Hallikas, and Dahlberg, 2017), a combined stack of standardized technologies is a major enabler for the accelerated development of a many to many integration model. In general, the architecture of Blockchain technology (design elements and functionalities) is commonly shared, and such standardization has facilitated its integrated use over the Internet. IoT integration is implemented in our platform with the use of standardized IDS Connectors.

4 Towards implementation and acceptance

Two initial use cases, which emphasize the different aspects of the proposed concept, have been identified with various industrial partners. While each of these two use cases requires some specific implementation work, they both share the key technology platform introduced in this contribution. The concrete aim of such initial uses cases is to highlight at a smaller-scale, and hence at a reduced investment risk, how the logistics platform based on IDS and Blockchain technologies is able to improve the efficiency of logistics operations.

4.1 Secure tracking of deliveries

This use case originates from a company that delivers turnkey solutions for industrial machine and facility builders. The customer base runs 14'000 turbines for power generation, 700 paper machines and about 1 million power transmission systems in 70 different countries. Hundred sites are handling the delivery of these customized solutions to the customers, using dozens of different transport companies. Besides the shipment of heavy machinery parts, which have to travel thousands of kilometers cross-borders, a solution includes thousands of other vital components that are needed to complete the delivery. Collecting information during the in-transit phase is vital to be able to better predict the time of arrival of the components, and help planning to ensure on-time delivery with reduced lead-time.

This use case possesses all the facets needed to study how to facilitate on-demand based operations in a globally distributed project context, and how new technologies related to P2P, talking containers (IoT), and dynamic routing can lower the costs while improving performance in logistics related to large projects. In particular:

- Routing: on-time delivery, real-time estimation of time of arrival, and negotiation of a suitable delivery time. Both the shipper and the customer can better organize their delivery processes and avoid congestion on delivery platforms. Thanks to improved real-time routing information enabled by the gathering of real-time IoT data and IDS-based routing algorithms (from the carrier to the logistics service provider and the customer), the installation site can prepare its processes for on-time or

late delivery. In case of perturbations, real-time re-routing allows to minimize the lateness.

- Tracking: all parcels and containers are able to communicate their location and condition measured through different IoT sensors that are linked with the package and the components themselves.
- Security: all information throughout the delivery process is stored in a secured Blockchain for multiple purposes. During the delivery phase, the location and transportation circumstances of the containers are to be recorded and stored securely. Once assembled, the operational history can be stored in the same Blockchain to cover the whole lifecycle including the recycling procedure at the end of lifetime.
- Integration: existing transport management systems and mobile apps can be integrated in order to ensure the ability of the logistics platform to work together with legacy solutions and with standardized formats.

4.2 Blockchain and data integration for forest industry logistics

The Digital Business Ecosystem Consortium (DBE Core) drives the implementation and adoption of logistics API integration to Blockchain and Smart Contracts for end-to-end digital information exchange. The members of the DBE Core consist of industry companies in two large business domains: the bio-refinery process and the maritime ship building industry. They form a customer base for logistics services in land operations across Finland, as well as cross-border operations to global markets. The DBE Core companies are operating over 100 countries.

As a case example in Finland, the Lappeenranta region has one of the largest forest industry clusters in the world. Every day more than 1000 full truckloads of raw material is received in three regional bio-refinery industry locations, and some 300 truckloads per day are delivered to European customers. A new truck is unloaded every 3 minutes. The import from Russia (which crosses EU borders) is over 15 million cubic meters of wood. The distributed stocks in the forest are geo-located, and hundreds of Small and Medium Enterprises (SME) logistics companies handle their transportation on a daily basis.

Logistics operations in different industry locations, supplier locations, warehouses, ports and railroads require a well-conducted and interoperable logistics

management system. Logistics companies are generally using intermediate operators to transfer and map the data between organizations and their systems. Currently, lots of manual work is required to integrate the information, which generates high costs. Therefore SME suppliers are exposed to be replaced by Tier-2 or Tier-3 suppliers.

All stakeholders of DBE Core have decided jointly to move towards a common logistic integration based on open Application Programming Interfaces (APIs). The development is based on global business process standards (OASIS/UBL).

The development and piloting of Blockchain integration and Smart Contracting can be established by the following steps: (a) defining DBE Core consortium Blockchain (e.g. with IBM Bluemix and HyperLedger), (b) Logistic API integration to Blockchain, (c) Smart Contract integration to control and automate transactions, and (d) secure interoperability with IDS Connectors.

The P2P platform described in this paper will support the knowledge creation and sharing of concepts and tools to reach the DBE Core visions and goals in the following ways:

- Real-time visibility to logistics transportation: monitoring and control of logistics processes enables the development of demand supply forecasting algorithms based on pull model for delivery control, in order to reduce lead-time, waiting times, and manual work.
- Securing the data storing and sharing by Blockchain on B2B and IoT transactions.
- Automating the supply and logistics integrations in gross organizational environment.

5 Conclusions and future work

We present a fully decentralized platform for logistics management based on IDS and Blockchain technologies which, combined with the gathering of real-time IoT data, enables to address efficiently the challenges raised in the logistics networks nowadays. The proposed P2P framework allows for supporting interoperability between different actors in the logistic chains, sharing securely the data between the different parties, and using it for optimal planning based on IoT data.

The platform allows for an implementation that is not affected by scalability issues, and that is not limited by geographical borders. In particular, facilitation of cross-border transportation is one of the main issues that the platform facilitates. By lowering the threshold for new actors to join in, it is expected that new opportunities will arise both in dynamic transportation optimization, and in 3rd party development of new components and services to the platform.

Interestingly, the overall concept discussed in this paper also has applicability beyond logistics systems. There are a number of areas which share similar key characteristics: (i) cooperation and data transfer between multiple independent parties is essential, (ii) splitting the market into separate silos run by different companies reduces the benefits, and (iii) a dominant platform company can have an unhealthy role in controlling the market. Examples of such services include auction sites, travel rental booking sites, and most importantly social media sites. In these contexts, we typically observe strong network effects where the value of the network rises with the number of participants it is able to attract. As a consequence, the dominant player has a major advantage and is able to push the smaller players away from the market, resulting into monopolistic positions (for an overview see e.g. Haucap and Heimeshoff, 2014). While the shared economy helps smaller players to enter the market to perform the actual work (Einav, Faronato, and Levin, 2016), the competition at the more lucrative management layer tends to fade. Being able to provide the similar service in a P2P fashion represents a way to gain the benefits of network effects without facing the problems of dominant, monopolistic parties. For instance, Munsing, Mather, and Moura (2017) have explored Blockchain technology in connection with electricity networks to eliminate the need of a microgrid operator.

It is important to note that towards the implementation of the proposed platform, business model implications will have to be investigated in parallel, in order to unveil the associated new innovation opportunities and ecosystem effects, as well as the additional needs for development, standardization, and other activities, which are necessary to bring the enhanced logistics solutions into operational use.

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