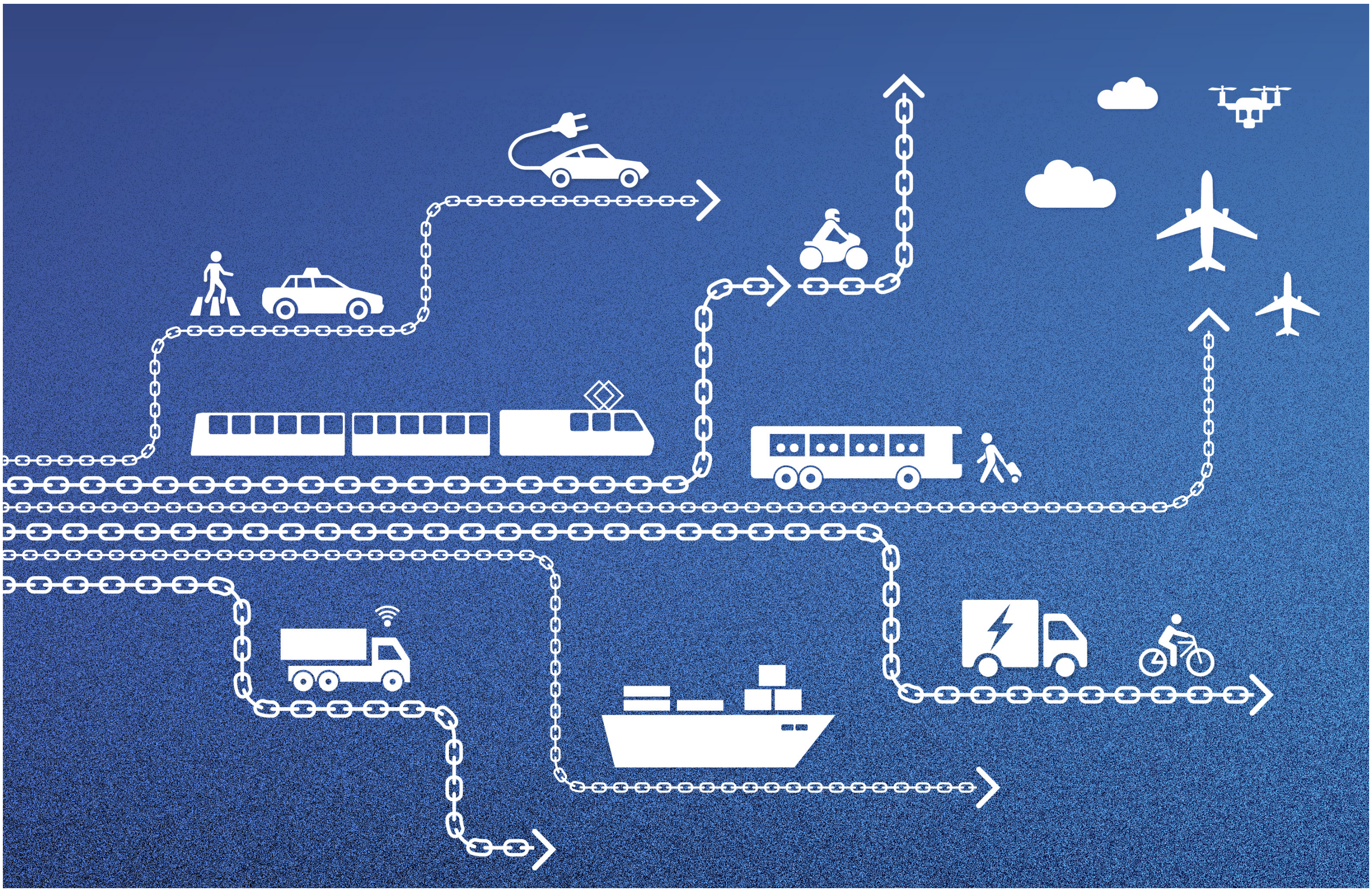
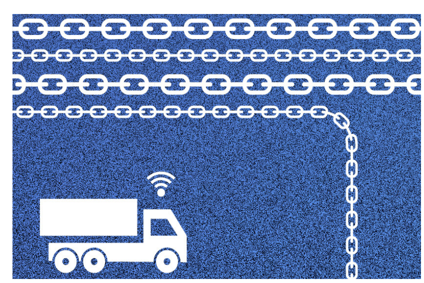
International Transport Forum | CPB Corporate Partnership Board



Forging Links
Unblocking Transport with Blockchain?



Corporate Partnership Board Report

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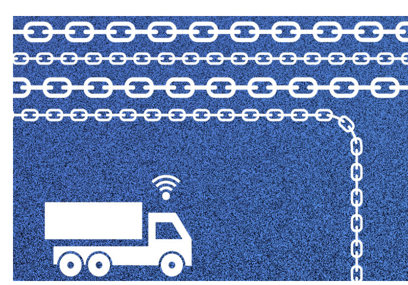

Corporate Partnership Board Report

The International Transport Forum

The International Transport Forum is an intergovernmental organisation with 62 member countries. It acts as a think tank for transport policy and organises the Annual Summit of transport ministers. ITF is the only global body that covers all transport modes. The ITF is politically autonomous and administratively integrated with the OECD.

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

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

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

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The principal authors of this report are Katja Schechtner and Andrew Lombardi, with contributions from Philippe Crist. The project was managed by Katja Schechtner of the International Transport Forum. Sharon Masterson manages the Corporate Partnership Board and its activities.

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The report draws conclusions from the ITF CPB Workshop "Blockchain and Trusted Provenance in Transport Supply and Trip Chains" held 11 September 2019 at the OECD Headquarters, Paris, France (www.itf-oecd.org/blockchain-and-trusted-provenance-transport-supply-and-trip-chains-corporate-partnership-board). Participants in this workshop are listed in Annex A.

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What we did

This report assesses the potential of Distributed Ledger Technology (DLT) to address persistent transport policy challenges and provides transport policy makers with recommendations on how to maximise the benefits of DLTs in the transport sector. Eight use cases from supply chain, logistics and multi-modal passenger transport examine how DLTs can help policy makers to address some persistent transport sector problems. The report discusses several cases where governments have initiated regulatory adjustments to help the transport sector exploit DLT's potential.

The report expands on the findings of an expert workshop with 15 experts in September 2019 and the previous ITF report *Blockchain and Beyond: Encoding 21st Century Transport* (2018).

What we found

DLTs are shared databases maintained by a distributed set of users without oversight from any central authority. Blockchain is one type of DLT in which each piece of new data (a block) added to the shared ledger is attached in sequential order to all previous blocks (the chain). At their core, DLTs address a recurrent question in a number of economic sectors including transport: how can a group of actors who do not know or trust each other carry out transactions amongst them and reach consensus?

Transport services rely on various trust mechanisms based on centralised record-keeping and third-party audit which enable transactions and help prevent fraud. This trust architecture has improved transport services and trade, but also contains costly frictions and inefficiencies. DLTs can address some of the persistent challenges in the transport sector relating to trust and consensus – challenges linked to clearing transactions amongst multiple parties with divergent interests, provenance authentication, asset management, and auditability.

Addressing these challenges through DLTs could reduce friction and save costs. To make DLTs a success in the transport sector, savings need to outweigh the costs of new soft- and hardware, in reconfiguring well-established systems and training, attracting and retaining digitally savvy workers. The high cost of adopting DLTs and technical challenges revealed by pilot programmes have somewhat dampened the initial excitement around blockchain and other DLTs.

Public and private stakeholders continue to explore the potential of DLTs to support regulatory enforcement and increase efficiency in transport despite this disillusionment, which follows the typical hype cycle for technology innovation. DLTs are capable of maintaining secure data records and enabling peer-to-peer transactions through auto-executing algorithms called smart contracts. By simplifying transactions, improving data history auditability, and removing data from single points of failure, DLTs can simplify enforcement and foster sustainability in the transport sector.

The absence of trust in supply chains and multi-modal passenger trip chains can lead to exclusionary business practices where opaque transaction rules are determined by just a handful of actors. Examples include a lack of price transparency for shippers or for passengers who use different mobility providers along their trips. Moreover, the lack of trust between actors and difficulties with data interoperability among the distributed stakeholders create frictions that undermine transactional and regulatory efficiency.

By sharing encrypted data securely through DLT, businesses and regulators would be able to detect attempts at tampering with transaction histories and track products across different handlers. A decentralised database also increases data security by making a hack more difficult. Smart contracts can facilitate secure peer-to-peer transactions, potentially providing an alternative to the processing delays and fees incumbent in ledgers maintained by a central authority.

DLT's main features can enhance regulatory enforcement and transaction efficiency in the transport sector. They can result in fairer competition, less pollution and congestion, and better mobility options for travellers. To reap such benefits, public authorities may need to adopt policies that encourage investments in DLT technology, which will improve its performance and generate stronger use cases.

At present, most regulatory frameworks do not account for technological developments like DLT, which can prohibit innovation. Through regulatory adjustments, the public sector can ensure that DLT-related innovation is taken up where compelling use cases exist.

What we recommend

Make regulations more flexible to accommodate the use of blockchain and other distributed ledger technologies

DLTs are used and developed in many sectors simultaneously and may not fit neatly into the jurisdiction of any existing ministry or regulatory framework. Authorities should adopt a regulatory framework for DLTs that ensures oversight and coordination without stifling innovation. This might include establishing an inter-ministry working group to determine institutional responsibility for certain DLT uses, and setting basic legal parameters for DLT that enable industry self-regulation. By adopting a flexible approach, regulators might discover more effective methods of regulating this new technology compared to existing regulatory frameworks for digital innovations.

Use regulatory sandboxes to promote innovation while minimising risks

Regulatory sandboxes combine a conditional exemption from certain regulatory constraints with enhanced public oversight. They allow firms to experiment with transport solutions based on DLTs under the watch of regulators with more flexible or relaxed rules. Firms can run pilots within defined legal, geographical, use-specific parameters in a way otherwise not permitted under prevailing regulation. Experimentation in such a controlled environment may reveal the best approach for DLT regulation, as well as identifying use cases aligned with public sector objectives that warrant further development.

Actively engage with transport industry initiatives around distributed ledger technologies

Authorities should engage from an early stage with consortia working to set standards for transport DLTs. This will allow regulators to contribute public sector views and concerns to important debates within the industry and to gain experience with different DLTs, preparing authorities for potential large-scale implementations later.

Require some level of open data access for transport applications of distributed ledger technology

Supply chain stakeholders and passenger mobility providers shield data to preserve competitive advantage, hiding it from each other and from authorities. This lack of transparency forces shippers and travellers to rely on data brokers and may deprive them of access to information about the best transport options. DLTs allow shared data to be encrypted and be accessible to legitimate parties only. For DLTs to provide users with compiled data from different sources, however, that data must be accessible. Governments can mandate that transport actors publish semi-open data access protocols, allowing the integration of data from disparate sources. By combining open data and DLT encryption, data interoperability between transport stakeholders may lead to increased transparency in supply chain transactions, and a more complete suite of mobility options for transport users.

Make transport policies machine-readable

Beyond assuring that distributed ledger technologies can incorporate data from competing firms, regulators must be able to engage with DLTs directly. Certain regulations can be made machine-readable to simplify and improve compliance. Algorithmic code-based laws can be written directly into DLTs standards and smart contracts. Robust official identifiers for individuals, firms or vehicles, for example, can also be attached to DLT accounts thus increasing accountability and improving verification processes. This would require authorities to invest in their capacity to understand, deploy or regulate DLTs, but could drastically improve the efficiency of customs enforcement, quality control, security check procedures, fraud detection, and other regulatory procedures.

Run pilot projects to identify use cases for distributed ledger technologies in the public sector

To understand how Distributed Ledger Technologies work and where they are most useful, government-run pilot projects will be useful. They would signal that the public sector is taking DLTs seriously and thereby encourage further development of the technology by the private sector. Gaining familiarity with DLTs will help authorities to draw independent conclusions about the utility of blockchain and other DLTs, rather than relying on industry stakeholders. Government support of local academic research and technology firms could be an entry point to create such pilots. Launching low-risk pilots through interested ministries and other public sector agencies tasked with scoping the potential of emerging technologies could be another way to scope the potential of DLTs.

In what ways are distributed ledger technologies relevant for transport?

The transport sector generates value through the coordinated action of multiple, distinct stakeholders. As such, it is not unlike other sectors such as the energy, health and finance sectors where streamlined coordination and reduced friction amongst different actors can deliver greater efficiency and improved individual and societal outcomes. In this context, the emergence of new forms of digital record-keeping and processing, such as those that leverage blockchain and other distributed ledger technologies (DLTs), fits into the broader context of the significant digitisation of multiple economic activities, including transport. These technologies create possibilities for more streamlined operations and lower costs and enable the creation of new organisational and business models that further build on these efficiencies.

The benefits of DLT solutions are inherently linked to, and dependent on, broader digitisation trends – but the benefits of digitisation and DLTs are distinct and should not be conflated. Digitising trade documents or public transport ticketing generates significant benefits and could conceivably involve DLTs, but much of the value stems from electronic record-keeping, not from the particular form of electronic record-keeping represented by distributed ledgers.

What value, then, do DLTs create for transport applications? At their core, DLTs – including blockchain – address a recurrent question in a number of economic sectors, including transport: how to get a group of actors who do not know or trust each other to reach consensus? These actors may be participants in a complex global supply chain or may be different mobility service providers who may have competing interests. The question of transactional trust has been the impetus for third-party intermediaries to manage and coordinate transactions amongst these actors. These trust mechanisms have built on centralised record-keeping and third-party audit as a way of preventing fraud. The systems that have emerged from this trust architecture have been robust and have improved trade and transport outcomes – but they also contain frictions and inefficiencies that impose costs. Until recently, these were seen as an inevitable cost of doing business amongst distributed parties.

Specifically, DLTs have the potential to address a certain number of persistent challenges in the transport sector as they relate to establishing trust and consensus – challenges linked to clearing transactions amongst multiple parties with divergent interests, provenance authentication, asset management, and auditability.

Addressing these challenges through DLTs could potentially remove much friction and deliver significant cost savings. The successful uptake of DLTs, however, is contingent on these savings outweighing the costs imposed by the DLT technology and the cost of shifting from old practices to new ones. These are not insignificant and include investments in new technologies and hardware, the cost of reconfiguring well-established systems and costs associated with training existing workers and attracting and retaining a digitally savvy workforce.

Blockchain and other DLTs hold promise, but their application is not inevitable, nor is it even likely beneficial in many cases. Thus the central question for public authorities is, what stance they should take vis-à-vis this technology and what actions should they take now to ensure that policy action supports, or at least does not block, the most promising DLT applications? Answering this question is not straightforward as there is considerable hyperbole regarding the putative benefits of DLTs and much uncertainty regarding future development of the technology. Nonetheless, there are clear use cases where DLTs can already deliver benefits. This report examines several of these in the context of logistics and passenger transport.

Hype and reality: Where do we stand regarding blockchain and other distributed ledger technologies?

After much early hyperbole around the benefits of blockchain and other DLTs, practitioners and commentators from various industries appear to be growing increasingly sceptical of the technology's real-world utility (Hajric, 2019). The Gartner 2019 Hype Cycle states that blockchain has now entered the "trough of disillusionment", with market interest waning as expensive experiments and implementations fail to match lofty expectations (Rimol and Goasduff, 2019). This is a far cry from the initial excitement around blockchain that saw it as the antidote to at least 187 of the world's gravest problems (Griffith, 2018).

It seems likely, however, that current disenchantment with blockchain and other DLTs is a product of initial overhype and a poor understanding of these technologies strengths and limitations, rather than proof of the DLT's underwhelming capabilities (Bello Perez, 2019a). As with any new technology, learning through doing is necessary. Pilots unable to scale up are not necessarily failures, but necessary parts of a process that gradually may help to reveal where DLTs can deliver real value.

Though DLTs' descent into a "trough of disillusion" has signalled to some that its moment has passed, Gartner also stated that important developments are underway that may soon lead to greater mainstream adoption of DLTs (Bello Perez, 2019b). Despite scant evidence of tangible impact so far, DLTs continue to attract attention from experts across sectors. This suggests that, like in the early stages of the internet, there is value hidden in the "raw material" of the technology. Just because the raw material has not yet been converted into real value does not mean it does not exist. It may simply mean that the kinds of use cases that deliver real value have not yet emerged from current experiments with the technology.

The challenge is to invest in DLT experiments in a targeted and informed way, so firms and authorities do not feel like they are wasting valuable resources. Targeting investment in a potentially expensive and poorly understood technology requires a clear understanding of what problems are to be solved, how blockchain and other DLTs function and what they can and cannot do, and in what contexts they have shown promise so far. DLTs are not the solution to every problem, but they may be the solution to some.

The goal of this report is to build on these efforts by clarifying what DLTs like blockchain can do in the context of transport, accompanied by illustrative use cases to serve as a reference for transport policy makers and industry stakeholders. Special focus is given to the role of transport regulators, so that the public sector may better understand its role in unlocking DLT's potential.

Abandoning DLT now would mean forfeiting potential benefits resulting from its eventual improvement and widespread adoption. Industry actors and regulators may take a "wait and see" approach due to the costs associated with putting in place DLTs, but it is nonetheless productive to develop a critical understanding of how it works and what it can be used for. To dismiss DLTs altogether would be to risk becoming a "late adopter" forced to play catch-up if it reaches maturity, similar to entities that suffered later for ignoring the rise of email and the internet (Gai, 2019). This report aims to increase the understanding of where, how and under what circumstances DLTs could have a role to play in improving transport outcomes in order to guide policy.

Technology basics of distributed ledger technologies

DLTs are "a type of shared computer database that enables participants to agree on the state of a set of facts or events in a peer-to-peer fashion without needing to rely on a single, centralised, or fully trusted party" (Nelson, 2018). Instead of one entity managing and recording all transactions, these are recorded on the shared ledger all permissioned actors possess such that each one has access to the same up-to-date information. Crucially, these records are not copies of the ledger; there is still one unique ledger, but it is digitally distributed among all members. The decentralised database thus has no single arbitrator or monitor (BBVA, 2018), and is instead managed by participants via network consensus, which can take many forms and is decided by the type of DLT used.

Distributed ledgers can also be encrypted so that the complete record of transactions is viewable by all members, but sensitive details relating to these transactions are obscured to all except specifically permissioned users. Encryption ensures privacy and the protection of commercially sensitive information while retaining the benefits of decentralised record-keeping. This feature may be particularly appealing to commercial entities which see the benefit of establishing a mutual ledger system, but fear that their competitiveness could be compromised through the exposure of sensitive information. The decentralised nature of DLTs also makes it extremely difficult to tamper with transaction histories or other data without detection, since any changes would be recorded on all participants' ledgers. While this is sometimes referred to as *immutability*, DLTs are not so much immutable as "tamper-evident". Some DLTs are "append-only", which means that once data is recorded on a ledger it can be adjusted by a subsequent addition, but never removed.

Together, these features create a distributed ledger system that offers increased transparency and faster exchanges of reliable information, effectively eliminating the need for a third-party intermediary to authenticate and secure sensitive data or broker transactions between unknown parties. However, unresolved challenges around the transaction speed, security, scalability, cost effectiveness, and ease of adoption of DLTs remain.

Distributed ledger technologies and blockchain

DLT has become an "umbrella term for technologies that store, distribute or exchange, publicly or privately, value between entities/users/peers based on shared transaction ledgers" (OECD, 2019a). Blockchain is a specific kind of DLT in which each piece of information is securely sealed in a cryptographic record (a "block") and attached in sequential order to all previous blocks on the ledger (the "chain") (BBVA, 2018). As with any DLT, the transaction history of this "blockchain" is shared among all platform participants without any single central authority.

Preference for one form of DLT over another is dependent on priorities regarding transaction speed, transparency, anonymity and security. How to distinguish between DLTs according to needs and preferences relative to the transport sector will be discussed throughout the report, but a basic distinction between models is provided below.

DLTs can be broadly categorised as either "open" or "closed" networks, with tiers of access for each. The most decentralised, and least subject to control by one actor, are open DLTs that are both public and permissionless. This means that there are no restrictions to accessing the distributed ledgers. Anyone in the world can conduct transactions, view others' transaction histories (encrypted for anonymity), and validate transactions via the consensus process. Bitcoin and Ethereum are two examples of "public permissionless" DLTs.

Open permissionless distributed ledger technology ("pure" blockchain)

The main benefits of a public permissionless DLT, like the Bitcoin blockchain, are security and anonymity, ensured by full decentralisation and robust data encryption. The dispersal of data across all platform users makes it extremely difficult to hack, and the encryption of user IDs ensures that while every transaction is visible on the blockchain, details of those engaged in those transactions are not exposed. These features are partly responsible for Bitcoin's reputation as a method for illicit trading (Blundell-Wignall, 2014), though such features also have a broad range of potential applications.

Public permissionless blockchains rely on network consensus to validate transactions in lieu of any central controlling entity. Though highly secure, this process requires immense computing power and is prohibitively slow compared to conventional transaction methods like bank certification and credit cards. This has proven to be a barrier preventing public permissionless blockchains from significantly scaling up. There is also no authority to appeal to should an error or malfeasance occur on the platform. Nonetheless, the neutrality of public permissionless blockchains has attracted the attention of some in the transport sector, including those who believe its anonymity and decentralisation could resolve mobility providers' reticence to share their data. Such a breakthrough might help bring a fully integrated Mobility as a Service (MaaS) ecosystem to fruition.

Open permissioned distributed ledger technology (similar to a "read-only" shared online document)

By contrast, a "public permissioned" DLT is still "open" but slightly more constrained in the way in which actors engage with it: while anyone in the world can view its content, writing transactions on a public permissioned ledger is limited to those with authorised access. This design offers more transparency than fully centralised data systems, but it requires some central management to establish a method of authorisation and enforcement. For some blockchain purists, this undermines what they consider that technology's main advantage. But public permissioned DLTs may be beneficial for certain purposes: transparency is ensured by keeping the ledger content open and public, while data accuracy and user compliance with platform protocol are ensured through authorised access.

The public permissioned DLT is analogous to a shared document (like a Google Doc) that allows all viewers "read-only" access, but extends "write" permission to only a few vetted actors. It is also similar to public record databases for documents like property deeds, where the public has access to transaction history but sensitive information may be obscured and only authorised parties can alter details. Indeed, public authorities are already exploring the use of permissioned blockchains to manage property records (Berryhill, Bourgey and Hanson, 2018).

One potentially effective use for a public permissioned blockchain in transport could be monitoring automobile histories and registration details. Certain data elements like odometer readings, ownership history, and registration status are often falsified or erroneously recorded. These could contribute to crashes, increase maintenance costs and otherwise impact owners or manufacturers. Relevant information about a car's history could instead be stored securely on a distributed ledger as a matter of public record. Though the vehicle's ID would be obscured via cryptography to ensure the privacy of owners, the "read by all, write only by selected authors" functionality would ensure transparency. Only certain authorised car industry actors could add to the vehicle's data history, including regulators, manufacturers, retail agencies, insurance companies, mechanics, and car owners. This could reduce the risk of vehicle data fraud, bolster consumer data protection, and increase vehicle consumer protections by creating a single distributed vehicle history (see "Supply chain case 2: Fighting fraud in the car industry", page 30).

Closed permissioned distributed ledger technology (private "consortium" ledger)

Unlike open DLTs, "closed" distributed ledgers require authorisation from participants for all uses including reading, writing, and data verification (OECD, 2019a). This may make them best for uses where participants prioritise speed and efficiency over external transparency, full decentralisation, and/or perfect anonymity. Industry consortia, like those interacting in logistics chains, are likely candidates for the uptake of closed distributed ledgers (OECD, 2019a). Unlike open ledgers, no part of the platform's data history is visible to non-authorised members. A closed distributed ledger usually means transaction speeds are much faster as well. With speed and vetted access comes increased centralisation, which may undermine the potential benefits of a neutral DLT for smaller firms. Closed DLT networks can also be more susceptible to security breaches, due to the higher level of centralisation and lower number of participants.

A closed permissioned DLT may be an appealing method of record-keeping for those who rely on others' data to perform efficiently and comply with regulations. Closed DLTs offer consortia members a way to establish a "single source of truth" for industry data like shipping container numbers, fuel quality readings, and flight logs. A key question for these types of applications is how DLT-based systems compare to existing record-keeping and database management systems – and in particular, the cost of creating an alternative database and data access system, switching to that system and maintaining its use as compared to the cost of the system it would displace. This is especially relevant since the more closed and permissioned a DLT is, the more closely it resembles existing data management solutions.

Figure 1. Main types of blockchains segmented by permission model

Blockchain types			Read	Write	Commit	Example
	Open	*Public permissionless*	Open to anyone	Anyone	Anyone*	Bitcoin, Ethereum
		Public permissioned	Open to anyone	Authorised participants	All or subset of authorised participants	Sovrin
	Closed	*Consortium*	Restricted to an authorised set of participants	Authorised participants	All or subset of authorised participants	Multiple banks operating a shared ledger
		Private permissioned ('enterprise')	Fully private or restricted to a limited set of authorised nodes	Network operator only	Network operator only	Internal bank ledger shared between parent company and subsidiaries

Note: * Requires significant investment either in mining hardware (proof-of-work model) or cryptocurrency itself (proof-of-stake model).

Source: Hileman and Rauchs (2017).

What are the trade-offs between different distributed ledger technologies in the context of transport?

At first glance, open permissionless DLTs like blockchain seem appealing due to their ability to spread power and responsibility among actors. However, scaling up these applications and, especially, speeding them up is complicated by the time and computing power required for reaching consensus. Anyone can join a public blockchain, and their distributed system of consensus improves security and removes the need for a central third party; but a larger blockchain also means slower consensus. Ethereum, another example of a robust open blockchain platform, is highly secure and adequately decentralised, but slower than others (Peh, 2018). Blockchain and many other DLTs fail to replicate or even approach the transaction processing speeds of financial transaction clearance firms like Visa or MasterCard – and this is a concern since many, but not all, transport applications involve a large number of transactions and require reactivity and speed.

Closed DLTs are most useful for consortia that do not benefit from or seek increased participation. Limited participation means faster consensus, but it also means higher vulnerability. On a permissionless DLT, consensus is spread out across so many members that it is difficult to mount a wide enough attack that would compromise a majority of nodes. On a closed DLT, hackers need only to compromise the weakest link. Closed DLTs also feature some form of central authority that controls access and sets rules which takes away some of the benefits of decentralised governance inherent in open and permissionless distributed ledgers. Hyperledger Fabric is a closed DLT platform widely used by firms and industry consortia. It is considered fast and fairly secure, but also highly centralised (Peh, 2018).

Like any new technology, DLT can create new dilemmas while resolving old ones. The internet has accelerated the speed of communication and transactions, but has also created a platform for fraud and reduced accountability, endangering citizens and confounding governments. Despite the improvements the internet has brought to the world, society has struggled to isolate its benefits from its drawbacks. DLTs may present similar trade-offs (Lumb, Treat and Jelf, 2016). Auditability of transactions can guarantee that records aren't altered retroactively to obscure malicious tampering or conceal fraud, but it can make erroneous data harder to retroactively correct. Decentralisation can streamline exchanges, avoid third-party commission fees, and increase user data security, but at the expense of transaction speeds and the absence of an authority to arbitrate disputes. In practice, the immutability of inaccurate data could lead to costly legal disputes, and even poorer enforcement outcomes than without DLTs. Likewise, a decentralised MaaS platform underpinned by a sluggish public DLT could clog digital platforms and physical transport.

Despite little evidence of large-scale use cases in transport to date, interest in DLT persists because its potential impact could be profound. If actors with divergent interests could exchange sensitive information anonymously and directly without any risk of fraud, error, or loss, then transaction costs would decrease, records could be made open-access, and certain regulations could be enforced automatically.

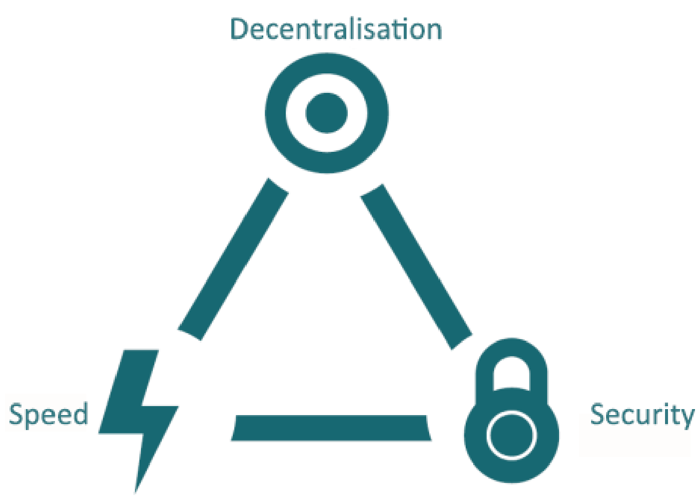
Below is a brief overview of DLTs' unique features, their advantages and disadvantages in their current iterations, along with ideas for improvement.

The "trilemma" problem

Some industry experts envision DLTs as the next internet: a neutral public good that enables users to connect directly, levelling the playing field for new actors, increasing trust, and streamlining trade (Towers-Clark, 2019). Despite this potential, DLTs have still not been deployed at scale in transport due to the aforementioned trade-offs between speed, decentralisation and security.

As shown in Figure 2, this is known as "the trilemma" problem (Asolo, 2018). Public DLTs offer users transaction security without needing central institutions to enforce terms, but intensive computing requirements result in slow transaction speeds. Permissioned DLTs can have high transaction speeds thanks to their consensus rules – but limiting membership requires centralised governance, which may compromise both anonymity and security without external (to the DLT) oversight protocols.

Figure 2. The distributed ledger technology blockchain's "trilemma" trade-off between security, speed, and centralisation



Source: Adapted from Debonneuil (2019).

A hybrid DLT aims to combine the transparency of public DLTs with the speed of private ones, while keeping centralisation to a minimum. For instance, the ability to conduct transactions can be permissioned, while certain data can be available "read-only" for the public. Such a hybrid platform could include private "side chains" that quickly process individual transactions, while posting transactions on a public "main chain" in regular intervals for transparency or when a verification by consensus is needed (Peh, 2018; Mearian, 2019). This structure could retain the speed of private DLTs while applying the security of the public one, allowing for scalability.

Ensuring interoperability and the computing power necessary for a hybrid DLT may present its own challenges. But industry experts continue to pursue solutions to the scale trilemma, with hopes that the eventual benefits will be worth the investment (Asolo, 2018).

Is distributed ledger technology data really immutable? And is that good or bad?

In the context of blockchain, immutability means that "once data has been written to a blockchain, no one, not even a system administrator, can change it" (Berryhill, Bourgey, and Hanson, 2018). This is because data on the ledger is distributed across many parties, requiring consensus from a majority of users to change it. The difficulty of changing data recorded on DLT was initially touted as a unique advantage, but real-life pilots quickly revealed that it is not always a good thing. Blockchain and other DLTs are considered secure because they prevent users from making changes without consensus approval from the network – but what if the data entered is wrong?

"Immutability" has become a term used to describe the difficulty in altering data entered on DLT platforms, when in certain cases the more accurate term would be "tamper-evident" or "auditable". DLT data is not so much "immutable" as able to identify conspicuous discrepancies in data that may help detect tampering. The level of a DLT's "immutability" depends on the type of DLT in use and platform governance design, which itself is determined by a platform's degree of centralisation.

How platform governance and centralisation impact immutability

Different types of DLTs may have different options for addressing erroneous or fraudulent information entered on a platform. Because a public permissionless DLT is fully decentralised with no limits on access and no central authority, there is effectively no way to remove or alter information once added, and no way to hold bad or negligent actors accountable.

Public permissioned DLTs have an authentication layer that prevents untrusted actors from contributing data to the platform. They also theoretically have a smaller number of contributors, which makes it easier to reach consensus regarding modifications to data stored on the digital ledger. But the potential advantages of more flexible "immutability" come at the expense of some centralisation.

This trade-off is even more pronounced for closed permissioned DLTs, whose users are often a small group of consortium members with some familiarity with each other. While closed permissioned DLTs usually have higher centralisation and a smaller group of users, this may make it easier to reach consensus quickly to correct a mistake. However, in all cases, correcting an error on DLT is cumbersome and requires significant buy-in from other users, which becomes increasingly difficult to obtain as groups of platform users get larger and less centralised (Lumb, Treat, and Jelf, 2016; OECD, 2019a).

These trade-offs underscore the need to get platform governance of permissioned DLTs right: platform operators must establish a system to vet and select who can add data to the network, how this data can be vetted, and a method of accountability. However, such governance rules should not be used to benefit certain actors and undermine fair competition. This issue is discussed in depth under "Supply chain case 1: Streamlining Payout for the Shipping Industry", page 26.

Direct ledger technologies can help detect inaccuracies – but cannot guarantee accuracy

Incorrect data can still make its way onto DLTs through negligence or intentional fraud. The weakest point within any DLT is the establishment of an accurate representation of the link between a digital record and a physical asset. Data entry mistakes and digital tags scanned onto a DLT platform while attached to the wrong physical item could be accurately confirmed at each checkpoint in the supply chain but would perpetuate the original misidentification (Yamada, 2018). Even once a mistake is discovered, legal accountability may be complicated by the fact that there was no discrepancy recorded in, or malfunction of, the DLT. Thus, DLT's immutability does not inherently guarantee the accuracy of data if it is incorrect upon entering the system in the first place; it merely ensures that data put on a DLT platform cannot be deleted or modified afterwards.

Even without providing legal recourse or guaranteeing accuracy, the "tamper-evidence" of DLTs may benefit firms and regulators who wish to learn from data. DLT tamper evidence may not be useable in a court of law, but it can be used by parties to identify suspicious activity. Firms could then revisit partnerships, and regulators could narrow the possible sources of illicit activity (Schmahl et al., 2019).

Garbage in, garbage forever

As in other computer systems, DLTs suffer from the "garbage in, garbage forever" problem. DLTs reliably validate the accuracy of data stored on the platform, and thus maintain its integrity – but these benefits are mooted when incorrect data are entered into the DLT in the first place. The difficulty in removing erroneous data can cause miscommunication between actors, pollute the database and enable fraud to take place undetected.

Thus the quality of initial data input onto a DLT platform is essential to achieving the potential benefits of the technology. Resolving this issue may be critical to how regulators approach DLT. While DLT can significantly reduce the falsification of data, it does not make it impossible. DLT is most vulnerable to fraudulent or erroneous data at the moment this data is first appended to the distributed ledger. Data can be accurately traced back to provenance, but if the original contributor assigns a digital tag to the wrong physical asset, such as a car part, its tag can be validated at each step in the supply chain and still reach the consumer (Yamada, 2018).

Box 1. Examples of immutability beyond DLT

Workarounds exist for other types of immutable documents. A popular analogy for a solution to the immutability of a DLT smart contract is the United States Constitution, where amendments cannot be removed but only addressed by other amendments. The 18th Amendment made alcohol illegal; since repealing an amendment is impossible, the 21st Amendment had to be ratified to repeal the 18th Amendment, making alcohol legal again. The 18th Amendment is still in the Constitution, but the 21st Amendment nullifies it.

Another analogy is an edited social media post. In order to prevent users from having to delete and re-post after discovering a typo, users can now edit a post after publishing. However, the post will be marked "edited", and viewers can still access the original text if they want. This ensures that, although the user can update a post as they see appropriate, they cannot erase previous versions from history.

The DLT equivalent would be to publish a new smart contract that includes an adjustment or nullification of the old one in its algorithm. For instance, if a smart sensor is discovered to be recording container temperatures one degree Celsius too low, a smart contract can be written that agrees to add 1 degree Celsius to each temperature from the original recordings. The new smart contract becomes the official record of the container's temperature history, even though the old data still exists on the DLT.

Smart contracts

Third parties have been essential to exchanges of value because they help validate the identity and trustworthiness of the other two contracting parties, act as a mediator and arbitrator, and record and enforce the terms of a transaction. Third-party intermediaries have helped stimulate trade around the world by guaranteeing security and equality of treatment for parties who want to make a transaction but do not trust each other. These intermediaries also charge commissions for their services, cause delays, and make mistakes, creating inefficiencies that diminish benefits to trading parties. Still, throughout history, intermediaries have found work in contexts marked by an absence of trust.

DLT may obviate the need for these intermediaries. Smart contracts can facilitate exchanges of value (whether currency or sensitive data) directly between two parties without any need for a third party. Value is exchanged securely, automatically, and in real time as soon as algorithmically encoded conditions are met. These conditions are mutually agreed upon beforehand between parties and entered directly into a smart contract, which can be designed for multilateral or recurring transactions as well (Schmahl et al., 2019).

Smart contracts may enhance regulatory compliance and enforcement by enabling direct peer-to-peer (P2P) transactions, even though they circumvent third parties like banks or governments. Regulators can work with DLT operators or consortia to embed legal standards into platforms and smart contracts, thus ensuring that smart contract transactions cannot, by design, violate the law.

For example, smart contracts linked to sensors embedded in private cars can record vehicle emissions and odometer reading updates on a DLT at intervals consistent with state requirements (for more, see "Supply chain case 2: Fighting fraud in the car industry", page 30). However, regulators would first have to adopt laws that can take advantage of DLT's capabilities in order to benefit (ITF, 2019a). In the case of car data, this would require a law mandating vehicles to automatically log and upload data to a regulatory DLT via smart contracts. Although achieving such coordination between law and technology would take some effort, the benefit would be simplified emissions monitoring and odometer fraud enforcement.

As discussed in the previous section, smart contracts have some inherent risks. Mistakes made in peer-to-peer smart-contract transactions on a decentralised database are difficult to amend, impossible to erase, and may provide no recourse for adversely impacted parties. DLT's potential to eliminate commission fees, accelerate transaction speeds, and automate regulatory enforcement, however, could produce tangible efficiencies for individuals, firms, and authorities.

Supply chains and the transport industry: Improving identity management and traceability through distributed ledger technologies

The large-scale linkage of suppliers and producers via global supply chains has expanded consumer welfare and extended labour markets to previously remote parts of the world. Counter-balancing these benefits, these far-flung logistics networks have also generated externalities – including pollution, congestion, and crime – that undermine social and economic objectives.

A single item's journey may pass through multiple continents, trade zones, countries, ports, factories, storage facilities, distribution centres and couriers before reaching a retailer or customer. These multiple touch points expose supply chains to fraud and error. Pressure from tight margins and schedules often requires supply chain participants to conduct transactions with unknown entities. Each stakeholder involved may have its own unique interests, software and legal jurisdiction, generating a lack of trust that can undermine fair competition, public health and regulatory enforcement efforts. Actors are often unaware of who has processed their cargo before them, and may not know who will take responsibility for it further on in the supply chain (Schmahl et al., 2019; Ganneriwalla et al., 2018).

Whether it is a logistics company delaying port traffic to verify a bill of lading, a car crash caused by counterfeit parts, a courier clogging streets to make multiple delivery attempts, or a cargo ship emitting low-quality fuel, inefficiencies in transport logistics and failures of regulatory oversight can have broad societal impacts. These persistent problems could be mitigated by leveraging industry data to enhance visibility and accountability, but currently data remains held and processed in silos due to firms' fears of losing a competitive edge and a lack of trust that other supply chain actors would process it accurately (Project 44, 2018). This absence of trust fosters dependency on centralised databases, often held by third-party intermediaries, to ensure interoperability. The absence of trust also heightens the role of central authorities like banks and governments to enforce transaction terms and settle disputes. But these entities are also vulnerable to hacks, cause processing delays, and may charge excessive commissions.

Allowing reputable firms and regulators to securely share data and exchange payment could address these inefficiencies and create a more sustainable, equitable, safe supply chain (Schmahl et al., 2019; Radocchia, 2018). As discussed in the case studies in the following chapter, the contents of containers could be verified more quickly and tampering could be more effectively ascertained. Fuel quality and the authenticity of spare parts could be confirmed, keeping dangerous or polluting products out of circulation. Vehicle histories could be shared between all stakeholders without risk of erroneous documentation. Last-mile logistics could be decentralised, allowing for more flexible delivery times and transport modes. Business partners on opposite sides of the world as well as couriers reaching a customer across town could exchange payment in real time. To date, however, the balance between decentralisation and secure data has remained elusive.

The potential impact of distributed ledger technology on supply chains

DLT features such as encryption, data distribution and smart contracts have already attracted attention in the supply chain sector. Supply chain actors typically compensate for the risks of unknown and potentially untrusted trading partners by building and relying on relationships with business partners. DLT potentially provides an alternative trust architecture that is more rapid and scalable through the use of smart contracts, which allow supply chain firms to execute transactions in real time from across the world as soon as pre-determined conditions are met. This could dramatically expedite the process of confirming shipment contents in total before releasing payment.

Although DLT cannot ensure the accuracy of data initially entered, decentralisation may partly relieve concerns of tampering or “fat finger” errors and bolster faith in supply-chain data history by creating an auditable trail that can help identify fraud. By placing odometer readings, car part serial numbers, and fuel quality readings on DLT, industry actors can prevent fraud and protect their brand integrity, while regulators can protect consumers.

Encryption can also ensure the privacy and integrity of DLT data, which may help encourage the decentralisation of tasks that typically rely on third-party intermediaries or central authorities. The delivery to a customer is the final link in many supply chains but is complicated by the heterogeneity of final destinations and the complexity of the urban context for many deliveries. The traditional, centralised hub-and-spoke model of delivery is challenged by the evolving reality and may not be meeting consumer expectations in many instances (Jones and Lanning, 2017). Encryption and smart contracts may allow for a decentralised model of last-mile deliveries, where couriers and end-customers can connect directly via a DLT platform (USPS, 2016; Drif, 2019; Lopez, 2017a). For more discussion on DLT and last-mile delivery, see “Supply chain case 3: A decentralised last-mile marketplace” on page 35.

Applied to the supply chain, these features of DLT can have broader societal impacts in line with policymaker goals. An accurate record of fuel quality contents stored on DLT can help enforce fuel quality standards in shipping and reduce pollution. A decentralised last-mile courier service with flexible delivery times thanks to couriers and users connecting directly on DLT can potentially reduce the road and curb congestion caused by delivery vehicles by shifting loads to smaller vehicles, including cargo bikes, or to off-peak delivery times. Odometer readings for the entire history of a vehicle stored in one DLT platform viewable by all permissioned parties can prevent consumer exposure to fraud. And streamlined supply chain transactions through smart contracts can increase efficiencies in the supply chain which can be passed down to consumers.

What are the benefits of distributed ledger technology for regulators?

The opaque nature of supply chains can have far-reaching repercussions, frustrating regulators far beyond the customs process. Even if counterfeit or sub-standard goods are discovered – and they often are not – authorities may struggle to pinpoint the source in the absence of any auditable and tamper-proof data history. Such quality-control breaches put the public at risk, but there is little incentive for firms to comply or hold partners accountable if regulatory enforcement is impossible.

Establishing a tamper-evident shared database for supply chains could simplify bureaucratic tasks and ease the burdens of enforcement. Protocols for customs checks, vehicle registration, last-mile delivery, and fuel quality verification could all be improved. Scandals around product recalls, unethical sourcing, inaccurate emissions data and package theft could be avoided, helping regulators save time and resources through a reduction of complaints, legal disputes, pollution and public pressure (OECD, 2019b). Similar to how medical resources are better spent on preventing disease rather than treating it, DLTs could facilitate enforcement that prevents future fallout from illegal activity.

Authorities could benefit from a tool that has the potential to reduce the siloing of data, auto-enforces contract terms, encodes compliance, increases accountability and establishes a tamper-evident transaction history (Schmahl et al., 2019). DLTs could help customs agents to better discern if a container has been tampered with, or if mandatory conditions (e.g. temperature) have been maintained. Regulatory standards for odometer and vehicle history could be incorporated into a DLT platform, encoding compliance in the used car market. Parcel delivery disputes could be mitigated, and polluting counterfeit fuel could be kept off the market.

Smart contracts

The case of addressing odometer fraud via smart contracts illustrates the use of DLTs in transactions amongst unknown parties. Two sets of smart contracts could greatly reduce odometer fraud. Authorities could require all vehicles to have a "smart sensor" that periodically records and stores odometer data on a DLT; and in order to legally sell a vehicle, the seller and buyer would have to confirm that the readings on the car and the DLT match. The first smart contract automatically sends car data to the ledger at regular distance intervals to ensure accurate readings. The second one ensures that the buyer cannot legally gain ownership of the car until s/he confirms the consistency of the odometer reading through the DLT platform. This would minimise active enforcement, allowing regulators to establish parameters that "govern" the transaction automatically through DLT far ahead of time. Read more about how DLT could curb odometer tampering in "Supply chain case 2: Fighting fraud in the auto industry" on page 30.

Smart contracts can also facilitate exchanges between supply chain firms that could significantly deter shipment disputes and payment delays. On any given day, as much as USD 140 billion in shipping-related payments are delayed due to disputes, with the average firm waiting 26 days for its payout (Krishnan, 2018). Such disputes and delays are usually due to erroneous information on supply chain documents like letters of credit or bills of lading, or to the convoluted multistep processes required to confirm the accuracy of those documents in order to avoid even longer delays. As discussed under "Supply chain case 1: Streamlining payout for the shipping industry" on page 26, smart contracts could remove the intermediaries and reduce the data errors that lead to these costly delays.

Thus smart contracts could not only reduce litigation and circumvent third parties, but also simplify regulatory enforcement. Container checks, car part and fuel quality authentication, last-mile package receipt, and other supply chain processes could be executed automatically in real time as soon as conditions – both private and public – are met. Instead of reacting to a counterfeit car part or contaminated fuel scandal after it happens, DLT could help regulators prevent them in the first place.

Smart contracts are automated algorithms that require technical precision and expertise, with little recourse in case of error. Although terms should be agreed between two parties ahead of time, there is always the risk that a misunderstanding or simple coding mistake generates an uneven exchange. The preeminent smart contract cautionary tale is the exploitation of a flawed smart contract for "The DAO", a start-up fund run on the Ethereum public blockchain. A user identified a flaw in The DAO's smart contract and extracted USD 70 million in just a few hours (Falkon, 2017). Technically, the "hacker" did not break any laws, and the designers behind The DAO had no legal method of recovering the lost funds.

Distributed ledgers: A shared online document model for supply chains?

A smart contract can expedite and automate transaction processes, but once the transaction is complete, a record must be kept in case of a problem "downstream" in the supply chain.

The shortcomings of legacy supply chain ledgers are analogous to what happens when one person emails a document to several other people. The sender and the recipients may have agreed to not make changes to the document – but if each recipient downloads it and alters the content, intentionally or not, numerous different versions now exist. Anyone with access to the altered document can claim theirs is the authentic version, and each person may believe they have the same document as the others. This is dangerous when a document contains sensitive data, especially when in the hands of an untrusted actor.

DLT ledger systems are more similar to shared collaborative documents like Google Docs. They maintain a single version of a document, allow owners to control who has access to view and edit it, and record who made which changes to the contents and at what time. But DLTs improve on the shared document model by requiring consensus from members before an addition or change is accepted, and allow for the encryption of records so that sensitive information is not exposed. The "garbage in, garbage forever" issue of erroneous data stuck on a DLT platform remains a challenge, and could create new problems for firms.

DLTs cannot unilaterally end supply chain fraud and human error, but their immutability could catalyse more efficient trade practices while helping to hold bad actors accountable. For example, the temperature of a container transporting perishable goods can be recorded onto a distributed ledger throughout its supply chain journey, and linked to the firm in possession of the conveyance at each point. If the receiving retail firm is dissatisfied with the condition of the shipment, it can review the DLT-authenticated temperature history and address the problem directly with the responsible supply chain partner (Morris, 2019). DLT has been deployed similarly in the bunker fuel industry, which is discussed under "Supply chain case 4: Cutting pollution through fuel quality tracking", page 38.

DLT features like smart contracts and tamper-resistant authentication could substantially improve authorities' ability to regulate the global supply chain, systematising compliance and establishing a single version of truth for posterity. But regulators may first need to facilitate further development of DLTs by stabilising the evolving digital marketplace, so that private actors continue to invest in unlocking its potential. Regulators could then leverage these improvements to augment regulatory enforcement mechanisms, redirect human capital and support broader policy goals.

Regulatory support to facilitate advances

In order to reap the benefits mentioned above, the public sector must develop an understanding of how DLT works and establish regulatory frameworks that enable and support the technology where appropriate.

By participating in DLT pilots and consortia with the private sector, regulators can gain experience with DLTs and ensure that desired policy outcomes are incorporated into platform governance and smart contracts from the beginning. They can also undertake their own low-risk, small-scale pilots to better grasp the utility and challenges of deploying DLTs. Such public sector interest and investment in DLTs could give the private sector the confidence to continue exploring the technology's potential, and allay fears that an eventual scaled-up platform would be rejected by regulators.

In addition to building knowledge and joining consortia, authorities can support DLT innovation by establishing a flexible regulatory framework. In February 2017, Belarus became the first country in the world to adopt an official regulatory framework for blockchain-like DLTs. The decree, called the Digital Economy Development Ordinance, formed a special tax and legal regime for blockchain and crypto businesses located inside Hi-Tech Park (Belarus's Silicon Valley) which exempted them from restrictions on issuing, storing or trading digital tokens. Blockchain firms within the Hi-Tech Park were also granted tax breaks until 2023 (Yafimava, 2019a).

Malta also addressed DLTs in July 2018 with a package of three laws designed to build a dynamic regulatory framework for DLTs by establishing parameters without being restrictive. The package established an official government authority for DLT matters, clarified legal parameters for DLT-related activity, and granted the authority the power to investigate and fine bad actors (Box 2).

Box 2. Malta: A blueprint for DLT regulation?

In July 2018, Malta enacted three laws intended to establish a coordinated regulatory framework that will promote the country as an attractive base for blockchain firms and other DLT initiatives. The Malta Digital Innovation Authority (MDIA) Act established an official government body to address and encourage DLT development of tech innovation in Malta, included DLT in its defined role, and empowered the authority to fine bad actors. The Innovative Technology Arrangements and Services (ITAS) Act enabled the MDIA to grant official certification to qualifying tech firms, and requires said firms to have a designated administrator. The third law, named the Virtual Financial Assets (VFA) Act, regulates initial coin offerings (ICOs).

All three bills provide a useful template for other regulators, especially when evaluated together. The MDIA and ITAS Acts set legal definitions for DLT initiatives and establish a designated entity to observe, promote, and enforce DLT sector issues. This is a notable progression from US attempts to regulate DLTs so far. Despite being "considered the most advanced country in the world in terms of blockchain and cryptocurrency adoption", US DLT regulation has been largely limited to financial applications, which are executed across three different pre-existing agencies that are neither sufficiently familiar with nor singularly focused on the technology (Yafimava, 2019a). The VFA Act, though seemingly outside the scope of DLT for transport, is also noteworthy for transport regulators: as discussed in passenger trip chain case 2, "Peer-to-peer ride-hailing" (page 49), overly stringent restrictions on ICOs may push DLT-related businesses to a more flexible regulatory environment, costing that state the benefits of innovation.

Source: Feikert-Ahalt (2018).

Germany announced in September 2019 that it plans to construct a growth-oriented regulatory framework for blockchain that promotes entrepreneurship while ensuring sustainability, stability, privacy and fair competition without the need for active state intervention (Peaster, 2019). France, too, has announced its intention to create a regulatory framework for blockchain, partly to leverage decentralised data management to counter the risk of emerging data monopolies (Drif, 2019). This suggests that policy makers recognise that DLT can do more than just stimulate the private sector: it may be able to improve regulatory compliance as well.

Public authorities should be mindful that DLTs' decentralised nature and broad applicability means that conventional regulatory structures may not be suitable. Regulatory sandboxes can relax rigid legal restrictions within a confined experimental environment, giving DLTs space to develop while minimising public risk (McQuinn and Castro, 2019). Authorities can form interagency working groups to oversee these sandboxes, helping them to discern when DLTs are relevant to certain sectors and how to govern these digital ledgers collaboratively. Sandboxes can be a pragmatic alternative to early or over-regulation resulting from poor coordination between public agencies, which may stifle innovation and discourage creativity (Barbaschow, 2017).

Regulators can also enable data interoperability by requiring supply chain actors to provide open application programming interfaces (APIs), and by seeking to identify where regulations can be converted into machine-readable formats. This would allow disparate data and legal standards to be incorporated directly into smart contracts and DLTs. Perhaps most important in an international context, authorities must coordinate to maximise interoperability amongst themselves. In the case of supply chains, one possible application would be a public sector cross-border DLT users' consortium of port and customs authorities.

In lieu of assuming the burden of developing digital infrastructure like the DLTs themselves, governments can incentivise the use of DLTs by market actors to construct fairer marketplaces. These incentives, including rules relating to DLT use, would signal long-term interest in DLTs to the private sector and establish rules of the game, convincing firms that efforts to improve the technology would reap benefits. Legal standards should focus on outcomes regarding safety, cybersecurity and accuracy, rather than on specific technology or software. This way, firms have the flexibility to experiment with novel ideas, while regulation can be more easily adjusted upon the emergence of an unforeseen technological development (McQuinn and Castro, 2019).

A spotlight on platform governance: TradeLens vs. IBM Food Trust

As discussed under "Supply chain case 1: Streamlining payout for the shipping industry" (page 26), TradeLens is a permissioned DLT platform designed for the supply chain industry. It was created through a partnership between IBM and Maersk, the world's largest shipping company, with the goal of creating efficiencies throughout the supply chain industry through a neutral platform that expedites and secures transactions. Maersk's rivals were initially sceptical of the TradeLens platform and of Maersk's intentions. Competitors were hesitant to share sensitive data on a system owned and controlled by Maersk, and many launched their own blockchain pilots instead. A DLT platform works best when it has a critical mass of users, but in its first few months TradeLens struggled to attract any significant industry actors (Allison, 2018).

By contrast, IBM's Food Trust blockchain pilot, which was designed for the commercial agriculture industry, attracted rival firms with relative ease. This has been attributed to the platform's approach to governance, which addressed data privacy concerns upfront by asking firms directly what they needed in order to participate. Firms insisted that since they would be sharing sensitive data on a platform with competitors, they needed granular control over their data, the ability to decide who has access to each transaction, and a say on who joins the platform in the future, with permissioned access (Allison, 2019a). IBM Food Trust honoured these requests and established the Food Trust Governance Committee to facilitate management and discussion among members.

This resulted in a more successful launch for IBM Food Trust compared to equivalent efforts in the banking and shipping industries, including TradeLens. For its part, TradeLens revised its partnership model after the slow start so that Maersk had no more control than other ocean carrier members over platform governance. This changed the tide for the blockchain platform, leading several industry leaders to join TradeLens and abandon rival pilot projects.

Various transport industry consortia, like the Blockchain in Transport Alliance (BiTA) and the Mobility Open Blockchain Initiative (MOBI), are helping to shape DLT standards and clarify regulatory needs in a collaborative way. But regulators should not leave the work of standard-setting to private sector consortia only. By engaging with such associations as appropriate, authorities can stay abreast of trends, successes and shortcomings in DLTs, gather best practices, anticipate regulatory hurdles, and provide feedback on platform governance standards to ensure they align with public sector goals.

Use cases for distributed ledger technology in the supply chain industry to improve transport

The remainder of this chapter examines four use cases of DLT and blockchain technology applied to transport-related supply-chain pain points. These cases explore how the technology has been deployed to improve shipping industry transactions, reduce auto industry fraud, simplify last-mile delivery and improve fuel management.

Each case describes the specific industry problem and its greater societal impact, how DLT has been applied to address this problem, the achievements and shortcomings of the projects so far, and important takeaways for regulators. Below is a brief summary of each use case.

Streamlining letters of credit and bills of lading for shipping

The shipping industry is part of a larger supply-chain network so vast that actors often do not know where their shipments are or who is handling them. Firms thus resort to expensive intermediaries and cumbersome documentation systems to ensure accountability. The latter increases the risk that associated paperwork is duplicated, erroneous, or lost – causing delays that halt trade, raise prices, and complicate customs checks. Other technologies can facilitate digital exchanges of data and money, but DLTs can do so while encrypting sensitive information and auto-executing agreements, enabling peer-to-peer (P2P) exchanges with no intermediaries. Regulators can leverage DLT to improve regulatory compliance and customs procedures, but a fundamental understanding of how the technology works is a prerequisite.

Fighting fraud in the auto industry

The auto industry has long suffered from odometer tampering and car part counterfeiting, made possible by poor data validation and traceability. DLT can be deployed to track car parts and vehicle data by establishing a "digital twin", or a virtual record of the object that is constantly updated. Blockchain's immutability means that fraudsters cannot falsify the history of a vehicle or part – its entire "lifetime" is stored on one platform. Manufacturers, logistics operators, retailers, mechanics and customers could all contribute and utilise the same digital information, generating a single record and providing equal transparency to all. Auto industry DLTs can help regulators reduce emissions from fake car parts, prevent car customers from being cheated, and make roads safer. But state registration and driver identification systems would need to be integrated into a DLT platform for it to be effective.

Simplifying last-mile delivery

The final link in any supply chain is the consumer – but last-mile logistics have been a persistent problem, especially since the rise of e-commerce. Customers now increasingly expect on-demand delivery, prompting a move away from traditional hub-and-spoke distribution models. Blockchain's smart contracts can facilitate direct P2P transactions between last-mile delivery services and customers, using decentralised parcel storage facilities. Secure ID management can ensure that couriers are held accountable for a package, and blockchain's tracking ability allows more visibility for all stakeholders. By decentralising last-mile delivery, regulators can reduce congestion and pollution caused by trucks while limiting thefts related to e-commerce. However, authorities must ensure that DLT platforms promoting last-mile P2P services are honouring consumer protection standards regarding privacy and safety.

Secure fuel management

Bunker fuel used by ocean carriers is essential to keeping global supply chains in motion, but it is extremely polluting. Regulatory attempts to reduce emissions produced by the shipping industry have been challenged by the difficulty of enforcing international rules combined with the high cost of clean fuel. Selective compliance with regulation can distort markets and exacerbate pollution. To circumvent this, authorities need a method of evaluating fuel content anywhere on the globe, at any time. DLT can address this need in combination with the introduction of synthetic DNA technology to record fuel content throughout its journey through the supply chain. Firms can avoid undeserved fines by being able to identify the source of fraudulent fuel, while regulators can leverage DLT to reduce emissions, accurately punish bad actors, and comply with broader environmental goals.

Supply chain case 1: Streamlining payout for the shipping industry

Global supply chains comprise a complex web of actors that can generate costly inefficiencies, with the average shipment passing through 30 organisations and requiring 200 unique interactions (Groenfeldt, 2017). This complex system requires logistics firms to rely on exhaustive documentation and third parties to ensure accountability, but discrepancies persist due to a lack of interoperability or reliable data (Schmahl et al., 2019). Currently, 10% of all industry invoices contain inaccurate data, and 20% of shipping containers are unable to be precisely located at any given moment (DHL and Accenture, 2018; Ship Technology, 2018).

This can result in delays, disputes, and financial loss, while the opaqueness of supply chains prevents private actors from identifying weak points and adjusting business practices. For regulators, enforcing compliance is complicated by not having a single and authoritative version of the "truth" regarding conveyances. Excessive and erroneous documentation slows down critical customs processes, and makes identifying the source of illicit activity virtually impossible. Authorities must be meticulous in order to uphold the law, but inefficient compliance checks undermine trade and, thus, tax revenue.

DLT can help address these supply chain challenges by establishing a single source of truth and enabling secure P2P transactions for valuable logistics documents like bills of lading (B/Ls) and letters of credit (L/Cs). By streamlining these fundamental processes, DLT can help both private and public stakeholders "see inside" their supply chains, increasing accountability and efficiency. DLT's decentralisation, encryption and immutability can avoid the shortcomings of centralised databases while ensuring the integrity of sensitive data. DLT smart contracts can also auto-execute exchanges based on pre-determined conditions that incorporate regulatory standards directly into algorithms, eliminating intermediaries and simplifying law enforcement.

DLT is still a nascent technology, and not a logistics industry cure-all. But it shows promise where numerous actors conduct sensitive transactions in the absence of trust. There is optimism that, with the proper support, DLTs "could become the new [standardised shipping] container of international trade." (Ganne, 2019).

How does it work?

DLT may be able to permit supply chain actors with divergent interests to exchange data and money on a decentralised platform without being exposed to competitors. A transaction on DLT can be encrypted so that proof of its occurrence is published, but sensitive details are accessible only to permissioned members. Smart contracts can auto-execute P2P transactions once pre-defined terms are met, helping to reduce disputes and delays regarding pay settlement. Third-party intermediaries that traditionally broker trust and enforce terms between two distrustful parties may no longer be necessary, potentially leading to reduced costs and fairer competition through more transparent pricing (Schmahl et al., 2019).

On DLT, there are no "copies" of a transaction or shipment. There is one version of a document shared among all platform members, so no actor can possess a different version than another. Any updates by one actor are diffused to the community for consensus approval, and approved updates are added to each member's database. All platform members add data using the same standards, ensuring interoperability and minimising mistakes. Once data is added, it cannot be altered without consensus approval. This could drastically improve the current B/L transfer process, for instance, which still relies on an antiquated courier system thanks to concerns about security and centralised control of electronic copies.

Although governance varies based on the type of DLT platform (see Figure 1), the data is always dispersed to some degree so that no central authority holds total control. These capabilities – permissioned access, smart contracts, immutable data and decentralisation – make DLT capable of improving on legacy systems to create efficiencies for all supply chain stakeholders.

Challenges and benefits

Due to the inherent risks of trading with businesses on the other side of the world, supply chain actors and state customs officials rely on rigid payment processes to instil confidence. Documents like bills of lading and letters of credit create a secure paper trail that can serve as a legal resource. But this increased confidence comes at the expense of speed and efficiency – and costly mistakes, delays or fraud can occur despite any checks and balances. DLT is beginning to be deployed in the shipping industry to improve the efficacy of trading amongst supply chain actors.

Bills of lading

A bill of lading (B/L) is a legal document that functions as a contract between supply chain stakeholders (DHL and Accenture, 2018; Tarver, 2019). It details shipment contents, documents responsibility, serves as a receipt, and holds tangible financial worth – making it both a valuable asset and a target of fraud (Tarver, 2019: Dubovec, 2005). B/Ls are intended to prevent theft, settle disputes and ensure accountability in the event of a problem.

But pre-digital legal requirements and a lack of trust have kept B/Ls paper-based (Dubovec, 2005), exposing them to manipulation and mistakes. A "clean" B/L is required to exchange cargo for payment, but discrepancies can cause delays, legal disputes and financial loss. B/Ls are often sent by courier for security, which may take weeks and costs the industry up to USD 5 billion per year (CargoX, 2019). Despite these inefficiencies, attempts to digitise B/Ls have largely failed. Centralised electronic B/L platforms created new challenges related to authentication and access, undermining any benefits of digitisation (Takahashi, 2016). Thus, while paper B/Ls can be inefficient, electronic B/Ls alone are not the solution.

Though not the only platform able to digitise B/Ls, DLT may be uniquely capable of establishing a single version of the truth mutually accessible to all relevant actors. DLT's auditability and encryption features can prevent a B/L from being tampered with or exposed. Erroneous initial data can still be uploaded, and physical shipment contents can still be altered despite any data verification on DLT. But compared to legacy B/L systems, DLT can improve stakeholders' ability to track fraud and negligence. Should a discrepancy be found, the victim could use DLT to trace a shipment's history and narrow down who may be responsible. This increased insight would reward good actors for complying with contract terms, while bad or negligent actors would be discouraged from illicit activity.

DLT cannot eliminate all B/L discrepancies. However, the increased accountability may limit reliance on costly intermediaries and reduce the likelihood of fraud or clerical error, producing time and cost savings (Tijan et al., 2019). A 2019 CargoX pilot who used DLT to transfer a bill of lading between a Chinese exporter and a Peruvian importer was able to demonstrate these benefits. B/L transfers using legacy systems can take up to ten days thanks to third-party couriers and several document exchanges (CargoX, 2019), plus any delays caused by misplaced or improperly processed documentation. In the CargoX case, these inefficiencies would have been in addition to the seven-week voyage of the shipment itself.

Instead, the DLT reduced the B/L transfer time from weeks to minutes while making the process more secure (World Maritime News, 2019). This type of supply chain "self-enforcement" through DLT can also benefit the public sector, whose resources are strained by sluggish B/L confirmations that can clog up harbours, warehouses and freight routes, plus result in lengthy legal disputes.

Letters of credit

Letters of credit (L/Cs) facilitate global supply chain transactions by relying on banks to release payment once terms are met, and are considered the most secure method of conducting international trade (Akbas, 2017). But the need for intermediaries creates an expensive and slow process, including bank fees and a back-and-forth between buyers, sellers, and their respective banks to avoid delays or refusal of payment.

Smart contracts can streamline the L/C process by automatically enforcing terms and executing transactions (Schmahl et al., 2019). In lieu of a lengthy verification process, a buyer and seller embed agreed-upon L/C terms in a DLT smart contract. The buyer confirms shipment conditions have been met through the smart contract, and payment is released in real time to the seller. The terms and details stored on the smart contract are immutable, serving to avoid data transfer mistakes and disputes. Smart contracts can facilitate recurring transactions as well, further expediting transaction processes. Fees and delays caused by processing L/Cs through banks can thus be avoided.

Banks have noticed DLT's ability to manage L/Cs, and may be attempting to adopt the technology in order to avoid being pushed out of the shipping process. Various L/C blockchain pilots by HBSC and ING have reduced the L/C process from 5-10 days to one, helping firms avoid costly delays (Wood, 2019a; Zmudzinski, 2019). But while using a bank DLT for L/Cs may save money due to delays and expensive pilot programmes, they will likely carry a user fee. Start-ups like Libelli (www.libelli.hk) aim to help buyers and sellers avoid banks altogether by executing smart-contract L/Cs while holding payment in escrow to ensure it is withheld and released properly (DHL and Accenture, 2018).

Platform governance

Industry scepticism of DLTs has revolved around governance, cost and scalability (DHL and Accenture, 2018). Firms are reluctant to share sensitive data on a platform used and/or governed by competitors, and have expressed doubt that the costs of adoption are worth the benefits.

TradeLens, a logistics blockchain platform developed by IBM and Maersk, has taken steps to address these concerns since its launch in 2018. TradeLens initially struggled to attract other top shipping companies, which feared that Maersk's ownership would undermine data security and equitable governance (Allison, 2018). Instead of enlisting "trust anchors" that attracted a critical mass of users, TradeLens inspired Maersk's competitors to launch rival blockchain pilots.

But a DLT is more effective the more members it has, relying on data contributions from various sources to enhance accuracy. Ultimately, TradeLens plans to sell platform access to supply chain actors seeking reliable shipment visibility – but so far, its prices are considered high compared to market alternatives (Johnson, 2019). Without a critical mass of major firms, TradeLens cannot generate benefits proportionate to its cost. This realisation seems to have inspired TradeLens to revise its governance structure – as well as improve its data privacy guidelines, publish application programming interfaces (APIs), and lower Maersk's oversight to the same level as other members (Allison, 2019b).

These changes helped TradeLens sign several top ocean carriers that had formerly resisted the project, including Hapag-Lloyd, Ocean Network Express (ONE), CMA CGM, and Mediterranean Shipping Company (MSC) (Kapadia, 2019). With more than 100 other supply chain stakeholders already signed up, TradeLens is now on track to host 60% of global shipping capacity (Johnson, 2019). By reforming its governance structure, TradeLens is now perceived as sufficiently neutral for stakeholders to find it worth joining, in exchange for more visibility into their supply chains.

What do policy makers need to know?

Despite its cost- and time-saving potential, firms will likely not invest in DLT if regulators do not recognise DLT-based transactions or if customs procedures are not interoperable. Regulations can be adjusted to recognise electronic logistics documents, with an eye toward coordination across ministries to avoid stifling innovation via siloed regulation for different aspects of DLTs, as has happened with cryptocurrency (Dubovec, 2005; McQuinn and Castro, 2019). Instead of regulating DLTs out of existence or playing catch-up later, authorities can strive to learn how the technology can be leveraged to improve customs processes, automate compliance standards, foster fairer competition and boost tax revenue (Schmahl et al., 2019).

The public sector can achieve this by participating in low-risk pilots and consortia, where it can also influence industry standards. The US Department of Homeland Security's technology and customs divisions took part in TradeLens' original 2017 pilot, giving the public sector advanced insight into the platform that has been adopted across the industry. This familiarity can support authorities in leading their own small-scale pilots, guide investment in research and development, and form public sector consortia to establish uniform regulatory standards. Machine-readable laws can be integrated into smart contracts, and customs operations can be improved via DLT-based B/Ls and smart container seals (Yafimava, 2019b). Increased traceability can simplify enforcement by preventing contraband, counterfeits and substandard goods from entering the market upfront. Although DLT will not eradicate fraud altogether, it can deter fraudulent activity and support investigations through increased traceability.

Trade efficiencies created by DLT could also save authorities resources and increase taxable trade volume by up to 15% (Tijan et al., 2019). But a flexible regulatory framework may be necessary to foster the experimentation that can yield technical improvements and widespread adoption. Inter-agency working groups and regulatory sandboxes with non-enforcement agreements would allow authorities to monitor DLTs' impact and manage parameters without stifling development. Authorities should also aim to regulate outcomes rather than specific technologies, including adherence to antitrust standards. This would give DLTs the space to mature, and ensure that all technologies face equal scrutiny (McQuinn and Castro, 2019).

Supply chain case 2: Fighting fraud in the car industry

Counterfeit car parts and odometer fraud have consistently burdened the auto industry, costing businesses and consumers billions of dollars while complicating enforcement actions by authorities. Poor visibility into the auto parts supply chain, and undependable systems of odometer verification, prevent regulators and other stakeholders from holding bad actors accountable.

Unsafe counterfeits of windshields, brake pads, airbags and seat belts violate quality control standards and directly jeopardise public health (Colonna, 2018). Car parts sold on grey markets foster illicit activity and lead to losses in tax revenues: in 2011, counterfeiting cost vehicle manufacturers as much as USD 45 billion (Colonna, 2018); in 2017, more than 500 000 fake car parts worth a total of USD 5.4 million were seized in the United Arab Emirates (UAE) (Ravishankar, 2018). Nissan has estimated that such fraud costs them USD 60 million each year in the Middle East alone, while in India roughly 20% of automobile accidents are attributed to fake auto parts (Arnold, 2014; FICCI, 2018).

Box 3. Different Vehicle, Same Problem

In 2011, the United States Senate's Armed Services Committee reported that numerous electronic parts installed on US military aircraft systems deployed in Afghan combat zones were counterfeit.

The equipment was produced by manufacturers Boeing, L-3 and Raytheon, but predominantly sourced from China. In response to the scandal, the Chinese government officially agreed to cooperate in discouraging counterfeit goods, but was criticised by the Senate committee for attempting to elude scrutiny. In response, the Pentagon opened criminal investigations into over 200 counterfeiting incidents.

A subsequent committee report discovered 1 800 total counterfeit incidents involving various US military equipment, and identified Chinese firms as the source of over 70% of 1 million total suspected parts.

The Senate committee notably "attributed the flood of fake parts to flaws in the US supply chain", as well as China's poor enforcement of standards. The ability of counterfeit products to infiltrate the world's largest and most sophisticated military underscores the lack of supply chain visibility.

Source: Johnson (2011); Airforce Technology (2012); Babich (2019).

An analysis of 2011 European Union (EU) customs checks was able to track 68% of car part fraud back to China, and 25% to the UAE (Williams, 2013). But accountability is impossible without deeper visibility into auto part supply chains – which is obfuscated by a lack of system interoperability between stakeholders, divergent regulatory standards among authorities, and insufficient technology (Colonna, 2018). This inability to track the source of counterfeiting challenges regulators, who lose tax revenue and are forced to mitigate fallout from public health risks and product recalls.

Odometer fraud exposes the public to financial loss and physical danger as well. Digitisation has actually made odometer tampering easier to do and harder to detect (Pastori and Vergnani, 2017). The practice is widespread in Europe, occurring in 50% of used car sales in Italy, 37% in the Czech Republic, and 33% in Germany, costing buyers across the EU up to EUR 9.6 billion (Pastori and Vergnani, 2017). Odometer fraud cost German used car buyers an average of EUR 3 000 per person (Pastori and Vergnani, 2017).

Used cars sold across borders are particularly susceptible to odometer tampering due to inconsistent authentication standards among EU countries, as well as a lack of coordination around data privacy. However, the auto industry can also be encouraged to pursue technological solutions that simplify regulatory enforcement.

Considering blockchain's strength in establishing a single source of truth for data contributed by a variety of non-aligned actors, it may be uniquely suited to addressing these auto industry challenges. Its ability to maintain encrypted, immutable data on a single decentralised ledger could be deployed to mitigate car part and odometer fraud, easing the burdens of regulation and enforcement.

How does it work?

The blockchain platform VerifyCar, created by BMW and developer VeChain, seeks to resolve these problems by using DLT to decentralise the storage of vehicle data. The partnership has identified the fragmentation of crucial vehicle data between key industry actors as largely responsible for pervasive odometer fraud, falsified repair history, and other data manipulation (VeChainFraser, 2019).

Instead of each car owner, manufacturer, dealership, insurance company and mechanic possessing their own copy of a vehicle record, VerifyCar uses DLT to establish a single history. This means that no one entity possesses VerifyCar data, thus increasing transparency and reducing delays associated with document sharing. A prospective buyer can easily compare an odometer reading on the VerifyCar app to the car dashboard; a mechanic can instantly access crash and repair history to help diagnose a problem; and authorities can immediately certify ownership, registration and other legal standards. Blockchain's encryption ensures that only permissioned parties can access sensitive vehicle data, and its immutability guarantees that odometers and repair histories cannot be retroactively tampered with.

VerifyCar records and stores every vehicle event, from routine tune-ups to part replacements and crashes, through Internet of Things (IoT) sensors and embedded SIM cards that automatically send data to its distributed ledger at regular intervals (VeChainFraser, 2019; Ngo, 2019). The raw vehicle data is stored on a secure private server, while an encrypted version is placed on the public blockchain to be verified and stored by the network (Ngo, 2019). By not overloading the public blockchain with data, VerifyCar can retain reasonable transaction speeds that support scalability, while also addressing customer privacy concerns. This improves on legacy vehicle history tracking systems, since centralised databases are more susceptible to security breaches, and infrequent odometer recordings present an opportunity for tampering (Pastori and Vergnani, 2017).

CarVertical (www.carvertical.com) is another blockchain platform working to track and verify vehicle history. Launched in Estonia and Lithuania in 2018 and supported by the European Union, CarVertical establishes a single distributed ledger for a car's entire history. With just a vehicle identification number (VIN), a user can view the car's entire history including ownership, crash and odometer history, as well as photos and tips on how to verify the VIN. This heightens transparency and efficiency, establishing a single-vehicle history without the delays or mistakes caused by third parties. This decentralisation also prevents tampering with vehicle histories, since no changes can be made to blockchain data without consensus approval from the network (CarVertical, 2018).

CarVertical pools this information from manufacturers, suppliers, mechanics, retailers, public authorities, and customers, and grants each one mutual access to the same version of data on its distributed ledger. It has also incorporated IoT into its on-board diagnostic (OBD) sensors, allowing for constant updating and storing of car component status. Car owners can thus use the blockchain platform's app to track engine status, GPS coordinates, and battery levels in real time, in addition to odometer history (CarVertical, 2018).

Though fighting odometer fraud through DLT is considered more achievable in the short term, it may also be uniquely capable of curbing individual car part fraud (Ledger Insights, 2019). Counterfeiting flourishes when stakeholders lack insight into the supply chain, and auto industry executives consider visibility their greatest challenge (Colonna, 2018). DLT can be especially effective at combating counterfeiting when combined with IoT to create a "digital twin" of the part. Car parts outfitted with IoT sensors can record any physical changes to a corresponding digital copy, generating data on both real-time conditions and incident history (Jones, 2017). DLT can support IoT by recording and storing this data securely in an immutable format.

VerifyCar and CarVertical are already deploying IoT in conjunction with their blockchain platforms, but they have so far prioritised addressing odometer fraud and creating full vehicle histories. Using blockchain and IoT to track individual spare car parts may be more reliable, but may also be more expensive and software intensive. CarVertical has stated its intent to work with manufacturers to ensure that individual parts can be tracked from provenance, and start-up CarFix has registered spare parts suppliers and dealers in order to verify replacement parts as well (CarVertical, 2018; Munford, 2017). But wider adoption of blockchain-backed IoT for individual parts may require further technological cost efficiencies.

Challenges and benefits

DLT's auditability ensures that vehicle history can't be retroactively altered to hide suspicious activity, and its decentralisation ensures that no third party acts as a data gatekeeper. A single distributed ledger also precludes any network member from passing off a falsified version to another. By making it easier to identify the entity responsible for a part or vehicle at the time of tampering, blockchain can increase accountability – or even deter fraud altogether.

DLT's encryption and network consensus requirements can also address concerns in countries with strict data privacy laws by reducing reliance on vulnerable centralised databases (Pastori and Vergnani, 2017), and its smart contracts can enable efficient peer-to-peer (P2P) transactions in car part supply chains and used car markets. These features allow DLT to offer more reliable car histories than third-party intermediaries while improving security, streamlining transactions and reducing fees.

However, digital tags and VINs can still be falsified at initial entry into a distributed ledger, and valid registration data could be attached to the wrong vehicle. The "garbage in, garbage forever" problem means that once erroneous data is added to the car part ledger, it cannot be removed. If a car's brake pads are counterfeited before they are registered on the ledger, they could successfully pass through each verification step undetected. A car owner might discover years later that the car's brake pads are counterfeit thanks to a thorough inspection, but if they were registered properly on the ledger, there may be little recourse.

While DLT's decentralisation may help pinpoint the source of fraud, it may also make it more difficult to fix data mistakes or arbitrate subsequent disputes. DLT can be centralised in order to establish accountability, but this could undermine platform security. Thus, while centralised third-party vehicle databases like Car-Pass in Belgium are vulnerable to privacy breaches and odometer manipulation, they can still cross-reference and update data if necessary (Pastori and Vergnani, 2017).

However, Car-Pass also benefits from regulation that legally requires auto industry actors and car owners to provide data in formats that comply with Car-Pass standards. Legislation adopted in 2004 and subsequent ministerial decrees have made it mandatory, when selling a vehicle, to provide a Car-Pass certificate that must include most information recorded by VerifyCar and CarVertical. With proper platform standardisation and regulatory support, a DLT-based vehicle database could improve on centralised systems like Car-Pass by increasing the accuracy and security of vehicle history through auditability, decentralisation and encryption, while minimising the “garbage in, garbage forever” problem.

In July 2019, the Mobility Open Blockchain Initiative (MOBI), which comprises major auto manufacturers, technology firms, blockchain start-ups, and government agencies, made strides toward this goal by launching the Vehicle Identification (VID) blockchain standard. The VID standard seeks to replace the classic VIN, which MOBI finds insufficient for establishing a vehicle’s “digital twin” on blockchain (Figure 3) (MOBI, 2019). By creating a VID number compatible with blockchain, any permissioned actor can verify vehicle data in real time by consulting the distributed ledger. MOBI’s VID standard focuses on the “birth” of the vehicle, so that it is properly registered to the blockchain from provenance (Pimentel, 2019). This helps ensure that digital twin vehicle data stored on the blockchain is accurate and verifiable, preventing the potential pitfalls of immutability and decentralisation.

Figure 3. Potential connectivity benefits of a vehicle ID hosted on distributed ledger technology

Source: MOBI, 2019.

What do policy makers need to know?

Properly applied, DLT can help regulators enforce auto industry standards and hold bad actors accountable. Through platforms like CarVertical and VerifyCar, distributed ledgers can improve vehicle owner data privacy while making it more difficult to falsify vehicle history or counterfeit auto parts. By establishing a single, mutually maintained car history, authorities can quickly access certificates of inspection, vehicle registration and car ownership, with confidence in their accuracy. DLT's auditability can make vehicle fraud riskier, helping to identify bad actors and deter nefarious activity. DLT can also help authorities strike the balance between transparency and data security.

These advantages over existing vehicle history systems could also help regulators achieve broader policy goals. By assuring the authenticity of vehicle history and spare parts, authorities can promote fairer competition in the auto market, reduce illicit activity, bolster consumer protection, increase road safety, and keep pollutant car parts off the road (Pimentel, 2019). Prospective car buyers would be more informed, honest mechanics and car dealers would benefit, and some accidents could be prevented.

Advanced IoT data stored on DLT could also be used by regulators to analyse broader market trends and audit compliance standards. The Volkswagen (VW) emissions scandal started when monitoring conducted in real time by the United States Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) recorded pollution levels 35 times higher than when the same vehicles were tested in a formal government setting (Jacobs and Kalbers, 2019). Though authorities eventually caught the discrepancy that led to the discovery of "defeat devices", or test-beating software, installed in VW cars, the company had already sold 590 000 vehicles equipped with these devices between 2009 and 2016 – each in violation of the Clean Air Act (EPA, 2020). Research by the Massachusetts Institute of Technology (MIT) predicted that pollution levels generated by VW vehicles in that time will lead to 60 premature deaths in the United States, and 1 200 more in Europe (Barrett et al., 2015). Regulators could require that manufacturers use DLT paired with IoT sensors to automatically, periodically record and share emissions levels, relying on the technology's features to ensure that the data is decentralised and immutable. This would make emissions standards enforcement nearly automatic, drastically shortening the time taken to identify fraud.

Authorities can support the development and adoption of DLT platforms like CarVertical and VerifyCar while building their own capacity to interact with them. This may include participating in "low hanging fruit" industry pilot programmes and sharing vehicle registration certificates and odometer readings on a distributed ledger.

Regulators can also solidify data format standards and require sharing for auto industry DLT through legislation, just as Belgium did in 2004 for Car-Pass, in order to induce adoption and compliance. Public sector data such as driver's licenses, vehicle registration, inspection certification and emissions regulations can be made machine-readable for DLT, yet kept flexible enough to be adapted in response to future developments. This type of commitment to an industry DLT system could create a virtuous cycle that spurs private sector investment and participation in the ecosystem, producing continued advances that lead to a broad set of policy achievements. Such increased activity could eventually lead to widespread adoption of more cumbersome DLT uses, like universal parts registration.

Supply chain case 3: A decentralised last-mile marketplace

Last-mile delivery refers to the final leg of a parcel's journey from distribution centre to end consumer (Lopez, 2017b), and its inefficiencies have been exposed by the rise of e-commerce. Global online sales have grown 24% per year, pushing the parcel delivery market to nearly USD 380 billion in 2018 – but as of 2016, the last mile of a parcel accounted for about 50% of total delivery costs (Proud and Chapman, 2019; Joerss et al., 2016). The ubiquity of on-demand e-commerce means that consumers expect flexible rapid delivery for less cost, but the last-mile logistics industry has not yet caught up to this development (Romaine, 2020; Ranieri et al., 2018).

The last mile has traditionally run through a "hub and spoke" model where packages are received at a central warehouse and sorted for distribution along fixed routes, but the market shift toward near-instant delivery, or the "Amazon effect", has put pressure on this model. Drivers are often required to confirm receipt with customers for security, but a missed connection means an unacceptable delay for the customer since the driver must continue on his timed route. This forces drivers into an "all or nothing" system that results in multiple time-consuming attempts to deliver one package. In the Global South, where e-commerce is growing particularly fast due to a burgeoning middle class, existing infrastructure may not support a resulting increase in delivery van trips. Rapid turnaround for online orders also requires complex delivery routes and flexible hours, which are not feasible under the hub and spoke model.

These inefficiencies create frustration for customers, couriers, logistics firms and policy makers. Customers often lose time trying to connect with a courier, and sometimes lose money due to package theft by "porch pirates". Drivers lose income to commission fees and performance-related fines caused by obstacles outside their control. Delivery trucks making multiple trips to connect with a customer contribute to traffic congestion and pollution. Fulfilment centres and warehouses occupy valuable real estate that could be used for other purposes, especially in urban areas.

Both public and private sector courier services are exploring how DLT can help resolve these inefficiencies and support broader policy goals (USPS, 2016; Drif, 2019; Lopez, 2017a). A decentralised last mile could help regulators reduce congestion and pollution, minimise disputes over package delivery, grow the courier job market alongside e-commerce, and combat the monopolisation of delivery services.

How does it work?

US-based NextPakk (www.nextpakk.com) is one of several logistics start-ups aiming to solve last-mile challenges through DLT/blockchain smart contracts, which allow entities on the same platform to write transaction terms into an algorithm that executes only once terms are met. This enables real-time, automatic, commission-free P2P processing of business agreements between parties who do not know or trust each other, with a mutual transaction record written onto DLT for reference.

NextPakk has proposed using DLT smart contracts to support secure P2P transactions between couriers and end-customers directly, including package pick-up from parcel storage lockers called Package Delivery Points (PDPs). Upon purchase, a major logistics carrier brings a consumer's package to a PDP. The customer then selects a one-hour window for final delivery, and pays through the NextPakk DLT app. Payment is held in escrow while a NextPakk courier accepts the contract and delivers the package on time. Upon confirmed receipt, the smart contract is executed and immediately releases payment to the courier. DLT's encryption protects customer and courier identity by creating proxy IDs that keep personal information private. NextPakk's "Pakka" digital currency tokens enable the internal exchange of value, requiring users to first purchase into the system (NextPakk, 2018).

This alternative last-mile model could lead to more sustainability. Instead of trucks attempting all-or-nothing deliveries along fixed routes irrespective of customer schedules, packages can be left in NextPakk storage lockers in case a customer misses a delivery or prefers to pick it up in person. Customers who still prefer delivery can post a request on the NextPakk platform, and a local registered courier who accepts it can deliver the package within a more predictable window. NextPakk envisions couriers as gig workers who deliver packages using their transport mode of choice for supplementary income during their spare time. Given the shorter distances and lower parcel volume of each delivery trip, couriers could trade in expensive and pollutant trucks for more sustainable vehicles like cargo bikes and scooters. The platform also reduces the risk of theft or loss through its escrow and smart contract systems, which hold both payment and courier collateral. Reliance on storage lockers could be complicated by limited access to or availability of real estate, but also presents an opportunity for property owners to lease underused space and reduce the need for large central distribution centres (NextPakk, 2018).

Other last-mile start-ups are deploying DLT in similar but distinct ways. Triwer plans to charge its DLT platform users a 5-15% commission, betting that customers and couriers will find the net savings produced by P2P contracts worth the fee. PAKET is attempting to build a fully decentralised blockchain platform that allows network members to exchange items for free. Relying on escrow, parcel locker storage, and package relays between platform-registered couriers, PAKET hopes to establish a delivery system without any central entity. ParcelX is focusing on running cross-border business-to-business (B2B) last-mile deliveries through DLT, hoping companies will want to avoid the overhead expenses associated with non-interoperable systems among multiple firms and customs agencies (Sherman, 2018).

Apps that hire couriers for individual deliveries with customer tracking, parcel lockers in local businesses, and deliveries made by cargo bike already exist. But combining these elements into one decentralised last-mile marketplace has thus far been too unwieldy to make a reality. In the current context, third-party logistics firms are still necessary to connect couriers and customers, insure packages, provide tracking updates, oversee route planning, and resolve disputes.

DLT can support a decentralised last-mile marketplace where logistics firms must only get a customer’s package to a local storage locker. The locker is secured with a digital key provided to the customer, who publishes a P2P smart contract on DLT with the price, time slot and delivery location. A local courier accepts the contract, using the digital key to open the locker and retrieve the parcel. By retrieving the parcel, the courier has assumed ownership of the package and is required to place collateral in escrow; the customer’s payment is held in escrow as well. Upon delivery the customer digitally confirms receipt, executing the smart contract that pays the courier in real time.

Challenges and benefits

Decentralising the hub and spoke model could potentially save customers and couriers money, create efficiencies for logistics firms, and promote sustainable transport. DLT could also improve customer privacy by anonymising transactions through encryption and storing the transaction on its distributed ledger to prevent future disputes. But DLT also has substantial room to grow and improve, and a decentralised last-mile marketplace might create new challenges.

Major logistics firms and governments are exploring how emergent technologies like blockchain, artificial intelligence (AI), the Internet of Things (IoT), autonomous vehicles (AVs), and drones can create more flexibility and efficiency in the last mile (Krishnan, 2018; Kerr and Różycki, 2018). IoT offers precise tracking of parcels, and AI can learn from data to optimise last-mile routes, but centralised networks collecting data from millions of devices and sensors are prone to cyber-attacks (Snitko, 2018; Behrens, 2019).

A last-mile DLT platform would be most effective when combined with these systems, and its decentralisation could enhance their security. But to be deployed together, they would have to be developed and invested in at a similar rate. The logistics industry is confident that these emerging technologies can create efficiencies, but blockchain adoption continues to lag despite interest (Kauschke et al., 2019). The high risks and professional development costs of DLT/blockchain remain prohibitive, while the benefits remain mostly theoretical.

A fully decentralised last-mile DLT platform may also create questions around liability, labour and privacy. Though third parties charge fees that reduce courier wages and raise prices, they typically provide customer service and employee legal protections. Without this mediator, labour and consumer disputes may fall to authorities unequipped to resolve these problems. A poorly governed DLT platform could result in courier protests similar to driver campaigns against Uber and others. Consumers could cheat a faulty platform, or become the victim of theft by a courier and be left with no recourse.

Though legitimate, these problems could be avoided through proper platform design, governance and public sector engagement. Couriers are currently charged an average commission of 30%, while last-mile DLT start-ups plan to charge at least 15% and perhaps more (Krishnan, 2018; Sherman, 2018). Parcels stored in lockers already reach customers at a much higher rate than home deliveries, but DLT could make secure locker-to-home deliveries possible (Kerr and Różycki, 2018). Couriers could replace expensive trucks for cargo bikes, which might help counter the rapid motorisation of the Global South. DLT can also ensure accountability by linking state identification to accounts, while maintaining anonymity on the platform.

Decentralised delivery through DLT may also be able to combat the monopolisation of the last mile. By limiting data interoperability, large firms increase vertical integration and bar smaller firms from competition. Establishing a neutral platform that allows secure sharing of data would enhance interoperability and help lower barriers to entry, diversifying the industry (Snitko, 2018).

What do policy makers need to know?

Applying DLT to the last mile could ease pressure on authorities, who have struggled to regulate the externalities of surging e-commerce and on-demand services. The rise of the gig economy has already changed the concept of employment, with “gig” work eroding traditional worker protections like insurance, safety standards and wage security (Dablanc et al., 2017; Darby, 2019). The struggles of “gig workers” such as couriers and drivers have sparked a backlash against digital platform providers around the world, forcing policy makers to explore regulatory measures that improve gig economy worker status (Newman, 2019; Bussewitz, 2019; Nova, 2019).

Customers can suffer from gig economy externalities, too, struggling to hold “independent contractor” couriers accountable when a package is lost, damaged or stolen. Citizens exasperated with package theft by “porch pirates” have demanded action from logistics firms and regulators – and, when ignored, have even created devices to sabotage thieves (Dvorak, 2018). Laws are being updated to address the rising trend, and public officials are warning customers that injuring robbers may lead to prison time (Hennes, 2019; Smith, 2019; KHOU 11 News, 2018). For both parties, the centralised “all-or-nothing” approach to delivery works poorly: couriers can be penalised for missing customers, while customers may grow frustrated by inflexible delivery options.

App-based services like Uber, Grab and DoorDash were initially groundbreaking because they leveraged the internet and smartphones to meet emerging demand for new types of personalised services. That demand is stronger than ever due to e-commerce, but app-based services that were once considered innovative now seem outdated for their reliance on high commissions and surcharges (Newman, 2019; Bussewitz, 2019; Nova, 2019). DLT could help curb these negative aspects of e-commerce in the gig economy era by allowing couriers and customers to connect directly through smart contracts without these fees and delays.

However, DLT for last mile may also raise new challenges. In a decentralised delivery system, who is ultimately responsible in the event of a freak accident? How do you choose the amount of collateral required for a courier who may not share the same concern for a package as the customer, or who may not have sufficient money to put in escrow? What if a typographic error causes an irreversible mistake in a smart contract? Who is responsible for screening parcels for dangerous content?

Regulators can explore answers to these questions by investing in research and development and participating in small-scale pilot programmes. For instance, a municipal government could assist a last-mile DLT pilot by establishing a designated “sandbox” area, installing parcel lockers in local public buildings, and deploying public postal service couriers to make deliveries via sustainable transport using the platform app. Indeed, the US Postal Service (USPS) and France’s La Poste have warned that DLT’s potential impact on last-mile supply chain management should not be ignored by public courier services (USPS, 2016; Drif, 2019).

Despite challenges, DLT’s potential to help address customer disputes, courier insecurity and street congestion as a result of e-commerce is worth exploring. Small initial steps toward integration may be necessary from regulators. For instance, state IDs can be made machine-readable to ensure accountability in case of an incident during DLT-based delivery. Such demonstrated interest and support in DLT from the public sector could also spur private development that leads to further technological improvements.

Supply chain case 4: Cutting pollution through fuel quality tracking

The growth of the international shipping industry has expanded economic integration and access to goods across the globe, but has also exacerbated pollution (Oceana, 2019). The sector is responsible for roughly 3% of all greenhouse gas emissions. In addition, it emits various other pollutants in the air and in oceans, including an average of 1.7 million tonnes of sulphur dioxide in the seas around Europe (Walker et al., 2019; Transport and Environment, 2019). The poor air quality generated by the shipping industry accounts for approximately 400 000 premature deaths and EUR 58 billion in societal costs per year (Transport and Environment, 2019). Recent research indicates that curbing sulphur emitted via marine fuel could reduce premature deaths associated with cardiovascular and lung cancer and childhood asthma, and generally improve air quality (Sofiev et al., 2018).

However, fuel quality in the shipping industry is not easy to ensure. Fuel quality irregularities are pervasive, exacerbated by undependable systems of documentation. The bunker fuel sector suffers from a history of fraudulent claims and costly disputes over fuel quality and quantity among stakeholders (Ledger Insights, 2019), partly due to the antiquated practice of recording fuel exchanges on paper documents called bunker delivery notes (BDNs). Because the supply chain consists of many actors who are often unknown to each other, BDNs are susceptible to manipulation and leave industry stakeholders exposed to fuel quality fraud (Ledger Insights, 2019). Even when regulations are in place, conventional enforcement methods may be inadequate to significantly improve fuel quality. In 2019, the owners of a container vessel were fined USD 3 million by the US Coast Guard for using fuel with excessive sulphur concentrations; the ship operator was criminally charged, despite arguing that he was only following protocol (Long, 2019). Such heavy punishment may deter some bad behaviour, but is likely to disproportionately burden smaller firms while larger ones perceive any fines as the cost of doing business. In order to reduce sulphur emissions from shipping, the International Maritime Organisation (IMO) has adopted a regulation (commonly known as IMO 2020) designed to lower the share of sulphur in fuel emitted by ships from 3.5% to 0.5% (ITF, 2016). The IMO plans to bolster compliance by giving port states more authority to enforce compliance through fines, criminal charges and revoking stakeholders' insurance.

Without a dependable method to determine the true source of high-sulphur fuel, the impact of well-intentioned regulations like IMO 2020 may remain limited. BunkerTrace (www.bunkertrace.co), a start-up that combines the accurate data readings of synthetic DNA with the immutable shared data storage of blockchain, may be able to address this problem. By recording fuel test data on an immutable ledger distributed among all stakeholders, BunkerTrace can improve accountability in the bunker fuel supply chain – which could support both regulatory enforcement of emissions standards and fair competition through the eradication of fraud.

How it works

Synthetic DNA consists of tiny molecules that can be added directly to fuel, and act as unique tags that generate codes containing data such as the quality and origin of fuel (BunkerTrace, 2020). These data must be securely stored and maintained in order to be useful. By pairing the accurate data readings of synthetic DNA with blockchain, fuel quality can be tracked, evaluated and verified rapidly and reliably.

BunkerTrace adds the synthetic DNA to fuel in multiple locations as it moves through the supply chain, recording both quality test results and transactions between stakeholders on a blockchain. Each exchange is linked to the fuel's unique identification tag, which can be traced back throughout the shipment's history even if the fuel content has been altered (Wood, 2019b). Blockchain thus creates an "immutable audit trail that follows the fuel, and any changes made to it, recording all activities and sign-offs by actors transacting the fuel." (Hughes, 2019). This ensures not only that changes to fuel content are detectable, but that those responsible for the fuel at the time of the change can be identified.

In October 2019, BunkerTrace successfully tested the quality of fuel bunkered onto a vessel using synthetic DNA tags embedded in the product, and recorded the data results on its blockchain (AJOT, 2019). The DNA tags were added to the fuel as it was loaded onto a barge and then tested once moved to a ship. The crew successfully confirmed the fuel's origins and content in less than two minutes, despite the synthetic DNA concentration being just 2 parts per billion (Wood, 2019b). The fuel transferred was found to contain 0.1% sulphur, confirming compliance with IMO 2020.

This trial built on previous pilots – carried out by Blockchain Labs for Open Collaboration (BLOC), the creator of BunkerTrace, and GoodFuels, a supplier of low-carbon sustainable marine fuel – that also successfully recorded fuel transactions using synthetic DNA and blockchain. Shortly after the successful October 2019 pilot, BunkerTrace announced its commercial launch (AJOT, 2019).

Challenges and benefits

Fuel quality tracking systems like BunkerTrace could be the key to efficient and equitable enforcement of regulations like IMO 2020, ultimately leading to marked reductions in sulphur emissions.

Blockchain's immutability ensures that neither fuel quality data nor the history of the fuel's possession can be retroactively altered to obscure fraud or negligence. This could improve several outcomes. By recording the chemical composition of fuel throughout its journey and linking it to the actors in possession at each point, stakeholders suddenly have high visibility into their supply chains. If any ship operator attempts to alter bunker fuels between its purchase and sale, the data written onto the blockchain will reveal the discrepancy, as well as who is responsible.

This improved transparency would allow firms to hold business partners accountable for illicit activity and general inefficiencies. A quick test could immediately reveal whether the fuel a firm is buying or selling is what it's supposed to be – and if not, a quick blockchain search could reveal who possessed the fuel when the changes were made. Blockchain fuel data could also be used as evidence to help fraud victims avoid undeserved penalties, enforce contract terms, and pursue compensatory damages from business partners. Even when no laws or contracts are broken, firms can analyse blockchain data to identify weak links in the supply chain where schedules or protocols are routinely circumvented.

A system like BunkerTrace could also help authorities streamline compliance checks and enforce regulations. Authorities currently enforce the regulation by checking logbooks and bunker delivery notes and by taking oil samples. Quality control tests via blockchain could provide an additional instrument that some observers believe would be more accurate – and if excessive levels of outlawed material are detected, the source of fraud can be pinpointed, no matter how far in the past a crime was committed. The IMO has decided to prohibit vessels from carrying heavy fuel oil as a means of implementing the IMO 2020 regulation (except for those which have scrubbers installed). This makes enforcement of IMO 2020 easier and would reduce the need for DLT-based applications for enforcement.

By adding accountability to the bunker fuel ecosystem, blockchain could mitigate fraud, encourage operational efficiencies, and bolster regulatory enforcement, yielding fairer competition and less pollution. However, as with use cases that involve IoT smart sensors and AI, blockchain's effectiveness in resolving bunker fuel chain problems is contingent on the technology it is paired with. Blockchain cannot generate data itself or guarantee the accuracy of data added to its database. Thus, the reliability of data written onto the BunkerTrace platform is entirely dependent on the accuracy of data recorded by the synthetic DNA tags embedded in the fuel. Though there is no suggestion that this technology is faulty, new adopters should be aware of which technology is responsible for generating trustworthy data.

Public and private sector adoption may also affect blockchain's contribution to improving fuel quality. If some supply chain partners do not participate, blockchain fuel data may tell an incomplete story – undermining its utility and obfuscating accountability efforts. Consortia could attempt to impose blockchain adoption by members, but transition costs might be an obstacle. The burdensome cost of DLT might be just as out of reach for small firms as low-sulphur fuel.

At the same time, authorities would have to ensure technical and regulatory interoperability to reap the enforcement benefits of blockchain. Without assurance that regulators will recognise blockchain data as legitimate, firms may not see the benefit of adoption. However, if public sector adoption translates to the cost-saving streamlining of compliance testing and accurate, consistent enforcement for the bunker fuel industry, the private sector may be more willing to embrace the technology.

What do policy makers need to know?

The shipping industry's environmental impact has made regulations like IMO 2020 necessary. The severity of such regulations, and the accompanying punishment for non-compliance, lose their meaning if they cannot be enforced. Without a system that simplifies fuel quality verification for both firms and authorities, equitable enforcement may be impossible: the former may be forced to absorb penalties for indiscretions that are not theirs, while the latter may struggle to identify the bad actor responsible even when an infraction is detected. Blockchains like BunkerTrace may assist the enforcement of regulations like IMO 2020, supporting authorities by simplifying procedure and mitigating pollution. But regulators may have to take certain steps to take advantage of DLTs' potential.

The public sector would first need to learn how to conduct synthetic DNA tests and navigate a DLT platform. Authorities can also make regulations machine-readable and push for their integration into industry DLT algorithms, ensuring that the compliance of fuel data be assessed automatically (ITF, 2019a). This can be encouraged through open communication between regulators IMO (www.imo.org), as well as private consortia like the WSC, Blockchain in Transport Alliance (BiTA), and others in order to establish blockchain platform standards.

Maritime authorities may also want to work together to explore incentives that induce DLT adoption across borders, in order to ensure fair market competition and equal enforcement globally. In September 2019, several shipping industry organisations responded to reports that Indonesia and India would not require IMO 2020 compliance for domestic trade by calling for all maritime countries to strictly enforce the new rule (Hughes, 2019). They warned that such selective enforcement would allow non-compliant firms to gain an unfair advantage by using cheaper, more polluting fuel in areas unencumbered by regulation – distorting the market and undermining mitigation of emissions.

Universal adoption of a system like BunkerTrace would ensure that all stakeholders from all countries are abiding by the same set of rules. However, one should be cautious in considering that technological innovation will solve what is essentially a problem of resources and capacity of the authorities in charge of enforcing regulations. As long as the costs of DLT solutions are not considerably lower than current enforcement methods, there is little hope for universal application.

Passenger trip chains: Improving identity management through distributed ledger technologies

For most people, daily travel typically consists of multiple individual trip segments which may involve various travel modes – including walking, driving a private car, car-pooling or hailing a ride, riding public transport, or cycling, among others. For any single journey, people may link together several of these trip segments into a "trip chain".

In addition to having multiple travel modes to choose from for any given journey, commuters may have one or more providers to choose from for each mode. Today, travellers are likely to have the option of several apps for ride-hailing, car-sharing, and a variety of shared micromobility services (e.g. bicycles, e-bikes, scooters); multiple route -planning apps for various modes of transport; and a subscription to the local or regional public transport system. These distinct mobility providers may compete with each other, and generally each provider collects payment and interacts with users using its own bespoke ticketing and payment systems. People may mix and match these services to meet their daily travel needs, but the cognitive load of transferring between modes and paying for each one can be burdensome and lead to inefficiencies.

The breadth of new mobility options has grown in connection with the rise of digitisation and on-demand services, and now includes both shared mobility and shared micromobility services. Increasing integration and transparency between mobility providers, users and regulators could support broader regulatory goals like universal mobility access, reduced emissions and traffic decongestion (Caywood and Roy, 2018).

Nonetheless, friction exists in such a mobility marketplace, which can undermine the potential benefits of multi-modal travel. Poor data integration between different providers that are often competing for the same travellers can deny the latter the necessary information to optimise travel speeds and choices based on preferences. For instance, if a person cannot arrange payment and scheduling for an e-scooter rental, a bus trip, and a ride-share for a single trip chain conveniently through one platform, she may opt instead to use a private car. Such a fragmented mobility marketplace may give rise to "platform wars", where providers compete over the same ridership while depriving that ridership of optimum trip-chain travel options (ITF, 2019a). Third-party intermediaries have responded to this state of affairs by offering brokerage services between mobility service providers and users – but in return for a commission fee that may discourage ridership or exacerbate inequity.

The potential impact of distributed ledger technology on trip chains

From international aviation to micromobility, the passenger side of transportation has increasingly begun to explore the potential of distributed ledger technology (DLT). Pilot programmes and research in trip-planning, ride-hailing, and flight data management have helped clarify exactly what DLT's unique value proposition is – and is not (Perez, 2019).

Initially, as in other industries, DLT – blockchain in particular – was heralded as the solution to transport and mobility problems related to transactional visibility, immutability, digitalisation, decentralisation, and security. But through their innovation departments and start-up partnerships, industry leaders have gradually learned that DLT is not yet mature or sufficiently scalable for deployment. Often, a more established technology can adequately perform tasks that were identified as a potential target for DLT.

While it is far from a universal solution, the spike of transport industry interest has also unveiled DLT's strengths and potential. In helping manage complex trip chains, DLT's most uniquely advantageous and consistently cited feature is its capacity to create and auto-execute smart contracts.

What are the benefits of distributed ledger technology for regulators?

For regulators, smart contracts present an opportunity to embed laws and legal standards directly into peer-to-peer (P2P) transactions, easing the burden of active enforcement. By incentivising or requiring the use of smart contracts, regulators could guarantee that all transactions occurring on the platform comply with the law without constant auditing. This could relieve authorities of expenses related to enforcement and compliance – by largely automating labour laws related to mobility services, geofencing of service zones, public transport ticketing, and the settlement of disputes.

Besides directly saving regulators time and resources, efficiencies created by smart contracts could contribute indirectly to other public policy goals. For example, DLT's potential to ensure accurate, automatic payouts to multiple stakeholders via smart contracts could help make Mobility as a Service (MaaS) a reality. Doing so could encourage people to swap their private cars for other transport options, contributing to decongestion and decarbonisation. A successful MaaS platform built on DLT could also bolster "feeder systems" that connect underserved transport areas to major mobility hubs, increasing equitable access.

DLT's ability to decentralise authority and encrypt data could also assist in the enforcement of antitrust law, providing mobility service users with direct control over their data. This could help counter concentration in the data collection and processing industry, where a few transnational actors are disproportionately represented. DLT's potential to grant users control over their own data is discussed in more detail under "Trip chain case 4: Spurring sustainable transport through micropayments" (page 55).

Smart contracts

As discussed previously in this report, DLT's smart-contract algorithms can auto-execute P2P exchanges of information as soon as certain conditions are met, reducing reliance on third parties to securely execute transactions. This could prove useful for passenger transport.

Smart contracts could empower a neutral MaaS platform by ensuring potentially sensitive data for competing mobility providers (e.g. fleet details, schedules, pricing and ticketing) can be shared automatically but securely. DLT's ability to encrypt data and automatically trigger exchanges through smart contracts without an active third party could assuage the concerns of mobility providers about sharing data which is critical to MaaS, but which could undermine their competitive edge. By supplying the infrastructure needed to induce more widespread provider integration into MaaS, DLT can also support regulators' efforts to promote sustainable transport alternatives to private car use – reducing emissions and traffic congestion.

Smart contracts' ability to auto-execute P2P transactions can also bring efficiencies to the ride-hailing app industry, which has seen protests from drivers over low wages thanks in part to high commission fees. Rather than managing ride-matching through a centralised platform, DLT smart contracts could enable secure P2P transactions between the drivers and riders based on pre-established conditions (e.g. pick-up and drop-off point, time of journey, price). A decentralised ride-hailing platform could potentially bring drivers a greater share of earnings for each ride, while expanding ridership by lowering the price of journeys for passengers.

Box 4. DLT smart contracts' potential impact on passenger trip chains

- Enable secure data-sharing and ensure operators are compensated proportionately for a multimodal journey by providing the infrastructure necessary for a neutral Mobility as a Service (MaaS) platform that offers users a full suite of route and payment options through a single interface (Carter and Koh, 2018; Andersson and Torstensson, 2017).
- Facilitate micropayments that can be earned and exchanged by all users of a blockchain, presenting a method of offering automatic behavioural incentives and imposing regulatory fines (de Wilde, 2019).
- Securely store and verify digitised identification data, which could improve the safety, security, speed and accountability related to a wide range of uses, from ride-hailing and car-sharing to airport check-in (MVL, 2018; Amadeus, 2017).
- Create direct peer-to-peer (P2P) transactions, which could decentralise mobility by eliminating dependency on platforms that charge commissions for connecting users and services.
- Provide a "single version of truth" for datasets, helping avoid disputes and mistakes.
- Track luggage throughout its journey, and automatically disperse frequent flyer miles (Amadeus, 2017).
- Instantly compensate mobility users when providers fail to meet terms such as departure or arrival times (Andersson and Torstensson, 2017).

Source: Andersson and Torstensson (2017); Amadeus (2017); MVL (2018); de Wilde (2019); Carter and Koh (2018).

Regulatory support can facilitate advances

While DLT's smart contracts have shown some potential to make these impacts through limited pilot projects, there are some regulatory changes that could be made to create a more DLT-friendly environment for deployment. These regulatory initiatives could potentially help level the mobility-sector playing field and encourage further investment in DLT innovation, ultimately yielding benefits for providers, users and policy makers.

For instance, the integration of mobility provider data is critical to the success of a MaaS platform, because it would make combined e-ticketing, schedule coordination, and proportionate pay-out between providers easier to execute through a single portal. Resolving these obstacles to MaaS could lead to a level of flexible on-demand access to multimodal transport that rivals private car ownership, which could reduce traffic congestion and pollution. As discussed under "Trip chain case 1: Making a neutral MaaS platform a reality" on page 44, authorities can foster MaaS integration by ensuring the participation of public transportation providers in a MaaS platform as the anchor that will attract others. Authorities can also adopt regulation that requires private mobility firms to share some common data. DLT has the potential to integrate data from multiple providers into a single MaaS platform using semi-open application programming interfaces (APIs), but regulators may need to first ensure through law that those APIs are accessible (as discussed under "Trip chain case 4: Spurring sustainable transport through micropayments", page 55).

Regulators may also want to update policies, collaborate with industry actors in anticipation of market disruption, and initiate pilots through research, development and funding support (Carter and Koh, 2018). Trip chain case 2: Peer-to-peer ride-hailing (page 49) reviews how outdated regulation may stifle innovation in mobility, costing drivers, riders and regulators the potential benefits. Regulators can work with the taxi/ride-sourcing and start-up industries to ensure driver's rights are protected. Authorities can also initiate or support adoption of machine-readable regulations and other official information, such as a small-scale pilot programme for digital identification in the aviation industry. Civil Aviation Authorities (CAAs) can require their air navigation service providers (ANSPs) to grant access to semi-open APIs as well, so that authorised parties can use DLT to record immutable flight records (see Trip case 3, "Distributed ledger technology takes flight", page 52).

It may also benefit governments to join mobility DLT pilots as observers, or run their own small scale pilots in order to understand how DLTs work and where their utility lies. By gaining this familiarity, authorities can target potential uses for DLTs and identify potential areas in which to update regulation. Armed with these insights, regulators may be better able to anticipate emerging DLT applications that could have relevance for public policy outcomes.

Use cases for distributed ledger technology and blockchain to improve passenger mobility trip chains

The remainder of this chapter examines four DLT use cases in the passenger mobility sector. DLT has the potential to empower users and generate better services, but key shortcomings must be addressed first. By properly regulating mobility data and encouraging the development of DLT/blockchain technology, public authorities may be able to better optimise the use of existing assets and contribute to improved transport and sustainability outcomes (ITF, 2019a; ITF, 2019b).

Making a neutral Mobility as a Service platform a reality

MaaS offers individuals access to multiple transport modes through a single digital platform that encompasses payment, ticketing and route planning (Carter and Koh, 2018). The convenience of well-executed MaaS platforms could potentially reduce reliance on private cars. One of the barriers to broad uptake has been the need to find a way to share data amongst potentially competing transport service providers on a single platform. DLT could allow providers to securely share data and help establish a neutral platform that functions as a public good. This would require regulators to agree on data-sharing principles and control for monopolistic behaviour. Moreover, it is not clear that DLT transactions could be handled as quickly as current, non-DLT technology can – for payments, for instance.

Peer-to-peer ride-hailing

Ride-hailing services leveraged the sharing economy and on-demand concepts to disrupt the taxi and broader mobility industry. But their business model relies on charging commissions that raise fares and undercut returns to drivers. With its decentralised structure and smart contracts, DLT can replace centralised platforms and enable peer-to-peer transactions directly between riders and drivers. A more stable, commission-free ride-hailing market could address driver resentment toward new actors – but both blockchain- and taxi-related regulations may have to be overhauled in order to allow market entry.

Distributed ledger technology takes flight

In the aviation industry, bloated ticket purchasing systems, laborious check-in processes, and narrow profit margins have to be balanced against exposure to social and technological disasters. People, luggage and data relating to both routinely pass through multiple airlines and jurisdictions during a single journey. DLTs can facilitate simpler ID verification, baggage tracking, customs procedures and ticket purchases. This would make flying more bearable for customers and mitigate losses for firms, but it could also make regulatory enforcement more efficient. Due to the distinctly international dimension of aviation, public authorities would have to collaborate across borders to establish uniform standards.

Spurring sustainable transport through micropayments

Although the emergence of big data has challenged authorities, the people who generate data may not always reap the benefits. With the right regulatory and platform standards, DLT smart contracts could empower MaaS users to earn and exchange tokens via direct micropayments. These micropayments could be leveraged by authorities to incentivise the use of sustainable transport and regulate traffic, while ensuring that users are given proper control over their own data.

Trip chain case 1: Making a neutral Mobility as a Service platform a reality

Mobility as a Service (MaaS) has the potential to revolutionise how people move around cities, regions, and the world. The growing interest in MaaS reflects broader shifts in modern society, including a shift from vehicle ownership and static public transport schedules to on-demand usership (Carter and Koh, 2018). Current transportation systems often force travellers to choose inconvenient transport modes due to a lack of information about other options. This is partly due to mobility providers' resistance to sharing data that could benefit competitors and reduce revenue. This leads to inefficiencies that undermine public policy outcomes. These barriers cause people to use private cars that cause congestion and pollution, occupy valuable urban space, and are more expensive than alternative transport modes (Kyyti Group, 2020; Intelligent Transport, 2019).

MaaS addresses these challenges by aiming to provide a convenient transportation service, through one digital interface, capable of combining travel modes in a way that satisfies the needs of the customer and minimises reliance on private cars (Carter and Koh, 2018). Europeans currently spend EUR 616 per month, or 85% of their personal transport budget, on owning and maintaining a car despite using it for just 29% of trips (Reid, 2019). Private cars in the United States sit unused 95% of the time, are used for trips of 1.6 km or less 28% of the time, and only carry 1.6 people on average (Schmitt, 2016). By contrast, the most expensive mobility package offered by Whim, a MaaS platform operating in Helsinki, Finland and a few other cities, offers access to unlimited public transport, unlimited taxi rides within 5 km, and unlimited rental car and bike share usage for EUR 500 per month total in Helsinki (Hartikainen et al., 2019). Indeed, shared cars and bicycles have higher utilisation rates, and public transport makes more efficient use of existing infrastructure than private cars do (Caywood and Roy, 2018).

Mobility providers remain apprehensive about sharing data with a third-party platform operator, or with other platform members they perceive as competitors. Other concerns include the allocation of revenue and liability when a MaaS customer purchases a single ticket for a journey encompassing multiple providers. Analysis of MaaS pilots has revealed that the success of a platform is largely determined by the level of integration between providers, making data access essential (Andersson and Torstensson, 2017). Low integration means that route-planning and ticket bundling, among other features, cannot be efficiently executed, undermining potential user benefits.

The solution to the trust issues that hamper MaaS may be found in DLT’s unique ability to facilitate secure data sharing, to enforce agreements and auto-execute payouts through smart contracts, and to create a neutral data ecosystem through decentralisation. By resolving mobility providers’ concerns about joining a MaaS platform, DLT can help regulators achieve larger policy goals of sustainable and equitable transport.

How does it work?

Fully launched in November 2017, Whim is considered the world’s first full-service MaaS operator (Huhtala-Jenks, 2019). The app was designed by start-up MaaS Global, which counts BP, TransDev and Toyota among its investors (de Wilde, 2019; Reid, 2019). Users can choose between subscription packages at different price points and ride limits, each featuring a combination of public transport, taxi, car rental, car-share and bike-share trip (Huhtala-Jenks, 2019). The tickets inside the subscriptions are pre-purchased and bundled by Whim. The app provides optimised routes with a mix of transport modes based on a user’s subscription and preferences (Haaramo, 2016). UbiGo, a small-scale MaaS pilot similar to Whim, was run in Gothenburg, Sweden, from 2013 to 2014 with 70 users (Andersson and Torstensson, 2017). UbiGo packaged tickets for various transport modes into single-payment subscriptions through its app, combined with universal smart cards for access.

Whim and UbiGo have served as “integrators” within the MaaS ecosystem, and integration levels can make or break a MaaS platform (Andersson and Torstensson, 2017). A MaaS integrator must acquire various pieces of trip information (prices, schedules, tickets, etc.) from different mobility providers, and ensure data fluidity for the platform operator – a tedious and cumbersome process, executed manually in the case of UbiGo (de Wilde, 2019).

Even before the practical challenge of data integration, providers may refuse to share data altogether. Despite positive reviews from users and providers, the UbiGo pilot failed to scale up – partly due to mobility providers’ unwillingness to join and supply data to a platform that also includes perceived competitors. According to interviews with mobility providers from the UbiGo pilot, the three requirements for a successful MaaS platform are identity verification, an agreement platform, and a route planning tool (Andersson and Torstensson, 2017).

DLT’s ability to auto-execute smart contracts can address these problems. Smart contracts enable transaction terms to be programmed directly into the MaaS platform, creating transparent yet secure data-sharing through the encrypted decentralisation of sensitive information. Identity confirmation, revenue allocation and route-planning can be automatically determined and the results selectively shared among MaaS actors with virtual certainty that the data is accurate. Through DLT, highly sensitive information can also be exchanged directly between the provider and the user through the former’s API (Andersson and Torstensson, 2017). These APIs do not have to be fully open, and the precise information included and withheld is enforceable through the smart contract feature without having to share it with a central authority.

Challenges and benefits

By deploying DLT to support a decentralised neutral MaaS platform, fair competition may be enhanced and users can be offered a higher quality service. Currently, the gaps in data-sharing and integration result in different modes operating inefficiently and in isolation. DLT can enable data from disparate sources to flow freely through a decentralised MaaS app with only minimal gatekeeping, granting users the flexibility to combine and optimise routes. This open ecosystem would replace “walled garden” models that undermine interoperability. This MaaS model would be roughly analogous to an “internet” model that leverages open data access to promote multimodality, fair competition and sustainable transport (Andersson and Torstensson, 2017).

Whim’s creators aim to replace private cars by offering citizens an affordable, intuitive alternative that curbs traffic and pollution, reduces demand for parking, increases safety for pedestrians and non-motorised vehicles, and makes more efficient use of alternative transport modes. Whim’s users take public transit and taxis more than the average Helsinki resident, and make mixed-mode trips without a private car more often. Early analysis of Whim users’ high level of multimodality suggests that increasing access to shared bicycle fleets (regular and electric), and integrating them into MaaS platforms, could reduce daily car trips by as much as 38% (Hartikainen et al., 2019).

Similarly, evaluations of UbiGo found that subscribers used their car less and chose public transit, walking and cycling more. They also felt more negative toward private car use than before (Sochor, Stromberg, and Karlsson, 2014). UbiGo discouraged private car use by paying participants to avoid driving, which suggests that MaaS can leverage incentives to alter commuter behaviour in pursuit of sustainable policy goals.

While these examples show that MaaS can theoretically promote sustainable transport without DLTs, the latter’s ability to ensure secure data sharing may be necessary to address operator concerns and induce large-scale MaaS adoption. The City of Los Angeles’ push to have micromobility operators share their data with public authorities has highlighted many of the sensitivities around data sharing for public policy outcomes (Marshall, 2019; ITF, 2018). Much of the tension in this and similar battles originates from data asymmetries between mobility operators operating in public spaces and public authorities mandated to deliver public policy outcomes.

This suggests that regulatory action may be necessary to establish an “even playing field” for all providers and build capacity for implementation of a neutral MaaS platform run through a public DLT. In May 2017, the Finnish Government took steps toward this goal by requiring all mobility providers to open data and publish APIs. This move was meant to create an open ecosystem that will allow any journey to be linked through one seamless travel chain and paid for through one mobile platform (Ertico Network, 2017).

Legislation requiring open data and APIs from all passenger transport operators can set the stage for DLT-facilitated MaaS. Smart contracts can use this data to create unified mobility offers and enforce predetermined conditions automatically, without exposing sensitive data (Andersson and Torstensson, 2017). In this context, when a user “requests” a journey through a DLT-based MaaS app, the platform sifts through open APIs to compile options and propose them to the user with the price, time and modes listed. The user’s selection auto-generates a smart contract that holds payment in escrow and distributes it to providers proportionately after the trip is completed.

However, this version of a DLT-based MaaS is contingent on convincing mobility operators that risks relating to privacy and commercially sensitive information are adequately addressed. Political efforts to force open data access without explicitly stating the intended use of that data and the data processing rules that will apply will likely be met with resistance. Further, private operators should feel confident that public authorities are seeking the minimum data required to carry out their public policy mandates. Even a decentralised MaaS platform will require some entity to manage integration and oversight functions in such a way as to minimise risks arising from market concentration. Because public transport operators are also potential competitors in the MaaS landscape, platform design should ensure that these actors do not exclude new market entrants.

What policy makers need to know

A MaaS platform controlled by one or a few mobility providers can exclude rivals, producing market inefficiencies that harm users and undermine the potential benefits of MaaS. By contrast, a decentralised and neutral MaaS platform – leveraging, for example, DLTs – could exist as a digital public good similar to the internet, facilitating fair competition for providers and beneficial outcomes for users.

In order to create an efficient mobility marketplace through a neutral DLT-based MaaS platform, access to mobility data is required (Caywood and Roy, 2018). Regulators must require some form of public access to platform data to make a neutral MaaS platform possible. Fears relating to data leaks and the release of commercially sensitive information can be addressed via DLT's secure encryption and smart contract capabilities. Incorporating DLT into MaaS platform architecture could improve access neutrality and ensure privacy concerns are addressed.

The Helsinki public transit authority's (HSL) decision to grant Whim access to its payment APIs has been crucial to the app's success, permitting the inclusion of popular HSL monthly passes in Whim subscriptions (Haaramo, 2016; Caywood and Roy, 2018). At the national level, the Finnish Government's requirement for transport providers to open their data and APIs paved the way for Whim. These kinds of regulatory frameworks are essential building blocks that could enable a neutral DLT-based MaaS platform.

In addition to adopting antitrust policies that promote a neutral MaaS platform and require mobility providers to publish open data and APIs, regulators can support and encourage research and development of DLT-enabled solutions. By inducing improvements to the technology, policy makers can learn how it works, gain experience using it, and determine whether and how to deploy it such that integration is maximised while centralisation is minimised. Indeed, many private mobility providers are diversifying offerings through their apps, indicating that there is both user demand and provider interest in MaaS-like offerings.

Regulators should invest resources in building capacity to understand and manage digital platforms, including those which could leverage DLTs, in order to reduce the risk of MaaS market concentration. They should also establish guidance and rules governing data-sharing and access, with a view to leveraging the ability for DLTs to address current MaaS shortcomings.

By encouraging the development and adoption of neutral DLT-enabled MaaS platforms, authorities may be able to deliver improved transport and societal outcomes.

Trip chain case 2: Peer-to-peer ride-hailing

Ride-hailing apps like Uber and Grab have been ground-breaking in the vehicle-for-hire market, leveraging the rise of smartphones to compete with conventional taxis around the world. But they are also embattled start-ups that have faced endless litigation in many cities, plus disgruntled drivers that criticise working conditions (Kelly, 2016; BBC News, 2019).

Ride-hailing platform providers have benefited from acting as the sole broker between supply (drivers) and demand (riders), charging commissions that undercut revenues for the former and raise prices for the latter (Carter and Koh, 2018). The apps' centralised models have also sparked concerns regarding data value and ownership: regulators seek their data to inform policy choices, while passengers and drivers could profit from owning their trip data.

While the business model for these ride-hailing platforms was considered innovative at first, DLTs could potentially render them obsolete. The technology has the potential to replace centralised ride-hailing apps with a peer-to-peer system that allows drivers to set their own rates and execute transactions directly with customers, eliminating reliance on any platform intermediary (Carter and Koh, 2018). DLTs can enable passengers and drivers to earn monetisable platform tokens in exchange for leaving reviews, sharing data, and providing quality service. DLTs could also enhance regulatory compliance via smart contracts, consensus incentives, and immutable record storage capabilities.

How it works

TADA (www.tada.global) is an app-based ride-hailing service that has leveraged blockchain technology in its design. Its parent, Korean-based start-up Mass Vehicle Ledger (MVL), applies blockchain to the wider automobile industry by storing and verifying vehicle, driver and mechanic data on a single distributed ledger (MVL, 2018). TADA represents MVL's entry into the ride-hailing market, with the former running its platform through the latter's blockchain. First launched in July 2018, TADA has 200 000 users and 27 000 drivers in Singapore, 2 000 drivers in Viet Nam, and a foothold in Phnom Penh, Cambodia, where Southeast Asian ride-share giant Grab and local stalwart PassApp had previously dominated the market (Do, 2019; Kanagaraj, 2019).

High levels of demand and fierce competition in those cities' ride-hailing markets create a situation where small competitive edges can have a large impact. This is the case with TADA's blockchain-enabled service. The peer-to-peer (P2P) efficiencies of blockchain allow TADA to charge 0% commission on drivers while retaining competitive pricing for users, limiting fees to payment processing (Fin Tech News, 2019). This is a milestone departure from the centralised platform models of Grab and Uber, where drivers are charged a minimum of 20% and 25%, respectively, in commissions (Grab, 2019; Uber, 2019).

In addition to a 0% commission, TADA's blockchain allows drivers to accumulate tokens on the MVL platform even when not driving for TADA. By driving safely and professionally, completing shorter trips and working during peak hours, drivers participating on the broader MVL platform can accrue tokens that can be exchanged on any electronic trading platform that accepts them (MVL, 2018; Do, 2019). Riders may also accrue tokens for adding accurate reviews to the MVL blockchain. In June 2019, MVL announced that it will integrate its token system with global cryptocurrency exchange Binance, expanding TADA drivers' and riders' ability to trade and spend tokens (Cordon, 2019). MVL's token incentives may manage to attract additional drivers and riders, while their data bolsters the value of its blockchain. In lieu of elevated commissions or fares, MVL plans to build up and then sell its database to interested researchers and insurance firms (Cheng, 2018). MVL platform participants have full ownership of their data, with the option to share it in exchange for tokened compensation and with confidence in its security on blockchain (MVL, 2018).

Challenges and benefits

Ride-sourcing company fees are not inconsequential and several start-ups, like TADA, have sought to develop alternative business models that reduce or eliminate these costs. For example, Uber's website states that its 25% service fee is levied in order to cover costs related to drivers' use of its software, plus fare processing, credit card commissions, and invoicing clients (Uber, 2019). TADA charges only a 3.4% transaction fee, plus USD 0.50 for credit card payments (Cheng, 2018). All other commissions charged by firms similar to Uber are eliminated for TADA drivers, due to blockchain's auto-executing smart contracts. This has freed TADA from using surge pricing to drive revenue, allowing them instead to offer riders a lower and more stable price during rush hour.

Uber also specifies that drivers' payments are issued every Monday but are not reflected in their bank accounts until Thursday or later (Uber, 2019). Through blockchain's P2P capabilities, TADA allows drivers and riders to conduct transactions directly yet securely, removing banking delays caused by exchanges that require a third party. Blockchain's smart contract and P2P capabilities enable TADA to elude the "middleman tax", thus providing an attractive alternative to commission-based models applied by platforms like Uber and Grab (Linnewiel, 2018).

TADA emphasises that it does not intend to compete with other market actors, insisting that its drivers are free to work for other ride-hailing companies (Ellis, 2018). Nonetheless, its 2018 debut in Singapore coincided with a number of other developments that contributed to the erosion of Grab's – Singapore's dominant ride-sourcing company – market share (Cunningham, 2018). Shortly after purchasing Uber's Southeast Asian assets, Grab cut its passenger discounts and driver incentives, and increased its surge prices. Disgruntled riders and drivers accused Grab of monopolistic behaviour, and expressed a desire for other ride-hailing companies to enter the Singapore market (Jones, 2018). These developments underscore the importance of stable pricing mechanisms and driver incentives in the ride-hailing industry – both of which were offered by TADA and its blockchain-based platform.

What policy makers should know

No matter how innovative certain DLTs may be, the success of TADA and other DLT-based ride-hailing services remains contingent on governance of platforms and the services they deliver. For instance, regulation favouring the incumbent taxi industry has kept ride-hailing services illegal in South Korea. MVL had hoped to launch TADA first in Seoul; but regulatory hurdles proved prohibitively burdensome, and so TADA was instead introduced in the more permissive ride-hailing market of Singapore (Lee, 2018). South Korea's tightened regulations on cryptocurrency trading, including a full ban on Initial Coin Offerings (ICOs), forced Korean taxi and parking service Kakao Mobility to withdraw its USD 620 000 investment in the start-up, representing 15% of total shares.

Business and start-up industry experts in Korea have expressed concern about the country's strict regulation of the ride-hailing industry, suggesting that resistance to new business models may cause the country to fall behind others (Korea Bizwire, 2019). A ride-hailing van service in Seoul, also named Tada but unaffiliated with MVL, has sparked intense protests from traditional taxi drivers intent on warding off competition (Kang, 2019). Actors in both the start-up and mobility industries have called for the government to allow innovation, while working to integrate the traditional taxi industry into the emerging market. Meanwhile, Seoul's Tada van service has exploited a loophole in South Korean transport regulations that allows vehicles with more than 11 seats to operate as taxis outside of the permitted window for smaller cars. While Tada and TADA are not connected, the case of ride-hailing in Seoul suggests that modernising existing regulations, such as those governing taxis in Seoul, may be preconditions for any further innovations – like the use of DLTs for ride-sourcing.

Trip chain case 3: Distributed ledger technology takes flight

Unlike the variety of options available for urban travel, aviation is often the only way to travel great distances in a reasonable amount of time. The aviation industry is essential to international business, tourism and freight (Mapperson, 2019; Ledger Insights, 2018). As for other transport sectors, aviation is still beset with inefficiencies: operations can be sluggish, regulation can be cumbersome, and journeys can be unpleasant for passengers. Extensive security precautions put in place following the 9/11 attacks have sought to increase security but can hamper operations. The international nature of aviation, and the dual importance of safety and security, have given rise to a complex web of regulations across jurisdictions. Moreover, multiple agents participating in international travel chains collect and process a wide range of sensitive passenger-related data.

On average 26 different entities participate in the processing of a single passenger's trip chain between the initial purchase of a flight ticket and arriving at a final destination, (IATA Blog, 2017). This includes airlines, airports, booking platforms, credit card companies and customs authorities, in addition to secondary vendors like hotels or car rental agencies (Accenture, 2019). Each of these actors collects and may share passenger information, producing a tremendous volume of sensitive data – which has ramifications for privacy, interoperability and trust in the aviation industry (Wood, 2019c).

Poor coordination amongst aviation industry actors can lead to breakdowns, resulting in lost luggage, settlement delays, refund disputes, lengthy security checks and overbooking. Airlines currently spend over USD 10 million combined on bank fees and lost baggage each year, totalling nearly 30% of the global airline industry's 2016 profits (IATA Blog, 2017; Joshi, 2019). These inefficiencies are also often exploited by intermediaries, which make travel more expensive. Two online travel agencies (OTAs) control 95% of the OTA market in the United States, and just three global distribution systems (GDSs) control 99% of non-direct inventory in the aviation market (Izmaylov et al., 2019). These dynamics potentially undermine fair competition, creating headaches for regulators while inconveniencing many travellers.

DLT features, including data tokenisation and smart contracts, are potentially capable of increasing operational efficiencies and customer satisfaction in aviation (Goudarzi and Martin, 2018). By leveraging DLT to more securely manage identification, payment, ticketing, booking, flight data and baggage, the airline industry could potentially reduce costs generated by intermediaries and lack of trust. Regulators can reduce expenditures on enforcement while improving safety compliance by using DLT smart contracts to verify identities and manage flight data. These efficiency gains for private and public industry actors could save passengers time and money, ultimately improving the experience of flying.

How it works

Aviation is a good use case for advancing digital identification technologies, and DLTs may have an important role to play in supporting these (Goudarzi and Martin, 2018; Bates, 2018). Aviation technology firm *Société Internationale de Télécommunications Aéronautiques* (SITA) reported that as of 2018, 40% of airlines and 36% of airports considered streamlined passenger identification a major benefit, while 59% of airlines have DLT programmes on pace for implementation by 2021 (Airport Technology, 2018). At present, travellers are required to use identification documents to make and change bookings, check-in with an airline, pass through security, board a plane and enter a new jurisdiction (Amadeus, 2017). This thorough procedure is intended to assure passengers, airlines and authorities that the appropriate person is benefiting from a ticket – but it can also be tedious and costly.

DLT can streamline this process by digitally storing identification details with encrypted access so that only permissioned actors can view them. Smart contracts can create different layers of access so that airlines or hotels see only the information they require to process a transaction, while security and customs officials can see more. Civic, a start-up specialising in digital identity management through blockchain, has piloted use cases in other sectors with plans to enter the aviation industry (Amadeus, 2017). Instead of storing sensitive data itself, Civic offers a way to digitally access ID verification already confirmed by highly trusted entities such as states.

By underwriting the privacy standards necessary to ensure security, blockchain-based ID verification could expedite the travelling process while creating both value-chain and regulatory efficiencies (Hussain Zaki, Panicker, and Rajan George, 2019). The International Aviation Trade Association (IATA) is developing the Digital Certification Authority (DCA) platform to facilitate digital ID management in aviation via DLT as well, which it sees as part of the broader digitisation imperative to keeping member airlines financially sustainable.

DLT's smart contracts can improve booking, ticketing, and payment processes beyond digital IDs. In the current process, a ticket purchase through a flight search aggregator generates a convoluted payout process that is prone to delays and disputes. This can include the aggregator site and OTA used by the customer, multiple airlines, and a GDS, each of which receives proportionate cash and commission settlements according to prearranged agreements (Amadeus, 2017).

Smart contracts can automatically and instantly execute these payouts, circumventing costly intermediaries and minimising delays. In July 2019, Siberia Airlines reportedly processed over USD 1 million in payments through blockchain, which reportedly reduced payment processing time from 14 days to 23 seconds (Rivers, 2019; ASEAN Post Team, 2018). The platform automates all booking steps, including the execution and verification of payment, which has reduced settlement times between airlines and agencies and removed any reliance on a third party (Ward, 2017). Simplifying the payment process for firms can also benefit customers: a well-integrated ticketing platform can generate one e-ticket that is stored on blockchain in a digital wallet, tied to a digital ID, and accepted at all links of a trip chain.

Payment can also be improved through blockchain by overhauling the management of airline loyalty programmes. Accessing and using points in current loyalty programmes can take up to six weeks, due to verification processes and a lack of interoperability between airlines (Amadeus, 2017). Smart contracts can enable automatic, real-time accumulation and spending of points between different actors on a single blockchain. Singapore Airline's KrisFlyer loyalty programme is a blockchain-based digital wallet where users convert miles into digital currency accepted by the airline and its partners. Another similar project is being piloted by the start-up Loyyal (Baydakova, 2018; Amadeus, 2017). Increasing the liquidity of frequent flyer and loyalty points through blockchain e-wallets can help simply payment and ticketing, helping to mitigate the processes of online purchasing and security checks.

DLT may also help bolster consumer protection. While some airlines and countries have rules or regulation in place regarding delays, cancellations and lost luggage, retrieving compensation can be laborious. Trustabit is leveraging blockchain's smart contracts to automatically reimburse passengers when flight conditions (such as time of departure and arrival) are not met, which may save airlines money and time. In response to stringent EU regulation, certain European airlines have departments specially dedicated to managing flight delay regulations, and one spent USD 500 million processing claims in 2018 (Yerman, 2019). Rega is an insurance platform leveraging blockchain's system of distributed responsibility to share risk across its community. Through this approach, it has reduced the cost of insuring luggage to USD 12 per year for coverage up to USD 5 000 (Mapperson, 2019).

The consistency of flight data is essential to security, but is typically spread across multiple jurisdictions and software systems without a single authoritative "source of truth" (Goudarzi and Martin, 2018). Actors often lack trust in each other and have bespoke data systems that cannot easily interface with others. Fragmentation of flight-related data can slow down critical exchanges between actors, causing expensive delays and compromising safety. DLT has the potential to overcome some of these blockages by establishing a high degree of trust in a single, shared and agreed data ledger (SITA, 2017).

FlightChain was piloted in 2017 by SITA in collaboration with British Airways and three international airports, using blockchain's smart contracts to arbitrate potentially conflicting flight data (SITA, 2017). FlightChain was able to resolve data discrepancies without any central authority through the pre-established terms codified in its smart contracts. These smart contracts successfully processed more than 2 million flight changes (Morris, 2018). Blockchain platforms like FlightChain are capable of assisting regulators in keeping passengers and crews safe while providing a single source of truth for air traffic control, airport staff, and customs agents.

Challenges and benefits

Authorities are unlikely to experiment with emerging technologies like DLT in such a high-stakes environment as aviation. Combining DLT with other technologies such as artificial intelligence (AI) and biometrics to strengthen a digital ID system is a potential way forward to leverage the benefits of DLTs – but this may add cost and complexity in the form of software and professional development (Goudarzi and Martin, 2018).

These challenges cut both ways. Current ID verification systems have largely not kept pace with more general advances in modern technology. Despite some disillusionment with DLT, it is consistently considered one of the strongest technological solutions to the problem of absence of trust among actors (Goudarzi and Martin, 2018; SITA, 2017; Schmahl et al., 2019). Potential benefits could be worth investment in time and money amongst aviation industry actors if DLTs lead to greater cost savings.

Uptake of DLTs will be challenged by the need to scale these technologies to cover the transactions of 4 billion yearly passengers. Standards would need to facilitate interoperability without compromising security. A DLT for global ID verification would require permissioned access ensuring extremely high privacy; but this may be complicated by having centralised private DLTs. Operating a private DLT for such a large group of actors may create platform governance problems. A public DLT would ensure proper decentralisation and security, but scaling such a platform presents tremendous technical challenges.

What policy makers should know

DLT could potentially produce savings for airlines, and might also facilitate smoother enforcement and compliance for regulators. By participating in pilot programmes and consortia, customs, security and air-traffic-control agencies can ensure that regulations are included from the start in smart contract parameters and platform standards. This can help reduce expenses related to government oversight, personnel and enforcement. Because aviation is more international than other modes of transport, platform governance will require robust collaboration between governments.

Regulators may also want to pilot blockchain themselves, especially in the realm of digital identification. Digital ID technology has the potential to save time and money by speeding up security and customs procedures, while increasing safety levels due to the immutability of data. An aviation DLT pilot programme with a small, low-security-risk airport would provide an opportunity to explore the costs and benefits of DLT and other new technologies, and help public authorities gain a deeper understanding of how they work.

Governments may also need to clear the way for deploying such technologies through updates to regulation around data privacy (Hussain Zaki, Panicker, and Rajan George, 2019; Bouffault et al., 2019). Digitising sensitive passenger data represents significant opportunities, but also poses security risks. Policies that permit, but also regulate, the secure exchange of passenger data may lead to wider adoption at airports. A critical mass of adoption is necessary to allow a decentralised digital system to function.

Trip chain case 4: Spurring sustainable transport through micropayments

In an increasingly interconnected world, data has become extremely valuable. Big Data has become its own industry, with top firms competing to gather, harvest and sell data generated by ubiquitous and portable devices. This data has become profitable because it can be leveraged to gain insight into human behaviour, both globally and at the individual level. The preferences and trends extracted from analysis of this data can be used to more accurately market to consumers, inform investment, and direct policy.

By 2021, there will be about 50 billion devices connected to each other worldwide, collectively producing more than 2.3 billion terabytes of data a year (Catapult, 2017). Properly curated and ethically managed, this volume of data could be leveraged to inform human decision-making such that it improves quality of life, simplifies common tasks, and expands market options. As in other sectors, the monetary value attached to data has led to protectionism among transport service providers who compete over users – and, subsequently, their data. While fair competition that improves service quality is good, the advantages won by a mobility provider that refuses to share its data deprive policy makers and the marketplace of the ability to make fact-based decisions. This siloing of mobility data may undermine service quality and limits peoples' options, potentially resulting in a poorer mobility experience for users. Even though mobility service operators collect and hold onto data to gain a competitive edge, these data silos may impose real costs: it has been estimated that non-sharing of mobility data will cost the United Kingdom up to GBP 15 billion in lost benefits by 2025 (Catapult, 2017). By contrast, increased data sharing could support new, integrated, sustainable mobility solutions that would better support economic, social and environmental challenges. A clearer picture of mobility users' behaviours and preferences would allow authorities to adjust policy in a way that supports innovative solutions, and would allow potential new market entrants to better identify gaps in service quality.

Despite recent regulations like EU's General Data Protection Regulation (GDPR) and the California Consumer Privacy Act (CCPA), the implementation of user rights within mobility apps still often requires "blanket acceptance of traditional terms and privacy policies, granting large organisations the permission to use and resell data with few, if any, controls on its use, and with little recourse or cancellation [options] if abused" (DOVU White Paper, 2018). Mobility users are driving providers' profits not only through ridership, but through data – without receiving any benefit or compensation beyond the value of the services they consume. While this incentivises mobility providers to boost ridership and collect data, it may not necessarily result in a better travel experience for users.

A mobility ecosystem that grants users control over their own data, and compensates them for sharing it, might benefit users, providers and authorities. The types of transactions that would characterise such a market are small and digitally-enabled – in other words, micropayments. The value of the compensation a user receives may vary from tickets to in-app discounts or points convertible to currency, with users transferring points to each other for micro-services like reserving parking spots.

Points accrued by such micropayment transactions could be put to several uses. They could encourage the use of sustainable mobility services. Providers could leverage user data to deploy fleets and set schedules more accurately. Authorities could leverage the point system to promote broader policy goals like emissions reduction and decongestion. Such a system of incentives could potentially replace a central authority by enabling direct real-time micropayments between users, providers and analysts through DLT. Still, any concerns about privacy and compensation would have to be addressed. DOVU, a MaaS platform using blockchain, aims to make this a reality.

How it works

DOVU (www.dovu.io) builds on blockchain attributes relating to smart contracts, data immutability and distributed trust mechanisms to establish a decentralised mobility marketplace governed entirely by incentives. With users in complete control of their data and no transaction fees, smart contracts enable users to selectively exchange granular amounts of data in exchange for platform tokens (de Wilde, 2019). DOVU users accrue “tokens” in exchange for sharing data or choosing promoted mobility options (i.e. off-peak travel), which are stored in users’ “wallets” and can be spent on other platform services. In DOVU’s case, a “token” is used as “a unique identifier of data” shared across the network, and is not representative of fiat currency (de Wilde, 2019).

In 2019, UK rail and bus operator Go-Ahead agreed to provide riders with DOVU tokens redeemable on its transport network in exchange for sharing travel data, which it plans to use to improve its understanding of travel habits and outreach to customers (Butcher, 2019a). In this instance, DOVU’s tokens act as a sort of Go-Ahead loyalty programme. While DOVU’s ultimate goal is to integrate more mobility operators to facilitate even greater data-sharing and token-spending across entities, the partnership with Go-Ahead already generates benefits for both users and providers.

DOVU has also partnered with Uber, providing qualifying riders with platform tokens for sustainable ride-sharing. DOVU allows users to link their Uber accounts to their DOVU wallets, and uses Uber APIs to automatically calculate the token reward based on the length of the journey as a proxy for carbon emissions saved (in comparison to travelling in a private car) (Butcher, 2019b). With blockchain, DOVU can connect with any API. This data-access channel holds tremendous potential, should other mobility providers open their APIs as well.

Blockchain’s encryption and smart contracts allow DOVU users to exchange their data for tokens anonymously and automatically. Encryption secures the user’s platform wallet while obscuring his/her identity, and smart contracts can execute any “transaction” as soon as certain conditions are met. This means that a DOVU user could use a smartphone app to track their data while using an e-scooter, bike share or car share, or even while walking, and add that data to their DOVU wallet (DOVU White Paper, 2018). Should a provider be interested in the data, they can transact directly through a DOVU smart contract that can be cancelled at any time via the smartphone app.

Challenges and benefits

DOVU's vision is a circular economy "linking partners and consumers while rewarding those sharing data or providing value through actions" – like rating and reviewing mobility providers on the platform (DOVU White Paper, 2018). DOVU intends to incorporate industry actors beyond mobility operators to bolster the quality of data shared and rewards offered, thus creating more value for participants. By including insurance firms, car rental companies and manufacturers in the DOVU ecosystem, users could accrue tokens for safe driving and carpooling that could then be spent on car-share services or public transit. Such incentives could potentially shift commuters away from private vehicles toward more sustainable transport. Bonus tokens could also be offered to new users in order to attract membership.

Blockchain's smart contracts allow these rewards for platform participation to be dispersed instantly and automatically, further incentivising platform users to take an active role in platform governance. Meanwhile, each rating, review, or piece of data generated by users helps mobility providers improve service and respond to customer desires. In such a decentralised system, instantly redeemable rewards for ratings and reviews – without any intervention by a central authority – foster participation that rewards quality service and generates data to inform further improvements (de Wilde, 2019).

Authorities can leverage these incentive mechanisms not only to promote fair market competition and better services for constituents, but also to achieve policy goals like decongestion and decarbonisation. In coordination with mobility providers, regulators could institute a graduated reward system for users who switch from a higher-energy mode to a lower-energy mode as part of a behavioural economics intervention: e.g. travel by car-share instead of private vehicle; by ride-sourcing instead of car-share; by public transit instead of ride-sourcing; and by active transport like bicycle, scooter or walking instead of public transit. Users could gain bonuses for combining sustainable transport modes for journeys as well.

DOVU's ability to influence mobility policy through MaaS micropayments is contingent on platform integration and the associated benefits. If users are granted control over their data but find the rewards offered insufficient, they may opt to preserve their privacy and not share. This risk would require substantial participation from mobility providers, and require them to offer promotions valuable enough to induce data-sharing.

Mobility operators with existing reward systems may seek to favour these over more-open platforms, even though the latter could lead to new sources of user data. Moreover, the potential downsides to participating in more-open platforms might outweigh the benefits of gaining access to new user data. For regulators, the potential benefits of data-related self-determination and privacy for users, and of data-based decision making for operators and policy makers, are powerful incentives for supporting the deployment of open platforms. Attaining these potential benefits may require authorities to actively promote the uptake of DLTs.

What policy makers should know

In the digital age, large tech companies have battled for access to and control over user data to support marketing efforts and increase profits. But poor regulation of the Big Data "arms race" has resulted in numerous privacy scandals, including the US Government fining Facebook and Google USD 5 billion and USD 170 million, respectively, for sharing user data without explicit consent (Isaac and Singer, 2019; Singer, 2019). Passenger mobility has also been digitised, with many mapping and mobility apps requiring access to location data and personal information, including calendar and contact lists. Mobility operator data is valuable because it can support provider decisions to redirect fleets, optimise schedules, and adjust capacity. Some of this data can serve to better deliver on public policy mandates. Increasingly, data asymmetries between the main stakeholders – individuals whose consumption of mobility services generates data, private sector firms collecting data relating to activities occurring on public roads, and public authorities with a mandate to manage those spaces and services – have led to tensions around access to, and control and ownership of, data.

By encouraging mobility data to be exchanged between users and providers on a decentralised DLT platform, regulators can address privacy concerns, reduce big data-related monopoly risks, and promote fair competition informed by data that rewards innovation and quality service. As discussed earlier under "Trip chain case 1: Making a neutral Mobility as a Service platform a reality" (page 46), mobility providers may not embrace this transition voluntarily. Regulators can incentivise or require mobility providers to publish basic data via sharing mechanisms like APIs so that their data can be integrated within a DLT platform like DOVU if desired. Such approaches can mitigate monopoly risks, create opportunities for new mobility operators and enhancing data privacy for users.

Authorities can also foster multimodal travel behaviour by incentivising the integration of public transport with other mobility services. Policies that facilitate linking public-transport passes to other mobility services could leverage uptake of these services amongst the large pool of regular public transport users. With a critical mass of users and operators interacting on open platforms, public authorities could then offer tokens to incentivise behaviours consistent with policy goals.

When interacting with operators and users on open platforms, public authorities have a responsibility to ensure that these interactions contribute to public policy outcomes. For instance, if the platform allows taxi users to reward drivers for faster rides, this may incentivise drivers to break the speed limit or drive recklessly. Instead, regulators could ensure that rewards issued via smart contracts factor into the car's speed versus the local speed limit by consulting car data and location data. Though potentially a helpful tool for enforcement via incentive, this type of regulatory integration may require expensive investment in digital infrastructure.

Regulators must also consider the potential consequences of incentive-based modal shifts that work "too well". For instance, if a platform like DOVU becomes so popular for its discounts on public transit that metros and buses are overwhelmed, this may undermine user experiences and/or provoke users to return to private vehicles. Therefore, regulators may want to coordinate with both the DLT platforms and their registered providers to ensure that the various vehicle fleets can handle the types of behavioural changes desired.

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Forging Links
Unblocking Transport with Blockchain?

Blockchain and other distributed ledger technologies (DLTs) could help create trust and consensus in areas of the transport sector where they are needed for efficient solutions but currently often lacking. Such challenges concern for instance clearing transactions amongst multiple parties with divergent interests, authenticating provenance, managing assets, and auditability. This report explores how DLTs can address these issues by providing an alternative to centralised record-keeping and third-party audit-based approaches. It offers recommendations for maximising the benefits of DLTs in transport based on several use cases in freight and logistics as well as passenger transport.

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