BLOCKCHAIN DISRUPTION IN TRANSPORT

ARE YOU DECENTRALISED YET?

CONCEPT PAPER

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In Partnership with

The University Of Sheffield.

EXECUTIVE SUMMARY

In this concept paper we explore how blockchain, a Distributed Ledger Technology (DLT), could disrupt the transport sector in the coming years. We report on use cases discovered through a literature review and insights gained from stakeholder engagement. We analyse further, potential blockchain use cases across Mobility as a Service (MaaS), freight and logistics, Unmanned Aircraft Systems (UAS), data sharing and Collaborative Digital Transport Engineering (CDTE) (shown in the table below) of particular interest to the consortium.
We also consider the cyber security implications of blockchain.

Transport area	Use Cases		
MaaS	Automatic multi-operator delay compensation	Decentralised ride hailing	Decentralised MaaS network
Freight and logistics	Supply chain traceability	Single window system for maritime information	Communities of trust
Unmanned Aircraft Systems (UAS)	Drone registration and identification	Dynamic geofencing	Peer-to-Peer (P2P) system
Data sharing	Standard smart contracts	Data passports	Data sharing tokens
CDTE	Collaborative design traceability	Fluid organisational boundaries	Ledger of Things

We conducted a survey of transport industry and public sector professionals to find out their views on the impact of blockchain. Respondents were in strong agreement that blockchain will make supply chains more transparent, be important in the future development of intelligent and connected vehicles, and enable MaaS platforms.

Blockchain, a new decentralised database technology, could help to increase collaboration, the sharing of trusted information and efficiency, reduce costs and risk, and forge new business models in the transport sphere over the coming years. The features that generate these proposed business benefits are: consensus, immutability, provenance, finality, a single version of the truth, customisable transparency and decentralisation. These features enable traceability and auditability, disintermediation and smart contracts which also contribute to the business benefits.

We are not promoting blockchain as the answer to all questions but wish to stimulate debate and the identification of real value. There are currently several technological, social, and legal challenges to the use of blockchain. We encourage the transport industry to explore its potential, initially through experimentation and demonstrations.

For a blockchain use case to be a valid one it must involve a multi-stakeholder network, and especially one with stakeholders that have trust issues or different incentives. If there isn't such a network involved, then another technology will likely suffice.

Financial markets were the early adopters of blockchain, with the freight & logistics sector the first follower. Most blockchain projects are currently in prototype stage, the technology is immature and still some years away from mainstream adoption in the transport sphere. In the near term much will be learnt from freight and logistics projects as they move from experimentation to production, as well as other pioneering uses in other sectors.

Moreover, the convergence of blockchain, the Internet of Things (IoT) and Artificial Intelligence (AI) could add further value and have a transformational impact on transport including the acceleration of the Machine-to-Machine (M2M) economy.

To help unlock the potential value in blockchain for the transport sector and assist the UK to become a leader in blockchain based transport solutions, we make the following recommendations:

- Increase understanding and knowledge-sharing of blockchain across the transport sector through the establishment of a Community of Interest (CoI).
- Stimulate the market through a dedicated Future Mobility Collaborative Research and Development (CRD) programme supported by the UK Government's Industrial Strategy Challenge Fund. This will enable new service models and technologies such as blockchain to be tested in-market, de-risk development and help prove the value of use cases.

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GLOSSARY

- **Altcoin:** A name for all crypto-currencies except Bitcoin, i.e., an alternative crypto currency. Examples for an alternative to Bitcoin are Ether or Monero
- **Bitcoin:** The first widely known cryptocurrency based on blockchain technology
- **Blockchain:** A technology providing a distributed trustworthy ledger that records in a non-modifiable way a sequence of transactions on which the participants of a blockchain agree (consensus)
- **Customisable transparency:** The ability to tailor, at a granular level, which information in a blockchain is visible to which member
- **Consensus:** An agreement between members of a blockchain that information is valid, allowing it to be added to a blockchain
- **Consensus mechanism**: A method used to reach agreement among members of a blockchain that information is valid and can be committed to the chain e.g. Proof of Work, Proof of Stake, voting-based (definitions for these given below)
- **Cryptography:** a method of storing and transmitting data in a particular form so that only those for whom it is intended can read and process it
- **Decentralisation:** The management and control of blockchain is distributed across a network of 'computer nodes' or members, as opposed to a single controlling entity
- **Decentralised Application (dapp):** Software application where control is decentralised and built on top of blockchain
- **Disintermediation:** Reduction in the use of intermediaries, e.g. those between producers and consumers
- **Distributed database:** A database in which storage devices are not all attached to a common computer processor
- **Distributed ledger:** A distributed ledger or shared ledger is a decentralised (replicated, shared and synchronised between multiple partners and locations) storage that provides a corruption-resistant ledger, i.e., a list of consensuses
- **Finality:** Dispute resolution finality as the addition of data to and execution of smart contracts on blockchain is irreversible
- **Hybrid blockchain:** A hybrid blockchain has a mix of the characteristics of both public and private blockchains
- **Immutability:** The inability to change or delete information
- **Internet of Things:** the network of physical devices, vehicles, home appliances and other items embedded with electronics, software, sensors, actuators, and connectivity which enables these objects to connect and exchange data
- **Machine to Machine (M2M) economy:** The flow of money generated from machines interacting commercially with each other without human intervention
- **Natural language contract:** A formal legally binding agreement using natural language, i.e., language that has evolved naturally in humans through use and repetition (as contrasted with artificial language or computer code)
- **Node:** A computer, member or stakeholder that is connected to a blockchain network
- **Private blockchain:** A blockchain that is only available to a restricted set of participants. Moreover, not all entries of a private blockchain are accessible by all participants, i.e., entries (transactions) can be shared using fine-grained policies
- **Proof of Stake:** A consensus mechanism where members are required to put some of their own wealth at stake when validating information, if they validate incorrect information they lose that stake
- **Proof of Work:** A consensus mechanism where members of a blockchain are required to solve a computationally expensive mathematical puzzle to validate and approve that information can be added to the blockchain
- **Provenance:** A chronological history of ownership, possession and/or changes to a tangible (consignment) or intangible asset (data, Intellectual Property) recorded on a blockchain
- **Public blockchain:** A blockchain that has no criteria for membership i.e. anyone can join and all information is visible to the public
- **Single version of the truth:** Each member of a blockchain holds an identical database or single version of information validated through consensus
- **Smart contract:** A small distributed computer program (a protocol) that controls the automated facilitation, verification or enforcement of the negotiation or performance of a contract or other conditional logic. Smart contracts can be implemented within a blockchain and some blockchains such as Ethereum provide them as a standard feature
- **Smart dust:** a system of many tiny microelectromechanical systems (MEMS) such as sensors, robots or other devices, that can detect, for example, light, temperature, vibration, magnetism, or chemicals
- **Transaction:** A discrete action performed on a database, e.g. adding a piece of information
- **Voting-based Consensus Mechanism:** A consensus mechanism where blockchain members take part in a voting process to validate information

1 INTRODUCTION

Don Tapscott, a Canadian business executive and author who specialises in the role of technology and society calls blockchain the second generation of the internet[1]. Just like the first, it could transform the social, economic and technological spheres, and every sector over the coming years, including transport[2].

Blockchain, a Distributed Ledger Technology (DLT), emerged in 2008, as underpinning the trustless decentralised peer-to-peer (P2P) cryptocurrency called Bitcoin[3]. Note though, that this concept paper is not about Bitcoin or cryptocurrencies. Instead, we will explore how the underlying blockchain technology could disrupt the transport sector in the coming years.

There are two reasons that could explain why blockchain has taken a decade to start to reach transport and other sectors outside of finance. The concept is difficult to grasp, which means it is less likely to be proposed by professionals and pushed by decision makers. Also, when open source blockchains Ethereum and the IBM backed Hyperledger were launched in 2015 and 2017 respectively, the tools became widely available to enable widespread applications beyond cryptocurrency. Could the question being asked across the transport sector soon become: ***are you decentralised yet?***

Blockchain is unique among emerging technologies in that there appears to be an equal amount of both positive ***and*** negative hype. Arguably, positive hype usually outweighs negative for nascent technologies. Such polarised views include "blockchain is the answer, but what was the question?"[4] contrasted with "blockchain is a useless technology"[5] and "blockchain is dangerous"[6]. These are not positions supported by the consortium (Transport Systems Catapult, University of Sheffield and collaborators). We have conducted a project that set out to cut through both forms of hype and explore where blockchain could add real value in the transport industry over the coming years.

[1] THE BLOCKCHAIN CORRIDOR: Building an Innovation Economy in the 2nd Era of the Internet, Don Tapscott and Alex Tapscott, 2017
[2] Distributed Ledger Technology: beyond block chain, Government Office for Science, 2016
[3] Bitcoin: A peer-to-peer electronic cash system, Satoshi Nakamoto, 2008
[4] https://medium.com/@Saj_JZ/blockchain-is-the-answer-but-what-was-the-question-8143afdeec5a
[5] https://glennchan.wordpress.com/2018/02/20/blockchain-is-a-useless-technology/
[6] https://www.bloomberg.com/news/features/2018-03-09/bitcoin-is-ridiculous-block-chain-is-dangerous-paul-ford

PAPER STRUCTURE AND METHODOLOGY

The structure of this paper and the project methodology used is as follows:

Section 2	**What is blockchain?** describes the technological features, business benefits, uniqueness, and current challenges of blockchain ***Methodology:*** Desk-based state of the art blockchain technology analysis
Section 3	**Literature review and stakeholder engagement** highlights the use cases already identified within the transport sector and insight from transport professionals on the blockchain in transport landscape ***Methodology:*** Academic best practice literature review, use case prioritisation, stakeholder survey and semi-structured interviews
Section 4	**Potential use cases for blockchain across transport** looks at additional use cases of particular interest to the consortium in five transport areas: MaaS, freight and logistics, Unmanned Aircraft Systems (UAS), data sharing and Collaborative Digital Transport Engineering. For each use case, we describe the problem and how blockchain could provide a solution. In a table accompanying each use case we highlight specific features of blockchain that offer value, the potential beneficiaries and key challenges. ***Methodology:*** Builds on technology analysis, literature review and stakeholder engagement. Use of workshops and collaborative design thinking discussions
Section 5	**How secure is blockchain?** provides expert opinion on the general cyber security implications of blockchain ***Methodology:*** potential benefits vs challenges analysis
Section 6	**Shaping a new transport horizon block by block** summarises the key messages from the concept paper and makes some recommendations

We are not promoting blockchain as the answer to all questions but wish to stimulate debate and the identification of strong use cases. Moreover, we encourage the transport sector to explore its potential, initially through experimentation and demonstrations.

2 WHAT IS BLOCKCHAIN?

Blockchain is a Distributed Ledger Technology (DLT), which is a special type of distributed database. Each computer 'node' or member in a network stores an identical 'ledger' or database. This database takes the form of a chronological chain of unique groups of information called 'blocks', hence blockchain. They are securely linked together using cryptography.

> **100% of transport organisations will adopt blockchain in some guise, either public or private.**
>
> **Richard Nash** – Intelligent Transport Global Industry Expert, IBM

The information contained within each block could be details of events (e.g. changes to a transport model), value transactions (e.g. transport data changing hands), automated actions (smart contracts) or any other information, that would benefit from the features of blockchain. Before a new block is added to the chain, members in the network are required to come to a 'consensus' or agreement, and then the new block is added to the chain and replicated across all the identical databases.

The information stored in a blockchain is immutable and final. A block cannot be changed once it has been committed to the chain. Each block is timestamped and linked to the previous one, providing provenance. A simplified overview of how blockchain works is shown in *Figure 1*.

Blockchain can facilitate the sharing of trusted information across a network of stakeholders, especially those that don't trust each other or have different incentives. This can apply even in situations where members have never met or don't know each other. Peer-to-Peer (P2P) transfer of value can take place without the need for a trusted third-party intermediary. Blockchain bridges the trust gap to enable greater collaboration.

There are three different types of blockchain: **public** (permissionless), **private** and **hybrid** (permissioned).

Public blockchains, like Ethereum, have no central administration or control and anyone can become a member of the network where information is visible to the public. Private blockchains involve members who know each other or whose identity has been verified or who meet certain criteria. The control in private blockchains is spread across these members only and no information is visible to the public.

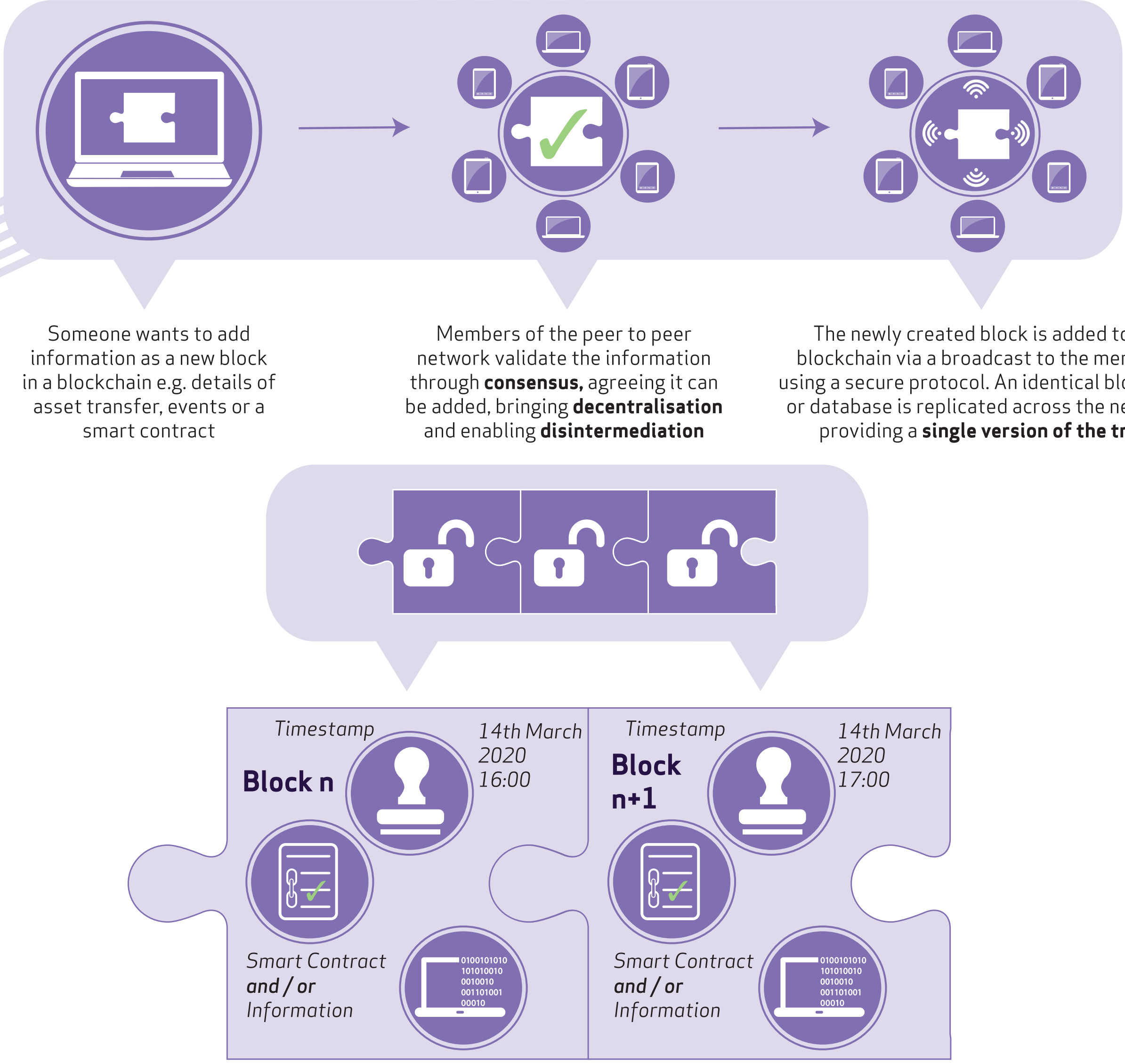
There are also hybrid blockchains, which mix the characteristics of both public and private blockchains. For example, the identity of members must be verified before they can join, and some information is made public.

Blockchains are configurable to suit the use case, including the information each member has access to and what information a member is able to add.

The majority of use cases in transport will most likely use private or hybrid blockchains rather than public.

There are other DLT's besides blockchain, such as IOTA's nascent Tangle[7] launched in 2017, however up to now the majority of all DLT implementations have been blockchain. Ultimately all DLTs have the same or very similar features and outcomes, they just achieve them in different ways at a technical level.

[7] The Tangle, Serguei Popov, 2017

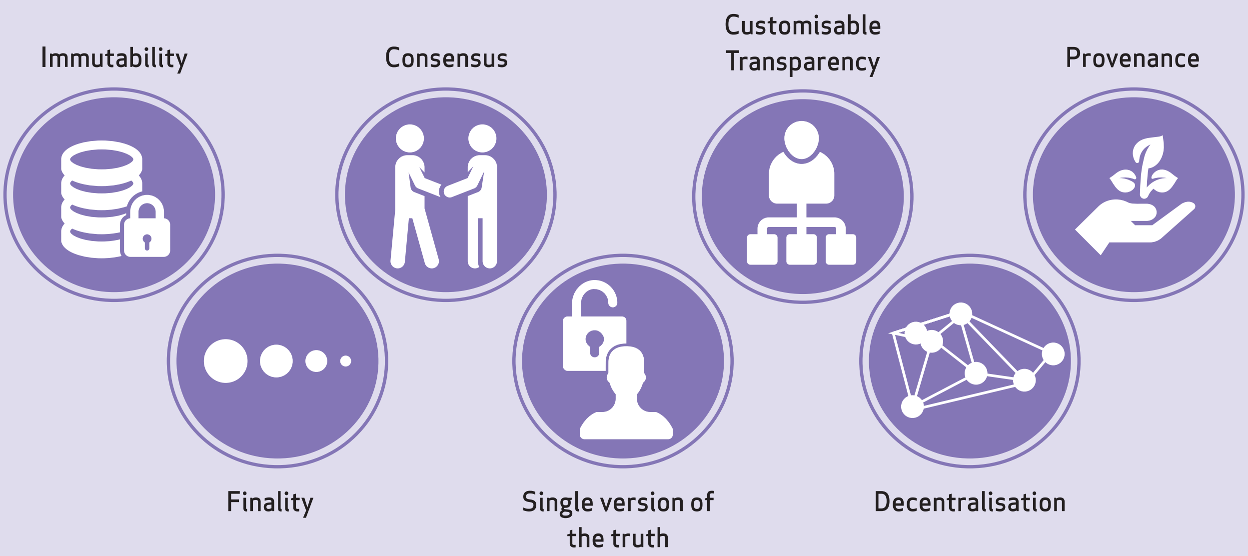


Each block is timestamped, providing **provenance,** and cryptographically linked to the previous block which ensures **immutability** and **finality.**
The information each member has access to can be tailored allowing **customisable transparency**

Figure 1 – Processes involved in blockchain

BLOCKCHAIN FEATURES

In general, blockchain and DLT have the key features shown below, which can be used as criteria to help identify use cases in transport. The definitions can be found in the glossary. For a blockchain use case to be a valid one it must involve a multi-stakeholder network, and especially one with stakeholders that have trust issues or different incentives. If there isn't such a network involved, then another technology will likely suffice. This is because blockchain's unique value comes from consensus distributed across different stakeholders.



As a result of these features blockchain can enable the following:

SMART CONTRACTS

Smart contracts take the form of 'self-executable' or automated computer code, that sit immutably within a blockchain and carry out particular actions when specified conditions have been met i.e. conditional logic.

These actions could be the deterministic terms and/or performance of a natural language contract, i.e. commercial actions. Equally, they could be any conditional actions or processes that members of the blockchain wish to automate. Smart contracts can be linked with a traditional natural language contract or operate alone to automate actions.

For example, the smart contract code could state that a wholesale manufacturing company shall automatically pay freight transport company £500 at the moment when a specific consignment has been received at the port of Southampton.

The smart contract is included in a blockchain, then when information confirming that the specific consignment has been received at Southampton it is added to the blockchain, validated through consensus, and the funds are transferred.

The concept of smart contracts is not new, having first been propounded by Nick Szabo in 1996[8], however with blockchain we now have the viable technology to enable practical widespread adoption. Blockchain appears to be the 'jet fuel' necessary for smart contracts to become commonplace[9]. The future vision is that natural language contracts will have an equivalent or be entirely replaced by code - but we are not there yet

HOW UNIQUE IS BLOCKCHAIN?

Distributed databases, where data is replicated and stored across different machines are not new. Oracle released a distributed database system in 1985.[10] Where blockchain differs is that the management of the database is uniquely decentralised, whereas Oracle's system, and other distributed databases that followed, are managed centrally by one controlling entity. There are also centralised databases, where data is kept on storage devices connected to a single machine. The simplified database landscape is shown in *Figure 2*.

The three main activities that are performed on databases are:

- **Read** (view the database)
- **Write** (add information to the database)
- **Validate** (authorise information can be added to the database)

In centralised distributed databases read, write and validate activities are controlled by one entity. Read access might be given to different stakeholders. In blockchain all three activities are performed and controlled by stakeholders across a network, and information is only written once it has been validated by other stakeholders. This increases trust in the information held in the database and enables disintermediation.

[8] Smart Contracts: Building Blocks for Digital Markets, Nick Szabo, 1996
[9] Smart Contracts: 12 Use Cases for Business & Beyond, Chamber of Digital Commerce, 2016
[10] https://docs.oracle.com/database/121/CNCPT/E41396-15.pdf

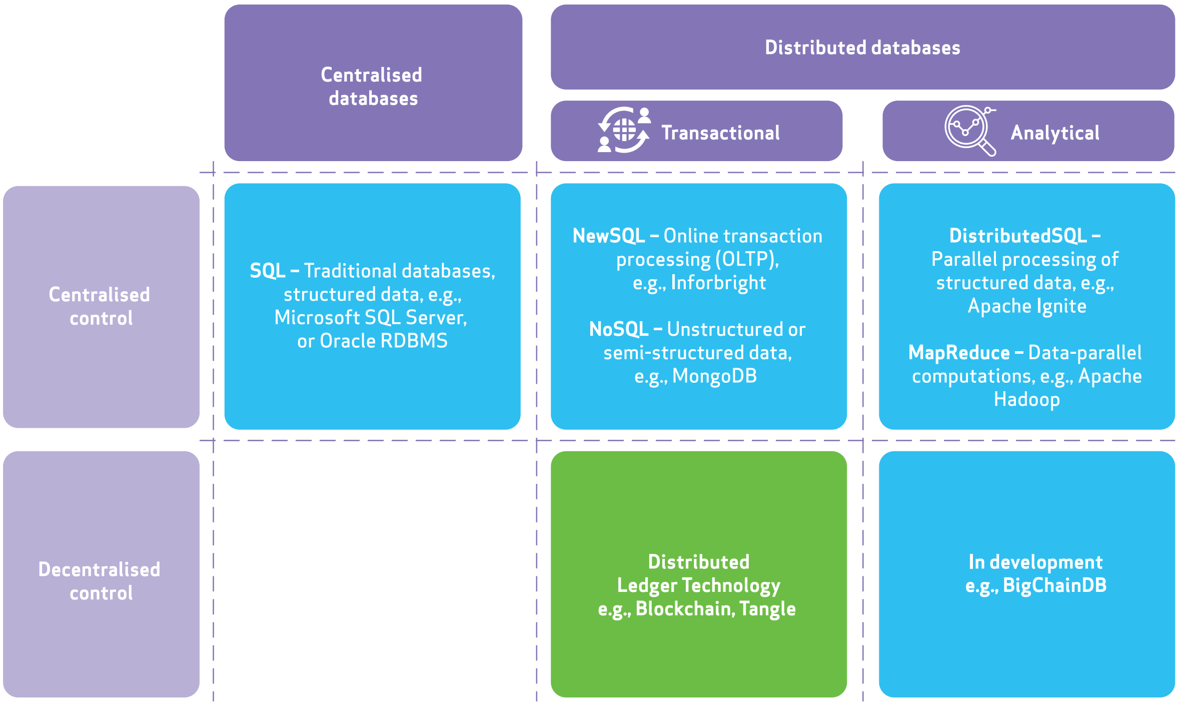


Figure 2 – Simplified database landscape including blockchain and DLT

Features like immutability, customisable transparency and single version of the truth, when taken on their own are not unique to blockchain. Other centralised and distributed databases exhibit immutability (e.g. Google HDFS), customisable transparency (e.g. MongoDB[11]) and single version of the truth (e.g. Apache Ignite[12]). However, blockchain is unique in its use of consensus across different stakeholders and thus combining consensus with the other features adds further value.

For example, to add new information to a blockchain, consensus must be reached across a network of different stakeholders, as opposed to being controlled by a single entity, *and* the newly added information is also immutable and there is a single version of the truth.

Consensus is reached in blockchain via different methods, called consensus mechanisms. Proof of Work (PoW), Proof of Stake (PoS) and Voting-based Consensus Mechanisms are described in the glossary. They are unique to blockchain and innovative new mechanisms are continually being proposed and developed.

Blockchain is also unique in enabling the first widespread use of smart contracts. A single version of the truth, customisable transparency, traceability, auditability, and disintermediation, combine to provide the necessary foundations for the execution of smart contracts without a trusted third party.

DECENTRALISED APPLICATIONS (DAPP)

Blockchain is not a product, it is part of a back-end. Value will be delivered to customers through front-end software applications.

Conventional software applications as well as Decentralised Applications or dapps, can be built on top of blockchain. There are many definitions currently being used for dapps in a blockchain context.

In general, they are 'open source' applications that operate autonomously across a network of computers and are not controlled by a single entity. They are the principles of blockchain applied to software.

[11] https://docs.mongodb.com/manual/core/authorization/
[12] https://ignite.apache.org/

CHALLENGES

There are currently several technological, social and legal challenges to the use of blockchain across the transport sector. They are specific to each use case, but some of the more common ones are:

- Transaction throughput (transactions per second). Further discussion can be found under Current performance constraints below
- Transaction latency (delay in information being added to the blockchain). Further discussion can be found under Current performance constraints below
- Attack surface still unclear. Further discussion on cyber security implications of blockchain can be found in *Section 5*
- Risk to strategic direction with decentralisation
- Immutability vs right to be forgotten through 'erasure' of personal data in General Data Protection Regulation (GDPR). Further discussion on this can be found in *Section 5*
- Innovation inertia due to radical nature of the technology and conservative elements of the transport sector

CURRENT PERFORMANCE CONSTRAINTS

Current blockchain implementations have constraints on transaction throughput (transactions per second), latency (time taken for new information to be added to the blockchain) and size (bytes per transaction). By transaction, we mean each time any new piece of information is added to a block, rather than financial transactions.

The transaction throughput, latency and size in blockchain are currently significantly different to established distributed databases.[13] However, blockchain is not meant as a replacement for them and the two can complement each other.

The limited transaction size constraint in blockchain is a function of design. Blockchain is not meant for large scale data storage. Its purpose is to validate and share small pieces of trusted information across a network of members. Though it could be repurposed in the future with technological developments.

Hybrid and private blockchains perform much better than public blockchains. A comparison of typical performance is shown in *Table 1*.

	Public Blockchain Technologies	Hybrid/private Blockchain Technologies
Transaction throughput (per second)	15	1000-2000
Latency (secs)	12	1-10
Transaction size	Up to 89 Kb	Up to 98 Mb

Table 1 – Comparison of typical performance of public and hybrid/private blockchain implementations excl. Bitcoin[14]

[13] BLOCKBENCH: A Framework for Analyzing Private Blockchains, Tien Tuan Anh Dinh‡ Ji Wang‡ Rui Liu‡ Beng Chin Ooi‡ Kian-Lee Tan‡, National University of Singapore, Gang Chen§, Zhejiang University

[14] Comparing Blockchain Implementation, Zane Hintzman, CableLabs, 2017

Public blockchains, such as Ethereum use the computationally expensive PoW consensus mechanism. They use PoW as it helps to make the network secure. Private blockchains, such as Hyperledger[15] do not use PoW. Instead, consensus mechanisms that have a fraction of the computational cost are used, such as those based on voting.[16]

The current transaction rate and latency is adequate for some transport use cases but precludes others for the moment. As the technology develops more use cases could be unlocked.

To put the current transaction rate in perspective in the transport sector, in 2016 all UK ports combined processed on average 16,000 container units per day.[17] If ten pieces of information for each container were added to a blockchain as they move through the port (two for each of the five container handling stages[18]), this would result in a transaction rate of two per second.

The average number of passenger journeys in England during the peak morning hour (8-9am) is 14 million.[19] If five pieces of information were added to a blockchain for each journey, and evenly over that hour, this would lead to a transaction rate of 20,000 transactions per second.

There are projects underway which look to address the current constraints such as the University of Sydney's Red Belly Blockchain, which boasts 400k transactions per second.[20] BigChainDB aims to combine scalable distributed data storage with blockchain.[21] The public blockchain Ethereum is also planning on moving away from PoW towards a new consensus mechanism called Proof of Stake (PoS), that is less computationally expensive.

BUSINESS BENEFITS

Some of the main proposed business benefits of using blockchain are:

- **Increased collaboration** – sharing information and processes between businesses (B2B) and customers (B2C)
- **Increased sharing of trusted information** – enabling consensus-based validation of information, via a distributed, replicated database, to ensure data integrity
- **Increased efficiency** – removing duplicated effort by maintaining a common ledger which can be used to manage smart contracts and dramatically streamline processes
- **Reduced costs** – removing the need for third-party intermediaries as well as the duplicated effort that is required for maintaining separate databases which contain the same information
- **Reduced risk** – minimising errors and the risk of malicious tampering, with traceable transactions that can show who did what and when to both tangible and intangible assets
- **New business models** – creating new commercial opportunities and revenue streams, as a result of decentralisation and disintermediation (cutting out the middlemen)

Gartner predicts that the global annual business value added by blockchain will reach $176 billion by 2025 and $3.1 trillion by 2030.[22]

> **Whereas most technologies tend to automate workers on the periphery doing menial tasks, blockchains automate away the centre.**
>
> **Vitalik Buterin** – Co-founder Ethereum

[15] Hyperledger Architecture, Volume 1, The Linux Foundation, 2017
[16] https://www.ibm.com/blogs/insights-on-business/government/consensus-business-blockchain/
[17] UK Port Freight Statistics: 2016 (revised), Department for Transport, 2017
[18] Estimating the Cycle Time of Container Handling in Terminals, Mai-Ha Thi Phan and Kap Hwan Kim, Pusan National University, 2015
[19] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/633077/national-travel-survey-2016.pdf
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates
https://www.gov.uk/government/statistical-data-sets/nts05-trips
[20] http://redbellyblockchain.io/
[21] https://www.bigchaindb.com/
[22] https://www.gartner.com/imagesrv/media-products/pdf/Talari-Networks/talari-networks-1-4A5JDFW.pdf

3 LITERATURE REVIEW AND STAKEHOLDER ENGAGEMENT

As part of this collaborative initiative, we carried out a review of the published literature including 26 academic journals, 22 conference papers / dissertations, and 35 industry and policy reports on blockchain, with a focus on blockchain in transport.

We learned that blockchain started to gain wider business attention in late 2014. Financial markets were the early adopters, with the freight and logistics sector following thereafter. Most blockchain projects are currently in the prototype stage, and the technology is still some years away from mainstream adoption. There is evidence that recent projects are increasingly consortium led for cross business network transformation. Blockchain applications include tracking (e.g., provenance, proof of origin), transfer (e.g., smart contracts) and payment (e.g., digital currency). Standards and business network governance continue to present challenges.

Of the 56 use cases for blockchain in transport that were identified in our literature review, the top ten most cited use cases are listed in *Table 2* in no particular order.

POTENTIAL BLOCKCHAIN USE CASES IN INTELLIGENT MOBILITY FROM LITERATURE REVIEW

1	Trusted vehicle information recording ownership, service history, accident history, condition and software version
2	Vehicle centric contracting and authentication systems to drive machine economy
3	Payment mechanism for electric roads usage
4	Self-authenticating network of delivery drones
5	Dynamic insurance products for autonomous vehicles
6	Autonomous vehicle-negotiated shared access to roads without central authority
7	Smart logistics and ticketing solutions
8	Traveller-centric integrated journeys, crossing transport modes and routes
9	Authenticated transport infrastructure components, with trusted audit trail of changes
10	Lifecycle supply chain transparency

Table 2 – Top 10 most cited blockchain in transport use cases from literature review

> **The majority of blockchain projects are currently in prototype stage, and the technology is still some years away from mainstream adoption.**

To better understand the top most frequently cited use cases, the potential use cases were ranked according to the degree of implementation difficulty and the potential value added by the use of blockchain.

In assessing implementation difficulty, several factors were considered, including:

- Similarity to existing blockchain projects in other industries
- Complexity of the business network
- System integration complexity with other systems
- Need for regulatory involvement
- Requirement for blockchain technological advancement

In assessing the potential for blockchain to add value, factors that were considered included:

- Need for transaction validation (consensus) across a business network.
- Need for provenance / audit trail of transactions
- Degree to which smart contracts could be leveraged
- Need for immutability / tamper proof transaction history

More detail on the methodology behind the use case ranking is included in *Appendix A*.

Figure 3 categorises the top ten most cited blockchain use cases into quadrants based on how much or how little value blockchain adds and how easy or hard it is to implement each one. Each quadrant is labelled with a suggested priority for the use cases contained within it.

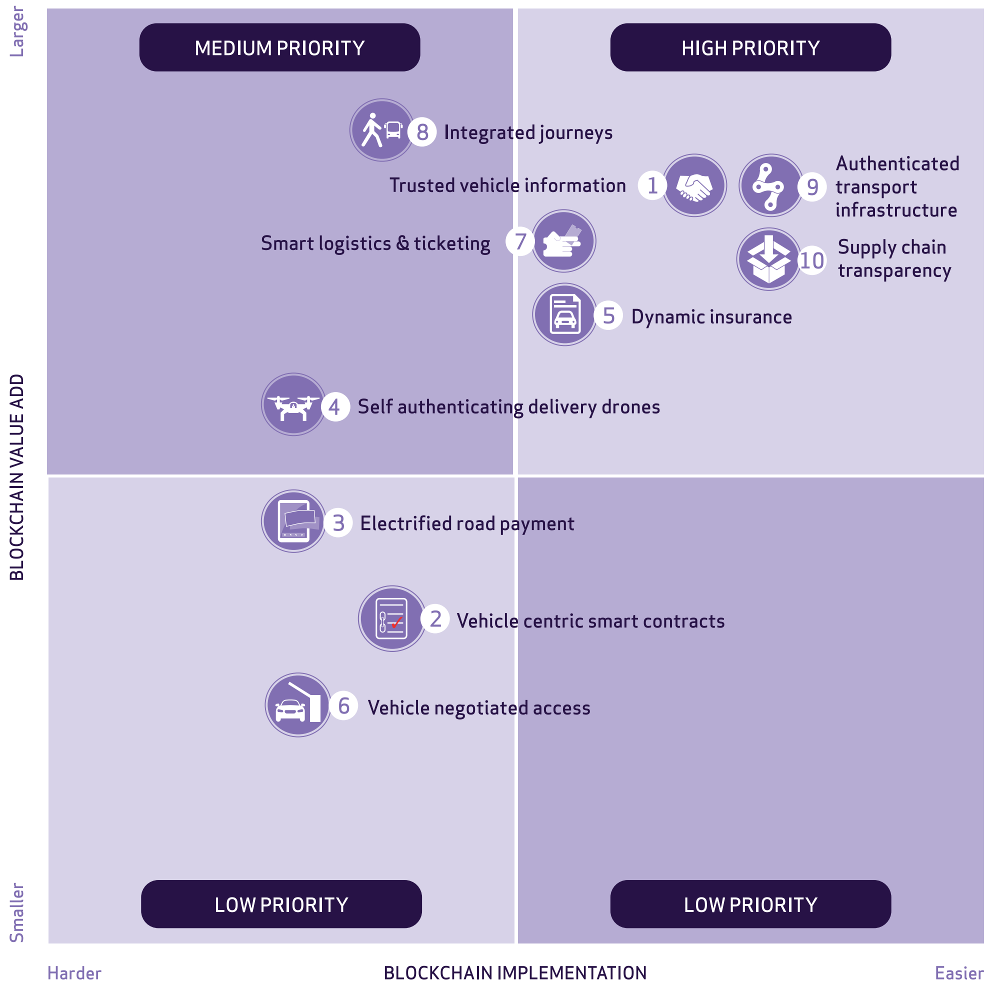


Figure 3 – Top 10 most cited blockchain in transport use cases: implementation vs value add

INTERVIEWS AND SURVEY

To investigate the supply and demand landscape of blockchain in transport we sent a questionnaire to survey 200 key transport industry and public sector professionals. The survey provided insights into current and future market conditions in a variety of contexts relating to transport and blockchain.

We received 14 responses to the survey (7% response rate). This low response may be due to only a small number of individuals feeling able to provide input into a fairly technical area of emerging technology.

In one key question in the survey we asked respondents to rate how much they agreed or disagreed with statements that described an attitude or expectation about blockchain in transport for the future.

The top three statements that received strongest agreement from the respondents were:

- Blockchain will make supply chains more transparent
- Blockchain will be important in the future development of intelligent and connected vehicles
- Blockchain will enable MaaS platforms

The detailed results to the question are shown in *Figure 4.*

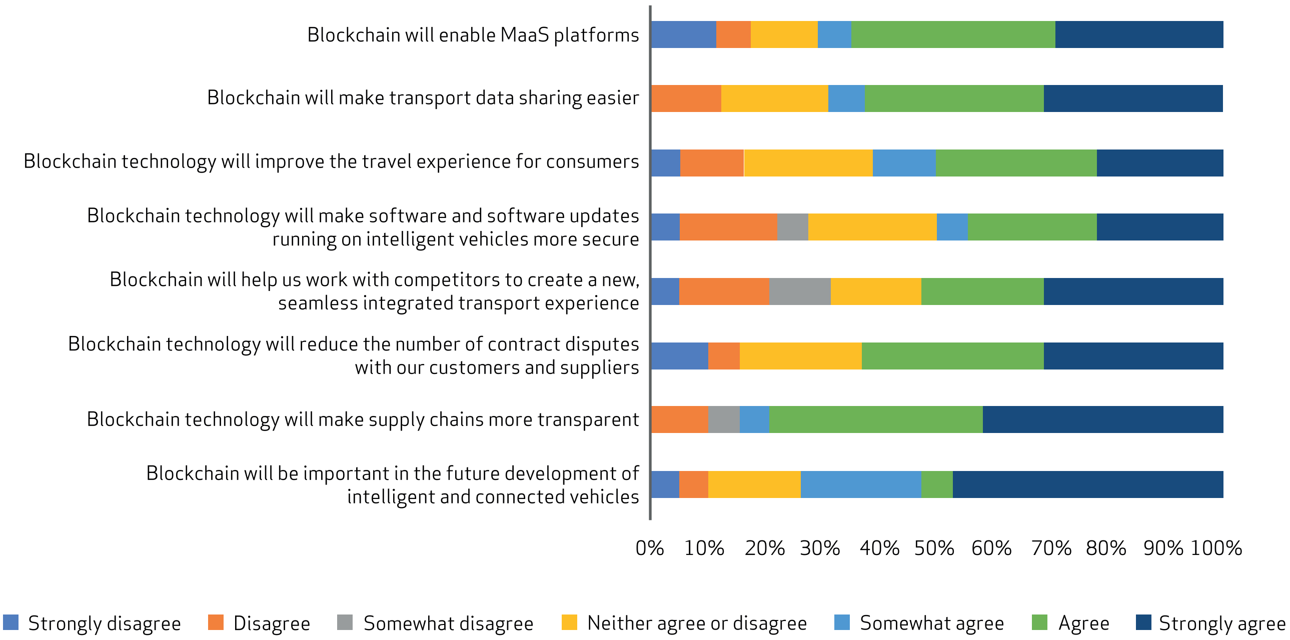


Figure 4 – Survey results of agreement or disagreement with statements describing an attitude or expectation about blockchain and transport in the future

Over 70% of respondents had already started a project or were planning to start a project in the next 12 months. Just over 20% had no plans to use blockchain, with the remainder not planning a project in the next three years, but not closing their options either.

To gather further empirical data on the ways in which the transport sector is engaging with and using blockchain, we conducted five semi-structured telephone and face to face interviews with professionals from the public and private sector with experience in blockchain and transport.

The key findings from both the interviews and survey are shown in *Table 3*.

KEY INSIGHTS FROM STAKEHOLDER INTERVIEWS AND SURVEY

1	Information and process flows that take time, waste money, are not effective or result in a poor experience for customers are a candidate for blockchain based solutions
2	Blockchain will be instantly discounted for a real-time or near real-time environment, especially one that is life-critical
3	There is enormous interest in blockchain across sectors
4	Blockchain is maturing technologically but the adoption rate is still slow
5	Blockchain applications infrastructure needs to be developed before value can be created for users
6	Blockchain makes sense when there are many people that have to take and pass on responsibility
7	There is enormous interest in blockchain across sectors

Table 3: Key insights from stakeholder interviews and survey

MARKET ESTIMATION

Given that blockchain is an emerging technology and most use cases in transport are in ideation stage or yet to be demonstrated, we believe that a market forecast for blockchain in transport vertical is not useful at this stage. The focus instead should be to prove the value of blockchain across the use cases discussed in this paper and others that will most likely spawn from it.

4 POTENTIAL BLOCKCHAIN USE CASES ACROSS TRANSPORT

4.1 Mobility as a Service (MaaS)

Mobility as a Service (MaaS) is a new business model that is gaining traction in the transport sector, and has the potential to change how we travel. There are many visions for MaaS, but most include a usership-based, personalised, end-to-end transport service, via any mode(s), with hassle free digital payment, ticketing, journey planning and management. Proponents see MaaS as having the potential to enable more efficient use of transport systems[23], which is of particular interest to policy makers.

Consumer demand for MaaS is being driven by several trends including the desire to move from a model of ownership to a model of usership[24]. This trend is now impacting the transport sector with innovators providing consumers with on-demand access to road vehicles and bicycles.

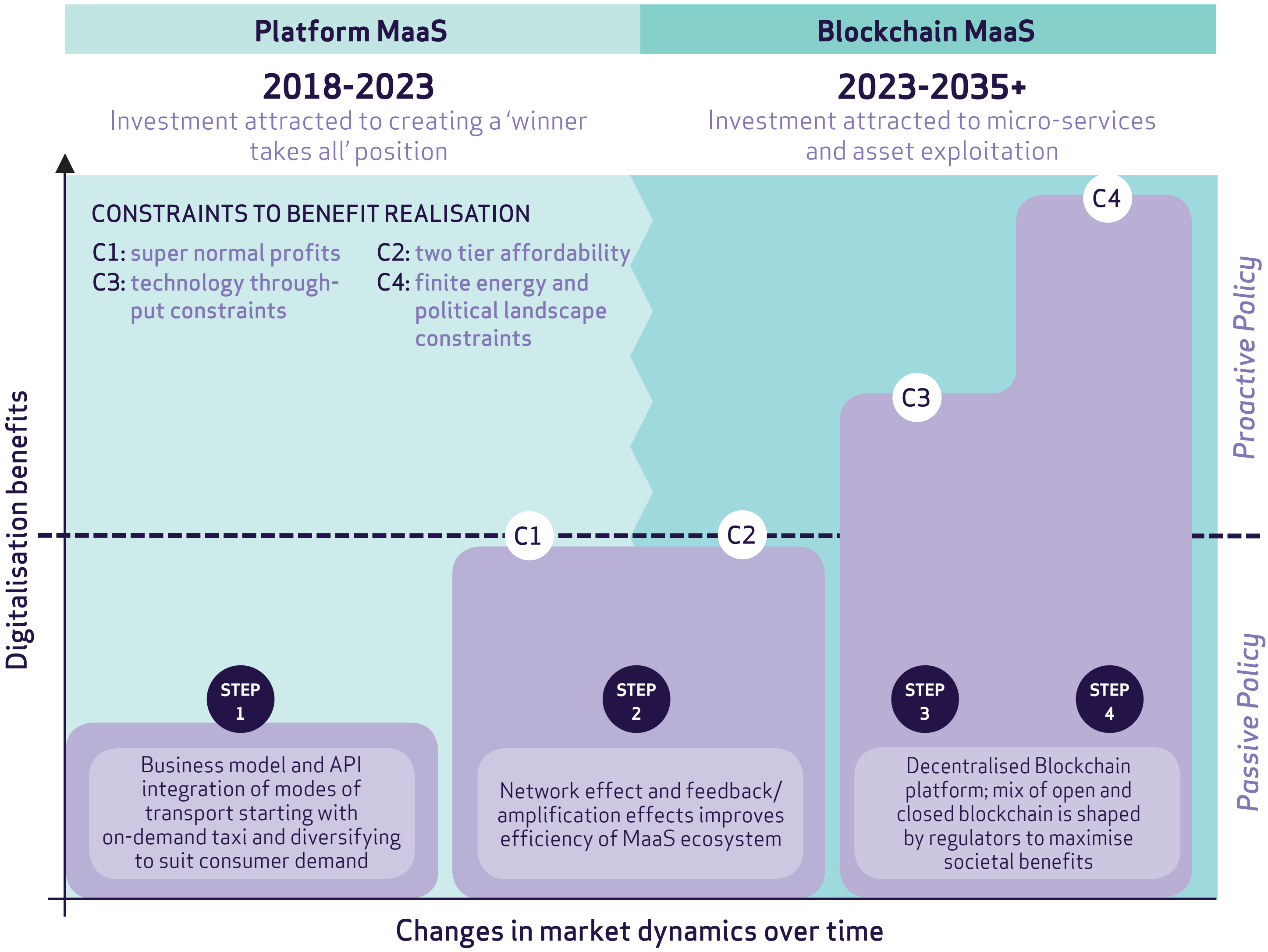
So how will MaaS play-out over the coming decade? One scenario is that only a handful of globally dominant MaaS providers will control the market. Leveraging powerful network effects, their centrally controlled platforms will give them sway over huge amounts of data, and who gets to provide transport services and on what terms. While this may be good for the consumer in the short term, it could lead to issues further down the line associated with a lack of competition, innovation and a range of market failures that limit any social and economic benefits.

Blockchain represents an opportunity to mitigate against centralised platform issues, with open, transparent and decentralised principles. It could shape new markets in new ways and push MaaS innovation in a different direction.

The realisation of MaaS benefits will depend on the interplay between the centralised platform economy, the decentralised blockchain economy, and policy and regulation (on a local and global scale). *Figure 5* illustrates how the MaaS ecosystem could develop over the coming years.

> **Blockchain represents an opportunity to mitigate against centralised platform issues, with open, transparent, decentralised principles. It could shape new markets in new ways and push MaaS innovation in a different direction.**

[23] https://www2.deloitte.com/insights/us/en/deloitte-review/issue-20/smart-transportation-technology-mobility-as-a-service.html



- Usership over ownership economic release
- Efficient allocation of supply (but limited modal coverage)
- Consumer uptake of MaaS value proposition grows

- Greater supply of multi-modal offers
- Greater geographic coverage of MaaS
- Supply side assets become more service orientated and consumer-centric

- Cities able to integrate infrastructure management systems
- Supply side asset diversity is fully enabled

- Systems of Systems optimisation
- Societal optimisation of transport operations and investment decisions

Figure 5 – Potential for blockchain in MaaS innovation

In *Figure 5*, the constraints C1 and C2 represent potential states of perceived market failure resulting from dominant centralised platforms. In this scenario socio-political concerns result in policy makers moving from a 'watch and wait' passive policy management position, to a more proactive approach to shape MaaS markets to realise greater digitalisation benefits.

C3 and C4 are the theoretical constraints on realising additional digitalisation benefits. These constraints are technical constraints associated with the scenario where the DLT services cannot fully satisfy market demand (C3) and where ultimately supply of mobility is constrained by finite economic resources e.g. energy and land availability as supplied by future political frameworks (C4).

USE CASE: AUTOMATIC MULTI-OPERATOR DELAY COMPENSATION

Some MaaS packages will likely specify guaranteed journey times, with compensation for customers when the service does not meet the mark. Compensation for delays to rail journeys and flights[25] in the UK has been available for decades, albeit through onerous processes[26]. In the last two years we have seen the emergence of automatic rail delay compensation for passengers in the UK, though only for individual Train Operating Companies (TOCs).[27] A system that works across all multimodal operators is required. A private blockchain for operators, passengers and regulators could provide consensus on which journey a passenger has paid for, which services a passenger travelled on, and the delay to each of those services.

A blockchain based system could 'shadow' existing infrastructure to speed up implementation and prove the effectiveness, scalability and business case. Delay compensation attribution across multiple operators and transfer of funds to the passenger would automatically execute via a smart contract when certain criteria has been met. The smart contract would ingest data from trusted "Oracles", e.g. Network Rail's open API for delay verification. Mobile phone GPS, WiFi router/Bluetooth beacon detection and other passengers' mobile phones, validated through consensus on the blockchain, would be used to prove a passenger's time and location (geostamping).

Automatic Multi-Operator Delay Compensation			
Blockchain Value	**A single version of the truth** across multiple transport operators, government and passengers is established through a distributed replicated database generated by consensus. This saves costs through reducing inefficiencies and errors	**Immutability** ensures that trusted information previously validated has not been tampered with, building trust in the system and allowing operators to release funds	**Smart contracts** execute automatically, streamlining processes, reducing admin. costs, and improving customer experience through timely repayment
Beneficiaries	Transport operators, transport authorities, passengers		
Key Challenges	• Transport data standards are fragmented across modes and therefore a complex adapter to feed data into the blockchain required • Attack surface still unclear		

Table 4 – Automatic multi operator delay compensation use case: Blockchain value, beneficiaries and key challenges

[25] Regulation (EC) No 261/2004, European Parliament, 2004
[26] Compensation for Delayed Passengers – Rail Regulator Acts, Office of Rail and Road, 2016
[27] https://www.virgintrains.co.uk/delayrepay/automatic

USE CASE: DECENTRALISED RIDE HAILING

Recently we have seen issues deriving from centrally controlled ride hailing platforms. Powerful third-party intermediaries between vehicle operators (value creators) and passengers (value consumers) have executed automatic commission increases on drivers and had issues with public authorities. These issues have led some to question the longevity of this operating model. The inherent attributes of blockchain technology could enable a decentralised peer-to-peer community where drivers can set their own fares and transact directly with customers, cutting out the intermediary. [28]

Members of the network would perform roles that enabled the system to operate, for example, ID verification and validation of completed journeys and enable the transfer of funds, all through consensus. Immutable and transparent driver and passenger reputation scores could be written to the blockchain thus incentivising good behaviour. Customers would engage in the network via a portable blockchain mobility account, giving them control over their own data and identity, and providing their mobility preferences to relevant parties.

Decentralised Ride Hailing			
Blockchain Value	**Disintermediation** allows big and small vehicle fleet operators alike to serve mobility customers more directly, reducing inefficiency in the system and increasing competition	**A single version of the truth** through a shared immutable database with smart contracts ensures transparency on rules of operation, fares and driver and passenger behaviour, increasing trust	**Consensus** between drivers, customers and regulators who may not trust each other or have different incentives creates trusted marketplace with sustainable, meritocratic value creation
Beneficiaries	Drivers, transport authorities, passengers		
Key Challenges	• Achieving a user experience equal to that of centralised ride hailing offerings • Throughput and latency • Immutability vs right to be forgotten through 'erasure' of personal data in GDPR		

Table 5 – Decentralised ride hailing use case: Blockchain value, beneficiaries and key challenges

USE CASE: DECENTRALISED MAAS NETWORK

An alternative decentralised approach could also be applied across all modes, creating a decentralised MaaS network *(Figure 6)*. A blockchain-based infrastructure could effectively join the supply and demand for mobility services and support the micro-services that enable MaaS business models.[29] Removing the need for the intermediary and decentralising the exchange of value in the MaaS ecosystem could change the way MaaS impacts society.

A Minimum Viable Community (MVC) of network members, including transport operators and passengers, would be required before implementation.[30] The blockchain infrastructure powering the community could be built through open source development and include Decentralised Applications (dapp). The customer interface and other micro-services could be opened up to for profit competition. Although, through consensus, decentralisation and transparency a company providing the customer interface that starts to abuse its power could be voted out of the network by the other members.

> **Removing the need for the intermediary and decentralising the exchange of value in the MaaS Ecosystem could change the way MaaS impacts society.**

[28] https://arcade.city/
[29] Open Mobility System, Concept Paper, MotionWerk, 2017
[30] TSio Protocol: The Internet of Mobility, Travel Spirit, 2018

Decentralised MaaS Network			
Blockchain Value	**Provenance** and **immutability** of details of transport services used by passengers, established through **consensus**, provides trusted information needed for payments	**Customisable transparency** ensures algorithms that provide customers with journey options is fair, open and transparent. This ensures new entrants, and big and small operators can compete	Community established **smart contracts** hold the rules for revenue apportionment and customer mobility packages. These self-execute when journey legs are completed, further boosting trust for all network members, and reducing costs
Beneficiaries	Transport operators, transport authorities and passengers		
Key Challenges	• Ensuring the network is set up in a way that ensures cartel like behaviour cannot occur • Throughput and latency • Immutability vs right to be forgotten through 'erasure' of personal data in GDPR		

Table 6 – Decentralised MaaS network use case: Blockchain value, beneficiaries and key challenges

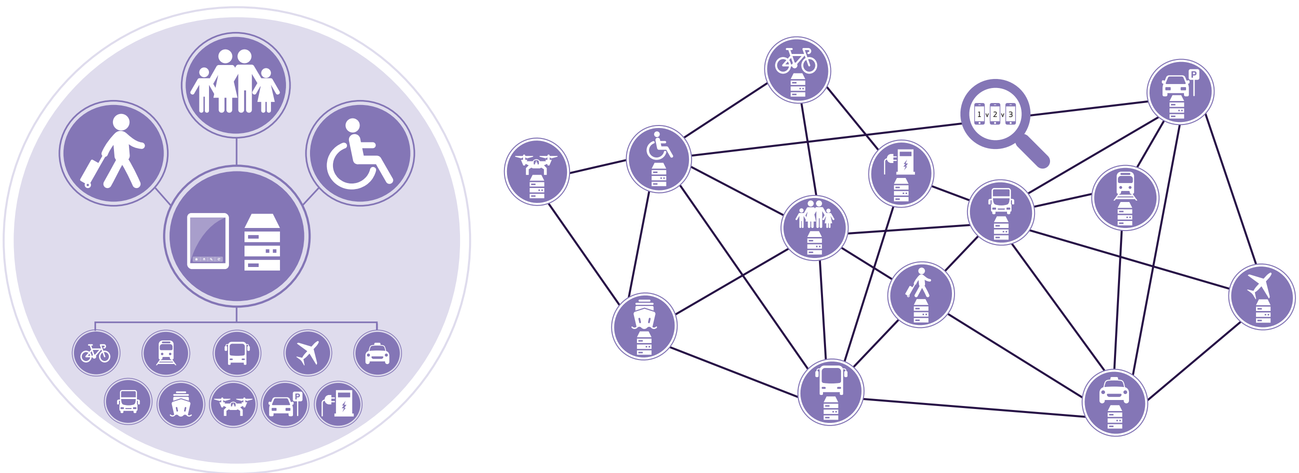


Figure 6 – Centralised (left) vs decentralised MaaS (right) diagrams

THE WINDOW OF OPPORTUNITY IS NARROWING

Blockchain could benefit MaaS regardless of whether a centralised or decentralised architecture for the system as a whole is adopted. Although the technology is immature, it is developing rapidly, and at a faster rate than regulatory frameworks can keep pace with. Markets may develop differently than planned for by policy makers, due to the impact of DLT. Will blockchain and other DLTs mature fast enough such that it can disrupt the growth of centralised MaaS platforms (if they grow as some predict[31]) over the next 5-10 years before they reach a position of market domination? The answer to that question can still be determined by the transport community, but the window of opportunity is narrowing.

[31] The rise of mobility as a service, Deloitte Review, 2017

4.2 Freight and logistics

MaaS is not just limited to the movement of people but also covers the movement of goods. The next decade will see the freight and logistics domain continue to grapple with rising demand driven by population growth and increased e-commerce, coupled with greater complexity from customers demanding a tailored service.[32]

Leveraging new technologies and facilitating collaboration will be key to unlocking capacity.

Global supply chain networks are very complex. Multiple stakeholders (manufactures, land transportation providers, warehouses, freight forwarders, custom brokers, governments, ports, ocean carriers and final customers) need to interact in different operative transactions.

Such complexity, especially with multiple data exchanges in the processes, can potentially lead to increased cyber insecurity and unclear visibility such as shadow accounts and tampered goods or data. Blockchain technology could bring collaboration, trusted information, consensus, immutability, and provenance to the movement of value, in this case a physical item, across supply chains.

The technology could help reduce inefficiency in the system, through removing duplicate effort across different stakeholders in maintaining separate databases and documentation about the same consignment, automating approvals and removing some intermediaries. A single version of the truth could be established in seconds, rather than hours or days, allowing capacity utilisation to be optimised. This could be especially beneficial in global trade, for example in the One Belt, One Road initiative to better link European and Asian countries, including the UK and China.[33] It could also improve competition and lower risk by increasing trusted information on supply chain actors, especially when two entities are transacting for the first time.

> Tracing the origin of mangoes using traditional methods took six days, 18 hours and 26 minutes, compared with 2.2 seconds using blockchain.
>
> **IBM and Walmart**

USE CASE: SUPPLY CHAIN TRACEABILITY

The ability to trace the history of a consignment from origin through the entire supply chain is critical when there is an issue with the good at some point. This is especially true for foodstuffs. Each actor along the supply chain could record on a blockchain when goods have been transferred from one entity to another. New asset transfer information would only be added to the blockchain once validated through the consensus of other members of the supply chain network.

A collaboration between food giant Walmart, IBM, and Tsinghua University to explore using blockchain to ensure supply chain integrity began in 2016. They found that tracing the origin of mangoes using traditional methods took six days, 18 hours and 26 minutes, compared with 2.2 seconds using blockchain.[34] Therefore, issues with a particular product can be identified and rectified quicker. However, a full benefit and cost analysis between the two methods is not publicly available.

[32] The rise of mobility as a service, Deloitte Review, 2017 http://www.peterbrett.com/thoughts-views/our-blog/the-changing-face-of-freight-and-logistics
[33] http://www.cbbc.org/sectors/one-belt,-one-road/
[34] https://www.forbes.com/sites/rogeraitken/2017/08/22/ibm-forges-blockchain-collaboration-with-nestle-walmart-for-global-food-safety/#69a1adb63d36

Supply Chain Traceability			
Blockchain Value	**Traceability** of freight items achieved through **provenance, consensus** and **immutability** within a shared database increasing trust in the supply chain, improving quality assurance and reducing costs	**Consensus** creates trusted information across supply chain actors that may not trust each other or have different incentives, reducing the likelihood of errors and fraud, increasing collaboration and improving efficiency	**Immutability** increases confidence that the information contained in the blockchain hasn't been tampered with, allowing supply chain actors and authorities to take swift action where required
Beneficiaries	Manufacturers and producers, freight transport companies, regulators		
Key Challenge	• Convincing actors along the supply chain that sharing data via a blockchain is not going to negatively affect their revenue		

Table 7 – Supply chain traceability use case: Blockchain value, beneficiaries and key challenge

USE CASE: NATIONAL MARITIME SINGLE WINDOW SYSTEM

The UK is currently piloting a national 'Single Window System' through which maritime reports can be exchanged by multiple parties, including data covered by the International Maritime Organisation's standard forms.[35] However, the current implementations[36] of single window systems rely on multiple underlying IT systems and non-integrated business processes for different documentation, particularly in sensitive areas like cargo declarations, electronic bills of lading and customs clearance on a global scale. This leads to inefficiencies and could hold potential for fraud, corruption and other unaccountable losses due to time delays and painstakingly slow manual processes.

Blockchain, as the choice of technology, has the potential to improve on the existing pilot implementations of 'Single Window' systems *(Figure 7)*. Blockchain would provide the seamless, permissioned exchange and visibility of sensitive documentation in a secure environment, with the promise of immutability and provenance.[37] Business processes could be more integrated, shared and automated using smart contracts. Further, this could potentially enhance and streamline customs applications, trade finance, chartering, marine insurance and other commercially significant areas.

Nation Maritime Single Window System			
Blockchain Value	**Provenance** ensures that who viewed and uploaded which documents and at what time is recorded, thus increasing efficiency and security	**A single source of truth** established across many maritime stakeholders, reducing duplicated effort in maintaining individual databases	**Immutability** provides authorities with confidence that information like customs clearances have not been tampered with, thus increasing security
Beneficiaries	Shippers, exporters, charterers, customs agents		
Key Challenges	• Paper based processes are widespread and entrenched leading to innovation inertia • Risk to strategic direction with decentralisation		

Table 8 – National maritime single window system use case: Blockchain value, beneficiaries and key challenges

[35] Guidelines for the Use of Electronic Certificates, International Maritime Organisation, 2016
[36] UK National Maritime Single Window (Pilot), Department for Transport, 2015
[37] https://www.vechain.com/#/

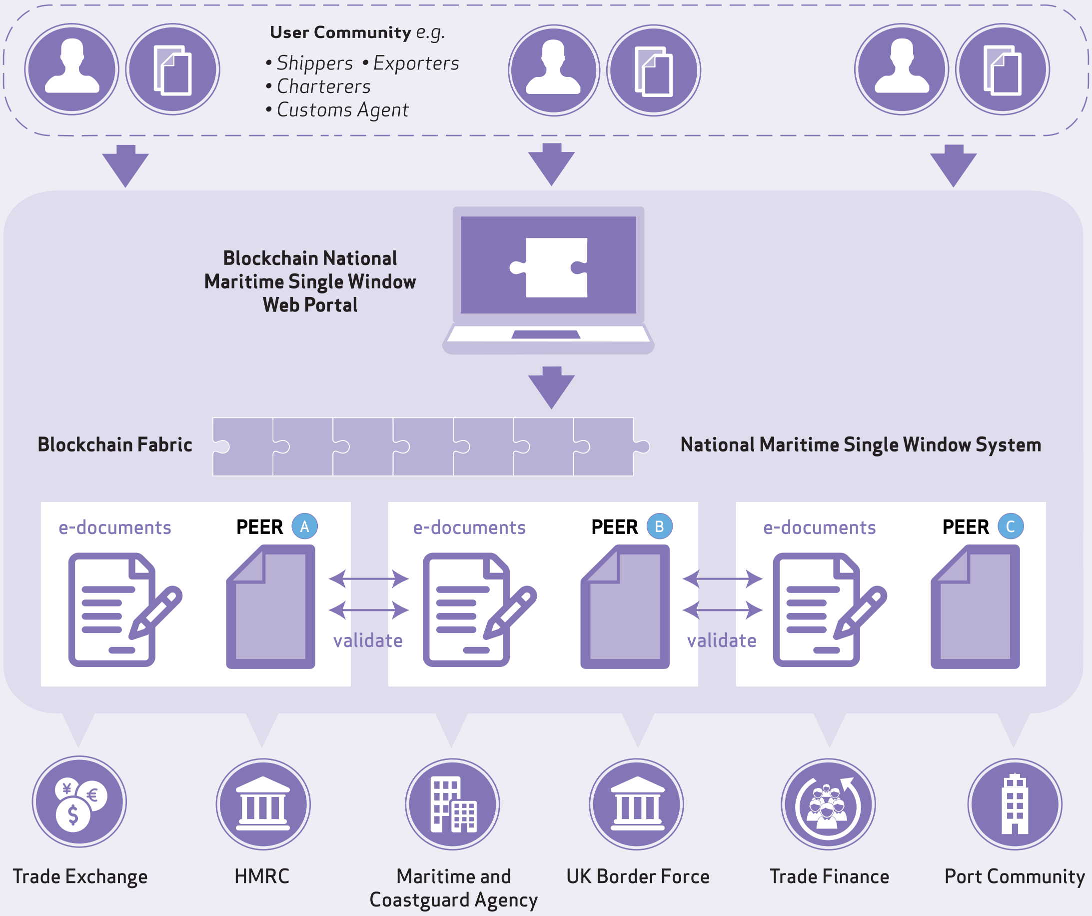


Figure 7 – Blockchain national maritime 'Single Window' system

USE CASE: COMMUNITIES OF TRUST

Organisations within the freight and logistics sector may take months and years to build up trust with their suppliers, which presents two key barriers to system optimisation. Whenever spare capacity is available which trusted suppliers cannot utilise, it goes to waste. And, existing 'trusted' suppliers might be experiencing operational difficulties at a particular time, which contracting organisations may not be aware of. The latter can lead to delays, congestion and negative impacts on revenue.

A smart contract-based industry, where real-time micro stage payments are made, and current performance ratings of companies are automatically recorded on a blockchain after each transaction, could lead to greater collaboration between organisations.[38] Transacting with new suppliers for the first-time would become easier and more reliable, helping to increase competition, utilise capacity and reduce the risk of poor performance.

[38] https://azure.microsoft.com/en-gb/blog/can-blockchain-secure-supply-chains-improve-operations-and-solve-humanitarian-issues/

Communities of Trust			
Blockchain Value	**Smart contracts** increase efficiency and lower risk by automating real-time micro stage payments as items move along a supply chain and recording the current performance of companies	The **immutability** of up to date performance ratings, validated through **consensus**, gives companies confidence when transacting with other companies. This increases efficiency and lowers risk	**Disintermediation** enabled by decentralised control of supply chain company performance ratings database removes the need for trusted third-party to manage the data and ensure its validity, reducing costs
Beneficiaries	Supply chain, regulators, customers		
Key Challenge	• Development and adoption of standard industry wide smart contract and associated Key Performance Indicators		

Table 9 – Communities of trust use case: Blockchain value, beneficiaries and key challenge

THE PHYSICAL TO CYBER LINK

The physical to cyber link – freight item to blockchain – needs to be as robust, reliable and trustworthy as the blockchain itself. This highlights the need for tamper proof integrated Internet of Things (IoT) systems and physical security across the supply chain that can increase the trust in this link. We will explore how blockchain applies to IoT in the Collaborative Digital Transport Engineering section, later in the paper.

> The physical to cyber link – freight item to blockchain – needs to be as robust, reliable and trustworthy as the blockchain itself.

4.3 Unmanned Aircraft Systems (UAS)

Connected and Autonomous Transport Systems (CATS) can contribute to increasing the efficiency and safety of the transport system. Road, aviation, waterborne and rail-based systems are at different stages of development and implementation, in terms of technology, regulation and supporting infrastructure. Blockchain looks set to influence all four areas of CATS significantly.

Road-based systems have received the most attention over the past few years, however, autonomous Unmanned Aircraft Systems (UAS) arguably have the potential for the greatest impact on society.[39] This is due to the untold and untapped capacity in low altitude airspace combined with a new mode of travel. How could blockchain technology and autonomous drones merge in the coming years?

Small autonomous UAS or 'drones' for carrying freight or passengers for civil or humanitarian[40] purposes are currently in prototype and demonstrator phases[41], with Google co-founder Larry Page and Daimler investing in 'flying-car' start-ups[42]. Autonomous drone delivery of blood samples in Rwanda beginning in 2016, is among the first commercial tests.[43] Significant regulatory and technological progress is required before commercial deployment. For the realisation of ubiquitous autonomous drone transportation an Unmanned Aircraft System Traffic Management (UTM) is required.[44]

The major underlying components of a future UTM are expected to include a vehicle registration system, electronic identification system, communication technologies, integrated air traffic control and airspace classification system (i.e. geofencing).[45]

These systems will need to provide the necessary data exchange and control mechanisms – at a high rate and with a high level of integrity. This is where blockchain features could be beneficial – including consensus and transparency throughout distributed UTM networks and immutable recordings of actions. Does the UTM remain centralised though with blockchain providing value in some areas or is the entire UTM built on blockchain and decentralised?

USE CASE: DRONE REGISTRATION AND IDENTIFICATION

A critical requirement of a UTM is to be able to identify and potentially authorise autonomous drones for take-off to ensure their safety and security. Ascertaining airworthiness, i.e. the ability of the vehicle to conduct a safe flight, and the detection of illegal activities are only two such checks that need to take place.

Blockchain could be used to store an immutable registry of license details, the ownership and service history including software versions, of every autonomous drone. All the information would be committed to the blockchain through the consensus of members of the UTM blockchain network, which could include regulators. When an autonomous drone requires flight clearance, a quick search of the blockchain registry would inform the approval decision. Autonomous drones that were determined to be conducting illegal activities could be identified and grounded.

Finally, one of the common objections from the general public is that the drones may be collecting information without consent by unknown entities. To overcome potential objections from the public the UTM must be transparent and universally trusted, which could be achieved by leveraging blockchain.

[39] https://techcrunch.com/2017/01/22/sorry-elon-driverless-passenger-drones-will-be-the-vehicular-disruption-of-the-future/
[40] FUTURE CARGO LOGISTICS PLATFORM: UAVS TECHNOLOGY FOR HUMANITARIAN SERVICES, Prof Lenny Koh, University of Sheffield, 2016
[41] https://www.engadget.com/2017/09/26/dubai-volocopter-passenger-drone-test/
[42] https://techcrunch.com/2017/11/08/are-flying-cars-the-future-of-transportation-or-an-inflated-expectation/
[43] https://www.technologyreview.com/s/608034/blood-from-the-sky-ziplines-ambitious-medical-drone-delivery-in-afrca/
[44] https://utm.arc.nasa.gov/index.shtml
[45] Distributed Sky White Paper, Distributed Sky, 2017

Drone Registration and Identification			
Blockchain Value	**Immutable** record of registration, ownership and service history of each autonomous drone, improving efficiency and safety	**Consensus** between UTM network members, who may not trust each other or have different incentives, enables flight clearance, through trusted information, reducing the likelihood of a drone incident	**Disintermediation** through **decentralised** control of drone registry, removing the need for trusted third-party to manage the data and ensure its validity, reducing costs
Beneficiaries	Transport authorities, passengers, autonomous drone operators		
Key Challenges	• Attack surface still unclear • Risk to strategic direction with decentralisaton		

Table 10 – Drone registration and identification use case: Blockchain value, beneficiaries and key challenges

USE CASE: DYNAMIC GEOFENCING

A geofence is a virtual wall that limits the low altitude airspace available to an autonomous drone. The restrictions could be due to proximity to sensitive areas such as military bases, airports, strategic objects, government buildings, quiet public spaces, and events. Additionally, oftentimes there may be a requirement to close an area of the airspace temporarily and in an instant.

The UTM should have the capability to communicate changes to existing geofences and create new geofences in real-time so that vehicles can automatically avoid no-fly zones.

Blockchain technology could solve the problem of geofence data synchronisation across all the stakeholders, through an immutable shared database. Changes to geofences and the creation of new ones, could be agreed through the consensus between members of the blockchain, including regulators.[46] The actions of autonomous drones could be written to a blockchain, thus providing a trusted record for interrogation should investigation ever be required.

> **Actions of autonomous drones could be written to a blockchain, providing a trusted record for interrogation should investigation be required.**

Dynamic Geofencing			
Blockchain Value	**A single version of the truth** provides synchronisation of dynamic geofence data across all UTM members thus improving efficiency and safety	**Immutable** geofences approved through consensus ensure tamper-proof no fly zones thus improving safety and security	**Decentralisation** through **consensus** across UTMmembers, who may not trust each other or have different incentives, allows drones and other actors to identify and implement geofences locally, reducing risk of accidents
Beneficiaries	Transport authorities, passengers, autonomous drone operators		
Key Challenge	• Innovation inertia due to radical nature of the technology and conservative elements of the transport sector		

Table 11 – Dynamic geofencing use case: Blockchain value, beneficiaries and key challenge

[46] The blockchain: a new framework for robotic swarm systems, Eduardo Castelló Ferrer, MIT Media Lab, 2017

USE CASE: PEER-TO-PEER (P2P) SYSTEM

As the volume of flights increase the need for a scalable system will become particularly acute. A UTM should be able to manage millions of flights which would be especially hard in densely populated areas with high demand for autonomous drone services. To increase the efficiency of the UTM, P2P technologies could be used for exchanging information between autonomous drones, local traffic control centres and other entities.

Just as with decentralised MaaS, blockchain could be used as the basis for a decentralised UTM with P2P messaging.[47] Where lower latency is required than that achievable with future blockchain developments, other P2P technologies with could be layered on top of blockchain. As there would be no single point of failure, the network could be inherently more resistant to attack by malefactors. A blockchain based decentralised UTM overview is shown in *Figure 8*.

Peer-to-Peer (P2P) System			
Blockchain Value	**Peer to Peer (P2P)** network ensures a scalable autonomous drone UTM, able to cope with a growing number of autonomous drones and flights	**Decentralisation** increases resilience and the safety of UTM with no single point of failure for attack by malefactors and reduces cost	**Traceability and auditability** of drone actions ensures that logs can be interrogated rapidly in the case of an incident to find the cause, increasing efficiency and reducing risk
Beneficiaries	Transport authorities, passengers, autonomous drone operators		
Key Challenge	• Throughput and latency		

Table 12 – Peer-to-Peer (P2P) system use case: Blockchain value, beneficiaries and key challenge

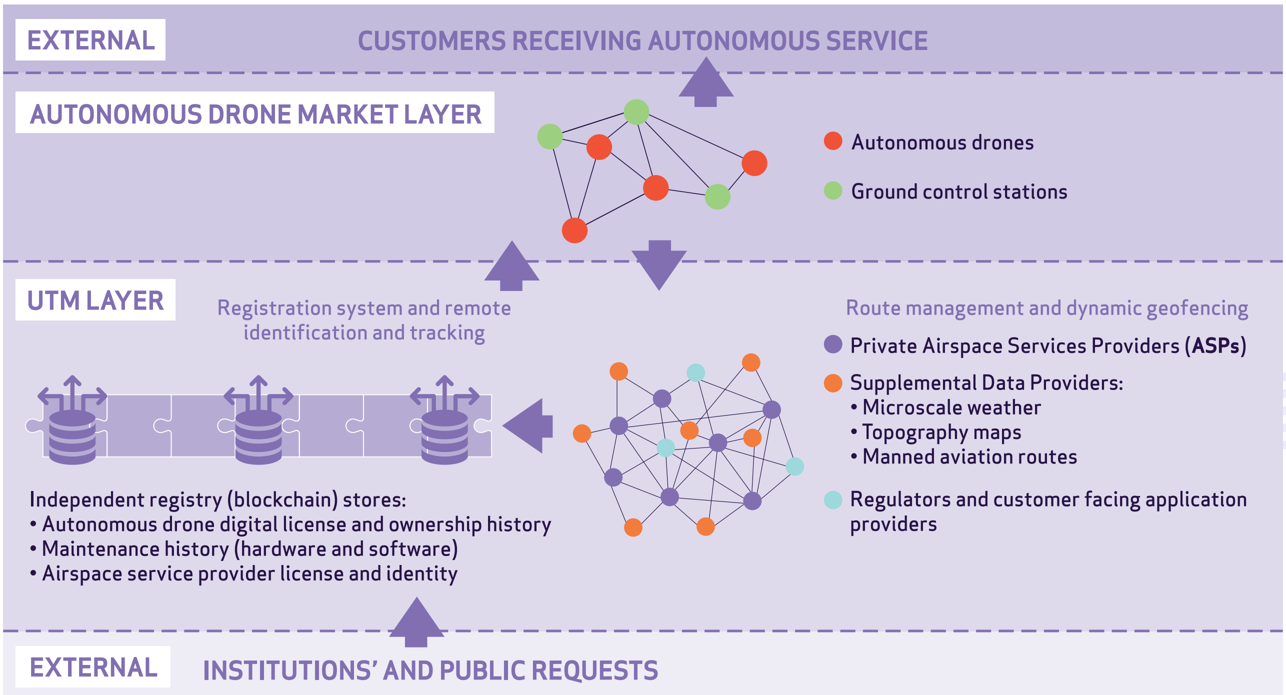


Figure 8– Decentralised blockchain based UTM proposed by Distributed Sky[48]

[47] Blockchain-based protocol of autonomous business activity for multi-agent systems consisting of UAVs, Aleksandr Kapitonov, Sergey Lonshakov, Aleksandr Krupenkin and Ivan Berman, 2017
[48] Distributed Sky White Paper, Distributed Sky, 2017

4.4 Data sharing

It's said that 'data is the new oil'[49], but for the benefits to be realised it needs to flow freely without being barreled up and stored away.

By the end of 2020 there will be over 50 billion connected devices across the world generating more than 2.3 zettabytes of data each year.[50] To achieve a truly intelligent system of systems that enables the efficient movement of people and goods, data liquidity – the ability to get the data you want, in the right format, for the right cost, at the right time and associated risk - is a necessity. The briefing paper produced by Deloitte and Open Data Institute for TSC: *The case for government to incentivise data sharing in the UK IM sector*, estimates that £15bn in benefits could be lost by 2025 if the current barriers to data sharing remain.[51] *Three key barriers were identified:*

1. Organisations being fearful of breaches in privacy, security and safety
2. Perceptions that the costs of sharing outweigh the benefits
3. Cultural barriers across the sector leading to siloed thinking and not sharing data beyond organisations' own mode of transport

Blockchain has (controlled) data sharing at its core. As we have discussed earlier, members of a blockchain share an identical database. When a member wants to add new data in the form of a new block, consensus is reached, and the new block is added to the chain and replicated across all the databases, i.e. it is shared. Blockchain technology has the potential to help remove the friction in data sharing through overcoming the barriers identified thus far.

USE CASE: STANDARD SMART CONTRACTS

Standard data sharing license templates could help to reduce the cost of sharing data, align the industry, and speed up processes. Templates could be made openly available alongside associated blockchain-based smart contracts that automate micro-payments for usage of data, across multiple suppliers where required, and with increasingly sophisticated logic.

Revenue share agreements, where data is shared with no upfront cost but a percentage of profits from resulting solutions are returned to the data owner, could be triggered through profit data fed from a 'trusted oracle' into the smart contract.

The legal community in the UK has already recognised the need for legislative change[52] precipitated by the advent of blockchain-based smart contracts.

50 https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/
51 The case for government to incentivise data sharing in the intelligent mobility sector, Transport Systems Catapult, 2017
52 https://www.coindesk.com/uk-judge-no-doubt-smart-contract-law-update-considered/

Standard Smart Contracts	
Blockchain Value	**Smart contracts** automate deterministic terms of standard data sharing licenses, with efficiency improving as a result. The features of blockchain combine to provide the necessary foundations for the execution of smart contracts without a trusted third party
Beneficiaries	Transport authorities, transport companies, passengers
Key Challenge	• Technology is developing at a faster rate than legal frameworks with lack of case law

Table 13 – Standard smart contracts use case: Blockchain value, beneficiaries and key challenges

USE CASE: DATA PASSPORTS

Just like the physical supply chain, we now have the data supply chain.[53] What if every transport dataset had a virtual 'data passport' associated with it, where the history of ownership and any amendments to it, were recorded? Blockchain is the technology that could enable data passports. Stakeholders, including owners, custodians and users could have visibility of who has done what and when with each dataset, and retain control.

A new blockchain, or data passport, could be created with each new dataset and include the creating entity's blockchain based 'data creation, handling and processing' rating. New information added to the passport could be validated by other entities in the blockchain network. If a dataset was fused with another, the blockchains of each dataset would fork and merge. This setup is shown in *Figure 9.*

Organisations that specialise in the cleaning and anonymisation of data, could add their immutable stamp of approval to the 'data passport', validated through distributed consensus. Data passports could increase trust in the data supply chain thus, increasing confidence in data.

> **What if every transport dataset had a virtual 'Data Passport' associated with it, where the history of ownership and amendments were recorded?**

Data Passports			
Blockchain Value	**Consensus** and **immutability** ensure organisations trust the information contained within the data passport leading to increased data quality and the services generated from it	**Provenance** provides a trusted chain of custody and timestamped modification of information on datasets, thus increasing confidence in the reliability of datasets	**Smart contracts** allow an original dataset creator to be automatically informed when actions are performed on their data, thus improving trust and efficiency
Beneficiaries	Transport authorities, transport companies, passengers		
Key Challenges	• Encouraging enough organisations to adopt the system such that it is viable • Innovation inertia due to radical nature of the technology and conservative elements of the transport sector		

Table 14 – Data passports use case: Blockchain value, beneficiaries and key challenges

[53] Data supply chain (DSC): research synthesis and future directions, Konstantina Spanaki, Zeynep Gürgüç, Richard Adams & Catherine Mulligan, 2017

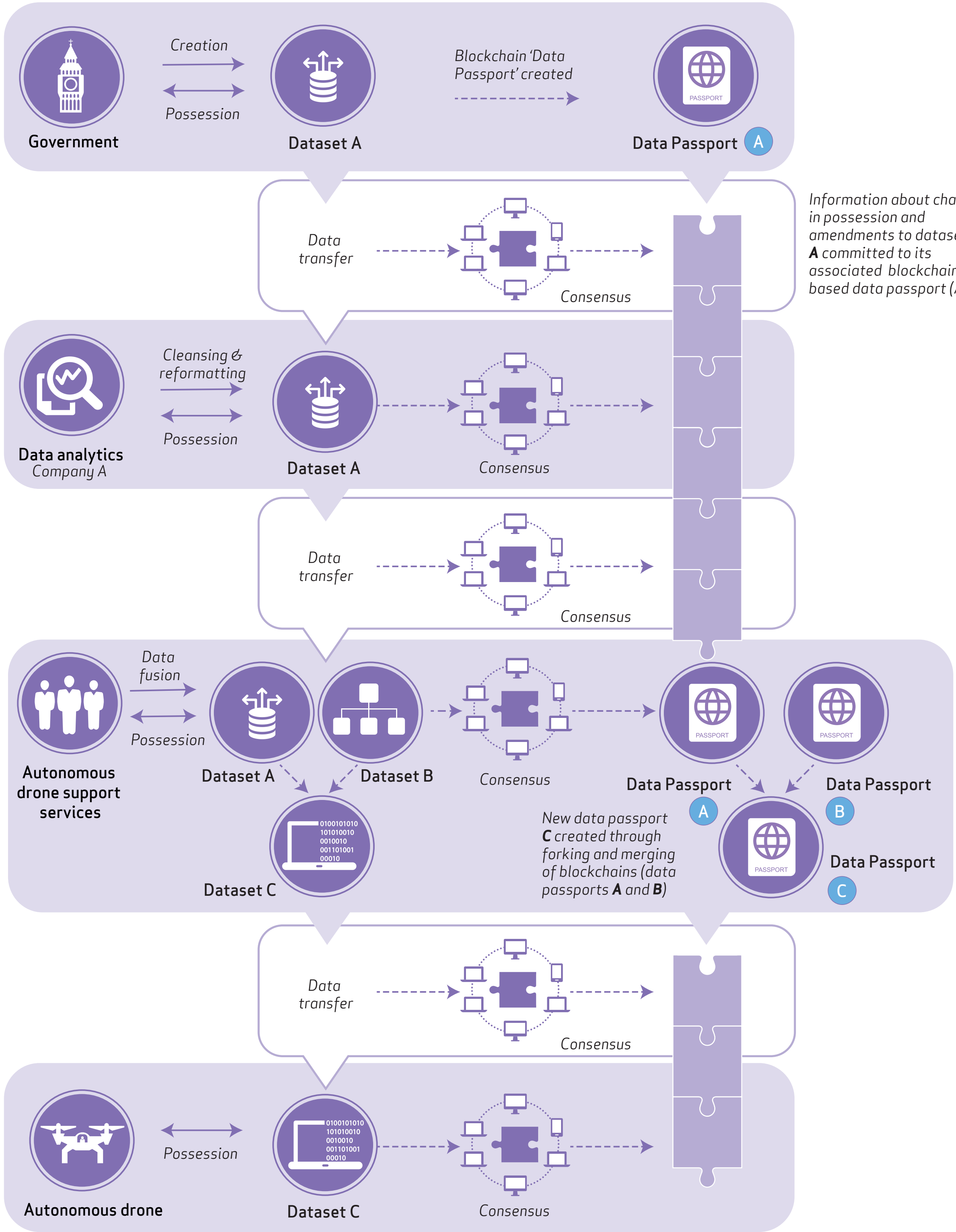


Figure 9 – Blockchain 'data passport' process

USE CASE: TRANSPORT DATA SHARING TOKENS

2017 was the year of the Initial Coin Offering (ICO) with 235 offerings globally, raising $3.7bn of funding for blockchain start-ups, with $11m for those in the transport sector.[54] This trend looks set to continue in 2018 with $6.5bn and $130m raised respectively by the end of April. [55]

Bundled up in the ICO terminology are both alternative Bitcoin like coin offerings or 'Altcoins', and cryptotoken launches. Cryptotokens, or just tokens, are a different breed altogether. They are a digital asset that can store complex, multi-faceted levels of value and are specific to an ecosystem or 'micro economy', such as transport data.

Tokens rely on the features of blockchain, especially immutability and cryptography, such that they cannot be deleted or copied. They can only be generated through the method designed into the ecosystem, which is open and transparent.

Tokens can only be used within their specific ecosystem. They could be used in a transport data sharing ecosystem to assist in freeing up the flow of data. They could be generated, earned and exchanged for transport information.[56]

As an example, in such an ecosystem a passenger in a driverless vehicle, could retain ownership of data collected by the sensors on the vehicle, and could receive tokens for sharing it with transport authorities. The driver could then exchange those tokens for upgraded predictive journey planning information from an Artificial Intelligence (AI) start up.

As well as generating funds for start-ups, Table 15 describes some of the potential benefits of tokens:

Transport Data Sharing Tokens			
Token Benefits	To **align the incentives** of all stakeholders in an ecosystem, including users, developers, investors and service providers	The **emotional value** of tokens and reward mechanism creates a gamification driver, thus increasing participation and engagement	The **stimulation** of a nascent open decentralised network, allow a Minimum Viable Community (MVC) to form earlier
Beneficiaries	Blockchain based transport SMEs, transport ecosystem stakeholders		
Key Challenges	• Overcoming negative press around ICOs to achieve an MVC • Immutability vs right to be forgotten through 'erasure' of personal data in GDPR		

Table 15 – Transport data sharing tokens value, beneficiaries and key challenges

[54] https://www.coinschedule.com/stats.html?year=2017
[55] https://www.coinschedule.com/stats.html?year=2018
[56] https://dovu.io/

CASE STUDY

PERSONAL DATA SHARING FOR MOBILITY

Personalisation is a key principle of MaaS. To enable individually tailored services, MaaS users will need to share more personal data with MaaS providers. Research by KPMG in 2016 found that globally, on average, 56% of people are either 'concerned' or 'extremely concerned' about the way companies handle their personal data.[57] The TSC's Traveller Needs survey in 2015 found 57% of respondents would not mind sharing their personal data in order to get a better service.[58] Currently we have little idea where our data gets to, what various organisations do with it and what we get in return. A barrier to personal data sharing is also a barrier to the realisation of MaaS.

SME Explorations

Transport Systems Catapult and The University of Sheffield have been working with UK based SMEs Gospel and TravelAi to explore the use of blockchain to give passengers greater control when sharing their personal data for mobility purposes. Gospel have a platform that leverages the Hyperledger Fabric blockchain to enable increased trust when sharing sensitive information across a network of stakeholders. TravelAi lead the CATCH (Citizens At The City's Heart, an Innovate UK funded) consortium building a solution that leverages Artificial Intelligence (AI) to extract insights from crowdsourced personal mobile phone GPS data.[59]

The University Of Sheffield. Travelai Gospel®

The project confirmed, in a virtual environment, that blockchain technology could be used to give passengers control and visibility of which organisation has done what with their personal data. Dummy personal data was used in the project.

Consent for the use of different types of data, e.g. mobile phone GPS trace and salary range, could result in different rewards such as retail offers, free journeys or details of how sharing personal data is improving the transport network. Organisations that are interested in the data could include transport authorities, autonomous vehicle fleet operators and advertisers as shown in *Figure 10*.

The use of passengers' personal data fed from TravelAi could be managed by Gospel's private blockchain. Each time an organisation requests access to data, the passenger could give consent to them becoming a member of their blockchain-based personal mobility account. Moreover, smart contracts could be used to trigger a reward transfer to the passenger. Data requests, consent, reward transfer, and data read and write actions could be recorded immutably on the blockchain, with the personal data itself 'off-chain'.

> **Transport Systems Catapult and the University of Sheffield have been working with UK SMEs Gospel and TravelAi to explore using blockchain to give passengers greater control when sharing personal data for mobility.**

Blockchain and Zero Knowledge Protocols (ZKP)

Access to the actual personal data record could also be avoided through Zero Knowledge Protocols (ZKP).

A ZKP is a method by which one party (the prover) can prove to another party (the verifier) that a given statement is true, without conveying any information apart from the fact that the statement is indeed true.[60]

Combing ZKP with the blockchain based systems described above could create added value. Passengers could reveal answers to questions about their data, without revealing the personal data itself. For example, a transport authority could ask a passenger, "are you over 35?", to which the system answers "yes" or "no", without ever revealing the passenger's birthday.

Although ZKP have existed for two decades, blockchain could provide the auditable trusted multi-stakeholder environment that's needed for widespread ZKP deployment.[61]

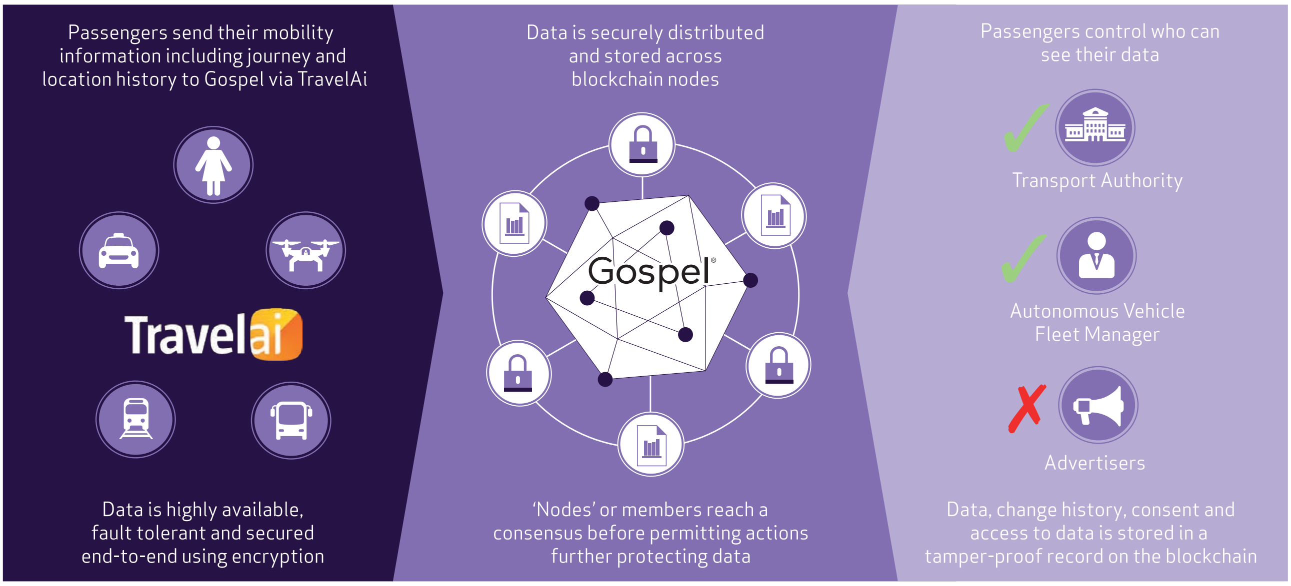


Figure 10 – Personal transport data sharing using blockchain

[57] Creepy or cool? Staying on the right side of the consumer privacy line, KPMG, 2016
[58] IM Traveller Needs and UK Capability Study, Transport Systems Catapult, 2015
[59] http://www.travelai.info/catch.html
[60] A Primer on Zero Knowledge Protocols, Gerardo I. Simari, 2002
[61] https://www.technologyreview.com/s/609448/a-mind-bending-cryptographic-trick-promises-to-take-blockchains-mainstream/

4.5 Collaborative Digital Transport Engineering (CDTE)

Transport infrastructure, is one of the great digital ecosystems. The UK Government's Building Information Modelling (BIM) programme, boosted efficiency, lowered risk and stimulated innovation through the promotion of a common data environment.[62] Architects, engineers, modellers, construction staff, asset managers and Intelligent Transport Systems (ITS) operators, moved from a siloed approach, to a collaborative approach.

The number of different disciplines and stakeholders, and the value exchanged between them, both within organisations and between organisations, makes the Collaborative Digital Transport Engineering (CDTE) ecosystem highly complex. Opportunities for increasing the level of collaboration, consensus, trusted information, provenance and immutability appear to make blockchain a natural fit with CDTE.[63] Blockchain could help augment BIM, or Digital Built Britain, as the initiative is now called.[64]

USE CASE: COLLABORATIVE DESIGN TRACEABILITY

The digital design of a new transport infrastructure scheme goes through many iterations, including quality reviews and sign-offs before delivery begins. It is important that all stakeholders contributing to the process have sight of the single version of the truth, agree that new information can be added to the design, and agree that it has passed the necessary quality checks.[65]

Each time events in the process occur the details, could be added to a new block on a blockchain. An immutable shared record of who did and agreed what, could increase confidence when collaborating. Employing consensus mechanisms linked to smart contracts, including micro stage payments, could increase efficiency and lower risks for the contracting companies.

For example, on a £500k project, a smart contract could state that the Local Authority shall pay the design consultancy £1k, when a quality check on specific design information has been approved through consensus. Updates on progress to project stakeholders could automatically be triggered too.

> **While technical challenges remain for use of blockchain in IoT and transport, the technology certainly merits consideration for use in the transport sector.**

Prof. John Davies – Chief Researcher, BT

[62] Level 3 Building Information Modelling - Strategic Plan, Digital Built Britain, 2015
[63] BIM+Blockchain: A Solution to the Trust Problem in Collaboration? Malachy Mathews, Dan Robles, Brian Bowe, Dublin Institute of Technology, 2017
[64] https://www.cdbb.cam.ac.uk/
[65] http://thoughts.arup.com/post/details/612/blockchains-will-change-construction

Collaborative Design Traceability			
Blockchain Value	**Smart contracts** automate payment and other actions on design task completion bringing elements of procurement into the design environment, thus increasing efficiency	Automating **consensus** between members of the network on which information can be added to the design and quality checks, saves time and cost	**Immutability, provenance** and **finality** of design amendments creates a robust audit trail. Disputes are quicker and easier to resolve, increasing efficiency
Beneficiaries	Digital transport engineering companies, transport authorities		
Key Challenges	• Developing a consensus mechanism that is intelligent and robust enough to stop sub-standard information which is complex in nature being added to the design • Innovation inertia due to radical nature of the technology and conservative elements of the transport sector		

Table 16 – Collaborative design traceability use case: Blockchain value, beneficiaries and key challenges

USE CASE: FLUID ORGANISATIONAL BOUNDARIES

When an entire organisation is based on blockchain and smart contracts the boundaries become more fluid, and what it means to be an organisation changes.[66] A new definition is needed and ConsenSys[67], a new software company is exploring exactly that. Their flat structure empowers collaborators to come up with new ideas and work on projects where they see they can contribute. Its self-organising and facilitated by blockchain technology.

When consensus is reached that a task has been completed to the desired quality, a smart contract is triggered, and the collaborator is paid and/or rewarded with tokens, of which there is a finite supply.

This same model could be used in the CDTE ecosystem, with architects, engineers, modelers who may not know each other exchanging value without a trusted third-party intermediary. Thus, the conventional organisational boundaries disappear.

However, there is a question mark over whether what may work for a new company, would work across a sector.

Fluid Organisational Boundaries			
Blockchain Value	**Consensus, immutability** and **provenance** ensures trust in token rewards, that are only created when tasks have been completed in line with community set rules	**Smart contracts** automate actions across the community including the issuing of token rewards, helping to align the incentives of all members of the ecosystem	A shared database with **customisable transparency** allows stakeholders, especially the sponsor, access to a single version of truth as a particular project progresses, building confidence and reducing risk
Beneficiaries	Digital transport engineering companies, transport authorities		
Key Challenge	• Risk to strategic direction with decentralisaton		

Table 17 – Fluid organisational boundaries use case: Blockchain value, beneficiaries and key challenge

[66] Blockchain Revolution, Don and Alex Tapscott, 2016
[67] https://consensys.net/

USE CASE: LEDGER OF THINGS

Transport operations and asset management are being revolutionised by the impact of the Internet of Things. The prevalence of connected sensors and devices is providing high quality, real-time data that enables insight discovery and improved decision making; resulting in better quality of service and significant cost reduction.

The next generation of data rich, evidence-based transport modelling is on its way.[68] But how can we trust the information provided by the multitude of IoT devices? Blockchain could help here through what is being described as the Ledger of Things[69] *(Figure 11)*.

The Ledger of Things is a blockchain based immutable spatio-temporal record of IoT devices. The record would be transparent to the systems and devices that make use of the data in order to trust that IoT devices are what and where they say they are, and that the data they produce is reliable. There may also be multiple sensors that are measuring the same physical attribute in a particular location, e.g. weather, traffic speed, vehicle occupancy. A single version of the truth, established through consensus, could be enabled through blockchain.

Heathrow and SITA have recently used blockchain technology to come to an agreed version of the truth for flight delays across many stakeholders.[70] Previously, each stakeholder used a different flight delay from a different system. More information on this case study is provide in the next section.

As the number of networked devices increases, they could use smart contracts to interact commercially with other devices and systems, by way of example perhaps automatically trading data and ordering replacement parts and repair services. If a device was malfunctioning, it could assign its responsibilities to another device, while it is repaired.[71] This would help to maximise the value of IoT data. Blockchain could accelerate the growth of the Machine to Machine (M2M) economy.[72] However, the technical challenge of new storage and processing requirements for low capability devices would need to be addressed.

Ledger of Things			
Blockchain Value	**Consensus** allows stakeholders to agree on information from IoT devices and systems, establishing a **single version** of the truth from different values about the same attribute	**Smart contracts** enable IoT devices the freedom to interact commercially and autonomously with other devices and systems, thus increasing efficiency and enabling new value propositions	A shared **immutable** ledger that records device type, software updates, hardware changes, status, malfunctions and position, increases trust in the devices and their data
Beneficiaries	Transport authorities, transport operators, passengers		
Key Challenges	• New storage and processing requirements for low capability devices • Throughput • Attack surface still unclear		

Table 18 – Ledger of Things use case: Blockchain value, beneficiaries and key challenges

[68] Transport Modelling in the Age of Big Data, Cuauhtémoc Anda, Pieter Fourie, Alexander Erath, Future Cities Laboratory, 2016
[69] Blockchain Revolution, Don and Alex Tapscott, 2016
[70] Flightchain, Research into Usability and Practicalities of Blockchain Technology for the Air Transportation Industry, SITA, 2017
[71] Blockchain Revolution, Don and Alex Tapscott, 2016
[72] Welcome to the machine-to-machine economy, Commonwealth Bank of Australia

> Blockchain could accelerate the growth of the Machine to Machine (M2M) economy

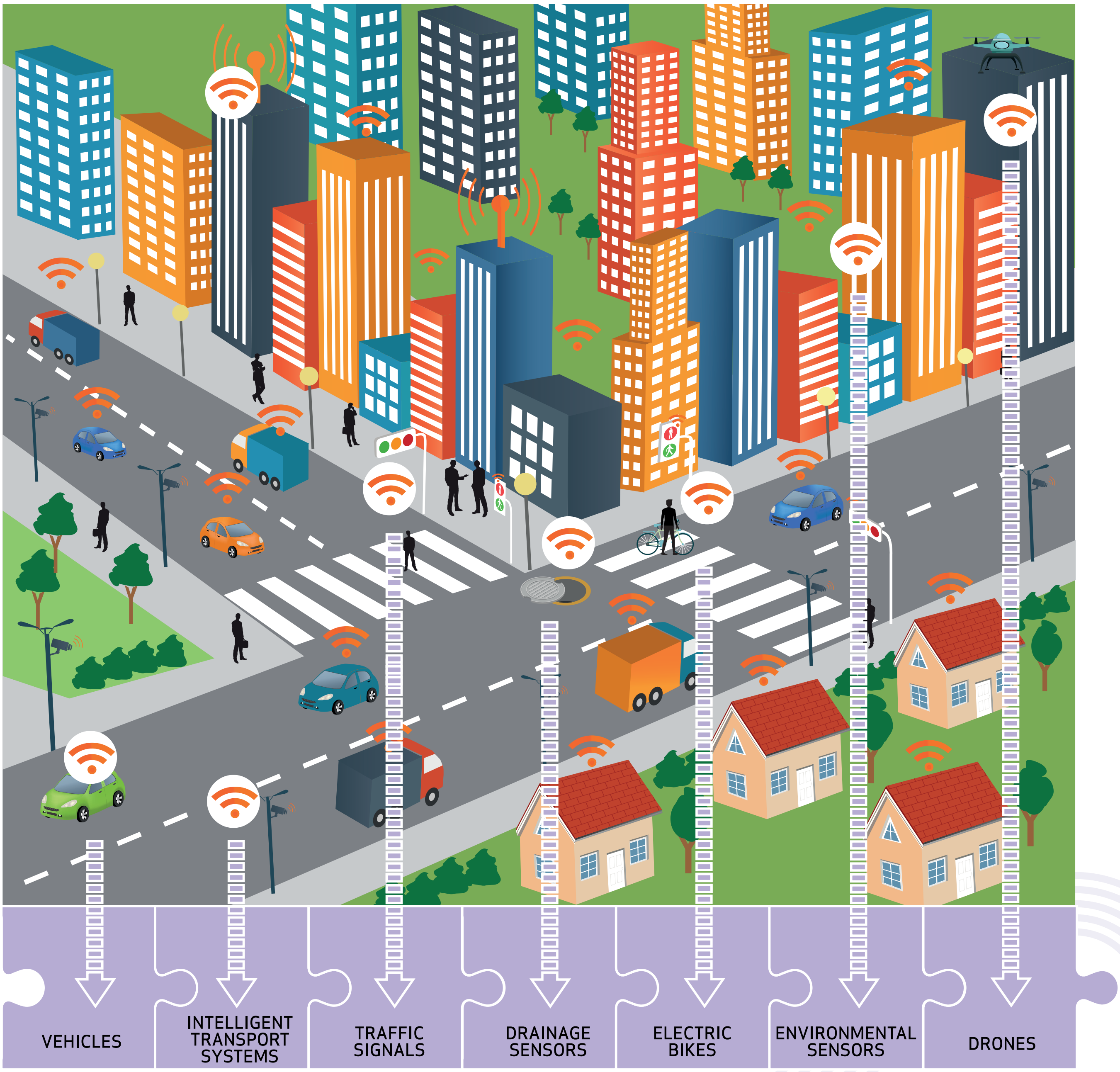


Figure 11 – Ledger of Things

CASE STUDY

CONSENSUS DRIVEN FLIGHT INFORMATION AT HEATHROW

In 2017, SITA Lab, Heathrow Airport (LHR), British Airways (BA), Geneva Airport (GVA) and Miami International Airport (MIA) carried out a collaborative blockchain project, described in the FlightChain whitepaper.

The project aimed to investigate the suitability and practicality of using blockchain to provide a single version of the truth for flight status data. There are currently multiple copies of flight status data and they are not easily accessed by all parties. Agreed flight status data improves customer experience and enables better optimisation of capacity. The project partners identified a need for a distributed database with decentralised control spread across multiple stakeholders, hence the use of blockchain.

A private blockchain was implemented on both Ethereum and Hyperledger Fabric, to store operational real-time flight information using a smart contract to arbitrate potentially conflicting data. Data from LHR, BA, GVA and MIA was merged and stored on a blockchain. The setup is shown in *Figure 12*.

The resulting single version of the truth for each flight status combined data from the operating airline, the departure and arrival airports. During the project, the smart contract processed more than two million flights.

The partners conclude that "blockchain is a viable technology choice for the use case of providing a single source of truth for real-time flight information". Smart contracts and the shared control of data set blockchain apart from alternative technology choices, thus improving trust in the data.

The lack of maturity in the technology made the bespoke implementation complicated and error prone, therefore Blockchain-as-a-Service offerings would be of interest moving forward. The transaction rate throughout for both Ethereum and Hyperledger Fabric FlightChain implementations were less than 5 per second, with computational load and memory requirements described as "modest" and "quite low" at < 10% and < 0.5Gb respectively.

The next steps for the initiative were identified as (a) adding more airlines and airports, (b) increasing the sophistication of the smart contract and (c) developing a business model. A future vision for the air transport industry was also identified, where industry standards are written directly as smart contracts instead of being published in PDF format. The standard smart contracts would be made available for industry actors, so they could embed them in their systems.

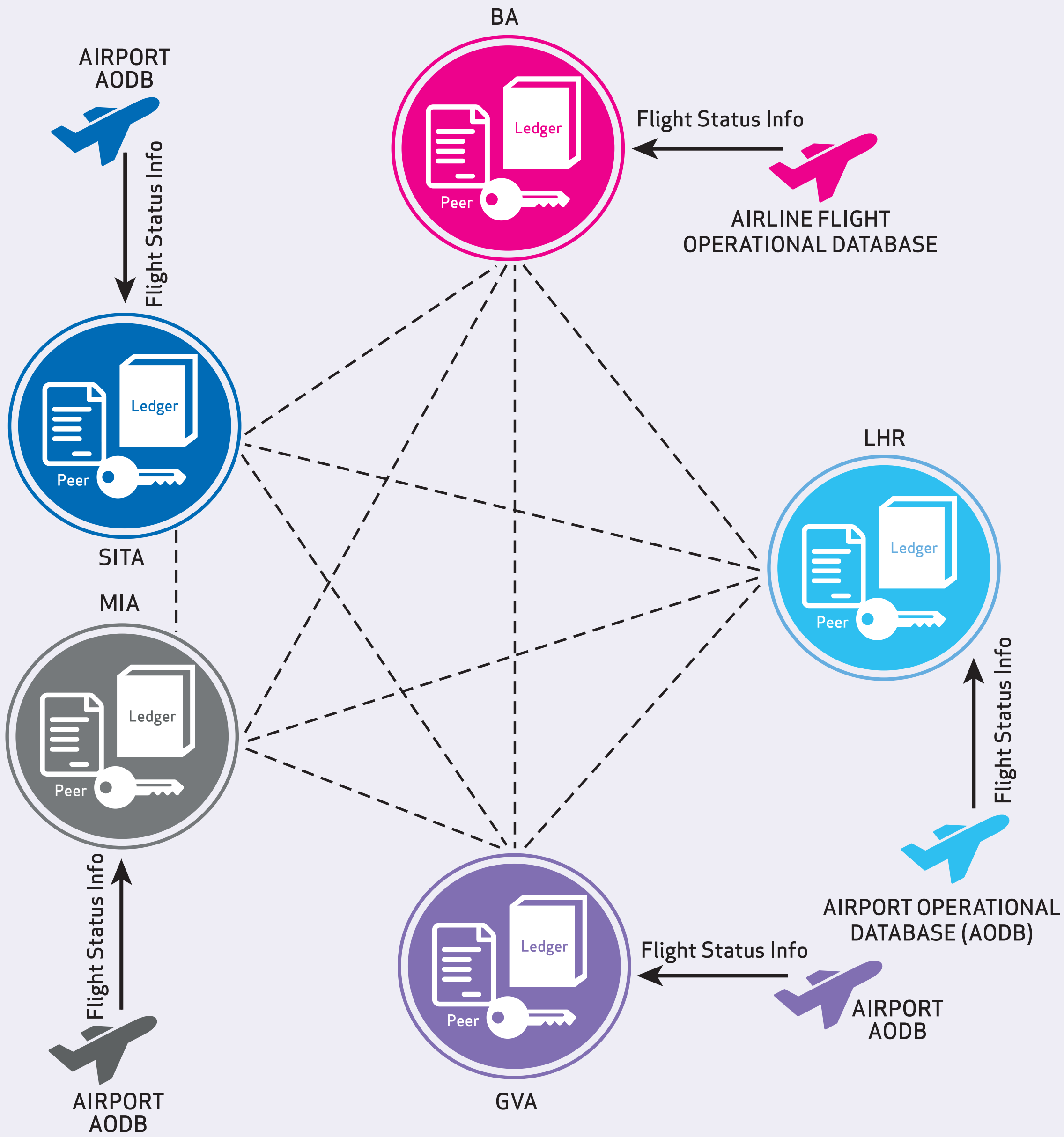


Figure 12 – FlightChain setup

5 HOW SECURE IS BLOCKCHAIN?

The world of transport is undergoing significant change. This new world also brings a fresh challenge: cyber security. As with any sector undergoing rapid, impactful change, transport is facing technological threats to its evolution. The Transport Systems Catapult led collaborative research in 2016[74] which revealed some fundamental insights for cyber security in transport:

- The rapidly changing security and mobility landscape is likely to mean more cyber-attacks, more often, and potentially with more severe consequences
- Understanding the nature of the existing cyber security issue is still a challenge
- The UK is well positioned to respond to the challenge as it already has strong capability in cyber security
- The technology the UK needs is not an issue – secure intelligent mobility requires a robust strategy and cultural focus
- Privacy will remain an ongoing consumer debate, and opportunity. Privacy is increasingly being promoted as a selling point for technology products, with 35% of consumers having made purchasing decisions based upon privacy concerns

POTENTIAL BENEFITS

On the one hand, blockchain technology offers many new opportunities to improve the security and privacy in transport. For example, the use of cryptography within a private blockchain has the potential of improving the *confidentiality* in certain scenarios. The *integrity* of data might be improved by the use of blockchain due to validation of data through consensus, secure linking of blocks using cryptography as well as the distributed data storage. An attacker would need to compromise several parties instead of only one party controlling a central storage.

The distributed nature of blockchain also contributes to a better availability of data as copies of the blockchain can be obtained from multiple sources. As blockchains avoid a central controlling entity, business scenarios can be implemented in which end-users control the conditions under which they are willing to share data with any parties they wish – thus giving users more control of their *privacy*.

CHALLENGES

On the other hand, blockchain technology is creating new cyber security challenges where more parties have access to data, the more likely it is that data is leaked. There are further fundamental problems in that data in a blockchain cannot be deleted. Thus, the use of blockchains in some scenarios might conflict with data protection regulations such as General Data Protection Regulation (GDPR) enforceable from 25th May 2018 across the EU, especially the right to be forgotten.[75]

There are two potential approaches that have been suggested. Change the design of the blockchain to allow personal data only[76], to be deleted , or store personal data off the blockchain, with only references to that data stored on the chain.[77]

A possible third way has also been suggested, which is that the cryptographic keys needed to access the personal data on the blockchain could be deleted, such that no one could ever view that data in an unscrambled form.[78] Given that GDPR provides no

[74] Cyber Security and Intelligent Mobility, Transport Systems Catapult, 2016
[75] https://www2.deloitte.com/dl/en/pages/legal/articles/blockchain-datenschutzrecht.html
[76] https://www2.deloitte.com/dl/en/pages/legal/articles/blockchain-datenschutzrecht.html
[77] https://medium.com/wearetheledger/the-blockchain-gdpr-paradox-fc51e663d047
[78] A guide to blockchain and data protection, Hogan Lovells, 2017

definition of 'erasure of data' this method is ruled out without further clarification.

Also, the technical limitations of blockchain, e.g., the rather small amount of data that can be stored might require technical complex architectures that are hard to operate securely. Finally, blockchain, needs to be implemented correctly to avoid bugs which may result in security vulnerabilities, just as with any complex technology.

APPROACH

The potential benefits and risks of using blockchain needs to be assessed in detail for each and every application individually. Security analyses of blockchain technologies have primarily focused on the Bitcoin application, with respect to the incentives of participants.

Threat models for blockchain use cases in transport, largely involving private or hybrid varieties may have significantly different characteristics to Bitcoin. The key to utilising blockchain technology across transport, is understanding the source of potential threats, the associated risks to business operations, and the measures required to mitigate them.

Where incentives to participate honestly and motivations for acting maliciously differ significantly from the Bitcoin use case, alternative (and, in some cases, more aggressive) threat models must be considered. The broader security implications must be rigorously analysed and understood.

Blockchain is not a silver bullet – for many applications there may be other technologies (e.g., traditional distributed data bases) that provide more security and an architecture that is easier to implement than blockchain. *Figure 13* highlights some of the potential security benefits and challenges to blockchain.

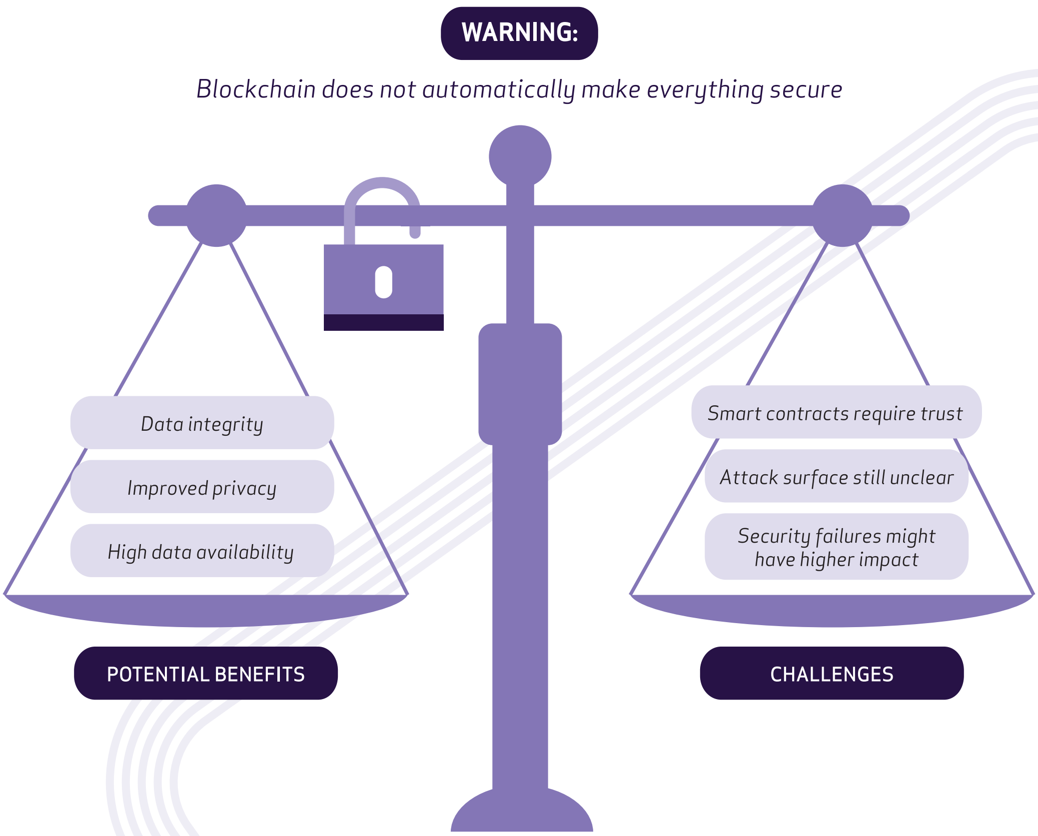


Figure 13 – Potential security benefits and challenges of blockchain technology

6 SHAPING A NEW TRANSPORT HORIZON, BLOCK BY BLOCK

Blockchain and DLT in general have the potential to impact every area of the transport sector over the coming years. The impacts range from helping to increase efficiency, to driving new business models. We have highlighted only some of the use cases in transport and there are many more to be generated.

In the near term, much will be learnt from freight and logistics blockchain related initiatives as they move from experimentation to production, such as IBM and Maersk's joint venture[79], as well as other pioneering demonstrators. Insights from these projects will be useful in calibrating new projects.

In the medium term, blockchain may offer transformational potential across transport by increasing the trust of passengers and end-users and eliminating expensive bureaucracy and back office processes. In this phase, the choice of the first blockchain project is critical.

Organisations must cut through the extensive hype around the emerging technology and prove demonstrable blockchain value. The most transformational benefit will be from the use of blockchain to transform the entire business network, such as with decentralised MaaS and UTMs. The most difficult challenges to overcome are more likely to be cultural than technical.

Most of the use cases identified in this paper assume that blockchain technology will develop over the coming years to enable them at scale. There are currently constraints on transaction throughput, latency and data storage. However, research is underway to address these constraints[80], including at University College London's Centre for Blockchain Technologies[81], among others. We are optimistic that the technology will develop rapidly and be able to overcome existing barriers, to unlock its full potential.

> **Could the convergence of blockchain, IoT and AI more accurately represent the technological singularity?**

RECOMMENDATIONS

To enable the UK to become a leader in blockchain based transport solutions, we recommend the following actions:

- Increase understanding and knowledge sharing of blockchain across the transport sector through establishment of a Community of Interest (CoI), meeting quarterly
- Stimulate the market through a dedicated Future Mobility Collaborative Research and Development (CRD) programme supported by the UK Government's Industrial Strategy Challenge Fund. This will enable new service models and technologies such as blockchain to be tested in-market, de-risk development and help prove the value of use cases.

TECHNOLOGICAL SINGULARITY

Futurists have talked in recent years of a 'technological singularity'[82], that is an Artificial Intelligence (AI) explosion leading to unfathomable changes to society, including transport. However, could the convergence of blockchain, IoT and AI more accurately represent the technological singularity?

IoT, supercharged with 5G[83] and 'smart dust'.[84] AI, advancing with deep learning and 'brain-on-chip' neuromorphic processors.[85] These two combined with a blockchain-based trust fabric to enable the Machine to Machine (M2M) economy, is a thought-provoking prospect for the transport sector.

In a blockchain-based future we could see Decentralised Autonomous Transport Organisations (DATOs) emerge and run entirely on interconnected smart contracts.

History teaches us that seemingly outrageous ideas and concepts, once laughed at, quickly become accepted and then realised. Let's embed this thought today. Being visionary appears to be the wise choice.

79 https://www-03.ibm.com/press/us/en/pressrelease/53602.wss
80 https://www.cryptocoinsnews.com/university-sydneys-red-belly-block-chain-scales-660000-transactionssec/
81 http://blockchain.cs.ucl.ac.uk/
82 The Technological Singularity, Murray Shanahan, MIT Press, 2015
83 http://uk.businessinsider.com/how-5g-will-revolutionize-the-internet-of-things-2017-6
84 https://internetofbusiness.com/future-of-iot-will-be-smart-dust-says-cambridge-consultants/
85 https://www.technologyreview.com/s/526506/neuromorphic-chips/

APPENDIX A

The methodology used to rank the use cases identified from the literature review according to the degree of implementation difficulty and the potential value added by blockchain is shown in the table below.

Blockchain in transport use case	Blockchain imp. difficulty (1 hard – 10 easy)	Imp. difficulty why?	Blockchain value (1 low – 10 high)	Value why?
Trusted vehicle information recording ownership, service history, accident history, service history and software version.	8	Similar to well developed use cases in other industries, but would need work	8	Provenance, Immutability and Consensus
Vehicle centric contracting and authentication systems to drive machine economy.	4	Complexity of business network and implementation	4	Smart contracts
Payment mechanism for electrified roads usage.	3	Hard to set up payment network with regulator involvement	5	Smart contracts & consensus
Self authenticating network of delivery drones.	3	Hard to set up payment network with regulator involvement	6	Self authentication and proof of delivery with provenance & immutability
Dynamic insurance products for autonomous vehicles.	6	Insurance companies would control; smart contracts would do bulk of work	7	Smart contracts drive value across business network + consensus & immutability
Autonomous vehicle-negotiated shared access to roads without central authority.	3	Hard to set up across network	3	Not clear on blockchain value
Smart logistics and ticketing solutions.	6	Several smart logistics initiatives	8	Provenance, immutability and digital currency
Traveller-centric integrated journeys, crossing transport modes and routes.	4	Would be hard to set up from an organisation & regulatory viewpoint	9	Provenance, immutability, consensus and digital currency + good use of smart contract
Authenticated transport infrastructure components, with trusted audit trail of changes.	9	Similar to existing use cases, including diamond provenance	8	Provenance, Immutability and Consensus
Through lifecycle supply chain transparency.	9	Similar to existing use cases, including diamond provenance	8	Provenance, Immutability and Consensus

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