UITP ADVANCING PUBLIC TRANSPORT

REPORT

DISTRIBUTED LEDGER TECHNOLOGY IN PUBLIC TRANSPORT:

USE CASES FOR BLOCKCHAIN

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INTRODUCTION

Digital technologies are currently remodelling the public transport ecosystem, and blockchain and distributed ledger technologies (DLT) are receiving attention from decision makers. With Blockchain and DLT, parties are able to enter into new direct relationships with each other based on a common set of rules and a high level of trust without any need of central management authority. This will give further value to data and reshape how users will access public transport. New possibilities of accessing, paying for and using public transport are set to appear.

But the potential for blockchain and its ability to transform the transport sector needs to be clearly assessed. The opportunity of an increasing number of decentralised applications running in peer-to-peer networks needs to be understood by the various stakeholders involved in the process.

This Report gives direction on how blockchain contributes to influencing current processes which provide and manage public transport services. Not only are the opportunities and constraints outlined but further exemplified through use cases. A strong focus is placed on the potential of blockchain to facilitate seamless urban mobility through delivering future-oriented Mobility as a Service (MaaS) solutions.

BACKGROUND AND DEFINITIONS

Being a new technology, it is difficult to find dedicated case studies using blockchain technology in public transport. There are several examples where blockchain can potentially be used for selected public transport services, but there are not too many examples of implemented blockchain solutions supporting holistic and complex public transport processes, except payments or ticketing systems.

However, there are already some general blockchain solutions for transport, and some of them or some of components of these solutions can be successfully deployed and used in public transport. General examples of blockchain solutions for various transport industries illustrate how such solutions or elements of these solutions can also be used in public transport. The general approach of this analysis is to show that **blockchain solutions can provide added value for public transport, and that such solutions can be built based on existing solutions in other transport sectors and easily implemented for public transport.**

Of course, other types of DLT could be used in public transport but they were not studied in this document. An example of other distributed ledger could be Tangle which is a permissionless, feeless, scalable distributed ledger, designed to support trustworthy data and value transfer between humans and machines.

Before entering the case study chapter, the definition of key terms is necessary. This will be followed by examples of blockchain solutions that can be implemented in public transport.

DEFINITIONS

Distributed Ledger Technology: DLT is a virtual decentralised database or ledger, often encrypted for security, maintaining a permanent and tamper-proof record of transactional data. It is managed by computers allowing a peer-to-peer (P2P) network, whereby each of the peers (computers) in the network maintain a copy of the ledger. Peers can add new transactions to the block as long as they comply with previously agreed protocols (rules). All copies are updated and validated automatically and simultaneously.

The defining characteristics of DLTs are that they are:

1. **Decentralised:** No single central intermediary or authority.
2. **Distributed:** The whole network of peers (computers) has access to the whole ledger based on an agreed framework of access rights.

3. **Transparency and trust:** The protocols (rules) are pre-determined and agreed by all, and all transactions visible and traceable to all.
4. **Encrypted:** The data exchanges between computing devices can be protected using cryptographic chains making them accurate, secure and immutable.
5. **Secure:** Tamper-proof, hindering unauthorised access, as there is no one central access point that can be hacked.

Blockchain: Blockchain, the technology behind Bitcoin, is an example of a DLT. One key difference between a typical data base and a blockchain is how the data is structured. A blockchain collects information together in group, known as blocks, that hold sets of information. These blocks have storage capacities so that when they become full, they close and a new block opens for new data. These blocks are then connected, forming a chain of data known as a blockchain. Different types of data can be stored in a blockchain but the most common so far has been as a ledger for transactions. As the data is coming from various decentralised sources, the data entered is irreversible and permanently recorded.

There are other examples of cryptocurrencies and open or closed platforms of which dedicated blockchain applications can be created. An example of such a platform could be Ethereum, and an example of an environment for building open and closed platforms could be Hyperledger.

REFERENCES

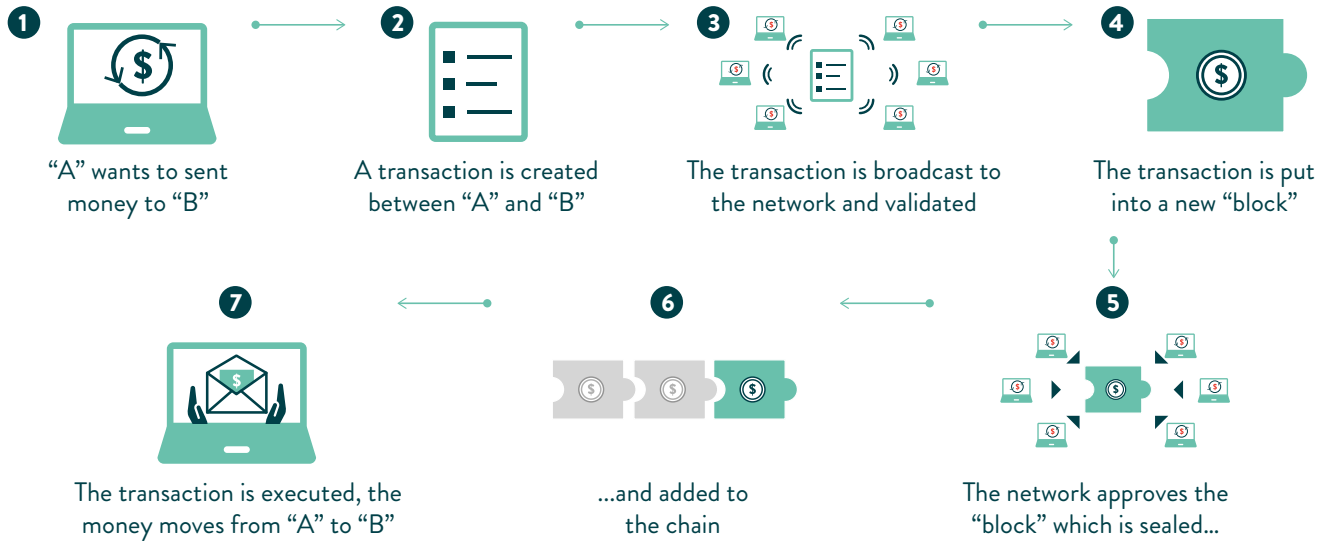
Below are examples of how other organisations define blockchain and DLT.

1. **TechTarget:** Blockchain is a type of distributed ledger for maintaining a permanent and tamper-proof record of transactional data. A blockchain functions as a decentralised database which is managed by computers, creating a peer-to-peer (P2P) network. Each of the computers in the distributed network maintains a copy of the ledger to prevent a single point of failure (SPOF) and all copies are updated and validated simultaneously.

2. **Gartner:** A blockchain is an expanding list of cryptographically signed irrevocable transactional records shared by all participants in a network. Each record contains a time stamp and reference links to previous transactions. With this information, anyone with access rights can trace back a transactional event, at any point in its history, belonging to any participant. A blockchain is one architectural design of the broader concept of distributed ledgers.

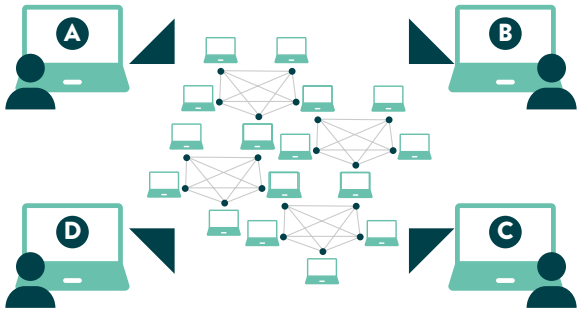
3. **International Transport Forum:** Blockchain is an example of a distributed ledger technology (DLT), a decentralised application running in peer-to-peer networks built on distributed ledger. Blockchain and other novel data protocols are starting to profoundly disrupt established economic sectors (e.g. finance, healthcare, provenance authentication, commerce). These applications allow agents to enter into direct relationships with each other according to a commonly agreed set of rules and a high degree of trust without having to go through a central authority. Combined with a common language and syntax for the "Internet of mobility" and new means of deriving insight from previously siloed data, these applications may help redefine how people access.

How blockchain works. Source: Accenture, 2018



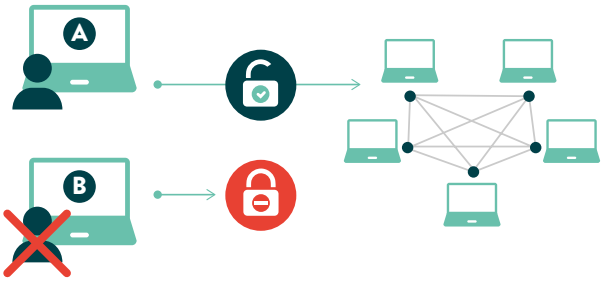
A DLT platform can be public or private as per the user's needs. For example, Bitcoin is an example of a publicly-accessible blockchain platform where anyone with the key (bitcoin passwords) can access the ledger and trade their coins. In secure blockchain applications where users are pre-defined, private DLTs are more applicable. There are also examples of hybrid DLTs where some information is publicly accessible whereas the rest of the information is accessible to selected users as defined by the pre-set rules.

Public versus private blockchains
Source: Accenture, 2018



PUBLIC, PERMISSIONLESS BLOCKCHAINS

- Anyone can join the network and submit transactions
- Anyone can contribute computing power to the network and broadcast network data
- All transactions are broadcast publicly



PRIVATE, PERMISSIONED BLOCKCHAINS

- Only safelisted (checked) participants can join the network
- Only safelisted participants can contribute computing power to the network and broadcast network data
- Access privileges determine the extent to which each safelisted participant can contribute data to the network and access data from the network

Overview of public, private and consortium blockchain ledgers.

	PUBLIC	PRIVATE	CONSORTIUM
Structure	Decentralised	Centralised	Partially decentralised
Access	Open read/write	Permissioned	Permissioned
Speed	Slower (around 10 mins)	Faster (same as a transactional system)	Depends on the number of nodes
Consensus	Proof of work, Proof of Stake	Pre-approved	Pre-approved
Identity	Anonymous	Identity known	Identity known
Use cases	Cryptoeconomy	Reference data management	Secure data sharing
Examples	Bitcoin, Ethereum, Dash	MONAX, Multichain	R3 EWF

THE BENEFITS OF BLOCKCHAIN

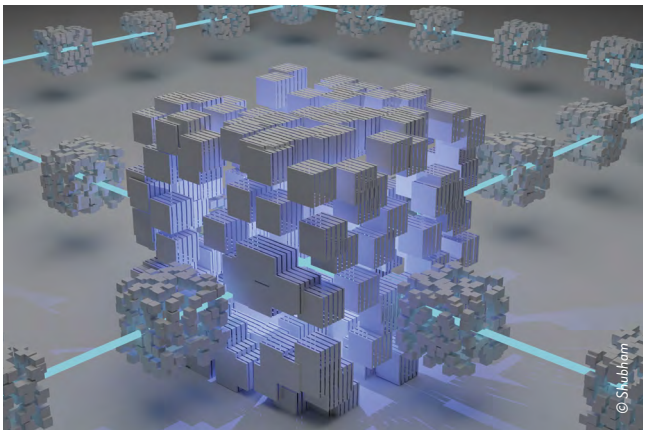
It is important to understand the value proposition of the blockchain technology for the transport sector. According to the Blockchain in Transport Alliance, blockchain can bring the following benefits to an organisation:

- Frees up capital
- Lowers transaction costs
- Speeds up processes
- Provides security and trust
- Market transparency
- Operational efficiency
- Carbon friendly
- Risk management
- Promotes interoperability

Blockchain improves efficiency by greatly reducing bureaucracy and paperwork in a multi-stakeholder process with lengthy paper trails as they could be automated by storing information in a tamper-evident digital format. They are also useful in services that currently require an intermediary such as insurance, legal, brokerage, and settlement services.

Modern public transport systems are fundamentally an agglomeration of distributed systems. Sensors and Internet of Things (IoT) devices are connected to each other for rapid data processing and assist with rule-based decision support systems (signalling, ticketing, telematics, asset management). Even the administrative functions supporting public transport operations require a high degree of distributed decision making. Activities such as manpower control, contract management, procurement supply chains, inventory management, and financial settlements require a trusted participation by several internal and external stakeholders. Therefore the potential for DLT application in the public transport industry is quite significant.

1 Clearing refers to the approval of a financial transaction by the financial institution.



Blockchain technology can solve the problems of long cross-regional revenue clearing[1] and settlement cycle, difficulty in checking for evasion and leakage, and high pressure on inspection. Blockchain technology can not only ensure the security of data, but support also an improved network availability of ticketing systems through increased fault-tolerance and the real-time performance of secured clearing and settlement. The main contribution of DLT is the reduction of disputes and reconciliation due to loss of transactions or errors in records. This technology can also provide real-time clearing and settlement of tolls to achieve the purpose of reducing costs and increasing efficiency. The data provides a basis for the transfer, deduction and settlement, and can provide users and operators with journey query, billing settlement management, and data analysis.

It is worth noting that blockchain solutions can also be a substitute for services provided by compensation houses/acquirers for payments for public transport services. Blockchain can also become a platform where multiple operators can securely deal with multiple acquirers and/or clearing houses with an aim to reduce transaction costs or other related benefits. Such 'arbitrage' is only possible when a DLT removes the information asymmetry.

Security and trust is what makes DLT a cutting-edge technology

It is a means of securing and validating/executing an electronic transaction.

Blockchain technologies promote a culture of collaboration where competitors can work with each other on a trust based transparent framework that allows complete traceability, security and always the single and most up-to-date version of the truth. When dealing with data, this solves a number of issues. Every single use of data strings can be traced back to the user, including its use purpose and use method. This also makes data monetisation easier by controlling when data can be used for non-commercial purposes and when it is used for commercial purposes.

USE CASES OF BLOCKCHAIN

SMART MOBILITY

Modern cities are full of urban sensors (traffic detection systems, CCTVs, Wi-Fi hotspots, streetlights, crowd sensors, parking sensors) which are constantly interacting with each other in order to provide better traffic management, emergency responses, disaster management and enhanced safety. DLTs allow these sensors and controllers to be connected using a common cryptographic chain of trust. This can enhance the accuracy of information, prevent disruptions, and improve decision making. Public transport vehicles can also be part of this DLT ecosystem and exchange data with these control systems to improve customer experience, service reliability and real-time responses.

Cross-border blockchains among security agencies and traffic police will strengthen sharing of enforcement related sensitive data through secure channels and allow better law enforcement against violators.

There are many areas of potential cooperation between operators in the context of blockchain. There are also many transactions between operators, such as a common tickets, the use of shared infrastructure such at bus stops, the interoperability of public transport services. Sometimes operators are wary of sharing information due to commercial confidentiality reasons or due to a highly competitive operating environment. **Blockchain allows a trusted central platform with rules-based access to individual operators but data can also be utilised by algorithms to provide a common journey planning platform to customers.**

Assuming that individual operators use blockchain solutions, **there are at least several potential areas of cooperation:**

Multimodal transport is a form of transportation organisation that integrates multiple modes of transportation and improves overall transport efficiency and quality by seamlessly connecting various modes of transport. In practice, multimodal transport is popular in the area of freight transport. The bill of lading, the document issued by a carrier to acknowledge receipt of cargo for shipment, is an important part of multimodal cargo transportation and has a greater impact on the operation efficiency and service quality of multimodal transportation. Although the traditional electronic bill of lading has high circulation efficiency and can prevent the forgery to a certain extent, due to the paperless and electronic characteristics of the electronic bill of lading, it is not like a paper bill of lading that can be occupied.

MODELLING THE TIMETABLE

based on analyses of the road network, number of stops, tickets sold, validated tickets in public transport vehicles (rule-based revenue allocations, clearing house functions, settlements).

OPTIMISING THE NETWORK

of stops for buses, trams, etc (operational schedules synchronisations).

COMMON TICKETING SYSTEMS

and pricing models (multi-modal ticketing integration or fare integration).

COLLABORATION WITH DIFFERENT INSTITUTIONS

to establish ticketing pricing models, including pack and discounts. (rule-based subsidy entitlements, special discounts by third parties).

INTEGRATION OF THE LOCAL TRANSPORT NETWORK

with the agglomeration and national network (integration with tolling systems), both from the road infrastructure point of view and from multimodal transport point of view.

Of course, blockchain is not merely an electronic transaction receipt. DLTs make the electronic transaction receipt (a bill of lading or an electronic ticket) traceable, immutable, unforgeable (DLTs always maintain single version of truth), unhackable and ensures that data layers can only be accessed by authorised users.

Very similar mechanisms can also be used in public transport. From the point of view of the blockchain, the difference is that freight transport uses a consignment note and public transport can use a common ticket. From the transactional point view, other elements are similar. In other words, from the point of view of a blockchain solution, you can approach the shipment in the same way as a passenger.

The future development of electronic bills of lading urgently needs to solve the problems of pledge in the circulation process, protection of the rights and interests of both parties to the transaction, and reasonable allocation of the responsibilities of the parties. The multimodal electronic bill of lading introduces blockchain technology to support multiple participants such as carriers, financial institutions, shippers, customs, commodity inspections, to collaborate online to complete electronic bill of lading issuance, electronic bill of lading transfer, payment for goods, and cargo inspection. Each record deposited in the blockchain network can ensure that the carrier and the shipper complete the transaction safely, transparently, fairly, and maximize the value of the electronic bill of lading.

As has been outlined above, the approach to the bill of lading can be very similar to the approach to a common ticket. This means that in such a scenario, from the point of view of the solution architecture, it will be possible to collect data related to blockchain transactions from different sources. Examples of sources include information about bus stops, ticket validations (in individual vehicles) and passenger connections between vehicles.

Thanks to the collected data, better cooperation between carriers is possible. This can optimise the transport network, timetables and other processes related to public transport by using an agreed blockchain model, regardless of whether it is one blockchain platform or a distributed model.

In each of this cooperation scenarios above, the main challenge is the establishment of rules standards between the intervenient organisations. This issue may be especially difficult to overcome when considering wide area networks, across regions and or countries, where various public and private institutions have different and often conflicting interests. In the current model, each transport provider uses different data models for tickets/user information. **In a cooperation model, standards and rules must be established between the parts, and actual transactions would follow the rules for settlement in a secure, tamper-proof framework.** Smart contracts allow for the standards to be set between the network or by a subset of it.

One pivotal standard to define is **the identity management model,** where the solution may be to use blockchain technology to support identity management by means of self-sovereign identity. In this model, the user is responsible for their data, thus removing the need for the network to hold private user information. A project like the European Union (EU)-funded European Self Sovereign Identity Framework (eSSIF) may hold the answer for a future where the user is in control of its data, removing the need for a third party.

Especially with a blockchain Self Sovereign Identity network, the traveller could contact government/ educational institutions more easily, as these would be directly integrated in the network, to get discounts based on government social measures or student status, for example. Entire passports can be digitised where biometrics of a person can be the security key to unlock tamper-proof information at the borders reducing the forgery or validating the humanitarian credentials of the person. UN started ID 2020, a digital identities programme to stop forgery and identity theft.

MOBILITY AS A SERVICE AND SHARED MOBILITY

Mobility as a Service

Blockchain and DLT could enable service providers to share data in a secure way and support the set-up of neutral managed platforms. Today, third parties provide the possibility to manage a journey chain for users in a convenient way through their platforms. These commission-based services lead to an increase of price for users and to a lack of integration due to difficulties in optimising travel chains once different platforms compete on the market.

The challenge of data sharing and integration requires agreements on data-sharing principles and antitrust policies. There are various elements where DLT could provide trusted operation of Mobility as a Service (MaaS) platforms. These include smart contracts which allow transactions on a MaaS platform to be transparent and secure through their encryption mode. Based on the genuity of data, a trusted revenue settlement can be established.

In addition, providers and users can directly exchange information. **Blockchain and DLT could lead to more open MaaS ecosystems promoting better interoperability and seamless travelling under the paradigm of fair competition and regulation.** Moreover, a user choosing a smart contract for a journey will integrate payment/ticketing and grant distribution of the revenue to the various concerned service providers.

Blockchain's ability to handle mass data in real time could open up to new forms of smart city management.

Loyalty schemes

Blockchain gives users the opportunity to obtain and exchange units of value e.g tokens through directly-linked payments. MaaS schemes that offer users control over their own data and compensate them for sharing it enables new market opportunities for loyalty schemes. In this case, a central management authority or regulatory body would not be necessary as smart contracts guarantee sufficient trust and enable the involved partners to interact directly, giving each single user the possibility to take an active part in the governance of the platform and reducing the risks linked to platform monopolies. In such configurations, authorities can still encourage the use of public transport with differentiated reward option for such travel patterns. Despite its potential, further knowledge on blockchain transactions is necessary in order to validate its performance compared with existing payment technologies.

Peer-2-Peer (P2P) System Ride sharing

More and more ride-sharing services have been entering the market over the past years and have challenged the ecosystem with their extensive use of technology to develop new business models. These link partners through platforms and rely on the charging of commissions. These models increase the revenue for the platform providers and lead to potentially higher fares for the users and less revenue for the service providers. **Blockchain and DLT are able to fully review this business model.** Due to its decentralised structure and smart contracts, (booking) platforms are no longer mandatory for the service provision. Smart contracts could allow new commission-free Peer-2-Peer relations under the umbrella of an authority, setting the necessary flexible regulatory framework. Such new approaches could lead to setting up new P2P networks, allowing dynamic pricing and a competitive market framework for the users by rendering costly (booking) platforms unnecessary.

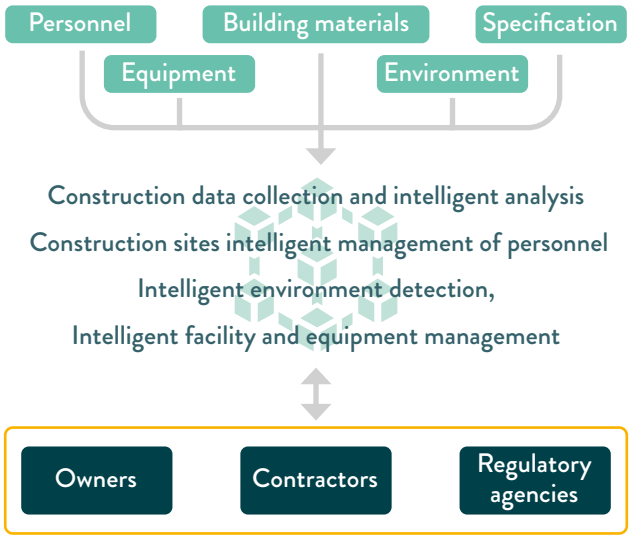
Vehicles, drivers and their respective data can be trusted with the use of blockchain.

Autonomous Driving

Blockchain is characterised by the ability to ensure different processes in managing and handling complex processes, meaning that it will strengthen the security dimension that is central to self-driving approaches. Blockchain will benefit particularly critical urban application areas because of its unique encryption features in the currency world, and it can assist in the driverless automotive world. **The greatest value of blockchain, especially with the advent of autonomous driving, will be the creation of a holistic urban transition experience, with full and ultimate optimisation.**

Contracts, legal and procurement

Blockchain technologies are also an opportunity to solve many problems at the operational level. Based on blockchain technology and IoT technology, taking the construction site as an example:



This approach can ensure the safety and credibility of engineering data, optimise management procedures, reduce institutional transaction costs, and improve the quality of construction and maintenance. This, of course, has a positive effect on public transport both within and outside the cities.

Here, the role of the blockchain is mainly reflected in several aspects:

1. **Project management** uploads the information of contractors, suppliers, and supervisors to the chain, and truly records the entire process of project management, which is conducive to the transparency of the construction process, avoids illegal subcontracting, cutting corners, reducing prices and preventing problems in traditional construction machinery management.

2. **Fund management:** The multi-party alliance chain can efficiently synchronise transaction data in real time, accurately track project progress, procurement data, consumption data, standardise project fund management, optimise fund management processes, and real-time request for payment and payment settlement. This also saves a lot of time and manpower.

3. **Safety supervision:** In response to the formalisation of safety inspections during the construction process, difficulty in management of construction personnel, and low execution efficiency, blockchain technology will link the quality and safety information during the construction process to the chain, discover potential risks in a timely manner and arrange various supervisions. This also improves safety management and control.

For a long time, small and micro enterprises have experienced difficult, expensive, and slow financing due to their own lack of credit, a relative lack of collateral and asymmetric information. With the development of financial technology, **blockchain technology is regarded by the industry as a solution to the current dilemma of supply chain finance,** and "blockchain + supply chain finance" is increasingly used in actual businesses.

GLOBAL BLOCKCHAIN CHARACTERISTICS

The exploration and use of blockchain technologies vary around the world. In Europe, complex inter-regional transport networks and multi-faceted service contracts are well established and common. This complexity has led to further evaluation over the use of blockchain-based systems. In contrast, American and Canadian transport systems tend to utilise fewer service providers with simpler contracts. This results in a trusted environment, limiting the potential value of blockchain technologies. Instead, in these countries, focus is given to the exchange, storage, and publication of data using Application Programming Interfaces (APIs).

In Latin America, riders and transport providers are excited by the potential of blockchain to provide decentralised transaction systems. These systems may allow for increased coordination and trust without intervention by an authority. In Brazil, the city of Teresina has created the 'Observatório do Transporte', the Observatory of Transport, and partnered with the French Economic Development Agency (AFD) through the EUROCLIMA+ programme to launch a transportation technology innovation project. The programme envisions that blockchain technology might be used to improve transparency and sharing of information. Separately, in 2021, El Salvador declared Bitcoin a legal currency which may accelerate the adoption of blockchain technology in the county.

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A blockchain-based commodity traceability platform uses blockchain technology and IoT technology to realise the transparency of the entire process of commodity production, processing, transportation, and sales. Blockchain technology can ensure the validity and security of information, while the IoT technology can ensure the authenticity and reliability of data during the acquisition process. Consumers can trace product information through the traceability source code on the product.

For example, in the production process:

Through the IoT technology, the sensor nodes are arranged in the production base of the product, and various effective information of the product during the production and processing process is obtained in real time, such as the production environment, production time, and production process.

When the product is out of the warehouse, the manufacturer uploads product information, manufacturer information, packaging information, and storage information on the smart contracts on the chain to provide source information for the system.

After receiving the product, the logistics provider scans the product, uploads the enterprise information and product status information to the chain and records the transportation and logistics link information.

When the product arrives at the retailer, the retailer performs warehousing scanning and transaction information. Retail commercial information and product storage information are on the chain.

From the public transport point of view, when it comes to contracts, legal and procurement, there are many possible applications mentioned above. Possible applications can be related to many aspects of the operation of a public transport company and the transportation infrastructure.

BITCOIN TICKETING IN BRAZIL

With a population of 2.7 million, the city of Fortaleza has an extensive complementary transport system. One local provider, Cootraps, announced in 2019 that Bitcoin would be accepted as payment to reduce local bureaucracy and speed passenger boarding. The system is not yet implemented.

In São Paulo and Rio de Janeiro, where public transport systems accept credit and debit network payments, riders can also pay their fares using Bitcoin. Some passengers choose Bitcoin to help avoid fluctuations in the value of the Brazilian Real.

LEAN SUPPLY CHAIN MANAGEMENT IN HONG KONG

MTR Corporation has already embarked upon developing a Blockchain Minimum Viable Product (MVP) with some of their suppliers of spares and equipment using blockchain-based contracts. This is a process of developing the leanest version of a blockchain application with minimum functionality and is expected to provide greater visibility of the inventory to both MTR and its suppliers so they can better plan their supply chains. Once the orders are triggered when inventories go below a threshold, supplier are prepared and upon receipt of the spares, financial settlement can be done automatically through blockchain-based smart contracting. This is expected to reduce a lot of friction and make the entire supply chain more efficient.

Ticketing systems and payment

With regards to examples of potential uses of blockchain in public transport and the current solutions already in place, ticketing systems based on radio-frequency identification (RFID), near field communication (NFC) or QR-code should be addressed.

The QR-code has become a dynamic solution, especially for usage on mobile devices so that they can represent smart contracts assets in a more secure way. Here, blockchain is a tool/service for the analysis of validated tickets in public transport, clearing between carriers, clearing between service providers in the city such as passengers in public transport, and for integrating tickets for the services of multiple carriers. In a DLT-based ticketing system, a financial transaction can be converted into a smart tamper-proof immutable token reducing any settlement disputes, loss of transactions or possibility of evasion.

Based on the idea of a small number of properties of a blockchain, some dedicated use cases of ticketing can include:

- Procuring an entitlement
- Revoking entitlements
- Accessing a service
- Inspection
- Innovative ticketing products
- Involvement of non-transport players in the public transport ecosystem (for ticketing promotions)

One known case of DLT-based ticketing is in the Netherlands where VMC.ai in 2019 implemented a fully open and decentralised payment and ticketing platform. Transactions were undertaken using VAI token. Passengers used VAI to interact with the network while providers and stakeholders shared incentives and cooperated.

Data management

It is undeniable that open data and data sharing can generate a lot of unintended benefits to the economic environment. However, it also carries the risk of misuse or abuse which makes many organisations hesitant and go for secure closed systems.

Public transport organisations usually have a large amount of data from different sources, quite a bit of which could be of sensitive nature. Traditionally, this data is stored in one place centrally, making it vulnerable. Blockchain systems keep the data ownership at the multiple nodes and every single use, access or alteration is recorded. Access rights can be controlled through pre-set rules, thereby significantly reducing a risk of misuse or abuse.

From a non-fare revenue generation perspective, there could also be other opportunities. Passenger crowding data of a railway platform could be useful for trackside advertising. Every panel can be tokenised and traded over a blockchain platform (akin to Bitcoin) along with crowding data. This is bound to derive higher value due to transparency and high competition for the coveted spots. The tokens can also vary in value different times of the day, or days of the week etc. Station retail rental models can also be innovated using similar approaches to maximise economic value and to build a trust-based partnership approach with vendors.

Law enforcement

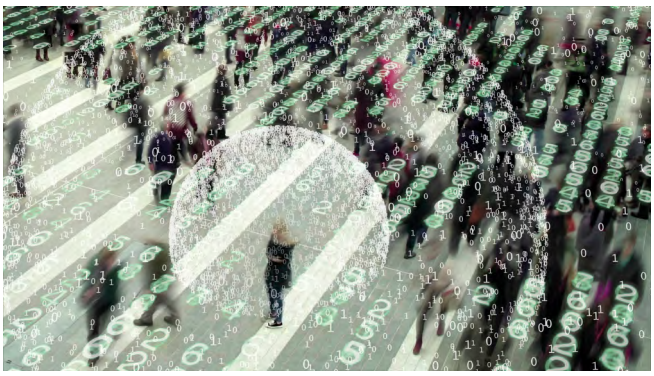
Comprehensive traffic law enforcement across the country has problems such as cross-departmental, cross-regional, and cross-professional information disconnection, low level of supervision information, and poor data timeliness and security.

Speeding up the integration of traffic law enforcement information and advancing smart law enforcement is a top priority.

Through the introduction of blockchain technology, it can promote the interconnection of various business information such as road transportation law enforcement, road administration and navigation law enforcement, maritime law enforcement, pollution prevention, and engineering quality supervision. In addition, it can also promote cross-departmental and cross-regional integrated law enforcement information data sharing. Put law enforcement procedures and records, administrative penalties, credit evaluation and other information on the chain, enhance the standardisation and transparency of law enforcement, and the timeliness and safety of supervision data throughout the transportation process vastly improves, and eases the pressure on the supervision department.

Cybersecurity

The world is waking up to the threat of hacking and cybersecurity. It is a risk that no industry can overlook or consider lightly. Transport systems that carry millions of passengers and are often the lifeline of a city or a nation could be particularly prone to such threats. A usual hack does not penetrate the system through its most strong defences but through the weakest links. Blockchain's decentralised architecture where devices or equipment do not make decisions based on a central command is particularly suited to fend off any such attacks. When any node within the DLT shows an abnormal activity or suspicious behaviour, it can be isolated and shut down, without impacting the rest of the network.



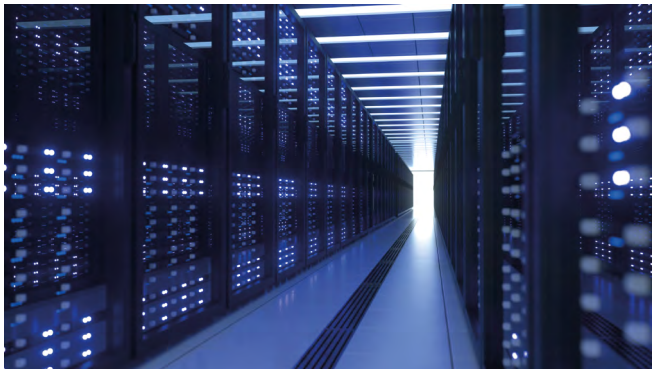
THE KEY CHALLENGES OF BLOCKCHAIN

Despite the clear advantages that DLT can bring to the public transport sector, there are limitations for the technology. **Dedicated advantages hinge around the ability of DLT to create and auto-execute smart contracts.** These advantages include the trusted revenue and data sharing within MaaS platforms, decentralised payments allowing direct links between users and service providers and the set-up of direct peer-to-peer (P2P) networks to allow decentralised mobility solutions without the need of platforms.

The main challenge is the aspect of **energy consumption.** Some blockchains consume a high amount of energy due to the algorithm they use to enhance their security blockchains which needs a huge amount of energy, mainly during the process of mining. The main reason for this is that in the process of evaluating the proof-of-work algorithm, all computers of the network are participating to the process. This is mainly true for bitcoin type systems where energy issues primarily arises for algorithmic mining of the coin. Coin exchange itself is not so energy intensive.

However, **in the case of industry applications supporting the process with so-called smart contracts, the problem does not necessarily occur.** Huge computing power is needed for cryptocurrency applications, such as financial

processes, but for IoT applications (e.g smart-contract and software for managing spare parts ordering processes, bill of lading, ticket validation, collecting and sharing traffic data), the computing power requirements do not significantly differ from non-blockchain solutions. When there is no need to mine cryptocurrencies and therefore perform complex mathematical calculations related to cryptography, the huge computing power (more than in non-blockchain applications) is not needed.

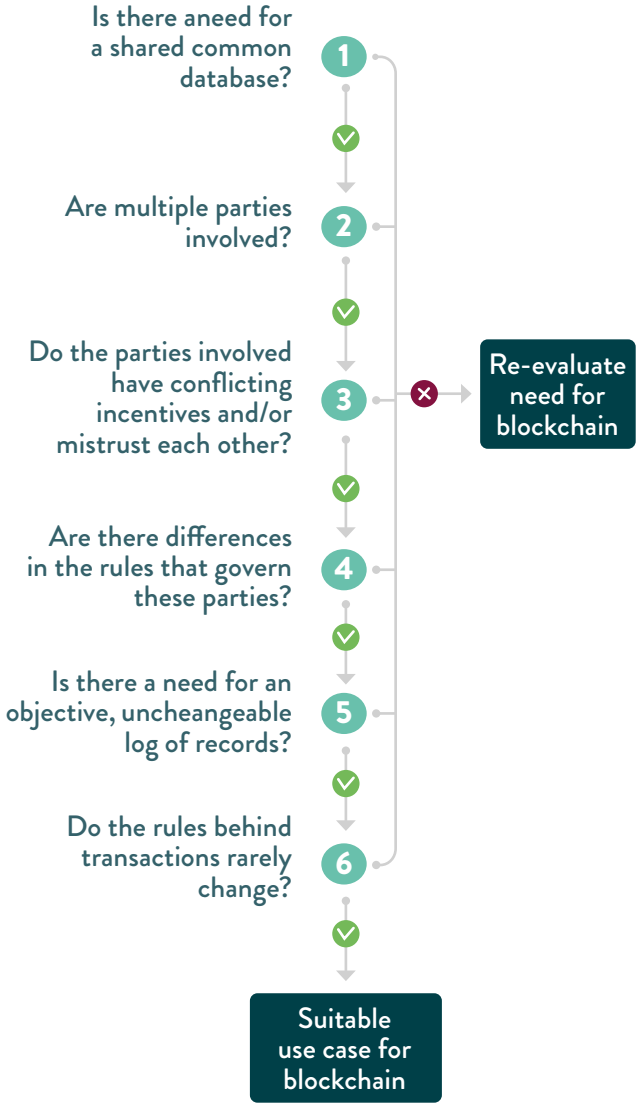


Solving the issue energy consumption is crucial for the market up take of blockchain. One very first idea could be to minimise the exchange of data where this is possible and to increase the use of off-chain transactions by positioning channels between the blockchain architecture users and permitting the transactions to be recorded. Fortunately, popular enterprise grade solutions already offer similar energy consumption outcomes to traditional centralised systems, thanks to different approaches to the consensus problem (removing the need for the mining process).

In addition, for private blockchains with limited number of participants, the energy consumption is reduced. Yet, proper specification of security requirements and means of consensus are still needed to reduce redundancy of execution/storage and excessive network usage. Still further research will be necessary to address this crucial question.

Independent of the outlined challenges DLTs might pose for upcoming projects, a decision tree has been elaborated to cross check if there is a real need for the technology adoption.

Blockchain Project Decision Tree.
Source: Accenture, 2018



CONCLUSION

Blockchain solutions have many applications in transport. Today, this technology is used in freight, logistics, the management of deliveries and purchases and in cooperation between various entities. It seems that many blockchain applications that are used in other sub-sectors of the transport sector can be easily transferred to public transport, and such transfer of solutions may also result in a synergy effect.

Generally, blockchain technology can be used in many cases, where we deal with transactions such as tickets, and cooperation of carriers, and in multi-

stakeholder environments. It is also worth noting that blockchain technology can be a component that will connect transport systems in cities with transport systems on roads and highways outside cities, e.g for better communication, transfer to public transport, park & ride. Blockchain technology can potentially be used in many public transport scenarios, where there are relationships between multiple carriers, multiple customers and with multiple third parties (in one transport system, e.g. city or region).

Still, blockchain and DLT are in the early stages. All use cases have been leveraged in a public transport context as well as any identified obstacles to overcome. Use cases have been selected where the advantages are undeniable, using a conceptual view of how these use cases can be 'reorganised' with the blockchain approach. Through the investment required at the beginning and with the support of pilot projects, the implementation of DLT in public transport will become a reality. Such knowledge of blockchain shows that, in many cases, deployed technology may fulfill tasks that could be a target for DLT.

However, there are drawbacks to blockchain and DLT technology, notably the ability to create and auto-execute smart contracts and the huge energy consumption through the mining process. Further research is being done to tackle these crucial aspects currently preventing the market take up.

More information on potential use cases for future exploration can be found in the annexe below.

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ANNEXE: POTENTIAL USE CASES FOR FUTURE EXPLORATION

- **Service Contracts:** Blockchain contracts could be utilised in low-trust public transport environments. Many service provision contracts between providers and public authorities rely on a variety of metrics to determine payment amounts. The reporting of these metrics relies on trust between the parties, and today is subject to dispute that may result in business hardship or bankruptcy and subsequent service quality reduction. Smart contracts could increase trust between parties and automate payments.
- **Mobility Data:** Cities are increasingly concerned with the recent profusion of mobility devices and services such as transportation network companies and micromobility providers. In the United States, this has resulted in the creation and increasing adoption of the Mobility Data Specification (MDS) which consists of several Application Programming Interfaces. Blockchain technology could be used to enhance the MDS and other similar systems to decentralise the collection and monitoring of mobility data. This could alleviate privacy concerns and reduce governance effort.
- **Asset Management:** Public transport vehicles are highly complex requiring routine and corrective maintenance to optimise their lifetime value. In some cases, the asset owner and maintainer may be distinct and may have conflicting goals for the vehicle maintenance programme. In this case, blockchain technology could be used to enhance Enterprise Asset Management (EAM) systems by providing a common unchangeable maintenance record to improve condition tracking, warranty operations, and overall system safety.
- **Carbon Trading:** DLT can be used for the carbon asset transactions system, which can be used by high-emission organisations to monitor their carbon footprints and meet quotas by buying carbon credits from low emitters. Energy Blockchain Labs and IBM has created a blockchain platform to trade carbon assets in China. For trading renewable energy, DLT could also be used to develop of peer-to-peer platforms. Consumers could buy, sell or exchange renewable energy assets with each other, using tokens or digital assets.
- **Decarbonisation:** In climate policy making, transparent measurement, reporting and verification of climate action is important. DLTs can make greenhouse gas emissions transparent and make it easier to track and report emission reductions, also addressing possible double counting issues.
- **Supply Chain:** Public transport systems require a large array of spare parts from several suppliers. It is quite important to be able to trace lifecycle of the critical parts. Inventory at every stage can be tagged with electronic product codes. As the inventory flows from one end of supply chain to another, the tag is recorded on the blockchain, creating a history of each item—from its source to the end usage. If a faulty product is discovered, the blockchain enables the operator and the supply chain partners to trace the product, identify all suppliers involved with it, and identify production and shipment batches associated with it.
- **Workforce Management:** Public transport systems employ a significant number of people to operate vehicles. Many transport providers use workforce management systems for the scheduling, rostering, dispatching, and pay calculation of employees. It is important for workers to comply with safety and contract rules (for example mandatory rest between work shifts) which can be highly complex. Blockchain could be used to enforce these work rules automatically while recording any deviations. Changes that take place during the operational day (delays, service changes, operator swaps) and work data (clock in/out times) could be recorded on the blockchain to ensure a single source of truth for both employees and supervisors increasing trust in the resulting pay and performance data.

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