



Department of Management

Chair of Business Modelling and Planning

Blockchain application within the
Transportation and Mobility industry: Trenitalia
S.p.A. case

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Introduction

In the new global economy, emerging technologies are currently driving the born of new business models improving the speed and quality of many services that only few years ago most of the companies couldn't even imagine. Continuous business development and innovation has become mandatory for many organizations, who have demonstrated to be able to adopt new radical and innovative solutions to bring more sustainable value to their customers. As also illuminated from the recent pandemic crisis, there is a clear link between digital preparedness and business resilience, emerging always more and more the need for companies to adopt new technologies and build strong foundations for future businesses.

The processes of digitalization, the adoption of new digital technologies for the accomplishment of consumers 'everyday tasks, is becoming increasingly popular making significant changes to the traditional systems of social and economic relations. Among technological areas such as Machine Learning, Big data, and Artificial Intelligence, Blockchain technology has the potential to disrupt business models, and the way many companies conduct business in both growing and existing industries.

Since its introduction in 2008, Blockchain technology has been the protagonist of the cryptocurrency world, and it quickly became the synonymous of it, which is right on hand because it is the technology that enables and secure cryptocurrencies' transactions, but at the same time it is much more than that. Since the first time I have heard about blockchain I was fascinated about the "more than that above" and the impact this technology might have on existing and future business models.

Therefore, the purpose of the following work is to examine and determine the adoption of Blockchain, one of the most promising new technology, to the railway where it might deliver much more value than a slight competitive edge to the industry in the next years.

Blockchain is a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network. The basic concept behind the blockchains 'success is that this technology enables users to engage transactions without knowing and trusting each other. Transactions can be anything that involve the exchange of information, from assets to property acquisition contracts. Some of the most interesting and prominent applications of blockchain technology include supply chain and logistics monitoring, secure sharing of sensible data, real estate selling operations, and much more that will be further explored.

In the following chapters, the main blockchain capabilities will be explained to show the entire decentralized ecosystem and its main features.

The first chapter aims at providing the definition of the blockchain and all the technical specifications. It will illustrate the basics of the blockchain's network and the main points of the decentralization aspects. Moreover, the chapter will introduce the smart contracts and the basic features of Ethereum, one of the most popular blockchain for the development of enterprise decentralized applications.

The second chapter investigates the impacts of blockchain on the transportation industry, highlighting the railway and how it is leveraging on new technologies to achieve new safety milestones. It is focused on blockchain solutions specifically adopted within the train, automotive, airline and trucks industry.

This industry will drastically change in the next years in response to the growing demand for high quality services, where new technologies such as blockchain will play a pivotal role.

The last chapter focuses on how Trenitalia S.p.A., the major train player in Italy can leverage on blockchain to innovate its business model focusing on two main areas: A digital ticketing platform and tracking of the maintenance operations of both the infrastructure and high-speed trains. The main objectives of this chapter are to analyze and determine whether Blockchain can support Trenitalia S.p.A. to disrupt passenger rail transportation through the development of two different use cases. The use cases have been developed in collaboration with "FST technology", the company responsible for the implementation of new technologies for Ferrovie dello Stato Italiano S.p.A. Group. The major issues affecting the high-speed Trenitalia S.p.A. passenger transportation services have been highlighted through the launch of a survey utilized as a starting point to design both the use cases. They have been finally validated and approved by "FST technology" and will be presented to Trenitalia S.p.A. as part of a "new opportunity workshop" about the adoption of new technologies in the next months.

1.The Blockchain Technology

Blockchain technology is attracting massive attention for multiple projects in different industries, even if the financial industry is seen as the protagonist of this technology due to its many inefficiencies and cost bases, the blockchain has the potential to address disruptive innovations in many other areas. One way to look at the potential economics of blockchain is as a new cryptographically secure ledger upon which can be stored and exchanged any information requiring public validation (Ex: contracts, property titles, money, physical assets, etc.). Thanks to its key characteristic as decentralization, immutability, and transparency, that will be further explored in detail, blockchain is changing how organizations share information each other and the way they engage customers with new high-quality services.

The purpose of the next chapter is to investigate how blockchain works and the implications related to the adoption of this new technology.

1.1.1Introduction to Blockchain technology

The Blockchain concept has been introduced in 2008 by Satoshi Nakamoto, an unknown person who is considered the father of Bitcoins, with an article entitled “Bitcoin: A Peer-to-Peer Electronic Cash System”. It is possible to imagine the blockchain as a protocol which enables specific properties to the applications developed on the blockchain technology. Blockchain is a digital distributed ledger, structured as a chain of blocks responsible for data storage. New blocks with more information can be added to the chain but you cannot modify or remove blocks that have been previously added to the chain. Within this ecosystem, cryptography and consensus protocols guarantees data’s security and immutability. The result is an open, neutral, and reliable system where our capability to use and trust the system is not related to someone else intention. One of the main Blockchain’s objective is to store and share information reducing risk and cutting costs for all involved parties. There are different kind of information, it might be asset’s transactions, both tangible like a house, car, land or cash and intangible like intellectual properties, patents, or copyrights. Literally anything of value can be tracked and traded on a blockchain network.

To properly understand blockchain is useful to better define what a database actually is. A database is a collection of data electronically stored on a computer system. Database’s information is usually accessible through a table format, to make it easier searching and filtering for a specific information. The difference between a simple spreadsheet to store data and a database is that the excel file is designed for one person, or a group of people to usually

store a small amount of data. In contrast, a database is designed to house larger amount of data that can be accessed by any number of users at once thanks to huge servers made of powerful computers. So, how blockchain differ from a database? The first key difference is the way the data is structured. A database stores data into tables, whereas a blockchain structures its data into blocks that are connected building a chain. Each block has a certain capacity and when it is over, are chained onto the previously filled block, building a chain of data within an irreversible timeline. In fact, when a block is filled it becomes a part of this timeline with a specific time slot when it is added to the chain (Conway, 2020).

As mentioned above blockchain is a digital distributed and shared ledger. Ledgers have been used in double – entry bookkeeping since the 15th century (Gupta, 2020). But the need to rethink the exchange of information in a shared and easy way has led to the born of distributed ledger technology, consisting of recording all information on the network where all participants can access. The shared network allows to record all transactions across the business network where the shared ledger is the only source of truth. Each network's participant has a duplicate copy of the ledger, and it is permissioned meaning that participants see only those transactions they are authorized to view unless the blockchain is permissionless.

Lastly blockchain is characterized by immutable records. Participants cannot change or modify any data once the transaction has been recorded to the shared ledger. If a transaction record includes an error or need to be modified for any reason, a new transaction must be added to reverse and modify the error and both transactions are then visible. As I will explain later on each additional block strengthens the verification of the previous block and hence the entire blockchain. This feature builds a distributed ledger of transactions the network can completely trust, excluding the possibility for malicious actors to modify or occult data shared on the blockchain.

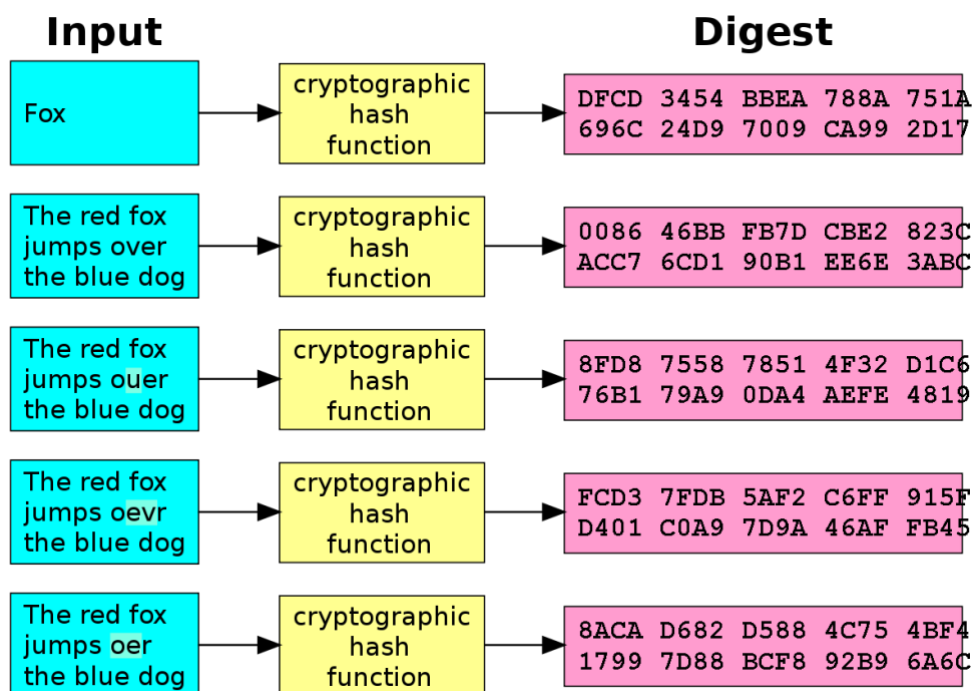
There are different actors within the blockchain environment: Blockchain users, Regulator, Blockchain developer, and Certificate authority. It might be useful to better define their roles to have a clearer idea of the Blockchain environment. Blockchain users are subjects with permissions to join the blockchain and conduct transactions with other network participants. The regulator is a blockchain user with special permissions to manage the transactions running on the network. It reserves a primary role especially within private blockchains. Regulators usually have special permissions and authority to create, manage and monitor the blockchain network. Then there are blockchain developers who create the applications that enable blockchain users to conduct transactions on the network. Finally, certificate authority who is

typically an individual who issues and manages the different types of certificates required to run a permissioned blockchain.

1.1.2 Hash's function and the blockchain security

Blockchain only contains validated transactions, and it works by including the identifier of the last block into the identifier of the following block to create a secured and immutable chain. The key to keep blockchain data manageable and secure is through an algorithm called Hashing. Hash functions are one of the most largely used cryptographic algorithms in blockchain technology and are specifically designed to protect data integrity. It is a cryptography method that converts any form of data to a unique text string. Hash 's algorithm can convert an input of letters and numbers into an encrypted output of a fixed length. Once a set of data like a transaction has been generated and filled up into a block of the chain, it will be put through a hash algorithm to convert it into set of unique text string which is contained also in the set of data that compose the next block of the chain.

Figure 1:How data are encrypted using hash



Source: Wikipedia, 2020

So, each block contains the hash's string of the previous block generated. What makes hashes unique, and a key security feature for blockchains, is that they only work one way. The same data will always produce the same hash of numbers and letters, making it impossible to reverse the process using the same numbers and letters to read the original data. If the same data always

produce the same hash's function means that if someone try to change data within the blocks it will make the network aware of these changes because the hash's code will immediately be changed. So, given a trusted hash of the data, it is possible to calculate the hash of the data and compare the two values. If they match, it means that data has not been modified since the original hash was created. The only way to find a hash collision is through a brute – force search, but the number of tentative necessary to find the solution is large enough to make a brute force search infeasible. Blockchain's digital ledger is designed to store valuable information and hash functions have several different uses within the blockchain environment (Poston, 2020). They are a vital part of digital signature algorithms used for preserving data integrity and authentication for blockchain transactions and blocks. Hash functions are vital to protect the immutability of the digital ledger. If the hash function used by a blockchain is compromised, then the attacker could find collisions for crucial hash values managing to rewrite the history of the blockchain network and cause a blockchain system to fall apart. For this reason, the security of the Hash function is essential to the security of the blockchain.

1.1.3 Blockchain and its origin

The history of Blockchain dates to the early 1990s (Iredale, 2020). The first work involving a cryptographic secured chain of blocks, where documents timestamps could not be tempered was made by Stuart Haber and W. Scott Stornetta in 1991. The next year they enable the system to collect more documents into one block. However, it is in 2008 that Blockchain technology started to gain relevance, thanks to the work of Satoshi Nakamoto who is accredited as the inventor of the Bitcoin and the technology behind it. Unfortunately, very little is known about the name of Satoshi Nakamoto, there is no evidence to prove the name is referred to a single person or a group of people. Before Satoshi cut of all communications in 2011, he was claimed to be male, Japanese, and born around 1975. However, Satoshi's usage of English was so high that it is possible to be from a native English-speaking country. Also, most of the communications occurred during European working hours, so it's supposed not to reside in Japan. Satoshi Nakamoto in his whitepaper stated that blockchain technology is an electronic peer-to-peer system of which he created the first genesis block, from which other block were mined resulting in one of the largest chains of blocks carrying different pieces of information and transactions. Nakamoto improved the technology using an innovative method to timestamp blocks without requiring them to be signed by a trusted party. The design was implemented in the 2009 by Nakamoto as a core element of the Bitcoin, where it works as the public ledger for all transactions on the network. The full capabilities of Blockchain technology were reached

thanks to the contribution of Vitalik Buterin who started working on a new blockchain that can perform different functions in addition to being a peer-to-peer network. The new public blockchain called Ethereum born out in 2013 represents a pivotal moment in Blockchain history that will be further explored next on.

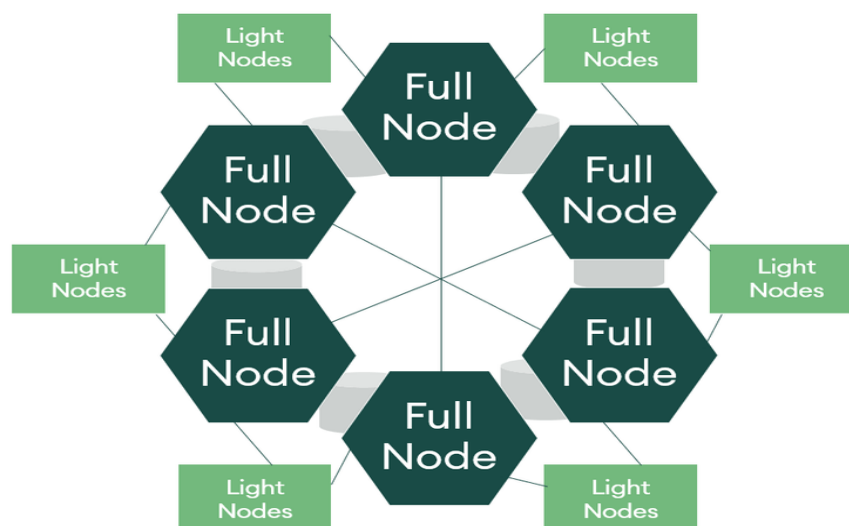
1.2Blockchain's network

One of the main Blockchain scope is to guarantee transactions from all over the world, and to do so it needs to work on a distributed network. The network can be defined as a group of connected computers that continuously exchange information each other through communication channels. A computer connected to the network is called node.

1.2.1 Blockchain's nodes

Every computer connected to the blockchain network is a node. It is possible to distinguish between Full node and Light node. The full node locally downloads and store a copy of the blockchain and check if every transaction on the network respects the rules defined by the system. If full nodes detect some anomalies the transaction would have been denied, even if it is considered valid by all network's nodes. Full nodes are completely independent, they do not need trust from other nodes and can easily block invalid transactions if they think so. Full nodes are the most secure way to interact within a blockchain environment but at the same time is also inefficient because it requires a complete download of the entire blockchain, which is around 300 gigabytes in January 2021 if we look at the Bitcoin Blockchain. Also, when making decisions full nodes are the ones that votes on proposals. If more than 51% of them don't agree with the proposition and cannot agree on a certain change two different chains might be created. The most well-known example of that happening is the Bitcoin Cash Fork (Evans, 2020). Scalability issues and "SegWit" implementation, a part of the Bitcoin 'community, decided to fork out in another direction with a new chain in the blocks and a new altcoin known as Bitcoin Cash Fork (BCH).

Figure 2: Full and light nodes representation



Source: Seba.swiss, 2021

The light node doesn't memorize the entire blockchain but only receives data it needs from a trusted node (Full node). Consequently, on one hand the light node implies a trusted third party to work but on the other hand it is easier to use. Most of users employ light nodes and do not have the possibility to independently verify the accuracy of data.

1.2.2 Network Architecture

Network Architecture is a main point in the definition of the Blockchain. There are three networks 'architecture models: centralized, decentralized and distributed. A centralized architecture is an infrastructure with a single point of failure that if compromised won't allow the entire system working correctly. To make it simpler also a car can be defined as centralized from the architecture perspective, in fact if engine stops working the car can't go on anymore. Within a decentralized architecture resources are instead distributed and possibly replied inside network's nodes. Consequently, applications are runned by all network's participants without generating any single point of failure. To make a decentralized architecture fail would be necessary to turn off all the network's nodes which for instance in the bitcoin blockchain are more than 10 000. Centralized architectures are characterized by a single decision maker authority who oversee all user's operation on the network. It owns the power to define network's rules demanding for unconditional user's trust. Blockchain has not a centralized authority which held network's control.

Finally, data on a distributed network are spread out across more than one node but the authority is always centralized. Distributed Networks work together to deliver specialized applications to different remote users. This means that an application may be hosted and executed from a single machine but accessed by many others.

Among all the blockchain's network configuration is possible to classify them into private/public blockchains, permissioned/permissionless blockchains, and consortium blockchains. Before jumping into the differences between them, it might be useful to first assess what are the shared features of a public and private blockchain. They are both distributed and decentralized over a peer-to-peer network, where each node contains a copy of the ledger. Moreover, on both blockchains records can be added but cannot be modified or delated and they are considered valid only when the majority reach the "consensus". Even though the "private" term might be considered a paradox related to blockchain purposes, private blockchain are becoming more and more popular. They are particularly promoted by

governments and companies which desire to benefit from decentralized ledger advantages (Decentralization, Validation, and Immutability). Private blockchain are so defined due to the control over the participants of the network achieved by assigning different access levels to the information or by restricting writing permissions to selected participants. This kind of Blockchain is characterized by a limited number of nodes needed to set up the network, that allow a faster and more efficient validation of transactions but also other consensus mechanism that are more convenient in terms of time and energy consumed. Lastly more advantages using a private blockchain can be identified in the free of charge transactions model which are also finalized quite instantaneously. When it comes to security, private blockchain may face more risks and other vulnerabilities having fewer nodes that makes it faster for bad actors to gain access to information. Giving permissions on the ledger to access information define the concept of permissioned and permissionless. Private blockchains are always permissioned while public ones could be both permissioned and permissionless at different levels. Most of the time public blockchains are completely permissionless like the Bitcoin or Ethereum one where anyone can join the network. There is no access limit or rights management with public permissionless blockchains and they are completely open to everyone. Public Blockchains are open and transparent, trustless, and most importantly secured because they are distributed on more nodes than the public, but at the same time they are quite slow and can easily deal with scalability issues. Finally, Consortium blockchain is a permissioned blockchain with a certain level of decentralization, in which reading permissions could be private or public. In a consortium blockchain, nodes composing the network not necessarily trust each other and the governance is not centralized, but it is distributed among the companies participating the consortium.

1.2.3 Decentralization's aspects

Decentralization is defined as the process to transfer the control and decision making from a centralized entity to a distributed network. Decentralized networks reduce the level of trust that participants must place in one another and deter their intention to exert authority or control over one another compromising the correct functionality of the network. The management and access to resources in a blockchain application are usually decentralized achieving a greater and fairer service. Decentralization typically has some tradeoffs such as lower transaction timing, but ideally, tradeoffs are worth the quality of service they produce (Amazon, 2021). The first benefit of a decentralized network to mention is the trustless environment it produces. In a decentralized blockchain network, no one has to know or trust anyone else. Each member

in the network has its own copy of data in the form of a distributed ledger. If a member's ledger is altered, it will be rejected by most of the members in the network. Decentralization also improves data reconciliation and real time access to all network's interested users. When data are exchanged within an organization and stored in each party's data silos they might be altered and transformed in an incorrect way. By having a decentralized data store, every stakeholder has access to a real time and shared format of data. Through Decentralization is possible to reduce points of weakness in systems where some actors like full nodes play a primary role within the network. These weak points could be exposed to systematic failure and risks which are covered thanks to the presence of a multitude of other players that can ensure the correct network functionalities. Lastly, decentralization could optimize the distribution of resources to provide services with better performance and consistency.

1.2.4 Consensus algorithm

Blockchain, as mentioned above, is a distributed decentralized network that provides immutability, privacy, transparency, and security. There is no central authority to validate and verify transactions, yet every transaction in the blockchain is considered secured and verified. This is possible thanks to the presence of the consensus protocol which is a core part of any Blockchain network. Consensus algorithm aims at finding a common agreement that is acceptable for the entire network. Various consensus algorithms and their functioning will be discussed below. The proof of work (PoW) consensus algorithm is used to select a miner for the next block to be added. Bitcoin blockchain uses PoW consensus algorithm and the central idea behind the algorithm is to solve a complex mathematical problem, which requires a lot of computational power to win the possibility of mining the next block in the chain. When a miner finds the solution, the node broadcast it to the whole network receiving a cryptocurrency reward provided by the PoW protocol. The most common alternative to PoW is the Proof of stake adopted by blockchain like Ethereum. Instead of investing in expensive hardware to solve complex mathematical problems, validators invest in the coins of the chain by locking up some of their coins as stake. Validators will validate blocks by placing a bet on it if they discover a block which they think can be added to the chain. A validator is chosen to generate a new block based on their economic stake in the network. Thus, PoS encourages validators through an incentive mechanism to reach an agreement. While PoW rewards miners for solving complex equations, in proof of stake the individual that creates the next block is based on how much they have "staked". So, to summarize Proof of Work requires all of its miners to attempt to solve a complex mathematical equation and the winner is determined by the person who has

the most powerful computers. Proof of stake model randomly chooses the winner based on the amount they have staked. Comparing the PoW and PoS that are the most frequently consensus algorithms used, the first one seems to be not so fair because it gives people and organization who purchase more powerful hardware devices a greater chance of winning the mining reward. The proof of work also uses a larger amount of electricity due to the hardware functioning while the Proof of stake does not need highly complex problems to be solved, meaning that the electricity costs to verify transactions are substantially lower (Patel, 2020).

1.3 Smart Contract

The term smart contract has been used over the years to describe a variety of different things. Back in 1994, Nick Szabo, a computer scientist, coined the term “smart contract” and defined it as: “A computerized transaction protocol that executes the terms of a contract” (Yano et al 2020). Nick Szabo conceived the smart contract as a set of promises in digital form, including protocols within which the parties perform on the other promises. Since then, the concept of smart contract has evolved to describe a computer code that automatically executes parts of an agreement and is stored on a blockchain based platform. There are different blockchain which support smart contracts, but the industry is currently dominated by the Ethereum one.

1.3.1 Introduction to Ethereum

Before going deeper with smart contract technology an introduction to Ethereum is needed to better assess its applications. “Ethereum is an open-source public service that uses blockchain technology to facilitate smart contracts and cryptocurrency trading securely without a third party” (M. Yano et al, 2020). Ethereum was conceived when people started recognizing the power of Bitcoin model and were studying different applications of the technology behind the cryptocurrency. Vitalik Buterin, Ethereum’s co-founder, was introduced and intrigued by blockchain technology when he got involved in Bitcoin as a young programmer, and started to imagine a platform that could go beyond the financial use cases and released a paper back to 2013 about a platform’s ability to trade more than just cryptocurrency. Ethereum’s purpose was clear since the beginning: building a blockchain that could support a broad variety of applications by being programmed (M. Yano et al, 2020). The idea was that by using a general and open blockchain platform, developers could have the possibility to program their application without having to implement the underlying and complex mechanism of peer-to-peer networks.

In 2014 Buterin with other co-founders of Ethereum launched a crowdsourcing campaign where they raised more than \$18 million (M. Yano et al, 2020). The first live release of Ethereum known as Frontier was launched in 2015 growing rapidly and counting today hundreds of developers involved. Ethereum shares many common elements with other open blockchain like a peer-to-peer network, a consensus algorithm for synchronization of state updates, the use of digital signatures and hashes, and a digital currency called ether, even if it is mainly intended as a utility currency to pay for use of the Ethereum platform.

Even if Ethereum and Blockchain share many common features they have two different purposes. Ethereum built its platform on blockchain technology to enable users of building applications without rigid regulations guaranteeing high security standards. Bitcoin, on the other hand, is built on blockchain technology to introduce a new and trustless global currency system with lower transaction fees. To accomplish their goal, Bitcoin's blockchain completely decentralizes the cryptocurrency by requiring a network of millions of miners to validate transactions. But this validation process makes Bitcoin much slower at confirming transactions than Ethereum, that has only a thousand of computers or nodes validating activities on the platform. Ethereum's average block mining time is only 12 seconds compared to Bitcoin's average of ten minutes. Unlike bitcoin, which has a very limited scripting language constrained to simple true/false evaluation of spending conditions, Ethereum blockchain runs a virtual machine capable of executing code of arbitrary and unbounded complexity. The Ethereum virtual machine is essential to the consensus engine of the Ethereum system. It allows any developer to execute code in a trustless ecosystem in which the outcome can be guaranteed. For every application built on the Ethereum virtual machine, a system that tracks the execution cost assigns to the instruction received a cost in Gas units. Gas is a mechanism that Ethereum uses as the platform's internal pricing fee for running a transaction or a contract. When referring to Gas, users can mean either Gas limit or Gas price. The gas limit is the amount of computing work needed to develop something on the Ethereum network. The gas price is instead how much a user has to pay for the amount of work to be done. Combining both Gas limit and price determines the total transaction fee which needs to be paid in Ether. When users want to initiate an execution, they have to pay in Ether the gas cost.

1.3.2 How smart contracts work

As mentioned above smart contracts can enforce certain types of agreements between parties that is why they are defined contracts, but at the same time are also smart because they can execute themselves without the need for lawyers or people to be involved. Smart contracts may

or may not have legal implications and still needs a traditional legal framework as discussed further below if used as part of a legal transaction. Smart contracts can be the sole manifestation of the agreement between the parties or might execute certain actions such as transferring funds from party A to party B. They are best suited for two types of transactions: ensuring the payments of money if certain events occur or imposing financial penalties if certain objective conditions are not satisfied. Smart contracts need to have certain characteristics to be defined as truly smart contracts (Levi et al, 2018). These characteristics are observability, verifiability, and privacy. Observability means that contract's parties should be able to observe each other's performance of the contract's terms or at least to be able to prove the fulfilment of their own terms to the other party. To evaluate each party's performance, it must be possible to verify that a contract has been performed. Privacy refers to the connection between parties to a particular transaction. It is the principle that knowledge and control over data of a contract should only be distributed among parties involved along the performance period.

The smart contract code is replicated across multiple nodes of a blockchain and therefore benefits from the security, permanence, and immutability of a blockchain network. Most Smart contracts are written in programming languages such as Solidity. Solidity is a language explicitly created for writing smart contracts in order to support their execution in the decentralized Ethereum environment. The main feature of solidity is to convert programs written in the solidity language to Ethereum virtual machine bytecode. Solidity also manages the standard binary interface for Ethereum smart contracts.

The input parameters and the execution steps for smart contract need to be specific and objective. When the contractual parties determine and finalize the contractual terms are translated into programming code using the solidity language. The code represents several different conditional statements that describe the possible scenarios of a future transactions. Once created the code is stored in the blockchain network and replicated among the blockchain's nodes. Then, the code is run and executed by all computers in the network. If a term of the contract is satisfied and verified by the network, then the relevant transaction is executed (Corporate finance, 2020).

Smart contracts present many advantages compared to traditional paper-based agreements. They can involve multiple parties who do not trust each other completely because the fulfillment and monitoring of contracts is completely automatic making trust unnecessary. Smart contracts eliminate the need for a third party such as lawyers, agents, and notaries: Contracts are monitored, and performed without human interactions and rights of the contracting parties can be enforced automatically. Since intermediaries are no longer needed,

the usually high fees they charge are eliminated. In addition, smart contracts can save a lot of time normally spent manually processing paper documents. Smart contracts are protected by complex cryptographic encryption, and no one can steal or lose documents because they are stored in a secure, decentralized ledger. Smart contracts hold tremendous power, but they do have limitations and disadvantages in different real-life scenarios. For example, since smart contracts are scripted as piece of codes, once set up, they cannot be modified easily. Unfortunately, especially long-term contracts need to be modified with amendment according to real life dynamics which keeps conditions continuously change (Nzuva, 2019).

1.3.3 Non – fungible tokens

Non fungible tokens have become quite popular out of the last year. From art to music, these digital assets have been sold for millions of dollars around the world. But before jumping into NFT markets, it is necessary to better define what a token is and represent. A token is a unit of value that represents an asset or utility in digital form, they are issued by a private entity, and stored on a blockchain. Tokens can be programmed to serve many different functions, but there are two main types of tokens: Security tokens and Utility Tokens. Security tokens represent a real word or financial security in a digitalized form with the same rights and function. A security token might be for instance a company's share including its voting rights. As security tokens represent securities they are usually regulated according to strict securities laws and regulations. Utility tokens represent the right to a specific functionality within a closed blockchain based ecosystem. Utility tokens can for instance work as tickets to access theaters, or as a coupon that can be exchanged with some services. The owner may use it at a specific time and location but cannot be used to pay something else and their use case is limited to a particular function. As utility tokens do not represent an investment vehicle, they are usually not regulated by securities laws. Tokens can be also differentiated in terms of fungibility or non-fungibility. The term fungible refers to the interchangeability of items during exchanges. Fungible tokens can be easily swapped between two parties without experiencing any gain or loss. Cryptocurrencies for example, are fungible tokens since one bitcoin is always equal to another bitcoin and they can also be divided into smaller units without affecting their value. Non fungible tokens cannot be replaced with another non fungible token of a similar type, they are unique with distinctive properties that make them hard to exchange (Bal, Ner 2019). The possibility to represent something with unique attributes makes non fungible tokens quite special, in fact they usually represent ownership of unique items, that can be owned by a single and identified owner. Non fungible tokens can be used for digital assets that need to be

differentiated from each other in order to prove their value. They can represent everything from artworks to ownership of house and are not traded on standard cryptocurrencies exchanges but on digital marketplaces. Scarcity is one of the most interesting not fungible tokens 's features, since the creator of an NFT has to decide the scarcity of its asset. Consequently, the creator can arbitrary decide how many asset's copies can exist. This stands in contrast to most digital creations, which are always infinite in supply. For example, an artist might decide how many artwork's replicas to sell, promoting the authenticity and ownership of the NFT and also pretending royalties every time the artwork is sold. Through blockchain technology artists no longer have to rely on galleries or auction houses to sell their work. Instead, they can sell it directly to the consumer as an NFT. Non fungible assets have a wide variety of use cases in present times where holding and restricting rights of individuals on specific assets, ensuring exclusivity for the owner, with built-in authentication, seems to be a modern priority (Geroni, 2021).

1.3.4 Decentralized Finance

The term Decentralized finance (DeFi) refers to an alternative financial infrastructure built on the blockchain, that has recently gained a lot of traction. In finance, intermediaries often play essential roles in expanding transaction possibilities and establishing trust between each party. Financial institutions have played essential roles for a long time in establishing connections and enforce agreements, but nowadays financial technology has started to take up some roles traditionally played exclusively by these institutions. Blockchain technology is empowering a new paradigm based on decentralization and disintermediation. It can increase the efficiency of peer-to-peer transactions, enabling a new innovative, borderless, and transparent financial environment. Through decentralization and disintermediation, blockchain produce distributed trust, reducing the costs associated with search or contracting by connecting peers directly to peers. As key intermediaries, financial institutions can grow to dominate economic activities, accumulating a lot of market power and profits. In a decentralized financial system, in contrast, by reducing the involvement of central institutions, it is possible to reduce transaction costs and create large network effects. Decentralized finance can enhance interoperability. In traditional finance, institutions have to maintain their own ledgers, and moving capital across different ledgers can be really costly. In contrast, DeFi is built on public blockchain where financial capital and value can be moved seamlessly across different borders, creating an "internet of value" (Chen, 2020). Innovators are exploring different options to reach full interoperability. The main option is to encourage the emergence of one dominant platform,

currently Ethereum is the most used for decentralized finance, and all Ethereum based projects have high interoperability. Decentralized payment networks are one of the most promising DeFi based business models. They promise to bring low – cost, instant, and global payments methods, enabling business models that are not viable today like micropayments, in feasible and profitable opportunities (Chen, 2020). Contracts are essential to regulate and facilitate collaborations within financial transactions, and they can be quite complicated and costly due to the drafting and renegotiating practices. Traditionally, parties rely on financial intermediaries to establish trust and reduce transaction costs. Blockchain technology has started facilitating financial contracting with smart contracts, enabling the so-called peer to peer financial contracting.

Unfortunately, decentralized finance has not reached its full potential yet. Volatility, usability, and regulatory uncertainty are the main challenges to overcome in order to facilitate a largely adoption of DeFi practices. So, to succeed, DeFi needs to cultivate a healthy ecosystem that encourages innovation, and to build a network based on a reliable and stable cryptocurrency.

2.Blockchain within the railway and transportation industry

The aim of the following chapter is to review blockchain applications within the transportation industry, highlighting the railway sector and introducing how the train industry is currently innovating by leveraging on new technologies. Shipping goods and people transportation are a significant part of the economy in each country, and the key to success in the transportation economy is offering the most efficient and flexible services (Stfalcon, 2021). With growing competition in the industry always more and more companies are already deploying new technologies to improve the quality of their services. Therefore, transportation companies will have to manage and understand new technological trends to maintain a competitive edge on the market.

The Blockchain is undoubtedly one of the most disruptive technologies of the modern times, and since its birth, it has been gathering a lot of attention across the transportation industry. While it is a complex technology that is still growing and evolving, it is clear how its design core pillars (decentralization, immutability, and trustlessness) can bring value to many businesses. Blockchain's considerable versatility reflects the various ways in which the technology's core properties can be utilized across different use cases among the transportation industry.

2.1 Overview of blockchain applications within different transportation industries

The transportation industry has experienced a long history of changes and innovations practices. Nowadays, profound implications of security and transparency of the digital age are requiring always more and more organizations to adopt and implement new technologies. Moreover, transportation companies are investing in digitization for faster supply chain operations and are embracing automation to increase connectivity and collaboration with clients (IBM,2020).

Blockchain is a natural fit for fragmented industries such as transportation, in which coordination between multiple and independent parties is essential. It has the potential to overcome some of the most persistent industry's challenges. For example, the possibility to access key transaction information in a private and secured way could easily allow transportation companies to gather data and insights of sensible parts of their businesses. Moreover, digitalizing important assets or data such as contracts or shipment papers and

uploading them on the blockchain would eliminate the need for unnecessary paperwork. A streamline digitalized process will guarantee a faster access to information for the parties joining the network, while at the same time preventing fraudulent activities and increasing trust. Finally, blockchain will increase the efficiency of the industry interactions through more smoothly relations among suppliers, freight, consumers, and the company itself. Accessing the same database with the same information can improve dispute resolution and spread a sense of transparency among industry players.

2.1.1 Blockchain in the automotive industry

The future automotive market will be quite different from that of today. It will need to offer more personalized services and integrated offer oriented including services like autonomous, shared and connected cars. Blockchain use cases can be grouped into three areas: Verification and process improvements, Vehicles management and lastly finance incentives, payment, and insurance operations. Across the automotive value chain, the blockchain enables the verification of different processes from the identity of suppliers to the quality and status of vehicle parts. A blockchain solution can verify supplier details, providing services to automotive organizations and verified supplier, and then data can be stored on the chain to support supplier performance into future contractual agreements. Blockchain can be used also to trace the provenance of spare parts enabling customers, service center and car manufacturer having more trusted information about spare parts. Thanks to Blockchain technology is finally possible to create a connected supply chain to offer an end-to-end solution in order to enable automotive players to manage tracking, payment, and documentation actions on a single platform. Blockchain enables car manufacturer to easily identify vehicles with defective parts and therefore issue specific recalls with lower transaction costs, managing to track the status of each recall.

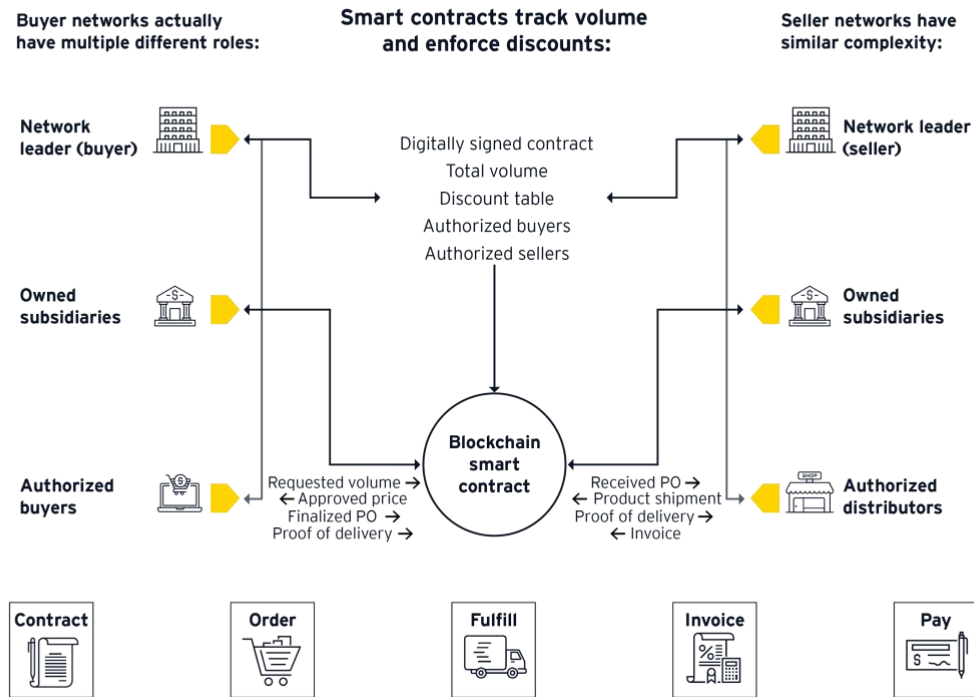
Among the most largely adopted vehicles management and incentives use cases, blockchain based solutions have been currently used to record dealer and customer purchases issuing loyalty points to be redeemed and used as a currency to purchase vehicle parts (Lawson, 2018). Vehicle data can be securely stored, updated, and shared across OEMs and with external parties using Blockchain. Shared vehicle data could include car's maintenance or ownership information enabling OEMs or other interested authorized parties to check vehicle history. The proof of vehicle mileage data is guaranteed on a regular basis accessing a blockchain digital

car logbook. Connecting the vehicle to the blockchain through IoT sensors, car owners can obtain a validated proof that certifies car's mileage and other detailed information.

Moving to finance, payments, and insurance use cases, blockchain based solutions on smart contracts enable insurance firms to offer personalized vehicle insurance contracts. They are based on drivers' behaviors and feature fully automating payments options following insurance claims.

EY, the global consulting services company, has developed a blockchain powered platform to support new mobility business, in order to enable an easy management of services related to vehicles. EY's mission is to support players across the automotive and mobility value chain to address the following challenges: 1) Management of shared mobility assets such as carsharing fleets, charging infrastructure and shared commercial vehicles. 2) Seamless integration of data and payments among different players. 3) Establishing a mutually beneficial model and creating trust between different parties. The EY Ops Chain Tesseract blockchain platform is so designed to support integrated operations for vehicles, fleets, and other transport services. It might be defined one of the first solution, powered by a blockchain based platform, to manage a fractioned and shared mobility asset. The platform has been designed for Original Equipment Manufacturers (OEMs) that provide a fleet of cars, with fractional ownership for users. Owners can make use of any car belonging to the fleet, without spending the entire cost, and OEM get profit shares depending on ownership percentage. Vehicles and trips data are digitally stored and secured on the chain, and transaction are automatically executed through smart contracts between operators, owners, and third-party service providers. The participants of the platform are multiple stakeholders: OEMs, car owners, mobility and transport companies, and infrastructure providers (EY,2020). The EY Ops Chain Tesseract finally delivers a lot of value to the industry enabling peer-to-peer interactions between owners and users, offering a reliable solution to sell the shares of cars, and recording on an immutable register all the usage payments.

Figure 3: Example of EY Tesseract Ops chain



Source: ey.com, 2021

Another interesting case study and validated solution of blockchain based platform applied to the automotive industry come from the BMW Group, one of the largest European car manufacturers. The company has developed a blockchain based platform, to ensure the traceability and transparency of components and raw materials in multi-stage international supply chains. BMW's supply chain is highly complex, involving many players at different delivery stages (BMW Group, 2020). A lot of effort is needed to clearly track a component's origin or supply route, because each supplier partner must manually insert and share data within its private IT systems, which are not always able to communicate consistently with one another. Therefore, for the BMW group's purchasing experts was quite difficult and time consuming to ensure transparency of their supply chain operations. So, the company launched a blockchain based platform, called "PartChain", to ensure seamless traceability of components and to provide immediate supply chain data transparency for all BMW partners. Long term vision and objective of the platform is to ensure not only a verifiable collection of component's origins, but also to enable complete traceability of critical raw materials from mine to smelter. Moreover, to leverage the full potential of an open blockchain based platform, the BMW group co-founded the Mobility Open Blockchain initiative (MOBI). It is a cross industry organization

comprising 120 leading technology, automotive, and mobility companies focused on solving supply chain issues through the Blockchain creating a common standard model.

Blockchain, as a secure and unique form of encryption, has the potential to disrupt the automotive industry contributing to the new era of smart vehicles, revolutionizing the role of data in the vehicles of the future. It will deliver to stakeholders a faster and more efficient operation service, and mainly more safety and convenience (cost saving) for drivers.

2.1.2 Airlines Blockchain based solutions

Leading airlines are experimenting with new digital technologies, such as advanced analytics, IoT and artificial intelligence. More recently blockchain promises to resolve issues of security, trust, and transparency with its ability to manage and safely share data. Airline industry is characterized by a complex ecosystem of players that airline companies must deal with. These include customers, travel agencies, airports, public authorities, suppliers, and service providers resulting in a very fragmented ecosystem, which makes quite challenging any kind of communication. Data security, the need of sharing them among multiple parties, and the required presence of intermediaries make the airline industry the perfect spot to develop blockchain based solutions (Bouffault et al, 2019).

Smart contracts to automate repetitive processes and payments is generating strong interest in the industry. A wide range of billing transactions can be automatized using smart contracts including billing between airlines and travel agencies, authority taxes, travel insurances and so on.

Most airline companies are developing blockchain based solutions to manage loyalty programs between their partners. Accounting for miles and points when passengers use different partner airlines can be difficult and time consuming. Therefore, smart contracts can easily automate the process minimizing the risk of error and increasing customer satisfaction making their rewards ready almost immediately (Bouffault et al, 2019).

Airlines companies are highly dependent to third parties when selling tickets, and therefore are forced to charge substantial fees. By reducing third parties' costs blockchain based platform will allow consumers to access and issue tickets directly from airlines. As for the automotive industry, blockchain provides transparency throughout the value chain recording sources of all airplane components ensuring a high level and secured predictive maintenance.

Health and safety in the airline industry are primary concerns and the combination of blockchain with other technologies such as IoT and robotics can seriously improve quality assurance throughout the entire supply chain covering a wider range of blockchain use cases.

One of the most promising blockchain work applied to the aviation industry comes from a company called "Aeron". Aeron is one of the first blockchain exclusively built for Aviation Safety. Their core business is to provide certified and secured Pilot's flight logs data, to boost security when hiring licensed private pilots or dealing with aircraft owners. The company stated that: "accidents related to air transport average to about 3302 yearly, mainly due to human

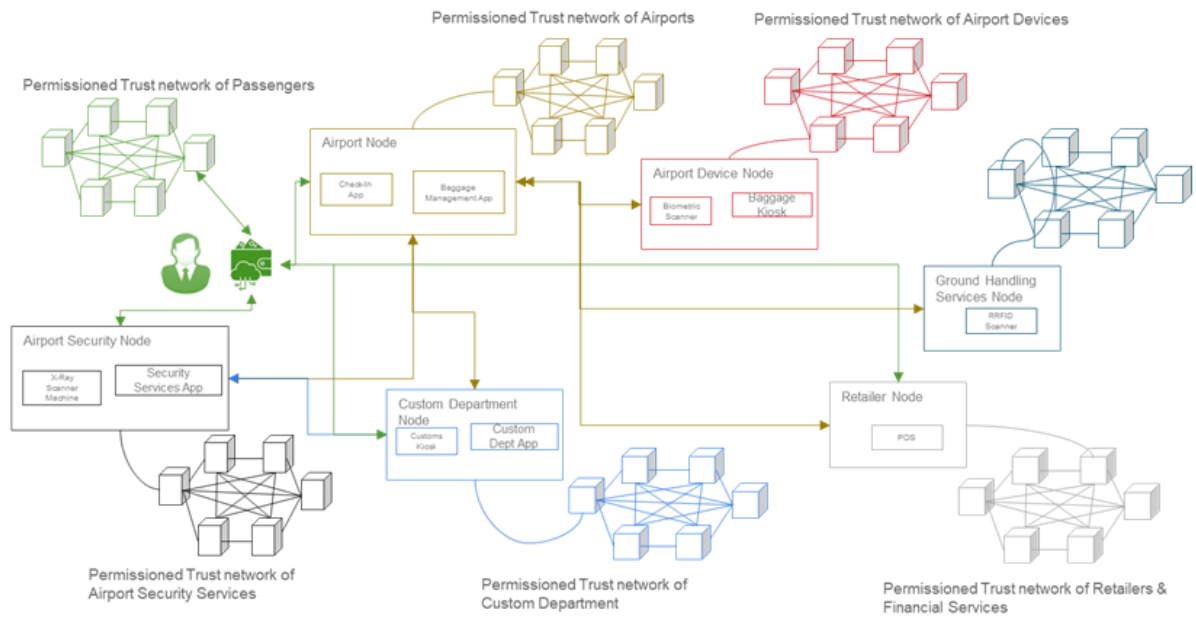
factor” (Aeron,2020). The key problems are that: 1) Pilots may lack experience, with corrupted flight schools that help pilots put in false hours on paper. 2) Aircraft operators often underreport the flight hours to save maintenance costs for the aircraft. 3) Database intrusion resulting in modification or distortion of data. The Aeron solution is simple. The pilot before a flight must complete an application format for personal flight logging, which is stored and secured on the Aeron Blockchain. The company automatically verify application data from aircraft operators, maintenance organizations, and flight schools’ operators. In case of any mismatch in data between the Aeron data sources with either the Pilot logbook, Air traffic control, or maintenance operators, the aviation authorities can quickly identify and detect the problem (Aeron,2020).

Aeron is currently working with national aviation authorities and international aviation agencies, to promote the acceptance of digital log records based on blockchain. The Aeron blockchain based platform enable integrity, reliability and transparency of record keeping, replacing an obsolete and unsafe log paper records. Moreover, the company has introduced its Ethereum compliant based token, with an initial supply of 20Mln units. The Aeron utility tokens were originally created to support and fund the development and marketing of the Aeron project with associated distributed database, online portal, and applications.

To conclude, Aeron connects different entities (Pilots, aviation companies, airlines, aircraft operators, flight schools, maintenance operators and many other businesses involved in the network) bringing a lot of value to the industry through a more transparent relationship between aviation businesses and a high level of security.

Not only airline companies but also airports are looking to adopt advanced blockchain solutions to improve the passenger experience and streamline operations. One of the most common use cases for airports blockchain solutions consists in the optimization of the identification processes. Usually, there are multiple decentralized systems and identity validation check point that each passenger must interact with when moving around the airport. A blockchain based solution would enable a decentralized identity management solution by setting multiple trust networks points, that will share the required amount of passenger’s identity information, while ensuring privacy requirements. Passengers’ identity information flow through these networks as decentralized identifiers-based proofs, disclosing information only to specific user’s network and validation points (Wipro, 2019). Passengers would only need to share identity proofs in the form of a digitalized document to confirm his eligibility to travel, significantly reducing the time needed to check each passenger’s document.

Figure 4: Blockchain airports passenger validation infrastructure architecture



Source: Wipro, 2019

2.1.3 The future of truck transportation

Blockchain provides one potential solution to the truck's industry need for traceability and transparency. Building a frictionless network for document transactions, shipment tracking and fleet management are the main points to be assessed with a blockchain based solution. Data stored and shared on the blockchain give everyone in the supply chain comprehensive tracking capabilities. Every time shipments reach a destination; data are recorded into a block creating a permanent digital history of the shipment phases from the original source through the final leg of the journey. Using IoT sensors blockchain can give customers, shippers and carriers detailed insights into vehicle and asset location. Fleet owners and customers can benefit of a more transparent and clear flow of information since shipment logs cannot be manipulated or altered once they are uploaded to the chain. Companies can also use this information to provide proof of legitimacy for any shipment, creating one version of the truth accessible to all the parties involved.

Blockchain combined with IoT technology can be particularly disruptive also for capacity monitoring (Winnesota Transportation, 2019). The adoption of IoT sensors will enable shippers and transportation companies to determine the exactly amount of space taken up in a shipment, defining costs accordingly to the precise volume used. Blockchain can also helping as in the automotive industry to create an accurate record of vehicle maintenance and history. Smart contracts can generate great value to the truck transportation industry for self-executing tasks, when certain conditions are met. They can enable the payment to a shipper only when the item reaches its destination under predetermined constraints and if they are not met the shipment company might offer discount policies. Currently, most of the industries' companies rely on paper-based work to process payments, and by adopting a blockchain based solution the efficiency of daily operations will much more increase. Everything from documentation storage to shipments management will be fully digitalized and automized, minimizing human errors and trustless related issues.

DexFreight is one of the first decentralized logistics platform powered by blockchain. The platform enables an ecosystem of open-source protocols, blockchain and machine learning to allow shippers and carriers to directly connect, negotiate and schedule pickup and delivery operations. The logistics industry is full of inefficiencies caused by data fragmentation, manual processes and further impacted by fraud and thefts. The DexFreight platform leveraging on blockchain highly secured standards, offers immutable identity and reputation, real time peer-to-peer interaction, and finally automated load and capacity matching. The company uses smart

contracts to transfer value and assets between platform's participants, delivering transparency and accountability based on-time key performance indicators such as pick-up and delivery efficiency, loading and unloading times, on-time payments, and freight claims. This data availability enables carriers, shippers, and third parties to lower associated liability risks. Each actor and member of DexFreight has to upload on the platform personal profile data, relevant documentation, licensing, insurances, performance records, and everything is automatically qualified based on unique business requirements. The system will issue alerts, or even preventing transactions when it finds documentation mismatching and qualifications drop below designated values (DexFreight, 2018).

The most relevant organization active on a mission to develop blockchain based solution in the transportation industry is the Blockchain in Transport Alliance (BiTA). BiTA is a member driven organization, with nearly 500 members in over 25 countries, from the freight, transportation, logistics and affiliated industries (BiTA,2020). The organization accomplish to develop industry standards, educating members and others on blockchain themes and distributed ledger technology with the aim to encourage the use and adoption of this new solutions. As mentioned above, building a common blockchain solution standard for the industry is strategically crucial to enable a wide and smoothly adoption of blockchain technology. Therefore, BiTA members are leading the effort to develop a common framework and standards from which transportations industry players can build and benefit revolutionary blockchain and distributed ledger technology applications.

2.2 How the railway industry is leveraging on blockchain and new technologies to improve services and operations.

Rail Transportation will drastically change in response to the growing demand for fast transportation between cities and countries, which will lead to significant changes in the way of conceiving travelling by train. Such growth is sustained by both social and economic progress, but it is also the result of a cleaner energy demand given the increased CO2 emissions levels and atmospheric pollution (Iea, 2019). A greater reliance on rail has the potential to challenge these issues, in a world becoming more urbanized than ever railways are well matched to urban needs and citizens expectations. High speed rail can work as an alternative to short-distance air travel, and freight rails can serve other transport modes to provide efficient mobility. Therefore, to be ready for the next future, railway companies need to leverage on new technologies to satisfy customer's expectations and achieve higher safety milestones while minimizing their impact on the environment.

As the industry push ahead with new forms of innovation, always more and more startups are entering the market offering innovative solutions, establishing themselves as the new suppliers of the railway industry (Smith, 2019). Notoriously slow to implement new technologies, rail companies are leveraging on startups to scale new solutions in order to achieve an extremely faster time to market. Major rail industry trends involve Internet of things (IoT), Artificial Intelligence or Big Data, which require high professional skills not always owned by train or railway infrastructures companies, so they need to leverage on open innovation practices to surf this new trend in order to generate value and impact for final customers.

According to the StartUs insights report (StartUs insights, 2021) there are 10 macro technological trends that are currently shaping the future of rail Industry: Autonomous Trains, Internet of Things, Artificial Intelligence, Decarbonization, Rail connectivity, Passenger experience, High speed Rail, Rail Automation, Big Data & Analytics, Augmented & Virtual Reality.

- Autonomous trains are an effective solution to improve punctuality, reliability, and safety, which are some of the major issues that have affected for a long time the railway industry. This technology is powered by advanced sensors and real time data transmission to improve traffic information flows while reducing technical errors. Driverless train promise better on time performance, smoother traffic and lower energy consumption reinforcing passenger confidence in rail efficiency.

- The reliability and safety of railway infrastructure has been strengthened also by the adoption of IoT to monitor and prevent train part failures and to optimize maintenance efficiency and costs, improving at the same time passenger's satisfaction. IoT technology will enable companies to conduct safety inspections more frequently and responding more quickly to technical issues. Perpetum, a UK based company part of the Hitachi Rail group, has developed an IoT condition monitoring system to monitor vehicle health. Their sensors can detect on-board vibrations and analyze real time information regarding the condition of critical train parts (CBInsights, 2020).
- AI has been used in rail applications to improve train scheduling by analyzing data in order to predict and reduce delays, to manage train speeds and also for predictive maintenance. As a consequence, AI help rail companies to ensure safety and enhance customer's satisfaction. Tokyo's Railways Research Institute and the Swiss Federal Railways are developing a deep reinforcement learning and a neural network to optimize train scheduling and reduce delays. The AI system allow operator to shorten decision times, providing adequate and reliable information when needed to schedule in time train routes. AI has a biggest impact also in improving customer service operations. For instance, East Japan Railway company and the MTR Corporation and Transport for London are using AI-powered digital assistants to better manage customer inquiries (Global railway review, 2020).
- Although trains are one of the most sustainable way of travelling, governments are looking to further decarbonize the rail industry. Decarbonization of transport is part of the European Union's Green Deal, to reduce CO2 emissions of 50% by 2030. Battery or Hydrogen fuel cells are going to be the most common decarbonization solutions so far adopted to replace diesel powered trains.
- Modern trains are always more and more connected, communication-based train control enhanced with 5G technologies enables an efficient rail traffic management and asset monitoring. 5G offers significant improvements to latency, power consumption, and data transfers, making it ideally suited to connect IoT and onboard devices. Tethir, a British Startup, has developed a vehicle-to-vehicle connectivity solution enhanced by 5G technology. The device, powered by solar batteries, provides high bandwidth communication capabilities at low power demand.
- To improve on board Passenger Experience, rail companies are currently employing automatic ticketing, video surveillance and setting up customized passenger service.

Video surveillance helps detecting theft and optimizing passenger load. Onboarding operations are further improved by app last minute booking, biometric identification control and infotainment systems to engage passengers during travel.

- Nowadays many countries have their own high speed rail systems that are aimed at making the transportation of people and good as more efficient as possible. In this manner, trains might be preferable to other modes of transportation also on long distances. Magnetic rail systems can reach speeds up to 550 Km/h. The train uses passive magnetic levitation and linear motor technology to reach these speeds and improve the overall train efficiency and customer experience.
- Automation of the railway industry goes beyond autonomous train operations described above, it consists of developing robotic systems for infrastructure cleaning and maintenance. Drones, combined with 3D computer models and virtual reality, will completely automatize infrastructure maintenance operations on inaccessible areas, improving the safety of all rail infrastructures. TerraDrone, an Australian company, has developed a drone-based technology to execute topographic and volumetric surveys, and 3D design models at high speed. The company has successfully conducted several railway bridge inspections of critical public infrastructure.
- Big Data & Analytics have been employed to improve train communication, passenger information systems and asset management. By adopting IoT sensors, many data points are gathered and analyzed to further improve passenger's satisfaction and safety. The enormous flow of data daily generated by railway infrastructures represents one of the most precious resource to exploit in order to improve customer' experience and implementing on board services.
- Finally, applications of augmented and virtual reality can sweep, in the train industry, from customer engagement to personnel training. On board interactive monitors provide entertainment and route information while augmented reality mobile apps can engage customers into rail infrastructure design. Additionally, augmented and virtual reality solutions are used to make personnel training more engaging, realistic and informative while strongly improving their skills. Tsuktat, a Ukrainian startup, develops AR/VR customer engagement applications for train stations. It allows passengers to interact with the railway station infrastructure, using their mobile devices. As regard the personnel training, a Dutch company called Vrtech, develops Virtual reality simulations to improve the skills of train inspectors and engineers.

2.2.1 An overview of different railways blockchain use cases

A Gartner report from 2019 review the blockchain technology, applied to the railway industry, into the final stage of development, and that railway blockchain projects have successfully been implemented in countries like Switzerland, China, and Russia (RSSB, 2020).

Blockchain network enables all its participants to obtain the same set of relevant data, which means that all trains can communicate with each other via smart contracts simplifying communications within the infrastructure. So, Blockchain means shared information for a shared infrastructure, where all the participants in the rail network have access to all the shared ledger data. This enables a direct coordination between all the parties involved speeding up communications between trains and infrastructures.

Conventional railway operations employ specialized software to ensure safety and efficiency on train operations and communications. Signals and other information from rail infrastructure controlling rooms are directly sent to drivers with a centralized scheme. This scheme leaves exposed the entire rail infrastructure to many risks like driver's communication systems failures or human errors.

However, leveraging on blockchain, railway infrastructure management operations can be decentralized by enabling trains to find routes and make decisions which are safeguarded and protocolled in auditable transparent manner. The most promising blockchain work about the automation of train communications comes from Germany where they have demonstrated how trains can choose their own routes and lock or release rails without a central control, minimizing conflicts and human errors (RSSB, 2020). The Blockchain based railway control system is an approach which pursuits the vision of building an automatic traffic management and interlocking mechanism software to enhance passenger's safety.

Blockchain specialists in Germany at Deutsche Bahn have also adopted Blockchain for predictive maintenance. Maintenance operations are normally highly labor-intensive, time-consuming, and cost-intensive. Still today, a relevant number of existing delays are directly or indirectly attributable to this area. A comprehensive digitization of this field includes tracking not only the states of all technical components in real time, but also the execution of repairs and maintenances, as well as the documentation that proof the work done (RSSB, 2020), supporting related train infrastructure actors to implement the efficiency of the entire ecosystem.

The adoption of Blockchain technology with sensors represents the basis for modern predictive maintenance operations, in which the individual components register their requirements independently and autonomously. Trenitalia S.p.A. for instance is currently building an MVP (Minimum Viable product) to test blockchain with IoT on its locomotives in order to predict failures. The railway company will be able to better manage the inventory, but we will analyze more in detail Trenitalia S.p.A. Blockchain improvements in the third chapter. IoT and sensors produce a lot of vital data which would have been stored on a centralized dataset exposed to many risks. Blockchain can help securing the network from possible failures while serving as a proof of work for a much clear management of the information shared. For this to be effective, a blockchain solution must require data from a network of actor ecosystem, such as the train component manufacturing ecosystem, warehouse management system, and last mile component delivery ecosystem to provide an effective visibility of all the maintenance steps.

Train companies are always more and more using rewarding prizes for travelers as a marketing tool to sell more tickets. Recently, in the USA a train company has developed a blockchain based platform to manage in an accurate and reliable manner all the score transactions, enabling a major interoperability between the companies and travelers improving their overall experience (BW Business world, 2021).

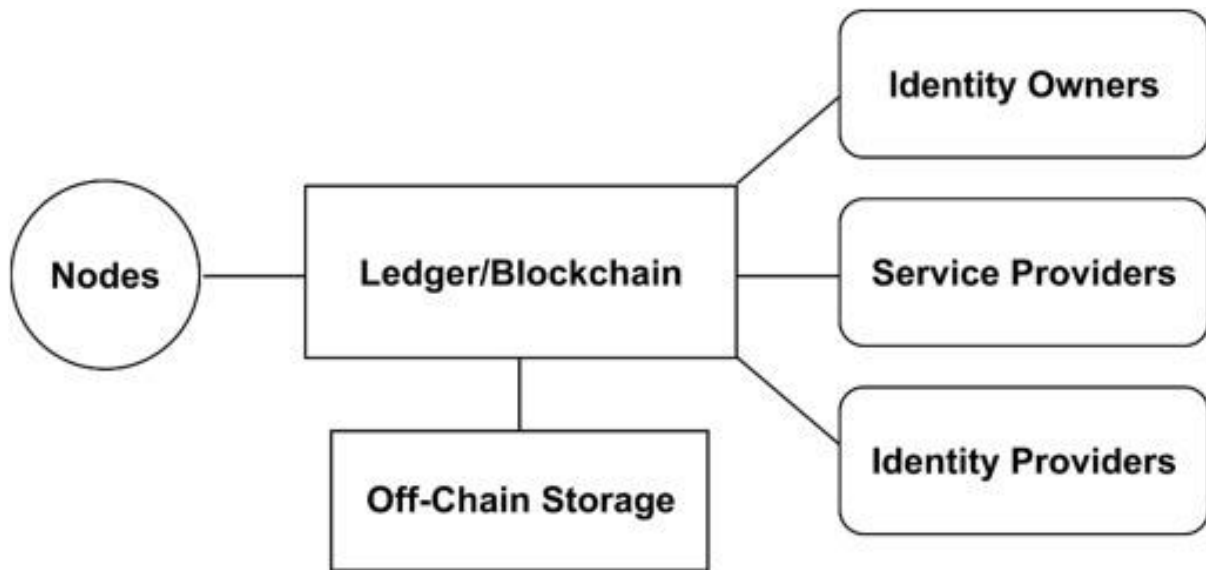
Blockchain has also been employed to digitalize train ticketing operations. Smart ticketing using blockchain can improve the passenger experience, cutting down on the waste of paper tickets. The Birmingham Center for Railway Research and Education is developing a smart ticketing system with blockchain. The platform will replace the traditional ticketing systems to create a true digital equivalent of the paper ticket, recognized by all passenger train operators across Great Britain (RSSB, 2020). The platform will be based on an IBM developed permissioned blockchain. It will maintain an access control layer, ensuring certain actions can only be carried out by defined authorized participants. The network is composed by train operating companies, ticket vending organizations, and other external organizations such as the rail delivery group. These organizations are responsible for the ticketing infrastructures, and accessing data and insights generated to produce also meaningful statistics to implement day by day the Great Britain railway ticketing operations.

More Blockchain based platforms have been implemented to improve operations among international rail freight logistics networks. The Deutsche Bahn (German Railways), Chinese

Railways, Kazakh Railways, Mongolian Railways, Russian Railways, White Russian Railways, and Polish Railways have jointly been implementing a blockchain solution for the trade and rail traffic control on the “New Silk Road” between Europe and Asia since the 2016 (Aritua et al, 2021). The main objectives of the platform are to improve the tracking and tracing of containers, ensure a safer and easier exchange of data, and finally reducing the amount of paper documentation usually needed for international rail transportation. The platform connects customers, rail operators, and other parties involved in the trade enabling an accelerated digitalization process. It provides a reliable, traceable, and immutable prove of freights transfers, as well as an auditable source for transactions auditing.

Finally, Blockchain technology has paved the way for the development of a distributed ledger platform for the Identity management across public rail transportation. A distributed identity management platform eliminates the need for multiple travel cards or ticket and enable passengers to have better control over the use of their identities while they utilize interoperable ticketing systems across Europe. The current public rail transportation in Europe is highly fragmented due to the prevailing variety of different solutions, data format, pricing models, languages. Some countries offer integrated systems for different transportation modes, whereas others offer different solutions for each city or region. The ticketing solutions range from paper tickets and smart cards to account based bills. One of the main challenges of this highly fragmented infrastructure is the management of users accounts across independent public transportation systems. Usually, identity management systems are hosted in centralized database managed by few services providing authority, while a unified international system for public transportation in Europe will involve many stakeholders from different countries generating sensitive user data through different sources. As blockchain is built to enable trustless networks, it is the perfect fit to manage different passenger’s identities. Compared to a centralized identity management system, the blockchain one relies on a shared ledger which is validated and stored by several network nodes. The stored data belongs to different users, which in a decentralized identity system can be split into identity owners, service providers, and identity providers. However, user sensitive data are stored off-chain and they are not accessible to anyone other than the authorized controlling authority (Stockburger, et al. 2021).

Figure 5: Components of a Blockchain based identity management platform



Source: Stockburger, et al. 2021

There is more than one company on the market which have used blockchain technology to develop a decentralized identity management in rail transportation. One of those is Sovrin Foundation, a private non-profit organization that aims at creating an infrastructure for passenger's identity identification utilizing its proprietary blockchain technology. Sovrin has developed a public permissioned blockchain using nodes to achieve a global consensus. All the private information is encrypted by the passenger's key, thereby giving them full ownership of their identity. User's private data are stored on their device, and they are not downloaded in any of the system's databases.

3.The potential use of blockchain technology by Trenitalia S.p.A.

The versatility of blockchain technology has paved the way for the development of new services across the transportation industry, and railways around the world are particularly moving towards digitalization to enhance their operations.

The past fifteen years have seen increasingly rapid advances in the field of railways in Italy, completely disrupting the way of travelling around the country. Railway companies are looking to become smarter through the adoption of new technologies, that can help improve passenger's experience and streamline operations.

The objective of this chapter is to propose the adoption of Blockchain based solutions by Trenitalia S.p.A., which is part of Ferrovie dello Stato Italiano Group S.p.A., a state-owned Italian company. The company has taken significant steps into the automation and digital revolution, and it is becoming more reliant on digital technology to achieve a higher performance and reliability. Major issues affecting the passenger's transportation services have been highlighted through the results of a survey. The survey was useful to validate rail passenger's needs and expectations, enabling the design of meaningful blockchain based solutions for real company's inefficiencies. As mentioned above, most of the blockchain based solutions developed up to now within the railway industry are focused on decentralized and autonomous train route control systems, or credential management system. In contrast, this work will present blockchain based solutions focused on improving both the passenger experience, through the implementation of a blockchain based digital ticketing platform, and the operations by tracking the railway infrastructure and train maintenance activities.

The use cases below have been designed in collaboration with "FSTechnology S.p.A.", the company responsible for the implementation of new technologies within Ferrovie dello Stato Group, which has supported this work in defining Trenitalia S.p.A.'s needs and requirements for the development of blockchain based solutions.

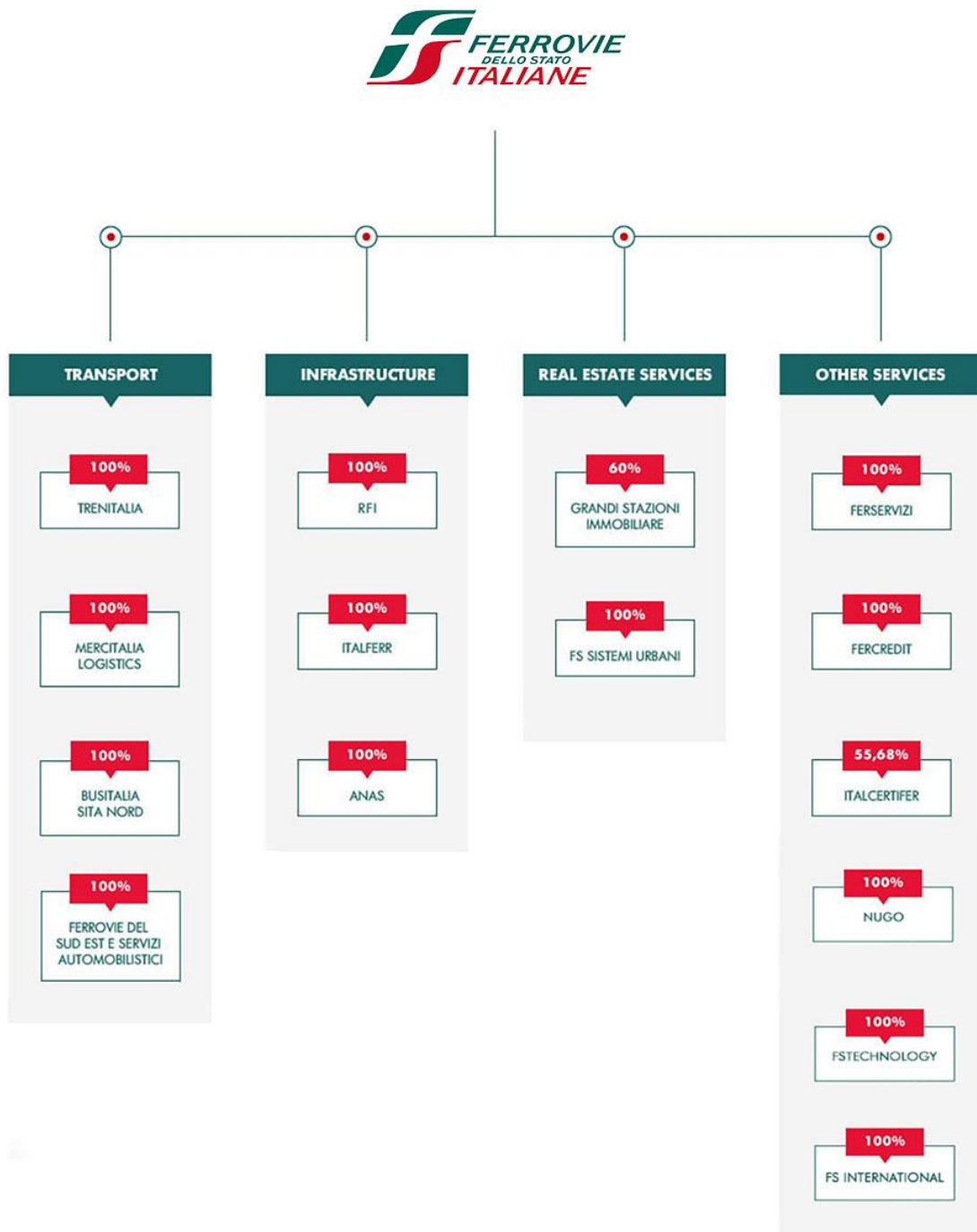
3.1 Introduction to Ferrovie dello Stato Italiano Group S.p.A.

The Ferrovie dello Stato Italiano S.p.A. is one of the largest Italian industrial companies, 100% owned by the Ministry of Economy and Finance since 1992. It is the leader in Italy in the passenger rail transportation with 88% of market share. The group has about 80 thousand employees, with 750 Mln rail passengers running on the railroads every year. The company's

mission statement is to actively participate in the progression of the country, taking care of people mobility while ensuring a safe and efficient transportation service (FS Italiane,2021). High speed and regional transportation, technological innovation, and digitalization, are the main elements that mark the effort of the company, which aims at developing sustainable synergies between the parent companies in order to implement new and innovative offerings. Ferrovie dello Stato Italiano S.p.A. has subsidiaries companies which operate within four different operating Business units (BU): 1) The Transportation BU (59%): It includes companies performing the transportation of both passengers and freights on railways, roads, and sea (Trenitalia S.p.A., Mercitalia Group, Busitalia – Sita Nord, Ferrovie del Sud Est e Servizi Automobilistici, M5). 2) The infrastructure services BU (39%): It includes companies responsible for rail infrastructures maintenance operations, and services related to the management of maritime connections with major Italian islands (Rete Ferroviaria Italiana, Italferr, Anas). 3) The Real estate services BU (1%): It includes companies that manage the main railway stations in Italy and all the properties of the holding (Grandi Stazioni Immobiliare, FS Sistemi Urbani). 4) Other Services (1%): It includes services not strictly related to the railways, like administrative operations, building and facility management, leasing, factoring, systems certifications, etc. (Ferservizi, Fercredit, FS Technology, Italcertifier, Nugo, FS International).

Innovation has always been essential for Ferrovie dello Stato Italiano S.p.A. Group to deliver peer-beating results. The group has put a lot of effort in implementing new services leveraging on the latest technologies to generate more value for its customers. As a result, they have founded FS Technology S.p.A., which is always a subsidiary of Ferrovie dello Stato Italiano S.p.A., exclusively dedicated to the development and implementation of new technologies within the group businesses. The mission of FS Technology S.p.A. is to strengthen and support the digital innovation, ensuring a high-quality implementation service of new technologies such as blockchain, artificial intelligence, robotics, and Internet of things (FS Italiane,2021). FS Technology S.p.A. is reducing the time to market of new technological products meeting Ferrovie dello Stato Italiano S.p.A. Group's strategic goals. It is possible thanks to the synergies created between the parent companies and the systematic assessment operations of new business opportunities.

Figure 6:FSI Group companies



Source: Fsitaliane.it, 2021

3.1.1 Trenitalia S.p.A.'s company overview and objectives

The purpose of this work is to present the adoption of two blockchain based solutions adopted by Trenitalia S.p.A., one of the most relevant parent company (Transportation BU) of Ferrovie dello Stato Italiano Group S.p.A.

Trenitalia S.p.A.'s objective is to develop a large-scale mobility service capable of contributing to the country's economic growth. The company's core business is the governance of rail passenger's transportation, both on high speed and conventional line, as well as regional and metropolitan services. It is responsible for the distribution and the accessibility of rail transportation services for the entire country, managing both commercial and operational (Ex: Train maintenances) activities. In fact, beyond the rail transportation activities, Trenitalia S.p.A. strictly cooperates with Rete Ferroviaria Italiana S.P.A. (The Ferrovie dello Stato Italiano Group S.p.A. subsidiary with the role of rail infrastructure manager) to ensure a safe access to the railway network through the coordination of all the necessary maintenance activities.

Trenitalia S.p.A. is divided into National, International and Regional Passenger Division which are respectively focused on the overall management of transportation business, while the head offices assume the responsibility of authorizing and controlling governance.

The National and International Passenger Division ensures the national and international passenger transportation service, including the high-speed line. It manages about 18 Mln passengers/Km each year, assuring through direct maintenance and production operations, rolling stock cleaning and purchases the correct programming and management of the service. The Regional Passenger Division guarantees mobility services at metropolitan and interregional level, addressing the demand from regional service contracts. The regional division provides 190Mln trains per Km, serving customers with about 7800 trains per day, and promotes forms of modal transportation together with the local transportation companies to ensure a greater territorial penetration (FS Italiane, 2021).

The company has always been committed to meet the mobility needs of passengers, while ensuring high safety level standards. The passenger's safety has been imprinted in the history and professional attitude of Trenitalia S.p.A. for over a century. However, new technologies are proposing to improve the safety of travelling by train, making it efficient and reliable.

Passengers are always more and more concerned about both the safety standards and the efficiency of rail services, and to meet these future demands Trenitalia S.p.A. is investing in new technologies such as the blockchain (FS Italiane, 2021). But, before jumping into the proposed blockchain use cases, that will improve both the efficiency of commercial services and operational activities, it is useful to get an overview of most relevant innovative projects pursued by Trenitalia S.p.A.

3.1.2 How Trenitalia S.p.A. is leveraging on advanced technology to improve its business operations

Trenitalia S.p.A. is constantly involved in research and development activities, promoting railway innovation and technology. In 2016, the company closed the most important call for the creation of a fleet of 450 new convoys to provide commuter trains, with high-level safety technology. Trenitalia S.p.A. is really focused to the question of safety and have equipped both the rail network and trains with some of the most modern technology in the world. These solutions and devices include SAP's IoT technology, which ensure an effective operational model and sustainable travel experiences, and Big Data to enable the optimization of application processes for predictive maintenance.

This paragraph will describe the main technologies and innovation activities pursued so far by Trenitalia S.p.A. to generate new value for customers: Telediagnosis, Digitalization, and Maintenance of the railway network.

- Telediagnosis: It is the remote diagnosis technology applied to managing dynamic and predictive maintenance. Trenitalia S.p.A. and SAP, a multinational software corporation that develops enterprise software to manage business operations, have jointly worked on a predictive maintenance system for trains. The system, based on IoT Technology uses sensors to access information and transmitting data. The entire innovative process is based on the SAP platform "HANA", where all that big data can be generated and accessed through the numerous sensors present on the new trains (FS Italiane, 2021). This system is completely transforming the way in which maintenance is handled, since all the anomaly and the end of a life cycle of a component are communicated in advance. Moving from a reactive to predictive maintenance operation helps Trenitalia S.p.A. to enhance its safe standard requirements, and to better manage train's components inventory. The telediagnosis has first been applied to high-speed trains, and then it was extended also to the regional trains, to reduce breakdown and breakages related costs. All the information needed are so accessible by special

instrument panel, from which it is possible to real time monitor the current state of the fleet during services and easily identify the appearance of any possible breakages.

- Digitalization: Trenitalia Spa's aim is to offer easy to use tools to travelers, that are useful from the first stages of planning a trip to its end. All in all, Trenitalia S.p.A. digital travelling solution is an effective travelling companion, that knows clients and advises them on what best to do, thanks to big data and advanced analytical tools. The Trenitalia S.p.A. App, available on both IOS and Android devices, literally creates an extended customer experience, where customers can access services such as indoor station mapping, delay notification, electronic wallet, and social seating (FS Italiane, 2021). Ultimately, it will provide travelers with regularly and punctually updated information on what is happening on the line and the train they have to get on.
- Trenitalia S.p.A. strictly cooperates with Rete Ferroviaria Italiana S.p.A., which is the Ferrovie dello Stato Italiano S.p.A.'s company responsible for the maintenance of the Italian rail infrastructure. Rete Ferroviaria Italiana S.p.A. to ensure high standards of safety, reliability, and quality of the railway infrastructure, uses to adopt certified maintenance processes and sophisticated diagnostic tools. More recently, Trenitalia S.p.A. and Rete Ferroviaria Italiana S.p.A. have jointly worked with Fondazione Ugo Bordoni to the development of an infrastructure diagnostic solution, which leverages on new technologies such as 5G to achieve an advanced level of safety on the rail network. The project, denominated DINO5G (Diagnostic Integrated Networks of Satellite and 5G), targets the creation of an integrated communication infrastructure to track the equipment of the national railway for predictive maintenance purposes. The macro-objectives of the project are the following: a) Defining the properties and main features of the distributed diagnostic application, its main entities in terms of sensors, data gathering nodes and central data processing nodes. b) Starting the testing of the 5G communication infrastructure with both terrestrial and satellite access. c) Enhance an integrated diagnostic view of communication facilities, to make performance parameters needed easy to be accessible in a technology transparent way (Telecom/ Artes, 2021). The DINO5G is an extremely flexible communication platform, which offers several enhancements to the predictive maintenance market. In fact, the system relies on a hybrid satellite and 5G terrestrial network, enabling the predictive maintenance applications to be fed with a greater amount of data than traditional products. The result is a superior periodic maintenance operation focused on leading

costs reduction and increasing customer experience through lower outage time and travel delays.

The relevance of themes, such as digitalized maintenance processes and new digital onboard services, for Trenitalia S.p.A. is clearly supported by the projects presented above. Trenitalia S.p.A. is really committed to the question of safety and have equipped its trains and the infrastructure rail network with the latest technology on the market. These solutions, which are extremely innovative are ensuring a more effective, sustainable, and quick travel experience. These continuously improved results in offering more efficient maintenance operations and new digitalized services to passengers are enabling Trenitalia S.p.A. to strengthen its position in Europe and other international markets.

3.2 High speed Train Passenger's preferences and need in Italy

To validate the hypothesis to build the use cases, based on blockchain technology solution to implement with Trenitalia S.p.A., a survey has been launched to gather data about train passengers needs and preferences in Italy.

The survey powered by Google Modules, has been sent via link through the major social network (WhatsApp, Instagram, Facebook), to get the as highest as possible number of respondents.

The purpose of this research is to study and collect data about high-speed train passengers' experiences among two main points: Passenger's concerns with a correct execution of railway and train maintenance operations and secondly their experiences with ticket's purchases.

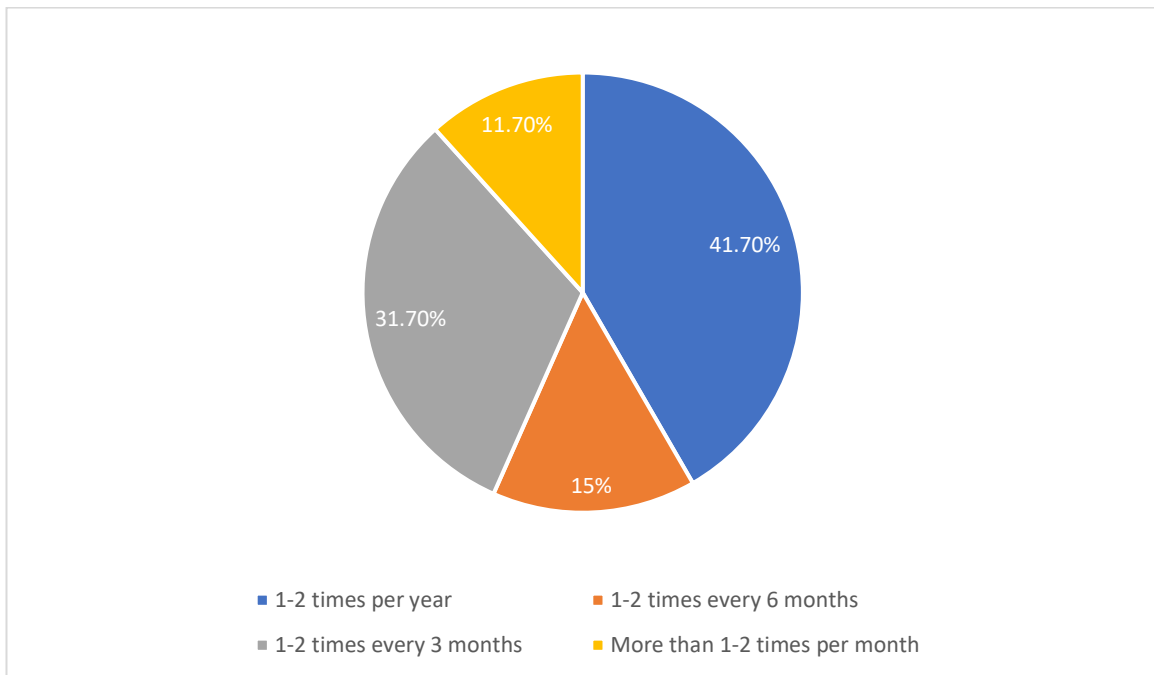
The survey has been structured as follow:

- The first section is about the description of the survey, the guaranty of questions' anonymity, and the time needed to fill the multiple-choice answers.
- The survey is 10 questions long, and the first three questions deal with cluster's definition, to have a clear data of surveyed people 'age and high-speed trains usage frequency.
- The remaining part of the survey is concerned with gathering data about passenger's experience with Train delays, ticket's purchases, and their reliance into the execution of maintenance operations.

3.2.1 Survey highlights and research findings

This section provides an overview and summary of key analytical points and findings of the survey. Most people surveyed (61,7%) are ranked between 15 – 24 years old, and a significant number of them used to get the high-speed train one or twice a time every three months before the Covid-19 pandemic.

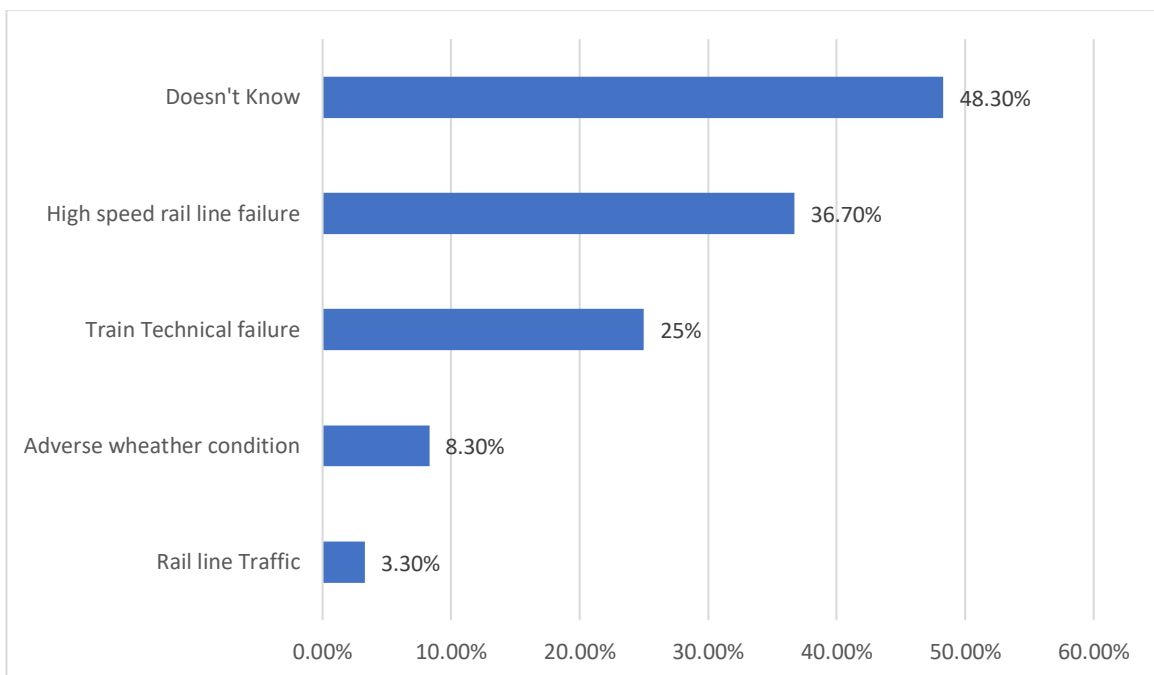
Figure 7: High speed train usage frequency distribution of people questioned



This study has found that most of the times people take the high – speed train in Italy it is on late, 31,7% of the respondents indicate that their train was on late half the time they decide to travel by railway.

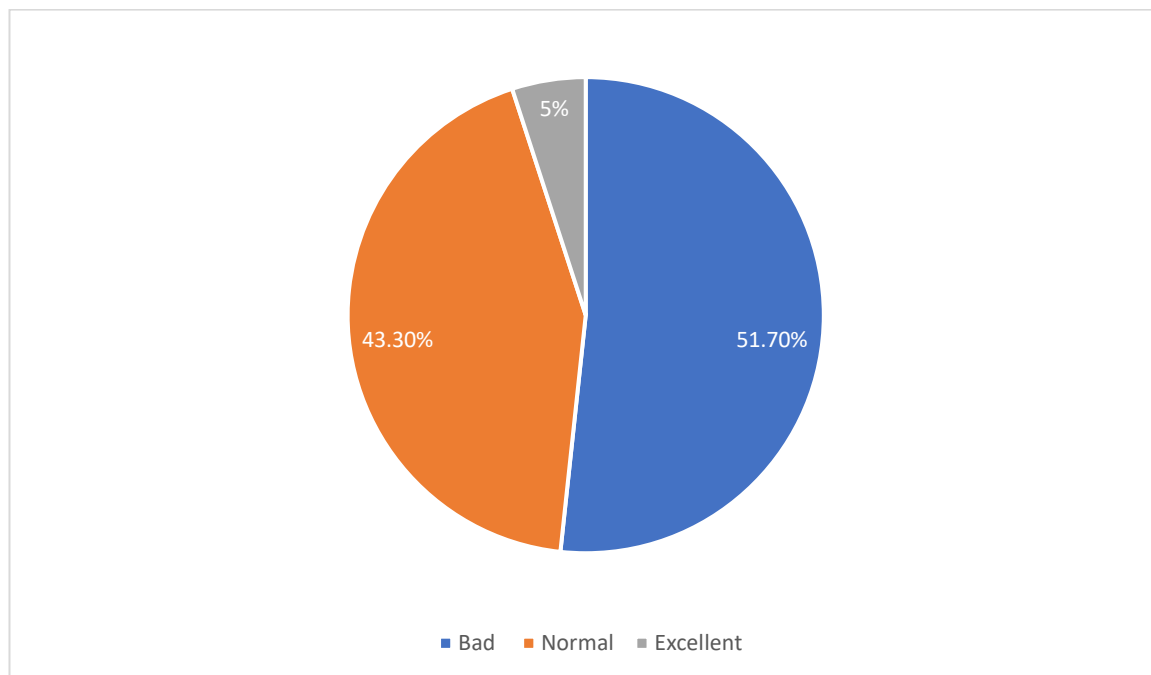
High speed line failure is the most common reason for train delays (36,7%), followed by other causes represented in the next chart:

Figure 8: Delay causes selected by people questioned



One of the most significant findings to emerge from this study is that over half of people who filled in the questionnaire experienced many troubles to refund their tickets. The key point that may be drawn from the data gathered is that high speed train companies have to rethink their refund policy and the way they go to market through it, since 60% of the people interviewed perceived, the actions required to get money back unclear and almost confusing.

Figure 9: How people questioned perceived their refund experience



The second major finding was that more than half people questioned were quite concerned about the correct execution of maintenance operation on the train and on the railway infrastructure. The relevance of making available and easy to be accessible in a digital transparent way all the information and certificates about maintenance operations, is supported by the fact that 85% of people questioned would like to have access and autonomously check the current maintenance status of trains and railways they are travelling on. This lack of confidence is probably endorsed by recent high-speed train derailed in Lodi, 50 Kilometers from Milan (The Local, 2020), questioning whether the aged parts of the Italian railway infrastructures are suited for purpose.

To sum up, the survey has highlighted few main findings, which represent the starting point to develop the Trenitalia S.p.A. use cases exposed below: 1) Passengers are concerned about the execution of proper train and railway infrastructure maintenance operation and ask for major

transparency and sharing of information related to the system's reliability they are travelling on.

2) High-speed line train in Italy are often on delay, and passengers find the procedure to purchase and refund their ticket complex, unclear, and quite annoying.

3.3 Use case: Blockchain maintenance operations traceability

Managing asset maintenance information in the railway industry is a sensitive problem. In such contexts, stakeholders face many difficulties in sharing critical asset information because of a lack of trust. The literature reviews the distinct challenges associated with explicit and tacit knowledge sharing, highlighting the difficulty of sharing this kind of knowledge because of its embodied nature. In contrast, sharing explicit knowledge is considered easier, because it is easier to articulate, codify, and finally store (Abbas et. Al, 2020). However, it is crucial to introduce trust mechanisms in organizations to solve the problem of trust to improve information and knowledge sharing which plays a pivotal role in the enterprise development. Building trust in asset maintenance information among stakeholders is not easy, and the sharing of inaccurate maintenance information can lead into misunderstandings among stakeholders and slow down maintenance processes.

Consequently, the objective of this chapter is to create a proof of concept for a blockchain application in the railway world, with an emphasis on improving the train and railway network infrastructure maintenance traceability. The railway industry, as many others transportation industries, manages complex systems and operations, where failures are not admitted. Railway needs to leverage on blockchain technology not only for safety improvements, but also for new business models to deliver more trust and more transparency to passengers.

Locomotives are considered secured and ready to go only after a released document that proves maintenance has been completed. Currently, these documents are kept in a physical format which might lead to mistakes, poor evidence tracking and lack of transparency.

Passengers who are the end customers, have no clear information about train fleet maintenance, which are premises for a safe and secured rail travel. As mentioned above, in the survey findings, passengers are quite concerned about the correct execution of maintenance operation on both the railway network and locomotives, since they have no certified accessible proof of it.

Moreover, models of predictive maintenance, which have been largely adopted by many train companies like Trenitalia S.p.A., cannot be properly developed if accurate data are not available. Predictive maintenance models work by continuously collecting many data through IoT sensors about the status of locomotives and rail infrastructures, however these data are not easy to be accessed for most stakeholders because they are centralized managed by intermediaries' parties.

These issues can be changed with the implementation of the below proposed blockchain application. Choosing a blockchain solution will bring transparency in the way that every train and railway infrastructure are used and maintained. In fact, based on the available data stored in the blockchain, original equipment manufacturer, maintenance operators, and Trenitalia S.p.A. can easily certify the quality of its services by tracking the journey of each material and component along the supply chain.

3.3.1 How the maintenance operations are currently managed by Trenitalia S.p.A.

Railway maintenance processes involve services either on the rail infrastructure and train's coaches. Both services are mainly managed by RFI (Rete Ferroviaria Italiana), except for the maintenance of high-speed train, that are assigned to a third-party company called SITAV (Società Italiana Treni Alta Velocità).

Rete Ferroviaria Italiana (RFI), is the company of the Ferrovie dello Stato responsible for the stations, lines, and systems, performing the rail network maintenance and ensuring the safe circulation across the entire infrastructure. The rail infrastructure maintenance process is organized into: 1) Extraordinary Maintenance, that is mainly concerned with rail accidents repairs, and train restorations activity called "revamping"; 2) Ordinary Maintenance, that is divided on two levels: the first level is aimed at corrective maintenance, while the second one to predictive maintenance.

SITAV is responsible for the execution of current and corrective maintenance on electric locomotives at Trenitalia S.p.A. depots. The company provides maintenance services on ETR 500 trains and Frecciarossa line (Trenitalia S.p.A. High speed line), including technical support to engine drivers to eliminate malfunctions during the business service.

Before entering the details of a Blockchain infrastructure suitable for the Trenitalia S.p.A. use case, it might be necessary to further explore how a supply chain of maintenance parts works and the value added by the blockchain technology. Asset maintenance information includes, maintenance event and task registration, maintenance guidelines and technical specifications. Effective management of such information is critical to design better assets, improving asset maintenance guidelines, and optimization of asset maintenance plans.

Supply chain is the process which makes materials and components travel from production to the final users through a network of manufacturers, which coordinates each other to make a product ready to be installed (Johal, 2020). Supply chains are notoriously complex to manage. In fact, it is quite challenging to guarantee the integrity of all the interested parties without using a centralized and trusted intermediary. Intermediaries are specialized in tracking assets and collecting data across the supply chain and sharing information with the stakeholder to guarantee that anything has not been manipulated or executed incorrectly. However, these kinds of processes are quite costly and time consuming, since each stakeholder is responsible for notifying the intermediary about its product's advances, and if they wish to track the entire

journey, they will have to buy data from the intermediary, which will barely be available in real time.

Blockchain is offering an alternative to a centralized supply chain network by tokenizing each material or component and transferring them to stakeholders with blockchain transactions. Each token will represent an item belonging to a specific stakeholder, where transactions can combine also more than one token to represent the combination of two materials or components. Blockchain trace the transaction of each item from one stakeholder to the other allowing users to determine the exact status of a project in real time without any intermediary.

3.3.2 Blockchain technology for Trenitalia S.p.A. High speed line maintenance traceability

Locomotives and railways are complex systems made up of millions of components and sub-components which work together to guarantee a safe ride. Therefore, ensuring the quality of the maintenance process for such a complex system is challenging. As showed above, Trenitalia S.p.A. and Ferrovie dello Stato maintenance process involves various parties like OEM (Original equipment manufacturers) part suppliers, and line maintenance service companies. What blockchain technology does is to connect all these parties to enable a transparent and accurate maintenance record.

The actors needed to certify the correct execution of Trenitalia S.p.A. High speed train line and the related rail infrastructure are:

- 1) Certified OEM suppliers: They are the only partners that have the authority and permission from Ferrovie dello Stato Group to sell to the service company components and spare parts for the maintenance of the rail infrastructure, and high-speed trains.
- 2) Service Companies (RFI and SITAV): They manually service the rail infrastructure and locomotives and are responsible for the correct execution of the operating maintenance process.
- 3) Trenitalia S.p.A.: It is responsible to verify through the blockchain platform the expected performance of the previous actors, and finally make this information output available for passengers via mobile app.

Linking information between parties in context of maintenance traceability is crucial to the functioning of the blockchain. Information is validated during each transaction through the shared ledger that is governed by the smart contract. Each transaction contains four value fields, and a combination of them would be confirmed against the state of the shared ledger to validate the transaction (Agrawal et al., 2021). These four values are: Traceability ID, Public Key, and Transaction signature. The traceability ID is a unique identification code differentiating each

traceability unit, and to bind it with the traceability information. It facilitates tracing of components and spare parts even after they are divided, mixed, or recombined. These ID codes are generated through a time-based function to ensure its uniqueness. The Public key is a key assigned to identify all the platform participants, and it is crucial to trace and verify the claim. The transaction signature is a combination of the private key and the ID of the authorized party that has initiated the transaction. The transaction signature will help in maintaining security of ledger and define the type and level of blockchain accessibility. d) Asset or component value: It is the number of assets being traded between the OEMs and service companies (RFI and SITAV). Each party can access the blockchain and subsequently add transactions including the asset value that they would like to trade.

Figure 10:Supply chain maintenance infrastructure

Tier	Stakeholder Category	Responsibility
1	Certified OEM Suppliers	They build the systems and spare parts necessary for the maintenance
2	Service Companies	They are responsible for the maintenance of both the rail infrastructure and the locomotives
3	Trenitalia	Trenitalia has a governance role and is responsible to verify the correct execution of each maintenance operation

OEM are certified components suppliers, with the authority to add and register transactions on the blockchain distributed ledger. OEM before shipping the components needed, requested by Trenitalia S.p.A. and its services companies, record the transaction on the chain identified by a unique ID. When SITAV or RFI receive the component, they start the maintenance process by respectively operating on the locomotive or rail infrastructure. Once finished the installation of the new component, this one is assigned with a new unique traceability ID that includes an impression of previous traceability ID provided by the OEM.

By this time, Trenitalia S.p.A. can connect with the blockchain and access the shared ledger, where it is possible to track all involved OEMs supply partners transactions thanks to the ID history created by the blockchain (The transactional data includes photos of the performed maintenance, components work order and number, how many components have been employed, prices, shipping times, and additional operator comments), and know if the component has been set up where needed by the service companies on the scheduled data. The entire maintenance operation has been stored in the blockchain with immutable hash. Everyone with permission to access the application can see the status of the registered maintenance event. At this point, based on the available data stored in the blockchain, key performance indicators of the works executed on each highspeed train and line can be identified, and they automatically reflect a maintenance score. The score is representative of the railway infrastructure and locomotive status (Under a predefined score the train or railway infrastructure are not acceptable to be used and cannot be moved from the service shop until they are completely serviced) to make passengers aware of the entire transportation system efficiency. Thanks to the blockchain traceability features Ferrovie dello Stato Group can efficiently trace the maintenance operations of its locomotives and railroads, providing a transparent proof of the quality of its services to passengers by simply enabling them to access the maintenance score via Trenitalia S.p.A. mobile app.

3.3.3 Maintenance Traceability use case discussion and final considerations

This use case has shown the value of blockchain technology in asset maintenance information management, with gains occurring in the form of increased trust in the quality of performed maintenance.

There are three key advantages blockchain will bring to Trenitalia S.p.A. to manage its maintenance operations: Transparency, Trust, and Cost-effectiveness. Transparency concerns the ability to make the maintenance supply chain traceable ensuring passengers a high quality ordinary and extraordinary certified maintenance service. Trenitalia S.p.A. can easily trace the journey of all the components necessary for both the infrastructure and trains, while sharing all this information with passengers (to make them aware of the works correct execution) which will feel more secure and comfortable about their travel.

Trust is strictly related to transparency. Tracking the entire journey of components and installation phases, the passenger can autonomously verify the validity of the processes executed by simply reading from the smartphone all the information desired.

Finally, adopting a decentralized trustless approach eliminates the need to use intermediaries to collect and receive data about maintenance operations making the blockchain technology cost-effective for Trenitalia S.p.A.

However, these benefits need to be balanced against some limitations inherent with the adoption of a blockchain based platform on a large scale. In fact, as for many other new technologies, tracking the supply chain and maintenance operations through the blockchain will require to assess some risks during the design phase of the project.

First, the life cycle of a blockchain platform implementation will strongly be related to the critical mass of suppliers and OEM that will join the network. If this number won't be reached it might be difficult to track all the supply chain's steps. It requires the development of a very diverse community of players committed to the adoption of a new and quite complex technology like the blockchain.

Moreover, when the number of OEM and suppliers joining the chain will increase it might cultivate the potential for some parties to be less willing to share valuable data with Trenitalia S.p.A. and other players, and for other companies to question the veracity of data shared. This could damage the value of the entire project, where the integrity and value of the blockchain is ultimately based on the legitimacy of the data provided by each party. So, it will be a priority for Trenitalia S.p.A., before eventually launch the project, to properly regulate the integrity of data shared by each party involved within the blockchain.

Blockchain led maintenance management in the railway industry is not discussed and researched enough in literature. Off-chain processes such as the insertion of followed maintenance instructions, the kind of performed maintenance task, photos of the performed activity, and additional comments of the service company create a relevant knowledge bank of the asset's performance. This data bank can be used by suppliers to improve the quality of their assets (Abbas et. Al, 2020).

Finally, this use case has attempted to bridge the gap between blockchain technology and maintenance information management, designing a maintenance event registration system to improve the quality of maintenance performed by Trenitalia S.p.A. enhancing the trust of passengers.

3.4 Use case: Digital ticketing platform powered by Blockchain technology

The following section provides the uptake of blockchain technology to lead significant improvements to the way customers purchase, store, and use tickets. Nowadays, passengers can get access to Trenitalia S.p.A. high speed train tickets through many channels, from websites and mobile apps to travel agencies and tickets machines and official stores directly at the station. However, the proposed Trenitalia S.p.A. ticketing systems and selling channels have shown to be not suitable for some purposes like:

- Tracking of relevant data about customer purchase behaviors and the production of related analytics
- The management of ad hoc and personalized tickets discounts for selected category of passengers
- The validation of tickets when passengers accidentally lose them and have no way of validating their proof of travel
- The way passengers have to request the refund of their tickets when the train is delayed or cancelled
- Sustainability issues: railway tickets contain metallic components making them incompatible with the general paper recycling process.

The uptake of digital technologies has the potential to disrupt the way customers use to think about railway tickets, offering a possible solution to the main challenges highlighted above.

The aim of this use case is to argue the adoption of a blockchain based ticketing platform to replace the current ticketing system adopted by Trenitalia S.p.A. (First as a pilot project for the high-speed train line) improving the passenger experience, whilst cutting down on the waste of paper tickets.

3.4.1 How Trenitalia S.p.A. passengers can currently get access to tickets

High speed train Trenitalia S.p.A. passengers may currently use two main methods to obtain a valid ticket: buying in person at the rail station; or buying from the official Trenitalia S.p.A. online website and mobile app. At present, passengers who choose to purchase in person can use a ticket machine or a Trenitalia S.p.A. official store. One of the advantages of paying at the station is that, once passengers have selected their destination and have paid with cash or with credit card, they do not require any form of technology to obtain and validate tickets. In addition, no extra fees are charged whether passengers choose to buy tickets directly at the station. On the other hand, the main disadvantage is that passengers only receive the paper

ticket as the only form of proof that they hold a valid ticket for the journey, and if they accidentally lose it there is no way to validate their permission of travelling by train. Moreover, paper tickets can be easily misplaced or incorrect because of errors through ordering tickets, usually occurring when passengers fraudulently enter information to obtain discounts they are not entitled to.

Purchasing tickets through the Trenitalia S.p.A. official website and mobile app has advantages over buying tickets at the station. It is easier for the passenger to compare prices between journeys, to reserve seats, and to ensure no mistakes are made during the process. Moreover, people prefer buying tickets online to spend less time at the station, and there is no need to carry a paper ticket on board. The disadvantages of buying online are that if a passenger opt to have a mobile ticket and runs out of battery or loses the phone, there is no way of proving ownership of a valid ticket, unless they have a backup printed version of it.

Many rail travelers and Trenitalia S.p.A. customers still use paper tickets (both printed from the online website and the traditional rail paper tickets purchased at the station), but many now purchase tickets via smartphone application. The passenger's choice between the digital and the paper ticket is usually related to his/her confidence with technology and the willingness to save digital tickets on the smartphone.

Before considering how blockchain might contribute to an improved rail ticketing system, it is useful to consider a couple of familiar scenarios sometimes encountered by travelers, personified here by the character of "Alessandro" and "Giulia".

Alessandro is a frequent traveler on the Trenitalia S.p.A. high speed line in Italy. One day, he buys a ticket at the station (paper format) and boards the train, takes a seat, and starts enjoying the travel. Seeing the train inspector approaching, Alessandro reaches for his pocket to retrieve his paper ticket but unfortunately it is no longer there, he accidentally dropped it on the platform. Because the paper ticket is the only way Alessandro can prove the validity of his travel, since he couldn't additionally store it on his smartphone, he must pay a fine.

Giulia is travelling from Rome to Milan to attend an important last minute working meeting. She is in a hurry, and aware of the negative impact of single-use paper tickets, decides to buy the train ticket using the Trenitalia S.p.A. smartphone app. However, Giulia's mobile phone accidentally runs out of battery, and she missed her charger at home. Once again, Giulia has no way of validating her proof of travel and has to pay a fine.

The lack of intuitive and largely adopted back up options to validate passenger's proof of travel is something that frustrate passengers, and that can be solved adopting a truly smart digital ticketing system.

3.4.2 Digital ticketing platform

A blockchain based digital ticketing platform will resolve the mentioned issues related to the actual methods of procuring tickets. The prerequisite to make a blockchain digital ticketing platform work is that any passenger wishing to purchase tickets will require a digital wallet.

Blockchain digital wallets are known in the cryptocurrency world as a digital place where users can store and manage their cryptocurrency, but they are also used to store and exchange utility tokens, which in the following use case will be the ticket purchased by Trenitalia S.p.A. passengers. It is a quite simple and diffused (Ex: Apple Pay and Google Pay) software-based technology which help to securely store confidential information and eliminate the need to carry a physical wallet by storing all passenger's payment data. Users will simply have to access their digital wallet by smartphone to check their tickets status, and other payment transactions.

Wallet addresses, where the ticket will be fiscally stored, are automatically generated from a private key, and can be accessible through different technologies, such as: a physical smart card or mobile application with a QR code, and NFC technology (Near Field Communication). Passengers will have access to their public, private, and wallet keys hosting their wallet on different platforms providing them with a variety of choices and reserve options. They can choose to show the ticket through smartphone, smart ring equipped with NFC technology, smartwatches, or physical smart cards having more than one back up option to validate the ticket if the main validation point (Ex: smartphone) doesn't work anymore.

The approach to design a digital ticketing platform for Trenitalia S.p.A. consists of leveraging on a permissioned blockchain maintaining an access control layer and ensuring certain actions can only be carried out by identifiable participants.

The Blockchain structure will consists of a technological architecture built on two different organizational level: At the highest level there is Trenitalia S.p.A., the train operating company, which will verify and monitor all the tickets transactions on the chain, and directly gathering data about tickets purchases. It will allow Trenitalia S.p.A. to collect in a reliable and transparent way relevant data about its customer purchases behaviors, and to redirect more efficiently personalized marketing campaign in respect of GDPR policies. Then, in the next level, there are both official Trenitalia S.p.A. ticket vending operator and external ticket vending organizations such as travel agencies. Ticket vending operators offers tickets to

passengers from an application. It can be any online terminal where passengers can buy tickets: Trenitalia S.p.A. mobile App, “Trainonline”, Travel agencies website, etc.

The entire process of purchasing a Trenitalia S.p.A. Ticket for the high-speed line will follow the next flow of four phases: Request, Propose, Confirm, Validate.

- Request: Passengers supply Trenitalia S.p.A., and other vendor organizations, with their wallet credentials and the information of the journey they wish to book. The wallet credentials act as a “username” to validate the passenger’s identity.
- Propose: Trenitalia S.p.A. cross-check the wallet address provided by the passengers or other external vendors, and if needed apply the discount passengers are entitled to and finally propose a suitable and discount compliant ticket to them. Thanks to the wallet addresses Trenitalia S.p.A. can quickly check the validity of any discounts to apply with its amount and on which route it is valid for. Adopting this protocol, Trenitalia S.p.A. will check first if the passenger credentials are suitable to receive the discount and there is no opportunity for the passenger to commit fraud.
- Confirm: Once the ticket is confirmed (from Trenitalia S.p.A. to the passenger), the transaction is issued, and the passenger can pay the ticket. At this point, a smart contract (between Trenitalia S.p.A. and the passenger) is initiated issuing a ticket token to the passenger’s wallet containing all the information of the journey (Seat number – Departure and Arrival time and destination – Platform number).
- Validate: When the passenger is requested to show and validate the ticket, they send their ticket token previously received by Trenitalia S.p.A. to a smart contract (by simply scanning a QR code available on the Trenitalia S.p.A. mobile app) which checks the validity of the ticket. By sending the ticket to the inspectors it is possible to confirm the ticket’s ownership, as passengers must digitally sign the transaction. Once the smart contract has validated the ticket, it is finally returned to passengers ‘wallet. If for some reasons passengers are unable to validate their ticket when requested by the inspector, they can do it also later. On the spot they will be requested to pay a fine and will receive a reference number which encodes the type and time of the issue. Then, the passenger can send the ticket token and reference number issued by Trenitalia S.p.A. to a smart contract, which will check if the ticket was valid at the time the passenger was travelling by train. Finally, if the train is delayed or cancelled passengers will be automatically refund by receiving back to their personal wallet address the ticket token issued in the beginning. The refund process as so processed, is fast and completely automatized.

Passengers don't have to request it manually through annoying customer services protocols, and they will just have to reschedule their travel.

3.4.3 Digital ticketing platform use case discussion and final considerations

A digital ticketing platform based on blockchain, as described above, provide many technical advantages. The architecture enables participants to share ticket data and system governance, with a high latency of up to 3K transactions per second (The number of transactions per second depend to the kind of blockchain chosen), it is more than enough to cope with the busiest periods of Trenitalia S.p.A. passengers passing ticket validation points. The new platform will improve the passenger experience. They are not restricted anymore to use only one device as a validation proof for their travel, allowing inspectors to check the validity of tickets on different devices and at any time. So, passengers no longer need single-use paper tickets, they can get access to their ticket in various ways such as Qr codes, NFC on multi-use smart cards, smart ring, and Trenitalia S.p.A. web applications. For Giulia, it no longer matters that her phone runs out of battery, because she can access the same ticket on her smartwatch or smart card, and she can immediately notify the network that the smartphone is no longer a reliable point of identity.

However, there are also some risks to be addressed to this technology. The digital ticketing platform, leveraging on blockchain, would require an overhaul of ticket validation points with a stable connection to the blockchain network to obtain the latest transactions on the ledger. So, providing a good internet connection along all the railway is necessary to make the platform work properly.

Moreover, one of the biggest issues with developing blockchain based platform is the requirement for users (passengers) to pay with fiat currency (euros), and not with the cryptocurrency of the blockchain at the basis of the entire system such as Ether for the Ethereum blockchain. Only a small target of passengers is going to be willing to use soon cryptocurrencies to pay for a train ticket, while the majority of passengers will pay with euros or other fiat currencies. So, Trenitalia S.p.A. and other external ticket vendors would be required to store a supply of the native blockchain currency used to develop the ticket platform. When the passenger confirms and accept the ticket, they pay in euros. Once Trenitalia S.p.A. and other vendors has received the amount of euros, they can use their own supply of the cryptocurrency to initiate the smart contract on the blockchain creating the ticket token and

sending it to the passenger's wallet. These protocols prevent passengers to own and store an amount of cryptocurrency on their wallets.

3.5 Which Blockchain should Trenitalia S.p.A. adopt?

This thesis was undertaken to design a possible implementation of blockchain technology with Trenitalia S.p.A. to improve some business operations. To conclude the work, it is necessary to evaluate and examine possible Blockchain that might be adopted by the company to develop the two use cases above.

Blockchain technology has evolved tremendously fast over the past few years. Public blockchains have particularly gained a lot of market shares with a lot of competition between different platforms among multiple fronts. Among the numerous Blockchain platform on the market, there are four (Ethereum, NEO, VeChain, and Hyperledger) that particularly aim at providing several functionalities for the technical requirements needed by Trenitalia S.p.A. to develop a digital ticketing platform and the tracking of the maintenance operations.

Ethereum is actually the most popular Blockchain to build decentralized application on the market. It enables developers to autonomously build and deploy applications for which the participants of that application are the decision-making authority. Ethereum's cryptocurrency, called Ether, is the fuel that runs the network, and it is used to pay for the computational power and resources offered by the blockchain to run the applications developed by the companies. Ethereum's strengths are the smart contracts which are revolutionizing the way how traditional contract works simplifying the exchange of any asset between two or more parties. Every time a smart contract is executed, an amount of Ether is sent to the wallet addresses where the contract is stored. The amount of Ether necessary for each transaction is determined by the GAS, which is the amount of computational power needed to make the applications run. Ethereum is designed to develop on top of it a multitude of different applications "without any possibility of downtime, censorship, fraud or third-party interference" (Preece, Easton; 2019), as the computation is equally distributed across the nodes of the entire chain. Moreover, developers can build their private token, even if they must meet the Ethereum protocols standards to make them work seamlessly with the entire network of other tokens.

The second Blockchain suitable for the scope is NEO, a platform for building Decentralized app as Ethereum. Founded in 2017, NEO was the first public smart contract platform in China and first global blockchain to adopt a dual token mechanism. It separates the rights of governance from the rights of using the network, focusing on becoming one of the preferred blockchains for business applications when is required a much stronger access control and ownership of tokens in a ledger under the regulation of central authority like governments. This feature might be quite relevant for the transactions of law-backed assets which need to be

strictly regulated, whilst maintaining the decentralized nature of the blockchain technology. One of the main differences between NEO and Ethereum is the programming language. Ethereum uses its own programming language called “solidity”, specifically created for writing Ethereum smart contracts, while Neo developers can use more familiar programming languages like JavaScript or Python. Having its own programming languages represents for sure a barrier for those companies who would develop Ethereum decentralized applications, as they have to hire developers with specific solidity writing skills. Another important point to consider when comparing the two platforms is the number of transactions per second each platform can handle. When scaling, both the two decentralized applications Trenitalia S.p.A. might build will have to handle a huge number of transactions, that can’t be slowed down by a slow transaction capacity. NEO wins here against Ethereum with 33 transactions per second against its 15 transactions per second (Exodus, 2020). Moreover, most of NEO transactions are free, users will have to pay only on a small category of transactions, unless they want to process them faster than the normal speed during times of high network congestion.

Ethereum is much more appreciated than NEO on the market right now, even if the latter has many valuable features as the possibility of developing with popular programming languages and its ability to handle a significant number of transactions per second.

The following blockchain, called VeChain, is the one specifically designed to build supply chain decentralized applications. VeChain provides a full blockchain platform for enterprise who desire to obtain a full view of the disintermediating information across their supply chain. According to the VeChain’s white paper the platform aims at providing a 360-degree view of all the necessary information linked to the production of products, and also for conducting transactions between Internet of things connected devices. These features are achieved by processes of asset digitization, where items that need to be tracked are assigned with unique identifiers codes to follow on the platform. The VeChain platform has two tokens: The “VET” is the former token that is adopted to carry value from smart contracts, therefore all the transactions of decentralized applications occurring on the VeChain use the “Vet” as token. The latter is the “VTHO” token which stands for VeChain Thor Energy, also known as VeThor Energy, and it is used to power and evaluate the cost of each transaction (Investopedia, 2021). The last relevant Blockchain for Trenitalia S.p.A. is Hyperledger. It is a global blockchain project that provide guidelines, tools, and frameworks to build open source blockchain based platforms. Hyperledger’s project works as an umbrella brand for a variety of permissioned blockchains, where network participants have intrinsic interests in participating in the consensus-making process. It is a global collaboration that includes leading firms from the

fields of Finance, Manufacturing, and IT with the purpose of providing interoperability between each participant. Hyperledger doesn't support a cryptocurrency like most of the solutions previously examined, but it is only focused on providing the necessary technological infrastructure for developing industrial enterprise blockchain applications. Since there is no currency affiliated to Hyperledger, transactions are validated through private and arbitrary consensus mechanism, making it one of the most customizable blockchain for enterprise usage.

3.5.1 Technological challenges Trenitalia S.p.A. should take into consideration

The idea behind the adoption of blockchains is to create a partially democratized infrastructure in which all stakeholders can easily, and safely share data requested by the network. Turning this into reality is quite challenging, starting from technical issues such as the kind of consensus mechanism, data distribution, and the scope of data storage. These different technical criteria can have far-reaching consequences on things like simplicity and practicality of the end solution or the associated costs. So, it is crucial to clarify three issues before launching decentralized applications: Scalability, Volume of data, and GDPR compliance (Roland Berger, 2021).

The scalability of a blockchain project is strictly related to the number of nodes needed to validate each transaction, the more nodes have to be used as a validating point the greater is the computing effort. The cost and time of each transaction can considerably change in relation to the consensus mechanism chosen. Trenitalia S.p.A. will probably opt for a private permissioned blockchain, where the number of validation point is limited to the necessity of maintaining a defined control over the entire technological infrastructure.

The second point is about the volume of data that should be stored on the blockchain which is limited. The solution to efficiently manage data storage on the blockchain is to store on it only document signatures, with access permission keys, and the actual storage positions of the documentation (Roland Berger, 2021).

This storage protocol will provide to Trenitalia S.p.A. a secure reference to each document, while the document itself is stored separately, either in the cloud or offline in the company main server. Unfortunately, the amount of data storage available on each blockchain is expensive both in terms of sustainability issues, as it works for many other databases, and the number of resources needed to physically maintain the computational power required which are quite costly.

Ultimately, the GDPR compliance and data privacy is indispensable for the success of blockchain applications and, as also mentioned above in the second use case, it must be strictly defined from the very beginning. The key point is whether it is possible to trace information back to individual users and their identities, which of course it is not admitted at least for all the network participants. Therefore, from the very first moment the structure is set up, it is essential to ensure that personal data are not stored on the blockchain, since its immutability property will not allow to delete them later.

3.6 Blockchain use cases implications on Trenitalia S.p.A. Business Model

New technologies, such as the blockchain, can foster the development of new sustainable business models in the transportation industry, enabling both the economic and social business transformation. Some years ago, studies were focused mainly on the impact of new technologies for improving transportation companies' competitive advantage to increase profits, and value for shareholders. Later studies have highlighted the need to expand the benefits gained with new technologies in the transportation industry to a new dimension, empowering two modern times performance indicators: the reduction of safety risks and the management of disruptions.

Trenitalia S.p.A. provides a safe and sustainable form of transport across the country. Inevitably, this level of safety comes with an associated cost, and balancing safety requirements, performances and costs is one of the key challenge the company has to address daily. Despite being the safest way of travelling in Italy for years, questions around safety have also plagued Trenitalia S.p.A. Therefore, the company has always involved in researching projects to search for new technologies, that can reduce the train derailment risk and improve its safety policies and practices.

On the other hand, Trenitalia S.p.A., as many other rail operators, suffers from significant costs of irregularities and severe passengers' dissatisfaction which are always more and more demanding for high quality services. Thus, it is indispensable for Trenitalia S.p.A. to develop new capabilities in foreseeing, avoiding, and ultimately managing disruptions. Levers for efficient disruption recovery include an appropriate investment in new technologies, that could improve the passenger's experience.

The blockchain is defined as one of the most disruptive technologies, and the two use cases proposed above allow to claim how it can enhance the creation of a new customer's experience. However, it will not completely disrupt the Trenitalia S.p.A. business model, since the proposed blockchain implementations are not going to change neither the service offering nor the revenue model. Both the proposed solutions will help Trenitalia S.p.A. to improve the quality of its services, by enhancing the safety standards, thanks to a more efficient management of the maintenance operations, and the quality of ticket's purchasing and validation services through a new digital ticketing platform.

The former blockchain implementation will bring Trenitalia S.p.A. the solution to trace critical assets maintenance information, by effectively enabling the company to have a clear and transparent real time view of each maintenance activity required. Therefore, the maintenance blockchain based platform will build much more trust among the stakeholders through a transparent asset maintenance information sharing. Moreover, it will speed up the maintenance processes, reducing the recovery times of trains at the maintenance shop, and more importantly share a certified proof of maintenance activities execution with passengers. As other stakeholders, passengers are concerned about the correct execution of all the maintenance operations required on the train they are travelling on and accessing this kind of information on their smartphone will make them feel more confident about their travel.

The latter blockchain use case, on the other hand, will be critical to manage and prevent disruptions, carrying out solutions to train delays and other ticket's related issues in an automatized and more efficient way. Passengers are always more and more demanding for faster and more efficient rail tickets purchases and validation services. The proposed digital ticketing platform will enable Trenitalia S.p.A. passengers with a new digitalized ticket purchase, and validation experience. They are not restricted anymore to use only one device as a validation proof for their travel, but inspectors can check the validity of tickets on different smart devices and at any time, speeding up all the tickets validation operations.

Conclusions

This work has given an account of and reasons for the widespread use of Blockchain technology in the transportation industry, focusing on the railway and the Trenitalia S.p.A. case. Transportation companies are a significant part of the Italian economy, and the key to build a sustainable business in this industry is to continuously deploy new technologies to generate innovation. Among the findings emerged from this study, the one that has highlighted the drastically changes in the demand of rail transportation services between cities evidence the urgent need for companies operating in this industry to innovate their business models with new digitalized services. High speed rail can work as an alternative to short distance air travel, and the only way to keep a competitive edge over other players is to modernize traditional rail processes, protocols, and services to satisfy future customer's expectations.

Trenitalia S.p.A. is constantly involved into innovation activities, it is really focused on passenger's safety issues, and have equipped both the infrastructure and trains with the latest technologies on the market to enhance the comfort on board. However, it is not enough yet, since high speed rail line passengers are currently demanding for better services around two main areas: 1) The way they can purchase, store, and use tickets; 2) The need to obtain more transparency about the execution of all the necessary maintenance operations on both the rail infrastructure and the train they are travelling on.

Blockchain technology has the potential to challenge the two points mentioned above, disrupting the way passengers are used to travel by train.

First, leveraging on blockchain Trenitalia S.p.A. will enable passenger to purchase tickets with a completely new user experience. They will purchase their tickets from the smartphone, use the wearable device they prefer to validate the ticket at the station or on the train, being not restricted anymore to use only one device as a validation proof of their travel. Moreover, passengers won't be involved into annoying tickets refund actions, since all the process is completely automatized through smart contracts that will autonomously give money back once the delayed is confirmed.

Secondly, tracking all the maintenance operations on a blockchain will help Trenitalia S.p.A. to reach supply chain transparency, trust, and cost effectiveness milestones. Supply chain transparency will improve the ability of Trenitalia S.p.A. to get more and detailed information

in real time about each component and material required to maintain all the rail infrastructure. Passengers will feel more secure and comfortable about their travel, having access to all this information through a simple user interface on the Trenitalia S.p.A. mobile app, where they can autonomously check the certified maintenance services executed.

However, as many other new technologies, the blockchain has some drawbacks and risks to be addressed before considering launching any project involving it. One of the major blockchain implementation challenges for Trenitalia S.p.A. is the cost of the whole process. Some blockchain platforms are quite inefficient in terms of costs of each transaction, and the software requirements are expensive. Moreover, blockchain is really a new and relatively recent technology, and unfortunately most of the organizations, which Trenitalia S.p.A. works with for the supply of the maintenance components, do not clearly understand the concept of blockchain due to an internal lack of technical competencies. Lastly the complexity of blockchain makes hard for the authorities and the government to clearly define the jurisdiction and the correct legal obligations of the parties involved in the transactions. Even if data on the blockchain will be highly protected, it is still not much clear how the Italian and EU's GDPR (General Data Protection Regulation) will threat it.

Regardless these challenges, there is no doubt the blockchain technology will play a pivotal role in driving innovation in the railway industry, representing an opportunity to really differentiate the companies which will adopt it. Trenitalia S.p.A. as a first mover player in the industry, will benefit of the blockchain technology positioning itself as a truly innovator company improving their passenger's travelling experience.

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Summary

This work gives an account of the blockchain technology applied to the railway industry to improve supply chain operations in the maintenance services, and to enhance the passenger's ticketing experience. Continuous business development and innovation, leveraging on new technologies, has become mandatory for many organizations to launch new solutions and to generate more value for customers. Therefore, the purpose of this work is to examine the adoption of Blockchain, one of the most promising new technologies, by the railway industry focusing on Trenitalia S.p.A. which is the major train player in Italy.

The blockchain technology is a digital decentralized infrastructure and distributed general ledger. It is highly utilized for establishing data security and trust for the exchange of information among unknown users. The first and most known application of blockchain technology was the cryptocurrency Bitcoin. Since its introduction, it has demonstrated to be a robust and reliable technology with beneficial attributes that goes far beyond the cryptocurrency's applications. The literature reviews the blockchain as "an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way" (Abbas et. Al, 2020). The three key features of the blockchain technology are: the ledger, which records all the data transactions based on the defined protocols; encryption, which protects the ledger from tampering; and distributed storage, which can identify not admitted changes to the ledger. These three main features provide users the confidence in the authenticity and security of their data.

So far, blockchain has primarily impacted the financial industry, but it has the potential to revolutionize many industries. Blockchain projects have been implemented in many fields, from the retail and consumer goods to the healthcare and food industry. This paper explores and investigates the applications of Blockchain technology among the transportation industry, focusing on the railway.

With growing competition in the transportation industry, always more and more transportation companies are deploying new technologies to improve the quality of their services. The blockchain technology is undoubtedly one of the most disruptive technologies of the modern times, and since its birth, it has been gathering a lot of attention across the transportation industry. It is a natural fit for fragmented industries such as transportation, in which

coordination between multiple and independent parties is essential. It has the potential to overcome some of the most persistent industry's challenges. Therefore, a short overview of some of the most relevant blockchain applications within the transportation industry is presented below:

- Blockchain applications within the automotive industry are mainly grouped into three areas: 1) Verification and process improvements: A blockchain solution can verify supplier details, providing services to automotive organizations and verified supplier, and then data can be stored on the chain to support supplier performance into future contractual agreements; 2) Vehicles management: Among the most largely adopted vehicles management and incentives use cases, blockchain based solutions have been currently used to record dealer and customer purchases issuing loyalty points to be redeemed and used as a currency to purchase vehicle parts; 3) Finance and Payments: One of the most interesting use cases in this area is the deployment of smart contracts to enable insurance firms offering personalized vehicle insurance contracts. They are based on drivers' behaviors and feature fully automating payments options following insurance claims.
- More recently leading airlines are using blockchain to resolve issues of security, trust, and transparency with its ability to manage and safely share data. Many airline companies are developing blockchain based solutions to manage loyalty programs between their partners. Accounting for miles and points when passengers use different partner airlines can be difficult and time consuming. Therefore, smart contracts can easily automate the process minimizing the risk of error and increasing customer satisfaction making their rewards ready almost immediately. One of the most promising blockchain work applied to the aviation industry comes from a company called "Aeron". Aeron is one of the first blockchain exclusively built for Aviation Safety. Their core business is to provide certified and secured Pilot's flight logs data, to boost security when hiring licensed private pilots or dealing with aircraft owners.
- Blockchain provides one potential solution also to the truck's industry need for traceability and transparency. The technology enables the build of a frictionless network for document transactions, shipment tracking and fleet management. Smart contracts can generate great value to the truck transportation industry for self-executing tasks when certain conditions are met. They can enable the payment to a shipper only

when the item reaches its destination under predetermined constraints and if they are not met the shipment company might offer discount policies.

- A Gartner report from 2019 review the blockchain technology, applied to the railway industry, into the final stage of development, and that railway blockchain projects have successfully been implemented in countries like Switzerland, China, and Russia. Some of the most diffused applications of the blockchain technology to the railway industry include: 1) The decentralized and automatized management of the railway infrastructure; 2) The adoption of blockchain for predictive maintenance operations; 3) The digitalization of ticketing operations; 3) The improvement of operations in international rail freight logistics; 4) Passenger's identity management.

The objective of this chapter is to propose the adoption of Blockchain based solutions by Trenitalia S.p.A., which is part of Ferrovie dello Stato Italiano Group S.p.A., a state-owned Italian company. Trenitalia S.p.A.'s core business is the governance of rail passenger's transportation, both on high speed and conventional line, as well as regional and metropolitan services. It is responsible for the distribution and the accessibility of rail transportation services for the entire country, managing both commercial and operational activities. The company has taken significant steps into the automation and digital revolution, and it is becoming more reliant on digital technology to achieve a higher service performance and reliability. Major issues affecting the passenger's transportation services have been highlighted through the results of a survey. The survey was useful to validate rail passenger's needs and expectations, enabling the design of meaningful blockchain based solutions for real company's inefficiencies. The work has proposed the Trenitalia S.p.A.'s adoption of two different blockchain implementations: 1) The tracking of both the railway infrastructure and train maintenance operations; 2) A digital ticketing platform.

Trenitalia S.p.A. provides a safe and sustainable form of transport across the country. Inevitably, this level of safety comes with an associated cost, and balancing safety requirements, performances and costs is one of the key challenge the company has to address daily. Despite being the safest way of travelling in Italy for years, questions around safety have also plagued Trenitalia S.p.A.. Therefore, the company has always involved in researching projects to search for new technologies, that can reduce the train derailment risk and improve its safety policies and practices.

On the other hand, Trenitalia S.p.A., as many other rail operators, suffers from significant costs of irregularities and severe passengers' dissatisfaction which are always more and more demanding for high quality services. Thus, it is indispensable for Trenitalia S.p.A. to develop new capabilities in foreseeing, avoiding, and ultimately managing disruptions. Levers for efficient disruption recovery include an appropriate investment in new technologies, that could improve the passenger's experience.

The blockchain is defined as one of the most disruptive technologies, and the two use cases proposed above allow to claim how it can enhance the creation of a new customer's experience. However, it will not completely disrupt the Trenitalia S.p.A. business model, since the proposed blockchain implementations are not going to change neither the service offering nor the revenue model. Both the proposed solutions will help Trenitalia S.p.A. to improve the quality of its services, by enhancing the safety standards, thanks to a more efficient management of the maintenance operations, and the quality of ticket's purchasing and validation services through a new digital ticketing platform.

The former blockchain implementation will bring Trenitalia S.p.A. the solution to trace critical assets maintenance information, by effectively enabling the company to have a clear and transparent real time view of each maintenance activity required. Therefore, the maintenance blockchain based platform will build much trust among the stakeholders through a transparent asset maintenance information sharing. Moreover, it will speed up the maintenance processes, reducing the recovery times of trains at the maintenance shop, and more importantly share a certified proof of maintenance activities execution with passengers.

The latter blockchain use case, on the other hand, will be critical to manage and prevent disruptions, carrying out solutions to train delays and other ticket's related issues in an automatized and more efficient way. Passengers are always more and more demanding for faster and more efficient rail tickets purchases and validation services. The proposed digital ticketing platform will enable Trenitalia S.p.A. passengers with a new digitalized ticket purchase, and validation experience. They are not restricted anymore to use only one device as a validation proof for their travel, but inspectors can check the validity of tickets on different smart devices and at any time, speeding up all the tickets validation operations.

