Potential Categories for the Application of Blockchain in Intelligent Transportation Systems (ITS)

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16. Abstract

The purpose of this document is to summarize for the United States Department of Transportation's (U.S. DOT's) Intelligent Transportation Systems Joint Program Office (ITS JPO), the potential blockchain applications in ITS categorized based on Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) taxonomy. The applications are selected based on the literature review of existing blockchain applications, conceptual use cases and pilot projects; relevance with U.S. DOT's strategic goals and research and development plans; and inputs from U.S. DOT.

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Executive Summary

The modern surface transportation system can be characterized as a collection of mobile and stationary entities signaling and exchanging information related to system control (i.e., a traffic signal indicating a protected left-hand turn is now allowed), near-term intent (e.g., an arm signal from a cyclist), vehicle priority (i.e., flashing red lights on an emergency vehicle), and status (e.g., Basic Safety Message). In addition, this complex ecosystem includes myriad exchanges of value within the system for transportation services (i.e., transit or taxi fares), vehicle rental, roadway access, parking, and tolling. Such a system yields millions of interactions between entities: vehicles, pedestrians, cyclists, delivery trucks, parking meters, fare payment systems, or entities coordinating the use of a shared resource, such as curb space or road access itself. Blockchain, or distributed ledger technology (DLT), can play an important role in enabling new decentralized systems of transaction with desirable attributes related to trust, enforceability, traceability, and privacy.

The report provides an overview of the current state of blockchain technology in the transportation industry through a literature review of existing applications, use cases, and pilot studies. Based on the findings, relevance with the U.S. DOT's strategic goals, and inputs from U.S. DOT, 15 potential blockchain applications specific to intelligent transportation systems (ITS) have been proposed and analyzed in detail, including summary description, potential stakeholders, benefits, and categorization based on the National ITS Reference Architecture (ARC-IT). The report serves as a resource for transportation agencies and industry professionals looking to understand and explore the use of blockchain in ITS.

The first two potential blockchain applications relate to streamlining trip planning and payment. A ***multimodal trip planning and fare payment system*** blockchain application is proposed which would allow users to plan, book, and pay for a multi-leg trip or journey from an origin to a destination. All data involved would be integrated into a decentralized ledger based on data sharing agreements via smart contracts. Users would be able to plan and book their multimodal trip from a variety of options integrated into the blockchain application rather than booking multiple trips on different platforms. Similarly, a ***peer-to-peer mobility/ridesharing service*** blockchain application is proposed. This blockchain-based system would allow for a more equitable distribution of fare/revenue and commissions and this system would be executed through smart contracts to allow for commission free peer-to-peer transactions.

The next potential blockchain applications fall into the category of improving the environmental sustainability of the transportation system. A ***congestion pricing*** blockchain application to manage travel demand is suggested in which the blockchain's DLT would be applied to back-office tolling processes and would record all toll transactions for all congestion pricing strategies on a blockchain. This would be executed and validated through smart contracts. The next blockchain application proposed is for the physical management of, and potential payment to, virtual power plants (VPPs) comprised of personally- and fleet-owned electric vehicles (EVs) or other distributed energy resources. The blockchain application would authorize EV owners, homeowners, office buildings, retail, and parking managers, etc. to securely send energy back to the electric grid during peak demand periods. The blockchain could also simultaneously track the financial transactions associated with that exchange of electrons. All the transactions would be recorded on an immutable and decentralized ledger. Lastly, an ***environmental gamification and/or carbon trading blockchain*** application would allow transportation agencies and

auto manufacturers, among other stakeholders, to incentivize participating drivers for eco-friendly driving behavior. The application would have the potential to allow state/local agencies and transportation authorities to encourage and promote sustainable transportation options by introducing emissions-based carbon trading, such as giving credit for eco-friendly travel and collecting carbon tax as a function of environmental emissions such as CO_2 produced by vehicles.

Parking management and commercial vehicle operation blockchain applications are proposed next. A potential blockchain based ITS application is for ***parking and curb space management*** that dynamically manages parking and curb spaces by allowing the participants to reserve and pay for a space in advance for various needs in a secure, transparent, and efficient manner. Also, in case of increased or competing demand for a curb space, claims could be resolved by awarding the space to the highest bidder executed by smart contracts. Following this application, a ***statewide truck parking information systems (TPIS)*** blockchain application is discussed. This blockchain application seeks to provide reliable and real-time truck parking information for both public and private rest areas along with amenities, such as shower facilities, places to eat and sleep, etc., to the truck drivers via a DLT platform that integrates data from ITS sensors. The application could also streamline transactions using a decentralized ledger that allows drivers to reserve and pay for a parking spot at private rest areas. Another blockchain application, ***freight management*** system is explored which aims to track packages and freight shipments by establishing a single source of truth on a blockchain ledger.

The following potential blockchain applications fall into the category of traffic and data management. First, a ***usage-based fees*** application proposes a blockchain-based DLT platform for assessing and collecting usage-based fees as a function of vehicle miles traveled (VMT) or kilowatt hours of electricity used to charge EVs. The platform will utilize blockchain's DLT platform to assess, collect, and validate transactions and fees associated with road usage defined by smart contracts among various entities such as tax collection agencies, State/Federal Government, and participating road users. Second, a potential blockchain based ITS application for ***traffic signal control*** is also suggested. This blockchain application proposes data exchange existing on a decentralized platform in conjunction with data analytics capabilities. Data from detectors leveraging DLT coupled with AI/ML technology for outlier/malfunction detection, and detector diagnostics can make traffic operations more resistant from attacks, exploitation of vulnerabilities and poor-quality data. Furthermore, performance measures/metrics can notify agencies to optimize the traffic control in real time as well as incorporate citizen requests in a blockchain thus improving the targeted maintenance, improved operations, and increased safety. Third, a potential blockchain application in ***emergency evacuations operations*** is considered. This application proposes a coordinated multi-agency response to large-scale hurricane evacuations and track progress of evacuation strategies on a decentralized blockchain ledger. Creating a secure and decentralized communication network allows emergency management agencies and state/local DOTs to communicate and share information in real-time during an emergency evacuation.

Next, potential blockchain applications are proposed for ***incident/crash reporting***. The solution to incident/crash reporting is to use a blockchain to mitigate issues pertaining to unreliable vehicle reports. A blockchain based incident and crash reporting can significantly enhance the coordination between various entities involved, thus improving the overall transparency and efficiency, and reducing hassle in retrieving incident reports. In a distributed ledger, once the incident report is verified and added, all parties involved in the blockchain have access to important records (based on the set permissions) thus streamlining the process.

Another potential application is for ***security and credentials management (SCMS).*** Among the potential SCMS-related blockchain applications, one of the more likely ones is DLT used to automate the certificate revocation process and speed up the approval of the infrastructure owner operators (IOOs) Certificate Revocation List (CRL) requests. A blockchain-based CRL creates confidence in the way untrustworthy devices/certificates are added. Smart contracts will be used to ensure requests to revoke or re-enroll certificates meet the pertinent requirements for the request to be granted. This will eliminate the wait for the SCMS Operations' staff approval, resulting in a more accurate and timelier list.

The last two potential blockchain based ITS applications are for ***asset management*** and ***road weather management***. Asset management application proposes to manage agency's physical assets such as traffic signals, bridge and roads inventories and communication networks using a DLT where assets are maintained and tracked on a decentralized ledger allowing agencies to share information with other agencies. Lastly, road weather management blockchain application would integrate weather data collection from various sources to communicate safe, reliable, and validated alerts and advisories to the drivers. Participating drivers and vehicles equipped with OBUs can communicate roadway hazardous conditions to the maintenance and operations center so that timely response measures are taken. The decentralized nature of blockchain network can enhance the security and validity of travel advisories since data from various sources is collected and can be verified on a blockchain network.

Chapter 1. Introduction

The purpose of this document is to summarize the potential blockchain applications in ITS categorized based on Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) taxonomy for the United States Department of Transportation's (U.S. DOT's) Intelligent Transportation Systems Joint Program Office (ITS JPO). ARC-IT provides a common basis for planners and engineers to conceive, design, and implement ITS systems using a common language as a basis for delivering ITS, making the systems more interoperable (ARC-IT, 2022). The applications in this report are selected based on a literature review of existing blockchain applications, conceptual use cases and pilot projects; relevance with U.S. DOT's strategic goals and research and development plans; and inputs from U.S. DOT. The application summaries include the context and background description for proposed blockchain application in ITS, status of application (pilot, deployment ready, use case/conceptual, etc.), potential benefits of application, potential stakeholders and system users, U.S. DOT's role (i.e., facilitates, provided funding, etc.), alignment with the U.S. DOT's strategic goals, and relevant ITS taxonomy from ARC-IT.

Blockchain Technology

To identify potential blockchain applications in the transportation and ITS industry, it is important to review some basic definitions and terminologies related to blockchain technology. Several blockchain technology definitions have emerged since its inception. For this document, the resources from International Business Machines (IBM) are utilized to define blockchain, the importance of blockchain, key elements of a blockchain, types of blockchain as well as benefits of blockchain.

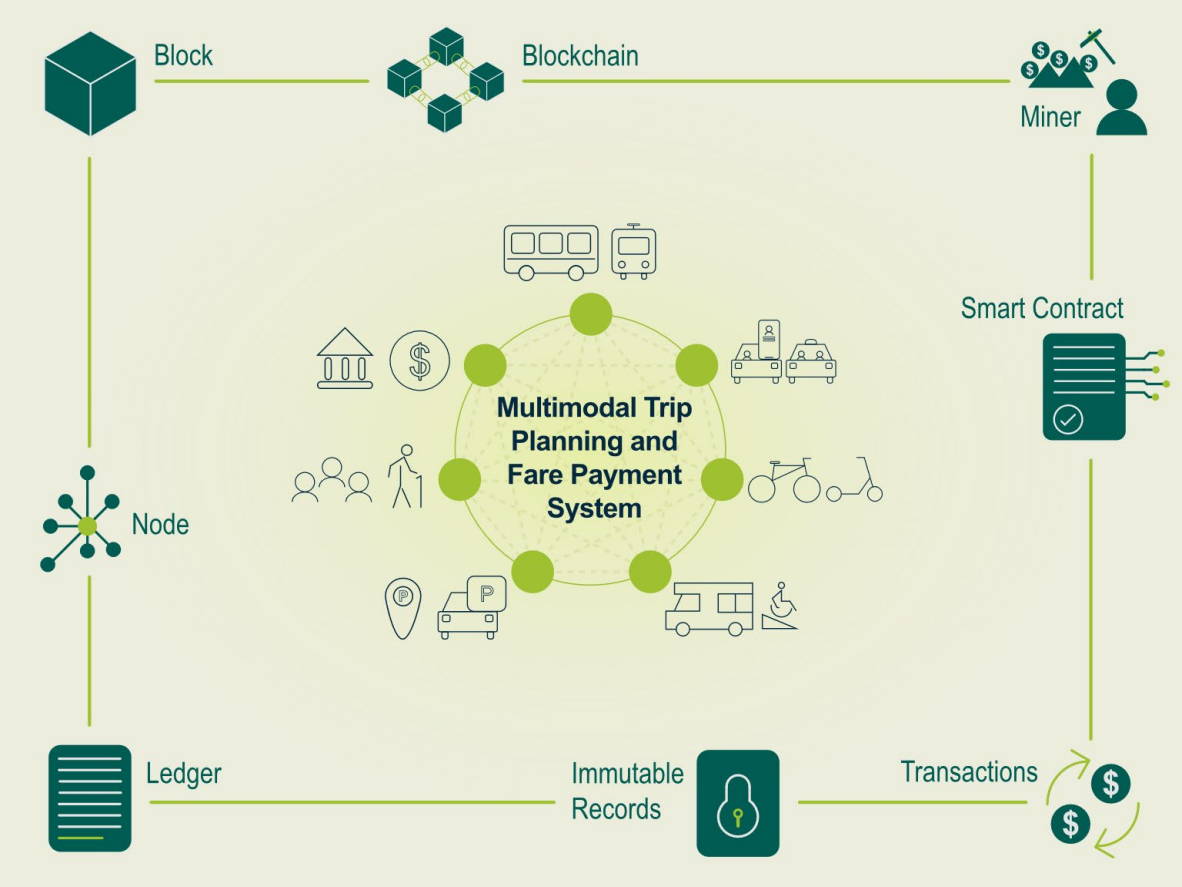
Simply put, a blockchain is made up of blocks, which contain information and are chronologically connected through peer-to-peer nodes. New blocks are created when new information is added or if previous information is modified. The information in those blocks is secure because a blockchain is a shared, immutable ledger that requires a consensus on data accuracy from all network members. A blockchain facilitates the process of recording transactions and tracking assets in a business network, and all validated transactions stored are immutable because they are recorded permanently. An asset can be tangible (a house, car, cash, land) or intangible (intellectual property, patents, copyrights, branding). Virtually anything of value can be tracked and traded on a blockchain network, reducing risk, and cutting costs for all involved.

Key Elements of a Blockchain

The blockchain is often interchangeably referred to as distributed ledger technology (DLT). DLT, immutable records, and smart contracts are the key elements of a blockchain. In a distributed and decentralized ledger, all network participants have access to the distributed ledger and its immutable record of transactions meaning no participant can change or alter a transaction after it has been recorded to the shared ledger. The access can be restricted based on permissions granted by the ledger administrators. Smart contracts refer to a set of rules, simple if/then statements, that are stored on a blockchain and executed automatically once the predetermined conditions are met. They are typically

used to automate the execution of an agreement so that all participants can be immediately certain of the outcome, without any intermediary's involvement or time loss. Within these agreements, participants must determine how transactions and their data are represented on the blockchain, agree on the if/then rules that govern those transactions, explore all possible exceptions, and define a framework for resolving disputes.

Blockchain miners authenticate, validate, and add the transactions to the ledger based on the smart contracts, and are connected to each other forming a chain. A hashing algorithm converts the transaction data into hashed values, making the data more secure as hashing data cannot be decrypted or reverse engineered. below shows the conceptual representation of key blockchain elements with an application of blockchain to facilitate multimodal trip planning and payment processing. A blockchain-based trip planning and payment processing application is comprised of various stakeholders representing multimodal transportation services such as transit authorities (i.e., bus, train, etc.), transportation network companies (TNCs), micro-mobility service providers (i.e., bike-sharing), parking management centers, paratransit, end users (including older adults and people with disabilities), financial institutions, etc. The application summary for a blockchain-based multimodal trip planning and fare payment system is provided in Chapter 4.



Source: Noblis, 2023

Figure 1. Blockchain Defined (Use Case: Multimodal Trip Planning and Fare Payment System)

Types of Blockchain Networks

There are four main types of blockchain networks: public, private, permissioned, and consortium blockchain. A public blockchain network is one with no authorized authority, that anyone can join. While anyone can join this blockchain network, a public blockchain is still secure due to the high number of nodes. A blockchain with many nodes is more difficult to hack because each block is connected, which makes it difficult to tamper with a single record. If a hacker wanted to hack a blockchain, they would need to change the block containing that record, as well as those linked to it to avoid detection. In addition to security, the advantages to a public blockchain are openness and transparency for users, while the disadvantages are scalability and energy consumption.

In contrast, a private blockchain network is a decentralized, peer-to-peer network controlled by one authority. This authority controls who is, and is not, allowed to join the blockchain. Private blockchains can be more secure because of this. However, due to the limited number of nodes, there is a higher risk of someone on the inside disturbing the blockchain. A benefit of this blockchain is that with less nodes a private blockchain is very fast and scalable.

A permissioned blockchain network is a combination of a public and private blockchain. This type of network places restrictions on who is allowed to participate in the network and in what transactions. Participants need to obtain an invitation to join, making this type of blockchain network very secure.

Lastly, a consortium blockchain is controlled by multiple organizations who have the authority to determine who may submit transactions or access the data. Similar to a private blockchain, a consortium blockchain controls who is, and is not, allowed to join the blockchain, also making it secure. This type of blockchain is ideal for businesses when all participants need to be permissioned and have shared responsibility for the blockchain.

The Potential for Blockchain in ITS and Transportation

Centralized nature of existing transportation/ITS applications often leads to insufficiencies such as, limited coordination among mobility service providers, unauthorized access to data leading to data breaches and tampering, vulnerability to cyberattacks, as well as increased time to resolve payment conflicts. For example, mobility service providers often operate in silos (i.e., less integrated with other modes of transportation) with centralized access to the mobility data leading to fewer trip options for the public (end users). Users must book and pay for multiple legs of a one-way journey using different applications due to lack of coordination among modes which can lead to unpleasant mobility experience and discourage the use of shared mobility options, including transit. A credit card transaction may take several days to process which includes authorization, authentication, clearing and settlement. The delays are even higher when it comes to credit card disputes and settlement. There is a great potential with blockchain to address some inefficiencies and security issues within ITS. As an example, a credit card company can work with the user's bank in an efficient manner and eliminate pending transactions. Additionally, blockchain's DLT can speed up the transactions via a set of rules, as governed by smart contracts, making the systems more efficient by executing these processes automatically. Centralized databases are often prone to cyberattacks and frauds. The decentralized, encrypted, and immutable nature of a blockchain ledger can yield greater trust and security. Many of the current ITS applications involve maintaining centralized databases (i.e., real-time traffic data, incidents, crashes, asset management, etc.), real-time transactions (i.e., transit fares, digital tickets, parking fee, etc.), as well as credential management (i.e., security credential management system (SCMS) for connected and autonomous

vehicles). Blockchain has a potential to improve the insufficiencies in the transportation/ITS sector by increasing agencies' efficiencies, building trust, transparency, traceability, and enhancing the security of our transportation systems.

In this document, we will provide an overview of existing blockchain applications, use cases and pilot projects in the larger transportation industry and within ITS. We will also utilize the National ITS Reference Architecture (ARC-IT), including service areas and service packages to categorize and provide summary descriptions for potential blockchain applications in ITS.

Organization of the Report

This document is organized into the following chapters:

- **Chapter 2.** – This chapter summarizes the literature review conducted of existing blockchain applications, use cases and pilot projects in transportation and ITS specific applications.
- **Chapter 3.** – This chapter identifies opportunities for blockchain applications in ITS sector and provides a mapping of potential blockchain applications based on ITS ARC-IT taxonomy and relevance to U.S. DOT's strategic goals.
- **Chapter 4.** – This chapter provides one-page summaries of potential blockchain applications identified in chapter 3.
- **Chapter 5:** – This chapter provides the conclusive remarks and next steps in the pipeline for this project.

Chapter 2. Literature Review

This chapter provides a literature review of existing blockchain applications in transportation and ITS specific applications. The information presented comes from various blockchain use cases, existing applications and pilot studies discussing various attributes like application/use case type, underlying problems where blockchain technology has potential to offer solutions, and any risks or potential barriers in the deployment or acceptance.

Existing Blockchain Applications and Use Cases in Transportation

The International Transport Forum (ITF), an intergovernmental organization with 62 member countries, highlighted several use cases for blockchain use in **transportation, logistics, supply chain, and freight** (ITF, 2021). The global supply chain is comprised of a complex web of actors and can contain costly inefficiencies such as: exhaustive documentation to track orders and shipments, reliance on third parties to ensure accountability and verification, invoices containing inaccurate or falsified data, and difficulty in locating individual shipping containers among many. Blockchain's DLT has been suggested as a means of addressing these supply chain challenges by establishing a single source of truth and enabling peer to peer (P2P) transactions for various documentations and processes. Blockchain's decentralization, encryption, and immutability have been promoted as a means to avoid the shortcomings of centralized databases, such as access rights and the reliance on a single party to validate information (ITF, 2021).

Blockchain has already begun to be implemented in the automobile supply chain. Poor visibility into the automobile manufacturing chain and the lack of a transparent and dependable system to test and verify parts, such as odometers, and prevent regulators from identifying bad actors and holding them accountable. This inefficiency is estimated to cost businesses and consumers billions of dollars per year (ITF, 2021). The ITF discussed using a blockchain-based platform to address these **automobile industry** challenges, by maintaining encrypted, immutable data on a decentralized ledger to mitigate parts fraud. A blockchain platform known as VerifyCar, created by BMW and tech developer VeChain, seeks to resolve these problems by decentralizing the storage of vehicle data, such as odometer readings and parts repair history (*How Blockchain is Changing Mobility*, 2019; VeChain Foundation, 2019). Through the blockchain platform, car owners, manufacturers, dealerships, insurance companies and mechanics no longer possess their own duplicative and partial copies of vehicle records. Instead, they may rely on the VerifyCar's ledger to establish an authoritative single-source history.

Blockchain is also revolutionizing **parcel shipping** by providing a solution for order tracking and authentication. A blockchain ledger can record and store all information pertaining to a transaction and acts as a single source of truth for customers, sellers, customs officials, and delivery services (*QAD Precision*, 2022). Smart contracts can reduce fraud by recording and verifying all aspects of a transaction. A company based out of Los Angeles, California by the name of Shipchain has developed a platform using blockchain to support the end-to-end shipping process. This blockchain platform shares the location and condition of goods with all the companies and organizations involved to make it easier to trace the

origin of goods and improve supply chain efficiency through a track-and-trace system (*Blockchain in Logistics*, 2021).

Another use case for blockchain is its potential to solve **last mile delivery**, the final leg of a parcel's journey. Inefficiencies in this phase include missed deliveries, package theft, and repeated unsuccessful delivery attempts that contribute to congestion and pollution (ITF, 2021). A decentralized last mile solution can help regulators reduce congestion and pollution, minimize delivery disputes, grow courier job market alongside e-commerce, and combat monopolization of delivery services (ITF, 2021). A logistics start-up known as NextPakk, is aiming to solve last-mile challenges through DLT smart contracts. Blockchain smart contracts is used to support secure P2P transactions between couriers and end-customers directly. Instead of trucks attempting all-or-nothing deliveries along fixed routes irrespective of customer schedules, packages can be left in NextPakk storage lockers in case a customer misses a delivery or prefers to pick it up in person (ITF, 2021). This platform provides a secure and convenient way to ship packages while reducing the risk of theft through its smart contracts systems which hold both payment and courier collateral.

Blockchain can also streamline the global movement of freight and digitize international trade by being used for **freight management**, alleviating many of the frictions in global trade logistics including procurement, transportation management, track and trace, customs collaboration, and trade finance (DHL, 2018). To unlock efficiency in ocean freight, Maersk and IBM started a venture to establish a global blockchain-based system for digitizing trade workflows and end-to-end shipment tracking (DHL, 2018). This blockchain-based system allows all stakeholders in the supply chain to view the progress of goods, the status of customs documents, and the bills of lading at any time. A similar effort by DLT Labs was adopted by Walmart Canada in 2020; the company's product, a system called DL Freight, acts as a ledger hosting all documents and data associated with freight shipments to allow for real-time shipping charge calculations and automated verification supported by **Internet of Things (IoT)** devices (Smith, 2020). According to a news release, the system—which takes advantage of the single-source-of-truth nature of blockchain technology—was responsible for reducing payment disputes with third-party carriers by 97 percent. Other research focuses on the potential of blockchain to impact maritime freight management, which has similar intensive requirements for paperwork and coordination that may be alleviated by the transparency brought by a blockchain ledger (Irannezhad, 2020).

The Airport Cooperative Research Program (ACRP) identified potential use cases for blockchain technology at **airports** (Sangan, 2021). Airports are highly transactional places, handling identity verification, flight coordination, and payment information. Incorporating blockchain technology to safely execute these transactions, assuming buy-in from the regulatory and financial institutions, has the potential to result in a wide variety of benefits. Potential impacts across management, operations, and technical infrastructure readiness include the increased availability of self-service options for passengers, powered by biometric token identifiers; cybersecurity improvements for data transfers; and a self-service focused approach to data processing that can increase efficiency.

In the field of air freight, SkyCell is a deployed pilot project with IoT and blockchain-enabled **refrigerated air freight containers**, specifically intended for biopharmaceuticals. Slight changes in pH, temperature, and environmental contaminants can make a pharmaceutical product ineffective and dangerous, making the transportation of these goods difficult and costly. The SkyCell cloud platform records documentation like bills of lading and customs forms for each container in a shipment on a blockchain ledger, providing a level of supply chain visibility (serving as a chain of custody) and security that complements the container's temperature security (*Big Data in Pharma,* n.d.). These ledgers may be used by

manufacturers and purchasers to verify the contents of the containers and to assess whether shipping conditions were sufficient to maintain product safety and efficacy.

Existing Blockchain Applications and Use Cases in ITS

Although blockchain technology has recently been getting more attention and acknowledgement in the ITS industry, there are very limited blockchain applications currently in real-world testing or deployment. This literature review predominantly captures conceptual use cases and potential applications articulated by researchers and industry experts for blockchain potential to revolutionize the ITS industry. Some of the pilot studies are also included in this section.

Emerging ITS applications, such as Adaptive Traffic Signal Control, Intelligent Intersections, Connected and Autonomous Vehicles (CAVs), and others, involve data and information exchange between multiple road users, traffic operators and roadside infrastructure devices such as roadside units (RSUs) and smart traffic controllers. This exchange of information is vulnerable to cyberattacks, malicious users, and the dissemination of false information, especially in the context of CAVs. Several use cases have been discussed by researchers to address vulnerabilities in the **data security** in a blockchain context. Li et al., 2019, proposed a blockchain based architecture for **traffic signal control systems** involving the use of signal phase and timing (SPaT) data. The architecture introduces a customized blockchain network for connected vehicles and a consensus protocol design for validation of source data through RSUs and witness vehicles. Astarita et al., 2020, discussed the potential of blockchain-based traffic operations system to promote cooperation among the connected vehicles. The system allows for incentivizing the drivers when they are willing to share the travel data such as floating car data (FCD) which can be used by traffic management centers (TMCs) in implementing traffic control strategies. Fernández-Caramés and Fraga-Lamas (2018) discussed the potential of blockchain to track, process, and exchange transactions among **IoT connected systems** overcoming the limitations of traditional approaches such as centralization, privacy and security concerns and cybersecurity threats. The authors proposed a blockchain network for data acquisition of driving events (i.e., mileage, speed, location) and safety/maintenance events (i.e., incident, accident warning, scheduled maintenance, etc.) shared among the authorized stakeholders. In a 2019 paper, Su et al. proposed a blockchain-based approach with **attack mitigation** to secure ITS networks. ITS technologies such as RSUs, traffic cameras, sensors and detectors, and traffic controllers share information with the goal of improving road safety, traveler mobility, and the overall efficiency of the transportation system. With an abundant amount of data being generated and exchanged among various entities in an ITS network, maintaining the integrity, authenticity, and non-repudiation of information for continual verification is of paramount importance. The authors proposed a blockchain-based architecture for ITS **information sharing** among entities to mitigate common types of cyberattacks and system weaknesses, such as record tampering, compromised logic, or rogue sensor data.

The ITF also identified use cases for blockchain application in **Mobility as a Service** (MaaS), **ride-hailing services** and **micropayment systems** (ITF, 2021). Mobility service providers are often reluctant to share mobility-related data, concerned about reduced revenue from competitors' access to such data (ITF, 2021). This leads to inefficiencies in transportation systems, with travelers receiving suboptimal service owing to reduced coordination between modes and providers; for example, private mobility services may not make trip information available to trip planning apps, making it more difficult for travelers to determine the best option for their route. The forum presented a use case for a blockchain-based platform, a MaaS marketplace, which integrates mobility data from multiple service providers and

optimizes trip planning for travelers while ensuring fair revenue allocation to providers and increased transparency for all parties. Forum participants do acknowledge that such a system would only work if mobility providers were willing to share data and are well integrated into the MaaS marketplace system. DLT's unique ability to facilitate secure data sharing and enforcing agreements based on smart contracts, can address trust issues that currently hamper MaaS deployment, allowing sensitive information to be exchanged between providers and users. Other benefits of blockchain include the ease of payment systems, where users can book and pay for multi-leg journey fares on a blockchain application rather than issuing multiple payments for different modes and mobility services, increasing convenience and customer satisfaction.

The International Association of Public Transport's (UITP's) report on distributed ledger technology in public transport sector presented several use cases for blockchain including **smart mobility, MaaS** and **shared mobility**, **peer-to-peer (P2P) system ridesharing**, and **autonomous driving** (Gambetta et al., 2022). The blockchain applications in a public transportation context can allow data sources from multiple mobility service providers to be connected using a cryptographic chain of trust, securing the data exchange between entities, authorities and system users, and enhancing the customer experience by provision of multiple trip options and recording transactions in a traceable and immutable manner (Gambetta et al., 2022). The report also presents a case study on a **P2P ridesharing system** with more equitable distribution of fares, revenues, and commissions. The existing model for ridesharing services includes a commission-based platform where riders pay a percentage of their revenue as commission, leading to higher fares and less revenue for the individual drivers using the platform to render mobility services to customers. The use case presented a blockchain-based system executed through smart contracts that allows commission-free P2P transactions under the umbrella of an authority setting the necessary regulatory framework.

The European Union (EU) funded a pilot project (known as CRITICAL-CHAINS) to increase the transparency and traceability of **toll transaction** by recording transactions on a blockchain (*Blockchain Makes Road Tolls More Secure,* 2021). Toll systems are prone to fraud, cyberattacks, hacking, system exploitation, and phishing emails affecting both infrastructure owner operators (IOOs) and system users. A technology consulting company named Indra was contracted to add a new blockchain-based transaction capability for tolling applications. The pilot solution is currently being deployed on Monterrey-Saltillo highway in Mexico. The solution is designed to not change the end-user experience of paying for tolls; all technical modifications are applied to the back-office transactions to avoid introducing friction to customers.

The increased telemetry capabilities of connected vehicles offer an opportunity to provide drivers individualized feedback on their driving habits. This, in combination with blockchain technology to verify results and manage a system of rewards, may be used to promote specific driving behaviors, whether the intended outcomes are safety, emissions reductions, or any other targets that an agency or vehicle manufacturer may wish to reach. One example of such an implementation was a promotional pilot operated by Daimler AG, a car manufacturer (Coin Insider, 2021). In 2018, it selected a pool of drivers to participate in a competition where they would earn cryptocurrency coins in exchange for environmentally friendly driving habits as reported by their vehicle's sensors. Participants could compete with other drivers to score points, and the coins could be redeemed with the manufacturer for rewards such as tickets to sporting events.

Chapter 3. Categories of Potential Blockchain Applications

This chapter identifies the opportunities for blockchain applications in the ITS industry which are categorized based on the taxonomy from ARC-IT service areas. As there can be several blockchain applications within the ITS context, the proposed applications are selected based on stakeholder inputs and relevance with U.S. DOT's Strategic Goals of safety, economic strength and global competitiveness, equity, climate and sustainability, transformation, and organizational excellence (FY 2022-26 U.S. DOT Strategic Plan). Furthermore, the potential applications are prioritized based on how well they align with U.S. DOT's research and development plans of improving mobility, reducing congestion, preserving the environment, and reducing transportation cyberattack risks (*49 U.S.C. Chapter 65, Section 6503, n.d.*). The detailed application summaries for each of the potential applications identified in this chapter are discussed in Chapter 4.

National ITS Reference Architecture (ARC-IT)

ARC-IT provides a common framework for planning, defining, and integrating intelligent transportation systems representing a broad cross-section of the ITS community including practitioners, systems engineers, developers, technology specialists, consultants, etc. (ARC-IT, 2022). ARC-IT provides a common framework and language for planners and engineers to design and deliver ITS systems. This report categorizes potential blockchain applications based on ARC-IT service areas as shown in Table 1. ARC-IT service areas are further decomposed into service packages that represent slices of the Physical View that address specific services, like traffic signal control, and are grouped into 12 service areas as follows (Source: ARC-IT, 2022):

- **Commercial Vehicle Operations:** This area addresses the management of the efficiency, safety, and operation of commercial vehicle fleets and the movement of freight. It includes activities that expedite the authorization process for freight to move across national and other jurisdictional boundaries, activities that expedite inter-modal transfers of freight and the operation of freight vehicles that exchange information on the motor carrier, the vehicle, and the driver.
- **Data Management:** This area addresses the management of data that can be used by some or all transportation agencies and other organizations to support transportation planning, performance monitoring, safety analysis, and research. Data is collected from detectors and sensors, connected vehicles, and operational data feeds from centers.
- **Maintenance and Construction:** This area addresses the monitoring, maintaining, improving, and managing of the roadways physical condition and its associated infrastructure equipment, as well as the available resources necessary to conduct these activities.
- **Parking Management:** This area addresses the management of parking operations including both space management and the electronic payment for parking. This area supports communication and coordination between equipped parking facilities and regional coordination between parking facilities

and traffic and transit management systems. It includes monitoring and managing parking spaces and in lots, garages, and other parking areas and facilities as well as loading/unloading zones.

- **Public Safety:** This area addresses the management by public safety agencies of emergencies or incidents in the transportation network. It covers public safety (police, fire, and emergency medical services) agencies using emergency management services to improve their response to emergency situations. The area also addresses how emergency operation centers interact with transportation and public safety agencies to support response to disasters and evacuations impacting the transportation network.
- **Public Transportation:** This area addresses the management, operations, maintenance, and security of public transportation to enable them to provide transit services that operate in a timely and efficient manner, as well as delivering operational information, which includes multimodal information to the operators and users. This area covers both fixed route and demand response systems, as well as those passenger rail systems operated by transit agencies.
- **Support:** This area addresses monitoring, maintaining, and managing of the connected vehicle system which includes, centers, field equipment, vehicles, and traveler devices. In addition, it covers the security and privacy of the communications in the connected vehicle environment as well as fundamental services, such as location and data distribution, that support the full range of ITS services.
- **Sustainable Travel:** This area addresses the operation of transportation system to minimize the environmental impact. It promotes a transportation system that balances accessibility, mobility, protection of human safety and environment. It covers all aspects of a transportation system from optimizing traffic signals and ramp meters, managing HOV/HOT lanes, monitoring vehicle emissions and managing vehicle electric charging stations.
- **Traffic Management:** This area addresses the management of the movement of all types of vehicles, travelers, and pedestrians throughout the transportation network. It deals with information collection, dissemination, and processing for the surface transportation system. It covers both automated monitoring and control activities as well as decision-making processes (both automated and manual) that address real-time incidents and other disturbances on the transportation network, as well as managing travel demand as needed to maintain overall mobility.
- **Traveler Information:** This area addresses the provision of both static and dynamic information about the transportation network to users, both prior to and during their trips. It includes information about multi-modal options and transfers and the status of other transportation modes for use by the users. Providing static and dynamic signage information directly to drivers through in-vehicle devices is also covered by this area.
- **Vehicle Safety:** This area addresses the vehicle's safety for automated, connected, and non-equipped vehicles. Its focus is on the enhancement of safety, security, and efficiency in vehicle operations, by warnings and assistance to users or input to the operation of the vehicle.
- **Weather:** This area addresses activities that monitor and notify users and transportation network managers of weather and environmental conditions that have an impact on the road transportation network and its users.

Categorization of Blockchain Applications

Table 1 below shows the 15 potential blockchain applications in ITS selected based on relevance to the U.S. DOT's strategic goals and R&D plans and are categorized based on the ARC-IT service areas mentioned above. Each application is supported by one or more service areas, for example, a blockchain-

based **Multimodal Trip Planning and Fare Payment System** is supported by service packages from both the ***Public Transportation*** (i.e., PT04: Transit Fare Collection Management, PT08: Transit Traveler Information, etc.) and ***Traveler Information*** (i.e., TI06: Dynamic Ridesharing and Shared Use Transportation, etc.) service areas. The detailed individual summary descriptions for these applications are provided in Chapter 4 of this report wherein high-level user needs, system overview, potential stakeholders, anticipated benefits, and relevance to U.S. DOT's strategic goals, among others, is discussed.

Table 1. Categorization of Potential ITS Blockchain Applications Based on ARC-IT Service Areas

Potential Blockchain Application	ARC-IT Service Areas Categorization
Multimodal Trip Planning and Fare Payment System	Public Transportation, Traveler Information
Peer-to-Peer Mobility/Ridesharing Services	Traveler Information
Congestion Pricing	Sustainable Travel, Traffic Management
Usage-based Fees	Traffic Management
Traffic Signal Control	Data Management; Traffic Management; Vehicle Safety
Transportation-based Virtual Power Plant with Payment	Sustainable Travel
Environmental Gamification and Carbon Trading	Sustainable Travel
Road Weather Management	Maintenance and Construction, Weather
Emergency Evacuation	Public Safety, Traffic Management
Incident/Crash Reporting	Support, Traffic Management
Freight Management	Commercial Vehicle Operations
Statewide Truck Parking Information Systems	Commercial Vehicle Operation, Parking Management
Parking and Curb Space Management	Parking Management
Asset Management	Maintenance and Construction, Support
Security and Credentials Management	Support

Source: Noblis, 2023

Chapter 4. Summaries of Blockchain Applications

Summary Overview

The 15 applications defined in Chapter 3 are elaborated in more detail below. Selected application summaries defined in this report will be further expanded into operational concepts in a future report to inform U.S. DOT decision making on which applications may benefit the most from federal research and investment. U.S. DOT may "down select" to a smaller number of promising applications between this report and a future report.

Each of the following application summaries contains the following attributes:

- **Name:** This is a short name for the application described, highlighting the primary functionality.
- **Context:** This section provides additional context and background for how the application applies to the existing transportation/ITS industry and briefly describes how the application might work.
- **Status:** Defines whether the application has been deployed, is being piloted, or is a conceptual use case. A distinction is also made whether pilot/deployment is implemented with a blockchain or not. Additional details are provided about the status.
- **Stakeholders:** Defines a list of potential stakeholders involved in the application/use case.
- **Benefits and Impacts:** Lists the potential benefits and impacts of a blockchain application/use case.
- **Benefit Scale:** This section highlights the anticipated benefits impact scale such as National or State level.
- **U.S. DOT Role:** This section of the application summary provides a preliminary assessment of the likely U.S. DOT role in advancing the research and development of the application summarized i.e., provide funding for pilot applications, facilitating deployments with active stakeholder community engagement, serving as a regulation authority, providing good governance, providing guidance, policies, and procedures, etc. The U.S. DOT role may change in future reports as additional research, use case analysis, and stakeholder engagement is conducted.
- **U.S. DOT Goals:** For each application, any relevant U.S. DOT strategic goals that are aligned are referred to in the application summaries. These strategic goals include safety, mobility, economic strength and global competitiveness, equity, climate and sustainability, transformation, and organizational excellence.
- **ITS Service Area(s):** This section identifies the primary ITS Taxonomy service areas, taken from National ITS Architecture (ARC-IT), that are most closely aligned with each application. One application can be categorized using multiple service areas depending on the purpose and function of application.

- **ITS Service Package(s):** The most relevant ITS packages for corresponding service areas, taken from ARC-IT, that support a particular application under discussion.
- **ARC-IT Gap(s) Identified:** This section captures an initial list of potential gaps in the National Architecture that may need to be filled or further refined to support state, regional, and local implementations of the blockchain applications as an integrated part of their ITS architecture and in an interoperable way.

Application Summaries

The following tables each summarize one potential application of blockchain to ITS aligned with the structure defined in the previous section.

Table 2. Summary Description of Multimodal Trip Planning and Fare Payment System

Item	Description
Name	Multimodal Trip Planning and Fare Payment System
Context	A blockchain-based multimodal trip planning application that allows users to plan, book, and pay for a multi-leg trip or journey from an origin to a destination. Data from transit authorities, transportation network companies (TNC), parking authorities/management centers, and other mobility services providers such as micro-transit, bike sharing, carsharing etc., is integrated into a decentralized ledger based on data sharing agreements via smart contracts. Users can plan and book their multimodal trip from a variety of options integrated into the blockchain application rather than booking multiple trips on different platforms. Furthermore, users only need to make a single (total) payment to a blockchain-based application which automatically splits the revenue to the service providers executed by smart contracts. For example, a user selects a multimodal trip itinerary through a blockchain-based application with bike sharing as a first leg (origin to transit station) and metro trip (transit station to Destination) as a second leg.
Status	**Deployed without Blockchain.** The concept of mobility marketplace is not new, "Whim" and "UbiGo" are considered among the early deployers of the MaaS platform featuring a combination of public transport, taxi, car rental, car-share, and bike-share trip options. Whim operates in several cities around the globe such as Helsinki (Finland), Vienna (Austria), Tokyo (Japan), etc. Though not on a blockchain, the MaaS platform serves as a mobility marketplace. A blockchain-based MaaS **pilot** project (Citopia MaaS) is currently active where users can plan/book multimodal trips with Citopia's blockchain-based platform (Mobiwp, n.d.).
Stakeholders	Transit authorities, TNCs, mobility and micro-mobility service providers, parking authorities, rental companies (carshare, bikeshare, etc.), end users (travelers), financial institutions (payment processing)
Benefits and Impacts	• Users benefit from only needing a single payment method that is interoperable between regions, so it can also be used when traveling to another marketplace's service area. • The integration of multiple mobility service providers into a single, decentralized blockchain platform allows users with more mobility options, fare split/allocation of revenues among participating mobility providers, and increased security of the system.
Benefit Scale	National
U.S. DOT Role	Facilitate development of interoperable, replicable models for local/regional implementation
U.S. DOT Goals	Mobility, Equity, Climate and Sustainability, Transformation
ITS Service Area(s)	Public Transportation, Traveler Information

Item	Description
ITS Service Package(s)	• **Public Transportation:** PT01: Transit Vehicle Tracking, PT02: Transit Fixed-Route Operations, PT03: Dynamic Transit Operations, PT04: Transit Fare Collection Management, PT07: Transit Passenger Counting, PT08: Transit Traveler Information, PT14: Multi-modal Coordination, PT17: Transit Connection Protection, PT18: Integrated Multi-Modal Electronic Payment • **Traveler Information:** TI06: Dynamic Ridesharing and Shared Use Transportation
Gap(s)	No service packages identified to support and integrate bike/car rental and shared micro-mobility service options such as bicycles, e-bikes/e-scooters, personal mobility devices, etc.

Source: Noblis, 2023

Table 3. Summary Description of Peer-to-Peer Mobility/Ridesharing Services

Item	Description
Name	Peer-to-Peer Mobility/Ridesharing Services
Context	A blockchain-based system for peer-to-peer mobility/ridesharing services that allows for a more equitable distribution of fare/revenue and commissions (Gambetta et al., 2022). This system is executed through smart contracts which allow for commission free peer-to-peer transactions under the umbrella of a legal authority. Current peer-to-peer ridesharing applications have high fees due to the involvement of intermediaries and a lack of transaction transparency. By removing those intermediaries and creating a decentralized platform, there is now transparency in pricing and increased economic opportunity. This system will work by storing all profile information for the driver and the rider in InterPlanetary File System (IPFS), with addresses hashed and stored on the permissioned blockchain. Through smart contracts, the legal authorities involved will perform background checks on those profiles. Additionally, ride information will be stored on the distributed ledger, which is visible to everyone. This allows for transaction transparency because the rider will be able to view reasons for the decided ride price, as well as alternative rides available. Payment will then go straight from the rider's wallet to the driver's wallet, for a commission free transaction (Takyar, 2018).
Status	**Conceptual Use Case with non-Blockchain Implementations.** There is no shortage of research in the technical implementation or socio-behavioral aspects of this blockchain application. Auer et al., 2022 presented an architecture for a blockchain-IoT-based platform for promoting shared mobility and explored how blockchain and IoT technologies together can advance shared mobility forward. TNCs such as Uber and Lyft are good examples of ridesharing implementations without a blockchain. A blockchain-based P2P ride-hailing company called **Drife** started its operation in an Indian city of Bangalore connecting riders with drivers without intermediaries (*Web3 Ride-Hailing App Drife,* 2022). The platform does not charge commissions on the fares to the riders and drivers get to keep the entire fare. There is, however, a monthly subscription fee to use the platform. Scalability of the blockchain platform was identified as one of the challenges as company plans to expand its operation to other cities in India.
Stakeholders	End Users, Mobility/Ridesharing Service Providers, Transit and Legal Authorities
Benefits and Impacts	Increased transaction transparency, safety, economic opportunity, and environmental sustainability.
Benefit Scale	National
U.S. DOT Role	Provide funding for pilot projects. Serve as a regulatory authority and provide policy, procedures, and guidance.
U.S. DOT Goals	Mobility, Economic Strength and Global Competitiveness, Equity, Climate and Sustainability, Transformation
ITS Service Area(s)	Traveler Information

Item	Description
ITS Service Package(s)	TI05: Travel Services Information and Reservation, TI06: Dynamic Ridesharing and Shared Use Transportation
Gap(s)	Modification to existing service packages to incorporate peer-to-peer ridesharing and transactions.

Source: Noblis, 2023

Table 4. Summary Description of Congestion Pricing

Item	Description
Name	Congestion Pricing
Context	Congestion pricing, often called value pricing, is an effective congestion mitigation strategy adopted around the world, with Singapore and Sweden as one of the early deployers of the concept. Congestion pricing encourages drivers to shift to other modes of transportation or make changes to their departure times considering majority of the rush hour drivers on a typical urban highway are not commuters (*What is Congestion Pricing*, 2022). Alternatively, congestion pricing, when it takes the form of express/tolled lanes, also allows drivers more reliability in terms of travel times. Congestion pricing strategies commonly used are High Occupancy Toll (HOT) lanes, express lanes, pricing on entire roadway facilities, zone-based (cordon and area) pricing, and regionwide pricing (*What is Congestion Pricing*, 2022). In this application, blockchain's DLT is being applied to back-office tolling processes. The software-as-a-service solution, which does not impact end-user transaction experience, will record all toll transactions for all congestion pricing strategies on a blockchain (i.e., toll lanes, HOT lanes, etc.). Transportation agencies can also provide incentive to the participating drivers via this blockchain application to avoid travel during rush hours or switch to other sustainable modes of transportation as an effective strategy to reduce congestion. This is all executed and validated through smart contracts.
Status	**Pilot (Active).** Congestion pricing technology is mature with several implementations in various jurisdictions. Blockchain for tolling pilot is currently active along the Monterrey-Saltillo highway in Mexico.
Stakeholders	State DOTs, Tolling Authorities, Freeway and Arterial Managers, Concessionaires, Drivers
Benefits and Impacts	• Enhanced security, visibility, transparency, traceability, and increased data integrity. • Reduced vulnerability to cyberattack, facilitate settlement and auditing, and more efficiently manage blocked users.
Benefit Scale	City, County or State level
U.S. DOT Role	Facilitate development of interoperable, replicable models for regional implementation for various congestion pricing strategies
U.S. DOT Goals	Mobility, Economic Strength and Global Competitiveness, Climate and Sustainability, Transformation
ITS Service Area(s)	Sustainable Travel, Traffic Management
ITS Service Package(s)	• **Sustainable Travel:** ST06: HOV/HOT Lane Management, ST07: Eco-Lanes Management, ST10: Low Emissions Zone Management • **Traffic Management:** TM10: Electronic Toll Collection
Gap(s)	N/A

Source: Noblis, 2023

Table 5. Summary Description of Usage-based Fees

Item	Description
Name	Mileage-based User Fees
Context	The Federal and State governments rely on transportation-related excise and gasoline/diesel taxes to maintain safe, efficient modes of transportation and finance highways and mass transit projects (*Mileage-Based User Fee*, 2022). With the ambitious goal of 50% EV sales share by 2030 and coupled with the fact that there has been more interest in clean energy and alternative fuel technologies, the current model of excise and gasoline taxes will not be a long-term and sustainable method to fund roads, bridges, and other critical transportation infrastructure projects. Several States are looking into alternative models for financing transportation projects. One such alternative that has been of growing interest is the introduction of road usage/mileage-based user fee which is different from congestion pricing strategies because it is based on the distance travelled (as a function of VMT) on a roadway network while congestion pricing is facility specific i.e., express lanes, managed lanes, HOT lanes, and cordon area congestion pricing *(FHWA - Tolling and Pricing Defined, n.d.)*. States are also looking to introduce EV charging station taxes where station owners and lessees must pay a combined excise tax and surface fee as a function of kilowatt hours of electricity used to charge EVs. For example, Kentucky has introduced an EV charging station tax of $0.03 per kilowatt hour of electricity used to charge EVs (Alternative Fuels Data Center, 2022). This application proposes a blockchain-based DLT platform for assessing and collecting usage-based fee as a function of vehicle miles traveled (VMT) or kilowatt hours of electricity used to charge EVs. The platform will utilize blockchain's DLT platform to assess, collect, and validate transactions and fees associated with road/charging station usage defined by smart contracts among various entities such as tax collection agencies, State/Federal Government, and participating users. While public acceptance is of utmost importance here and the concept of usage-based fee may face reluctance in public acceptance, the blockchain platform can also be used to provide incentive to the users for using public transit and other shared mobility options and/or reduce the assessed road-usage fees based on socio-economic indicators like household income, number of dependents, disability status, etc., all administered and verified on the blockchain. The application can be used for blockchain-based excise and tax collection related to vehicle sales, registration, buying and selling, etc., as well as usage-based fees as an alternative to gasoline tax for Highway Trust Fund.
Status	**Pilot (Active and Deployed without a Blockchain).** Deployment ready with strong concerns about privacy, equity, and administrative costs. Surface Transportation System Funding Alternatives (STSFA) Program has funded pilot projects in 13 individual states as well as two coalitions of states which aim to test the feasibility of regional mileage-based user fee systems (*Mileage-Based User Fee*, 2022)
Stakeholders	State/Local DOTs, Federal Government, Department of Motor Vehicles (DMV), and Financial Institutions. System users include participating motor vehicle drivers equipped with mileage tracking devices connected to the blockchain network.

Item	Description
Benefits and Impacts	• Increased transparency and traceability into road-usage fee collection, excise, and tax collection. • Increased efficiency and reduced administrative costs associated with blockchain-based automatic payment processing and validation. • Encouraging and promoting more sustainable modes of transportation. • Ability to personalize user fees based on socio-economic indicators.
Benefit Scale	National
U.S. DOT Role	Provide funding for blockchain-based road user fee pilot programs. Also helps coordinate among potential stakeholders as well as facilitate the deployment. This application is of interest to U.S. DOT and State agencies in generating revenue for Highway Trust Fund.
U.S. DOT Goals	Mobility, Economic Strength and Global Competitiveness, Climate and Sustainability
ITS Service Area(s)	Traffic Management
ITS Service Package(s)	TM11: Road Use Charging
Gap(s)	To support this application, new service packages will be required to facilitate usage-based fees collection. Moreover, some of the existing service packages such as PM03 Parking Electronic Payment and PT18 Integrated Multi-Modal Electronic Payment will need to be edited to accommodate blockchain-based payment processing.

Source: Noblis, 2023

Table 6. Summary Description of Traffic Signal Control

Item	Description
Name	Traffic Signal Control
Context	Traffic management agencies typically retime their traffic signals and optimize major corridors/arterials every three to five years. Other than scheduled optimization and signal timing updates, signal timing is evaluated on an ad hoc basis motivated by citizen requests for timing evaluation and can take a few weeks to months to address. For example, District Department of Transportation's (DDOT's) response to signal timing change request takes 30 days (*Traffic Signals DDOT*, n.d.) More recently, there has been a growing interest in the Automated Traffic Signal Performance Measurement (ATSPM) which is defined as a suite of performance measures, data collection and data analysis tools to support objectives and performance-based approaches to traffic signal operations, maintenance, management, and design to improve the safety, mobility, and efficiency of signalized intersections for all users (EDC, 2016). To ensure an efficient and adaptive signal control, detector/sensor health and quality of data collected is of utmost importance. This is specifically true for the connected vehicle operations where signal control data such as SPaT must be authenticated and validated since it is prone to cyberattacks. This blockchain application proposes data exchange such as traffic control data from detectors, SPaT messages, signal performance data, citizen requests for signal retiming evaluation, etc. on a decentralized platform in conjunction with data analytics capabilities. Data from detectors leveraging DLT coupled with AI/ML technology for outlier/malfunction detection, and detector diagnostics capability (i.e., no activity, max presence, erratic counts, etc.) can make traffic operations more resistant from attacks, exploitation of vulnerabilities and poor-quality data. Furthermore, performance measures/metrics such as arrivals on red, pedestrian/bicycle delays, split failures, detector failure, etc., can notify agencies to optimize the traffic control in real time as well as incorporate citizen requests (from multiple participants) in a blockchain thus improving the targeted maintenance, improved operations, and increased safety.
Status	**Conceptual Use Case with non-Blockchain Deployments.** Approximately 26 transportation agencies at both state and local levels are currently involved in implementing ATSPM (EDC, 2016).
Stakeholders	State and Local DOTs.
Benefits and Impacts	• Enhanced safety and mobility, targeted maintenance, and operations. • More transparency in addressing citizen requests for signal retiming and high customer satisfaction.
Benefit Scale	Corridor Level, City/Local DOTs.
U.S. DOT Role	Advance R&D, provide funding for piloting blockchain-based traffic signal control pilot projects.
U.S. DOT Goals	Safety, Mobility, Transformation, Organizational Excellence
ITS Service Area(s)	Data Management; Traffic Management; Vehicle Safety

Item	Description
ITS Service Package(s)	• **Data Management:** DM02: Performance Monitoring • **Traffic Management:** TM03: Traffic Signal Control, TM04: Connected Vehicle Traffic Signal System, TM06: Traffic Information Dissemination, TM09: Integrated Decision Support and Demand Management, TM26: Signal Enforcement, • **Vehicle Safety:** VS16: Automated Vehicle Operations
Gap(s)	N/A

Source: Noblis, 2023

Table 7. Summary Description of Transportation-Based Virtual Power Plant with Payment

Item	Description
Name	Transportation-Based Virtual Power Plant with Payment
Context	Less than 1% of the 250 million cars, SUVs, and light-duty trucks on the roads in the United States are electric (Reuters, 2022). As the market penetration for electric vehicles increases, it is expected to strain the power infrastructure especially when the number hits double digits. The existing power infrastructure coupled with scarcity of charging stations cannot cope with the increasing demand for EV charging. Thanks to the Bipartisan Infrastructure Law, an investment of $7.5 billion is expected to revamp the power grid system and build charging infrastructure at strategic, accessible, and equitable locations. While this historic investment will add more capacity and supply to meet the demand for EV charging in a strategic, phased manner, blockchain technology solutions can add more supply in a relatively short term. Built upon the blockchain platform and leveraging its P2P model, a transportation-based virtual power plant with associated payment allows utility companies to authorize EV owners, homeowners, office buildings, and retail and parking management companies to not only charge from the electric grid but also securely authorize them to send energy back to the grid during peak electric demand periods. The same blockchain may also record the associated financial transactions. The application tracks when energy is being drawn from a car's battery or when it is being charged, thus creating a history of credits and debits securely managed through blockchain technology that participants can monitor on their phones (Edwards, 2021). All the transactions (i.e., V2G, P2P, etc.) are recorded on an immutable and decentralized ledger.
Status	**Pilot (Active).** A pilot study is currently active in Toronto that utilizes blockchain technology to explore viability of V2G charging for multi-tenant office buildings where EV owners can lend electricity to the building during peak hours (Edwards, 2021).
Stakeholders	EV Owners, EV Charging Stations, Public Charging Stations (owned/operated by state/local DOTs), Homeowners, Building Owners/Operators, Retail and Parking Management Companies, IOOs, Power Utility Companies
Benefits and Impacts	• Data security privacy, transparency, visibility, and immutability for ensuring efficient, trusted, traceable, and auditable energy sourcing (Al-Saif et al., 2021). • Efficiently control and manage energy flow and associated finances between EVs, power utility companies, homeowners, and other participants • Helps accelerate real time transactions processing on a blockchain ledger with increased transparency and traceability.
Benefit Scale	National, State or Local level
U.S. DOT Role	Facilitate development of interoperable, replicable models for local/regional implementation; provide funding for EV charging infrastructure development and pilot blockchain-based transportation-based virtual power plants
U.S. DOT Goals	Economic Strength and Global Competitiveness, Equity, Climate and Sustainability, Transformation

Item	Description
ITS Service Area(s)	Sustainable Travel
ITS Service Package(s)	ST05: Electric Charging Stations Management
Gap(s)	New service package or modification to ST05 is required to accommodate V2G or P2P energy flows with payment as well as accommodate additional stakeholders such as power utility companies.

Source: Noblis, 2023

Table 8. Summary Description of Environmental Gamification and Carbon Trading

Item	Description
Name	Environmental Gamification and Carbon Trading
Context	Transportation sector accounts for the largest portion of total U.S. Greenhouse Gas (GHG) emissions with a staggering share of 27% (U.S. EPA, 2015). Within the transportation sector, light-duty vehicles account for 57% and medium and heavy-duty trucks account for 26% GHG emissions. There are several ITS strategies to limit the emissions from transportation sector such as electrification of buses (U.N. Environment Program, 2018), environmentally friendly routing guidance or eco-routing, environmentally friendly traffic signal timing (ARC-IT, 2022), driving behavior that promotes less usage of fuel like coasting and gradual acceleration/deceleration (Xu et al., 2021), etc. This blockchain applications allows transportation agencies, TMCs, and auto manufacturers among other stakeholders to reward participating drivers for eco-friendly driving behavior. The application also has the potential to allow state/local agencies and transportation authorities to encourage and promote sustainable transportation options by giving credit for eco-friendly travel and/or collecting carbon tax as a function of environmental emissions such as CO_2 produced by vehicles.
Status	**Pilot (Active).** A cryptocurrency coin using blockchain technology, dubbed "Mobicoin," was introduced in a pilot and was earned through analysis of telemetric data from participants' vehicles. Vehicle acceleration and speed were tracked, with currency being earned for relatively environmentally sound driving behavior such as coasting and gradual deceleration; the currency could then be exchanged towards reward vouchers such as sporting tickets. Pilot participants could see each other's scores and compete to earn the most coins. Another blockchain pilot project started as a part of "STARTUP AUTOBAHN" in 2020 in Stuttgart, Germany that tracks the emissions of climate-relevant gases along the complex supply chains of battery cell manufacturers (Daimler North America-Corporate Communications, 2020).
Stakeholders	Employers, State and Local DOTs, TMCs, Logistics Companies, IOOs, and Auto Manufacturers. System users include vehicle drivers and operator of vehicles with appropriate telemetric tracking.
Benefits and Impacts	Enhanced efficiency and reduced environmental impact from driving, increased engagement with driving behavior tracking applications, increased transparency on CO_2 emissions and seamless payments and claims settlement.
Benefit Scale	National
U.S. DOT Role	Facilitate development of interoperable, replicable models for regional implementation
U.S. DOT Goals	Mobility, Economic Strength and Global Competitiveness, Climate and Sustainability, Transformation
ITS Service Area(s)	Sustainable Travel

Item	Description
ITS Service Package(s)	ST01: Emissions Monitoring, ST02: Eco-Traffic Signal Timing, ST03: Eco-Traffic Metering, ST07: Eco-Lanes Management, ST08: Eco-Approach and Departure at Signalized Intersections, ST09: Connected Eco-Driving, ST10: Low Emissions Zone Management
Gap(s)	N/A

Source: Noblis, 2023

Table 9. Summary Description of Road Weather Management

Item	Description
Name	Road Weather Management
Context	Approximately 21% of the total roadway crashes in the United States are weather-related resulting in nearly 5000 casualties annually (*How Do Weather Events Impact Roads,* 2022). These weather-related crashes result from adverse weather conditions (i.e., rain, snow, fog, or floating debris) or hazardous roadway conditions (i.e., wet/slippery, snowy, or icy pavement). Agencies typically rely on weather predictions and forecasts, and data from field environmental sensor stations (ESS) to issue travel advisories to the public via dynamic message signs (DMS), plan for roadway maintenance and treatments such as salt spraying and other anti-icing material applications. The weather forecasts and data from ESS is not always accurate especially under extreme weather conditions, during power outages, with sensor malfunction and climate change (Washington Post, 2022). Furthermore, the travel advisories communicated to the public via DMS can be compromised by bad actors as has been the case with historical DMS hacks impacting the safety of critical infrastructure (Kelarestaghi et al., 2018). This blockchain application integrates weather data collection from various sources such as environmental sensors, field devices, public fleet vehicles, and vehicle OBUs that measure temperature, sense current weather conditions and vehicle operational status (i.e., use of headlights, wipers, traction control system, etc.), and local weather forecasts to communicate safe, reliable, and validated alerts and advisories to the drivers. Participating drivers and vehicles equipped with OBUs can communicate roadway hazardous conditions such as icy roads, foggy conditions, etc., to the maintenance and operations center so that timely response measures are taken. The decentralized nature of blockchain network can enhance the security and validity of travel advisories since data from various sources is collected and can be verified on a blockchain network. With multiple reports of an impending threat/hazard (i.e., slippery road conditions) by blockchain participants, maintenance crew can schedule appropriate response to weather events and conditions which can all be tracked on a blockchain making it more efficient and transparent.
Status	Conceptual Use Case
Stakeholders	State and Local DOTs, Roadway Maintenance Crew, Emergency Response Teams, TMCs, CVs, Public Fleet Vehicles
Benefits and Impacts	Improved roadway safety and operational efficiency, timely response to winter maintenance activities, and safe, reliable communication of travel advisories to the public. More transparency in the road weather management (operations and maintenance).
Benefit Scale	National
U.S. DOT Role	Facilitate the pilot deployment by providing funding for pilot projects and active stakeholder engagement.
U.S. DOT Goals	Safety, Climate and Sustainability, Transformation
ITS Service Area(s)	Maintenance and Construction, Weather

Item	Description
ITS Service Package(s)	• **Maintenance and Construction**: MC01: Maintenance and Construction Vehicle and Equipment Tracking, MC02: Maintenance and Construction Vehicle Maintenance, MC03: Roadway Automated Treatment; MC04: Winter Maintenance, MC08: Maintenance and Construction Activity Coordination • **Weather**: WX01: Weather Data Collection, WX02: Weather Information Processing and Distribution, WX03: Spot Weather Impact Warning, WX04: Roadway Micro-Prediction
Gap(s)	N/A

Source: Noblis, 2023

Table 10. Summary Description of Emergency Evacuation Operation

Item	Description
Name	Emergency Evacuation Operations
Context	The frequency and intensity of natural disasters such as hurricanes, wildfires, floods, etc. is on the rise globally. In the year 2021 alone, United States experienced 20 separate billion-dollar weather and climate disasters putting 2021 in second place for the most disasters in a calendar year (Smith, 2022). Natural disasters like hurricanes and wildfires often require large-scale evacuations of areas under threat putting a lot of strain on limited roadway network capacity. A coordinated multi-agency and strategic response is warranted for disaster preparation and recovery efforts especially in the context of hurricanes. For example, large scale evacuations in response to an impending hurricane threat (depending on the category) requires various agencies to coordinate and disseminate critical information to the public such as evacuation orders, real-time traffic information, use of operational strategies like contraflow and reversible lanes, providing food and shelter information, evacuation routes, information on evacuation zones, etc. In this application, blockchain is used to create a decentralized system for emergency management and operations with various agencies (i.e., state/local DOTs, local and federal emergency management agencies, etc.) to securely coordinate the emergency response and planning among themselves as well as communicate vital information in a trustworthy way to the public under threat from a disaster. There is a lot of uncertainty faced by the households as to whether they live in the evacuation zone or not, the nearest shelters open to public, or whether an evacuation order is real, etc. With the blockchain, agencies can share real-time data regarding evacuation zones, expected storm surge, public shelters, traffic management and operations strategies, and post disaster recovery efforts with other agencies and public. The immutable and decentralized nature of blockchain coupled with the fact that the information is coming from public officials (agencies) can reduce the uncertainty faced by households when making critical decision to evacuate or stay. The application also has the potential to improve transparency of communication as well as public trust.
Status	Conceptual Use Case.
Stakeholders	State and Local DOTs, TMCs, Federal Emergency Management Agency (FEMA), Local Emergency Management Agencies, Non-Profit Organizations (NGOs), National Hurricane Center (NHC), National Oceanic and Atmospheric Administration (NOAA).
Benefits and Impacts	• Create tamper-proof record of all evacuation-related transactions such as evacuation orders, evacuation routes, emergency resource allocation, shelter information. • Enhanced inter-agency coordination and real-time tracking of people and vehicles during an evacuation. • Tracking and monitoring the progress of evacuation and making adjustments accordingly. • Dissemination of secure/authenticated information in real-time during an emergency evacuation.

Item	Description
Benefit Scale	National
U.S. DOT Role	Facilitate the coordination with various agencies involved in emergency response and evacuations such as FEMA, State/Local DOTs, NHC, NOAA for a potential pilot study. Provide governance and guidance for a shared coordinated response to an impending disaster. Provide funding for a pilot study.
U.S. DOT Goals	Safety, Mobility, Climate and Sustainability, Transformation, Organizational Excellence.
ITS Service Area(s)	Public Safety, Traffic Management
ITS Service Package(s)	• **Public Safety:** PS01: Emergency Call-Taking and Dispatch, PS02: Emergency Response, PS04: Mayday Notification, PS05: Vehicle Emergency Response, PS06: Incident Scene Pre-Arrival Staging Guidance for Emergency Responders, PS07: Incident Scene Safety Monitoring, PS08: Roadway Service Patrols, PS09: Transportation Infrastructure Protection, PS10: Wide-Area Alert, PS11: Early Warning System, PS12: Disaster Response and Recovery, PS13: Evacuation and Reentry Management, PS14: Disaster Traveler Information • **Traffic Management:** TM01: Infrastructure-Based Traffic Surveillance, TM03: Traffic Signal Control, TM05: Traffic Metering, TM06: Traffic Information Dissemination, TM07: Regional Traffic Management, TM08: Traffic Incident Management System, TM09: Integrated Decision Support and Demand Management, TM12: Dynamic Roadway Warning, TM16: Reversible Lane Management, TM20: Variable Speed Limits, TM22: Dynamic Lane Management and Shoulder Use, TM24: Tunnel Management, TM25: Wrong Way Vehicle Detection and Warning
Gap(s)	N/A

Source: Noblis, 2023

Table 11. Summary Description of Incident/Crash Reporting

Item	Description
Name	Incident/Crash Reporting
Context	Information on a vehicle's history is not always reported accurately and this missing information, such as a vehicle's crash history, can often lead to serious risks for secondary owners. In an ideal world, all vehicle information would be stored somewhere it cannot be changed or deleted to create a more transparent and reliable depiction of a vehicle's history. The solution is to use a blockchain to solve the issue of unreliable vehicle reports (*Benefits of a Blockchain Vehicle History Report*, 2021). In addition, a blockchain based incident and crash reporting can significantly enhance the coordination between various entities involved such as law enforcement, insurance companies, DMV, etc. thus improving the overall transparency and efficiency, and reduced hassle in retrieving incident reports. In a distributed ledger, once the incident report is verified and added, all parties involved in the blockchain have access to important records (based on the set permissions) thus streamlining the process. Furthermore, insurance companies can make direct secure payments that are verified by network participants which reduces the insurance frauds and claims settlement time.
Status	**Deployed.** Carnomaly's CarrChain offers a blockchain based solution to the issue of unreliable vehicle reports. CarrChain is a web-based application that makes it simple to manage and update your vehicle's online profile. A user can aggregate their vehicle details, log maintenance activity, view vehicle recalls information, and access the current market value of their vehicle. To use this application, a user would input their unique Vehicle Identification Number (VIN) into CarrChain and CarrChain will then create a Digital Vehicle Identification Number (DVIN). The information stored in the blockchain under a user's DVIN cannot be changed or altered (*CarrChain*, n.d.).
Stakeholders	U.S. DOT (NHTSA, FHWA), DMV, insurance companies, law enforcement agencies (i.e., police), auto body shops, end users (blockchain participants)
Benefits and Impacts	Increased security, reliability, and transparency, and reduced vulnerability to frauds.
Benefit Scale	National
U.S. DOT Role	Facilitate development of interoperable, replicable models for local/regional implementation. Serve as a regulation authority and provide policy/regulations for reporting crash/incident data.
U.S. DOT Goals	Safety, Equity, Transformation, Organizational Excellence
ITS Service Area(s)	Support, Traffic Management
ITS Service Package(s)	• **Support**: SU12: Vehicle Maintenance • **Traffic Management**: TM08: Traffic Incident Management System
Gap(s)	New service packages or modification to existing ones is required to incorporate additional stakeholders such as DMV, insurance companies, etc.

Source: Noblis, 2023

Table 12. Summary Description of Freight Management

Item	Description
Name	Freight Management
Context	There is an enormous amount of information—such as contracts between partners, shipment details, scheduling, routing, and the condition of the goods themselves—associated with a freight trip (Irannezhad, 2020). Because of the extreme scale of many large freight operations, any weaknesses in the systems used to track and verify this information will immediately become apparent and will cost time, resources, and attention from shipping partners to resolve (Penske Logistics, n.d.). Disputes over terms that impact invoicing and payments can tie up revenue streams and lead to disproportionate impacts on service. Leveraging blockchain ledgers to track packages and freight trips can smooth conflict by establishing a single source of truth and thus ensuring that disputed values are able to be tracked and traced. Similarly, the information associated with each freight load, such as any underlying contracts, may be embedded in each block to ensure accuracy, mutual agreement, and ease of reference. Additional interaction with IoT devices may be used to automatically calculate the impact of delivery conditions on the final invoice (Smith, 2020). Blockchain-based freight management system solutions are already available to companies and have established the capability to scale effectively (Walmart Canada, 2020), and have potential for both overland and oversea freight movements.
Status	**Deployed.** Blockchain-based freight management systems are offered as products by some logistics firms, and several high-profile partnerships have been successfully instituted, such as with Walmart Canada. However, such solutions are still somewhat novel and the capabilities and integration with blockchain technologies are under development and expansion.
Stakeholders	Employers, Logistics Companies, IOOs, and Auto Manufacturers. System users include vehicle drivers and operator of vehicles with appropriate telemetric tracking.
Benefits and Impacts	• Improved efficiency tracking freight deliveries, vehicles, and parts due to consolidation of ledger. • Automated generation and settlement of invoices possible by incorporating payment logic into blocks. • Improved efficacy in settling disputes due to immutability of blockchain.
Benefit Scale	National Level
U.S. DOT Role	Help to coordinate between service providers and freight operators; explore integrating existing freight management software with government infrastructure to allow direct, automated communication; provide or highlight data standards and sample contracts or ledgers.
U.S. DOT Goals	Economic Strength and Global Competitiveness
ITS Service Area(s)	Commercial Vehicle Operations
ITS Service Package(s)	CVO01: Carrier Operations and Fleet Management; CVO02: Freight Administration; CVO04: CV Administrative Processes; CVO16: Electronic Driver Logs

Item	Description
Gap(s)	N/A

Source: Noblis, 2023

Table 13. Summary Description of Statewide Truck Parking Information System (TPIS)

Item	Description
Name	Statewide Truck Parking Information System (TPIS)
Context	Truck parking shortages pose a significant safety concern for commercial truck drivers. Truck drivers need access to safe, secure, reliable, and accessible truck parking spaces within the rest areas due to strict compliance to the hours-of-service regulations (*Truck Parking – FHWA Freight Management and Operations*, 2022). Tired drivers may continue to drive due to difficulty in finding a place to park or may choose to park at unsafe locations such as shoulders on entry/exit ramps, or vacant lots, if they are unable to locate official parking space posing safety hazards for truck drivers and traveling public. This blockchain applications seeks to provide reliable and real-time truck parking information for both public and private rest areas along with amenities such as shower facility, places to eat and sleep, etc. to the truck drivers via a decentralized DLT platform that integrates data from ITS sensors such as parking space occupancy detectors (Microwave radars, AI-based parking occupancy detection from CCTV cameras feeds), or loop detectors to share the status on nearby rest areas with number of available/empty parking spots. The application can streamline transactions using a decentralized ledger allowing drivers to reserve and pay for a parking spot at private rest areas as well as shop for other amenities.
Status	**Conceptual, Deployed without Blockchain.** Several deployments under the FHWA's TIGER grant funding to develop multi-state (Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Ohio, and Wisconsin) truck parking information management system (*MAASTO*, 2020)
Stakeholders	State DOTs, Private Rest Areas (i.e., Love's), IOOs, and Regulation Authorities. System users include commercial vehicle drivers and participating rest areas.
Benefits and Impacts	• Improved efficiency and utilization of parking spaces across rest areas, better asset management. • Enhanced security through decentralization, and blockchain's inherent capabilities such as smart contracts and payment automation (*Blockchain in Logistics*, 2021).
Benefit Scale	State or National Level
U.S. DOT Role	Provide funding for blockchain-based pilot projects. Facilitate the deployment with active stakeholder community engagement.
U.S. DOT Goals	Safety, Transformation
ITS Service Area(s)	Commercial Vehicle Operation, Parking Management
ITS Service Package(s)	• **Commercial Vehicle Operation:** CVO05: Commercial Vehicle Parking • **Parking Management:** PM01: Parking Space Management, PM03: Parking Electronic Payment, PM04: Regional Parking Management, PM05: Parking Reservations
Gap(s)	N/A

Source: Noblis, 2023

Table 14. Summary Description of Parking and Curb Space Management

Item	Description
Name	Parking and Curb Space Management
Context	With the proliferation of ridesharing, package and food delivery, micro-mobility services, as well as increased cycling and transit use in the dense urban environment, there is an increased demand for curb space with a limited right-of-way. This demand has resulted in competition among modes impacting the transit level of service and reliability, failed goods deliveries, roadway and curbside congestion, and illegal or double parking (Chang et al, 2022; NACTO, 2017). Public agencies are looking for innovative ways to manage the limited curb space such as shifting from parking lanes to flexible zones, clearing way for the transit, mobile parking payment applications, lane configuration at the intersection, dedicated bus and bike lanes, etc. (NACTO, 2017). While these strategies have addressed some of the issues to an extent such as illegal parking, improved transit times, reduced incidents of U-turns, and reduced pickup/drop-off activity in travel lanes, blockchain technology can offer a promising solution to dynamically manage parking and curb space in the dense urban environments and optimize the use of limited curb space in an efficient manner that is equitable for all road users. This blockchain application dynamically manages parking and curb spaces by allowing the participants to reserve and pay for a space in advance for various needs such as parking, goods delivery, loading/unloading, etc. in a secure, transparent, and efficient manner. In case of increased or competing demand for a curb space, claims can be resolved by awarding the space to the highest bidder executed by smart contracts. Furthermore, public agencies can offer incentives to the participants for utilizing nearby surface parking lots or side street parking to manage demand on the arterials/main corridors, all executed on a blockchain. The blockchain application also adds the capability to dynamically manage curb space for a variety of modalities while creating a new revenue stream to replace parking fees and introduce demand-based pricing and time limits during peak hours to discourage parking on congested corridors.
Status	**Conceptual Use Case with non-Blockchain Implementations.** Pilot Projects include Arlington County Curb Space Allocation Tool (Kittleson and Associates, 2021) and Curb Management in Washington, DC (PTP, 2019)
Stakeholders	City Parking Authorities (divisions), Local Transportation Departments, Commuter Lots, Parking Lots and Garages (public and private)
Benefits and Impacts	• Reduced time spent searching for a parking spot, increased safety, transit reliability and optimal use of limited spaces in dense urban environment. • Greater trust and confidentiality due to the immutable nature of DLT which reduces the need for enforcement.
Benefit Scale	National
U.S. DOT Role	Provide funding for blockchain-based pilot projects involving dynamic curb space management. Serve as a regulatory framework, provide policy and guidance. Engagement with stakeholder community to advance deployments.
U.S. DOT Goals	Safety, Mobility, Equity, Climate and Sustainability

ITS Service Area(s)	Parking Management
ITS Service Package(s)	PM01: Parking Space Management, PM03: Parking Electronic Payment, PM04: Regional Parking Management, PM05: Parking Reservations, PM06: Loading Zone Management
Gap(s)	A new service package or modification to existing parking space management service packages is required to accommodate dynamic usage of curb spaces.

Source: Noblis, 2023

Table 15. Summary Description of Asset Management

Item	Description
Name	Asset Management
Context	Transportation Asset Management (TAM) is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle (State of California, n.d.). Public agencies such as state and local DOTs maintain detailed inventories of their physical assets such as traffic signals and controllers, roads and bridges, pavements, field equipment and devices, power/communication networks, etc. This blockchain application proposes to manage physical assets and detailed inventories using a DLT where all the agency's assets are maintained on a decentralized ledger. The physical assets along with detailed history such as manufacturing, maintenance logs, technicians who installed/updated/repaired the equipment, diagnostic information, software and configuration updates, service logs as well as upcoming/scheduled maintenance can be tracked via a blockchain application. The application can also be used for vehicle fleet maintenance such as routine and corrective maintenance activities on vehicles and, maintenance and construction equipment.
Status	Conceptual Use Case.
Stakeholders	Public agencies such as State and Local DOTs.
Benefits and Impacts	• Efficiently maintaining the history of transportation/ITS assets (i.e., manufacturing and ownership, service calls, scheduled maintenance, etc.) • Improved inter-agency coordination and sharing of assets/resources i.e., shared Fiber Optics network. • Maintaining physical asset inventories (i.e., aging infrastructure such as bridges, bridge inspection reports, etc.)
Benefit Scale	City/County/State
U.S. DOT Role	Provide funding for conducting pilot studies and build partnerships with other public agencies such as State/Local DOTs.
U.S. DOT Goals	Organizational Excellence
ITS Service Area(s)	Maintenance and Construction, Support
ITS Service Package(s)	• **Maintenance and Construction:** MC01: Maintenance and Construction Vehicle and Equipment Tracking, MC02: Maintenance and Construction Vehicle Maintenance, MC09: Infrastructure Monitoring, MC10: Asset Tracking • **Support:** SU10: Center Maintenance, SU11: Field Equipment Maintenance, SU12: Vehicle Maintenance, SU13: Personnel Device Maintenance
Gap(s)	N/A

Source: Noblis, 2023

Table 16. Summary Description of Security and Credentials Management (Certificate Revocation List only)

Item	Description
Name	Security and Credentials Management (Certificate Revocation List only)
Context	The Security Credential Management System is a Public Key Infrastructure (PKI) solution for secure and pseudo-anonymous V2X communication and certificate management. The SCMS has misbehavior detection capabilities to identify messages that lead to false warnings and can adversely impact vehicle safety. If a vehicle on-board unit (OBU) or RSU device is misbehaving, the device's current and future certificates are added to a Certificate Revocation List (CRL) and blacklisted by the SCMS registration authority (RA). In this application, Blockchain DLT can be used to augment the misbehavior detection and certificate revocation process of SCMS across states. Currently, there is one CRL and devices have to download the latest version of the list to know which vehicles are untrustworthy. This will not be efficient when the SCMS system scales to the whole country and the number of connected vehicles increases. The Blockchain app will segment the CRL based on states so that devices only have access to the misbehaving vehicles in their local area. When vehicles cross state lines, they will be included in the new state's CRL and have access to that area's misbehaving vehicles. This ensures that devices only receive relevant information and the CRL is more manageable. Having a decentralized location for the CRL creates confidence in the way untrustworthy devices/certificates are added. In addition to the misbehavior detection app being able to add devices to the CRL, IOOs will be able to submit requests for devices to be added in the case that they have been compromised, stolen/lost, or sold to an organization that is not eligible to use the SCMS. Smart contracts will be used to enforce the conditions that requests need to meet for revoking certificates or re-enrolling them after the reason for being revoked is proven to be corrected. This will eliminate the wait for the SCMS Operations' staff approval, resulting in a more accurate and timelier list.
Status	Conceptual Use Case
Stakeholders	U.S. DOT (FHWA/Volpe/NHTSA), Crash Avoidance Metrics Partners (CAMP), Integrity Security Services (ISS), Auto Manufacturers, Traffic Management and Operations Centers
Benefits and Impacts	• Increased security, visibility, and traceability of revoked certificates. • Increased efficiency and reduced administrative costs associated with adding certificates to the CRL and re-enrollment. Increased scalability and manageability of the CRL
Benefit Scale	National
U.S. DOT Role	Piloting blockchain based certificate revocation application. Providing policy and procedures for deployment.
U.S. DOT Goals	Safety, Efficiency
ITS Service Area(s)	Support

Item	Description
ITS Service Package(s)	SU1: Connected Vehicle System Monitoring and Management, SU8: Security and Credentials Management
Gap(s)	N/A

Source: Noblis, 2023

Chapter 5. Conclusions and Next Steps

This report summarized 15 potential blockchain applications and use cases in the ITS industry which were categorized using the taxonomy from ARC-IT. High level user needs, application context and background, potential benefits and impact scale, potential stakeholders, application status, and the role and interest of U.S. DOT in advancing the blockchain applications in ITS was discussed. The selected use cases serve U.S. DOT's strategic goals across multiple ARC-IT service areas such as public transportation, traveler information, sustainable travel, parking management, traffic management, data management, maintenance and construction, and weather applications. Blockchain technology has the potential to revolutionize ITS systems by improving the security, visibility, transparency, and traceability of transactions involved in our day-to-day mobility needs. Many of the insufficiencies in the operations and management of existing ITS systems can be improved by blockchain technology's seamless and fast transaction processing, increased auditability, and automation in the form of smart contracts.

The summary applications for use cases documented in this report is the first step towards developing a program plan for research, development, and deployment of ITS JPO's Blockchain for ITS Program. In the subsequent reports, foundational research will be conducted to develop operational concepts for blockchain applications identified in this report. These operational concepts may include user needs analysis and assessment, conceptual drawings, operational objectives, enabling technologies, enabling policy, institutional arrangements, business models, strategic and tactical measures, performance measures, decision support, data needs, and stakeholder communication. Challenges and barriers to implementation, including operational, technical, and institutional will be discussed in detail in subsequent reports.

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