Blockchain for Unmanned Aircraft Systems

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Contents

What Is a Blockchain?

A **blockchain** is an immutable, time-stamped digital ledger that is distributed and managed by a cluster of computers and allows digital information to be distributed but not copied [14]. Blockchain technology readily allows for the introduction of trust into a group or network. As such, there are two essential prerequisites for a blockchain application: a business network—this can be at a local, national, or international level (e.g., a store, airline ticket agency, rental car business, real estate broker) and untrusted or anonymous participants (e.g., buyers, sellers, agents, administrators, producers, consumers, suppliers). A familiar example of these two prerequisites includes a person wanting to buy a used car from a stranger. Experts predict that the blockchain market will grow at a compound annual growth rate of close to 83 percent by 2022 [36]. The U.S. DOT Volpe Center previously reviewed the ideas behind blockchains and detailed their application to the transportation industry [31].

> *"Blockchain is poised to transform the way we think about and analyze safety data. This is particularly exciting for unmanned aerial vehicles. Blockchain can be part of the solution to collecting and sharing reliable data about drones. When you combine machine learning with the data blockchain can provide on UAS registration, accountability, and tracking, an entire world becomes available for drone safety analysis, decision making, and even regulation."*
>
> —**Regina Houston**, Chief of the Aviation Safety Management Systems Division,
> U.S. DOT Volpe National Transportation Systems Center

The Growth, Application, and Benefits of Drones

An **unmanned aircraft system** (UAS) consists of the unmanned aircraft and its associated communication links and control components required for its safe and efficient operation in the national airspace system (NAS). Often referred to as drones, the Federal Aviation Administration (FAA) began requiring the registration of unmanned aircraft systems in December 2015. Recreational (i.e., hobbyist) UAS weighing more than 0.55 pounds but less than 55 pounds are required to be registered using an online FAA system. As of the end of 2017, there were estimated to be 1.1-million recreational UASs while the projection for 2024 is in the range of 1.39 to 1.59 million [16]. The non-recreational sector is primarily commercial in nature and can be either consumer grade or professional grade. Consumer grade non-recreational aircraft are typically priced below $10,000 with an average price of around $2,500. Professional grade UAS are typically priced above $10,000, with a unit price often around $25,000. More than 110,000 commercial operators had registered their equipment by the end of 2017 with a projection of the non-recreational small UAS sector reaching over 828,000 by 2024. UAS weighing more than 55 pounds must be registered using the FAA's existing aircraft registration process (i.e., 14 CFR part 47) [18]. Many of these aircraft are operated within the NAS by federal agencies, state and local governments, and national research organizations.

> *"The steady development and expansion of Unmanned Aircraft Systems (UAS) has created a dynamic change in aviation that we have not seen since the dawn of the jet age…The progression of UAS innovation and the change in product cycles can generally be measured in months, not years. Similarly, the volume of UAS operations is outpacing manned aircraft. Currently, there are nearly four times as many UAS as registered manned aircraft."*
>
> —**Jay Merkle**, Director of the FAA Unmanned Aircraft Systems Integration Office [17]

Larger drones are undergoing experimentation in the hopes of carrying people. The Chinese drone company Ehang builds drones large enough to carry passengers and has flown thousands of test flights over the years in preparation for launching what it hopes will be the world's first autonomous air taxi service [21]. The autonomous air taxi (AAT, also called flying cars or electric vertical takeoff and landing—eVTOL—aircraft) sector continues to see growth as well as consolidation, including Terrafugia's acquisition by Volvo-owner Geely and Aurora Flight Sciences' acquisition by Boeing [41].

> *"We know that urbanization is taking place all across the world, more people are moving to urban centers and choosing to live in urban environments; we know about the shared economy, we hear about folks taking shared rides,…sharing cars; [and we know about] instant gratification,…dial it up…and it can be at the house in two hours."*
>
> —**J. Scott Drennan**, Vice President of Innovation for Bell [46]

The recreational UAS market has evolved with the advent of selfie drones and drone-racing competitions. With commercial UAS, there is a trend toward specialization in specific industries and with custom configurations. Promising commercial UAS applications include aircraft inspection [39, 22, 6], consumer and business package delivery [13, 1, 5], wildfire and emergency response [3, 15], medicine and organs for transplant delivery [20, 34, 48], rail and bridge inspection [35, 42, 27], search and rescue [44], safety and security monitoring [28], surveying [24], agriculture [2], Coast Guard inspections [45], and real estate development and sales [40]. All of these have seen some level of development and specialization, further augmented by unique aircraft configurations that have subsequently created new niches and unique selling points.

Potential UAS Challenges

Drones already have applications ranging from carrying medicine [48] and organs for transplant [38] to operating flamethrowers [26] and machine guns [33]. The number and variety of UASs and the diverse operations they are or may be expected to soon be involved in make these aircraft especially suitable to the trust and operational integrity provided by blockchains. For example, in 2019, Ghana formally launched the world's largest medical drone delivery service, with 30 fixed-wing drones making up to 600 on-demand delivery flights a day, around the clock, seven days a week, to 2,000 health facilities serving 12 million people countrywide, delivering 148 different vaccines, blood products, and other critical medications [48]. Swarms of drones can provide dramatic benefits in areas such as firefighting, but the integrity and compliance of any UAS swarm can pose challenges to bystanders, infrastructure, and controllers [47, 49]. As UASs can be remotely operated or fully autonomous, trust can be an additional concern since they are not manned. Blockchain can add trust with the use of policies and protocols. Commercial UAS applications, such as consumer and business package delivery, lend themselves to the integrity enhancements that a blockchain can provide [30]. Other challenges, such as safe and efficient air traffic management, reliable operations near high-risk areas (e.g., around crowds or airports), safety and security [49], tracking and enforcement of flight violations, or privacy and surveillance considerations, as well as vulnerabilities due to traditional meaconing, intrusion, jamming, and interference (i.e., the four types of aircraft navigation or communications interference abbreviated as MIJI [23]) could certainly benefit from the robust, trusted information a blockchain provides.

> *"Drones can fly over people and property and interfere with the operation of full-size aircraft. They could conceivably carry weapons or dangerous materials to critical locations. At a minimum, drones could take pictures, possibly committing privacy violations. There is also some concern that drones could aid in IT hacking by bringing sensors or disruptive electronics near a possible target."*
>
> —**Hy Chantz**, Associate Partner for Blockchain Solutions at IBM [7]

How Blockchain Could Support UAS Operations

Blockchain technology is being looked on to deliver a framework that can be used by stakeholders in the commercial drone industry, as it can ensure security and provide for identity management as well as providing a supporting role in aircraft traffic management, UAS conflict management, and flight authorization [11].

Blockchain has already been used to address some UAS trust and integrity issues. Flight data recorders (also known as black boxes) can provide data that could help investigators learn what a UAS was doing prior to some event or incident. A blockchain-based flight recorder would do so in real time and could also allow law enforcement to be proactive instead of reactive. One company has proposed a blockchain-based black-box UAS system that would enable industry regulators to track and review drone flight data, insurance companies to insure drones based on reliable third-party data, and pilots to ensure compliance with regulators [43].

With NASA and the FAA leading an industry-wide standardization effort for drone traffic management, in 2018 Boeing announced that it was developing a traffic management system for all drones that uses artificial intelligence (AI) and blockchain technology [8]. The system would efficiently track all drones flying through chosen traffic corridors. It would also blend a standardized programming interface to uphold industrial inspection, package delivery, and other important commercial applications. Google's Project Wing tried out its own UAS air traffic control (ATC) platform with plans to leverage the company's cloud computing infrastructure to handle the expected large volume of flight paths and adjust them in fractions of a second [29]. NASA has proposed a blockchain-based framework for the FAA-mandated automatic dependent surveillance broadcast (ADS-B) system to enable aircraft privacy while preventing spoofing, denial of service, and other risk factors [37].

Walmart has a plan for a network of autonomous robots controlled and authenticated through a blockchain network [9]. Their patent application for a blockchain-based authentication system allows mobile autonomous electronic devices to identify and communicate with each other to minimize the times at which components of the delivery process have to be trusted [4, 51]. Walmart's proposal documents a system in which multiple robots handle the delivery of a package throughout different legs of the supply chain using wireless signals to communicate and authenticate the identity of one another [27].

> *"In case of a package delivery operation, a blockchain-based repository could log information about the operations such as time, location, resources, delivery date, etc., and make the data accessible to authenticated users, and any other stakeholders along a package's route."*
>
> —**Amit Ganjoo**, Founder and CEO of ANRA Technologies [30]

IBM obtained a patent that uses blockchain for drone fleet security [50]. Their blockchain ledger would store data associated with UAS flights, ensuring that air traffic controllers could supervise an ever-increasing number of drones. The chain would be a chronicle of each UAS's path through time. When a transaction is conducted, the corresponding UAS parameters would be sent to one or more of the computing nodes in the system for validation and generate a new block. Once the new block was calculated, it would then be added to the stakeholder's UAS blockchain. Among many other advantages, the use of a blockchain infrastructure helps in identifying non-compliant UASs as such activities are recorded in a protected ledger. The permissioned blockchain could include variable block times that change in response to environmental triggers. For instance, if a recreational drone flies too close to a restricted flight zone, it could trigger a risk flag, increasing the network's time to provide airspace controllers with increased data on the UAS and, if applicable, its operator [50].

Machine learning for drone navigation and data analytics is also driving numerous developments. Along with AI, blockchain is seen as a way to make drones more secure and easier to regulate and monitor [12]. Blockchain is also being used to address drone cybersecurity concerns such as flight over people and property, and interference with the operation of commercial aircraft, as well as to address privacy considerations [7]. Blockchain can provide security by ensuring confidential and secure communications [12]; encrypted blockchain identifiers enable flexibility in establishing trust models across different devices. For example, a blockchain-based repository for package delivery could log information about the operation—such as time, location, resources, and delivery date—and make the data accessible to authorized users [12].

A Blockchain/Drone Case Study

While not every UAS operation may require, or even justify, the use of a blockchain, some are especially suited to this type of secure and accessible data storage. An example of this might be the case of using a UAS for organ transfer [10]. With many people either involved in or affected by this type of mission, a range of interdependencies, and a variety of safety and efficiency considerations including medical and air traffic issues, organ transfer by UAS makes for a particularly diverse case study of the use of blockchain with UAS.

Organ delivery by drone was first seen in April 2019 with the delivery of a donated kidney, and resulting successful transplant. The people involved described the many challenges with conventional organ transfers that can be addressed with the use of UAS. The group's leader, Dr. Joseph Scalea, an assistant professor of surgery at the University of Maryland School of Medicine, sought out the use of UAS in organ transfer after frustration with the amount of time this process traditionally took [52]. As soon as the organs are removed from the donor, they become progressively less and less healthy, so the time of transfer is critical to the success of the surgery. Detailing a 29-hour kidney transfer he was involved with, he lamented, "Had I put that in at nine hours, the patient would probably have another several years of life." This organ delivery flight took about five minutes [52].

Not only is time an issue, but another concern is that the enroute organ's progress is not normally known by the receiving hospital. And, while typically donor organs are delivered by chartered or commercial flights, issues can include air-traffic caused delays and even the organ being left on a plane [38]. About 1.5 percent of donor organ shipments did not make it to their intended destination, and nearly 4 percent had an unanticipated delay of two or more hours, according to the United Network for Organ Sharing [38].

Adding blockchain to this process adds provenance to the organ as well as the drone. For example, adding blockchain could involve up to five different entities and as many as five separate data sets. The devices, people, or organizations (i.e., the actors) involved could include ATC, the drone operator, the drone itself (including the attached container housing the organ for transplant), the hospital supplying the organ, and the receiving hospital (i.e., demanding) the organ. Each requires varying levels of access to the blockchain ledger (i.e., some need to read to the blockchain, some need to write to the blockchain, and some need to do both). The data streams could include the UAS's position (e.g., course, speed, altitude, etc.); the UAS's intent (i.e., planned, subsequent route and altitudes); the UAS's status (e.g., fuel level or state of charge, etc.); the organ itself (e.g., the donor's blood type and age, time of harvesting, etc.); and the organ container onboard the drone (e.g., the container's temperature, humidity, vibration level, etc.). See the table below.

Actors and Types of Data Needed by Each

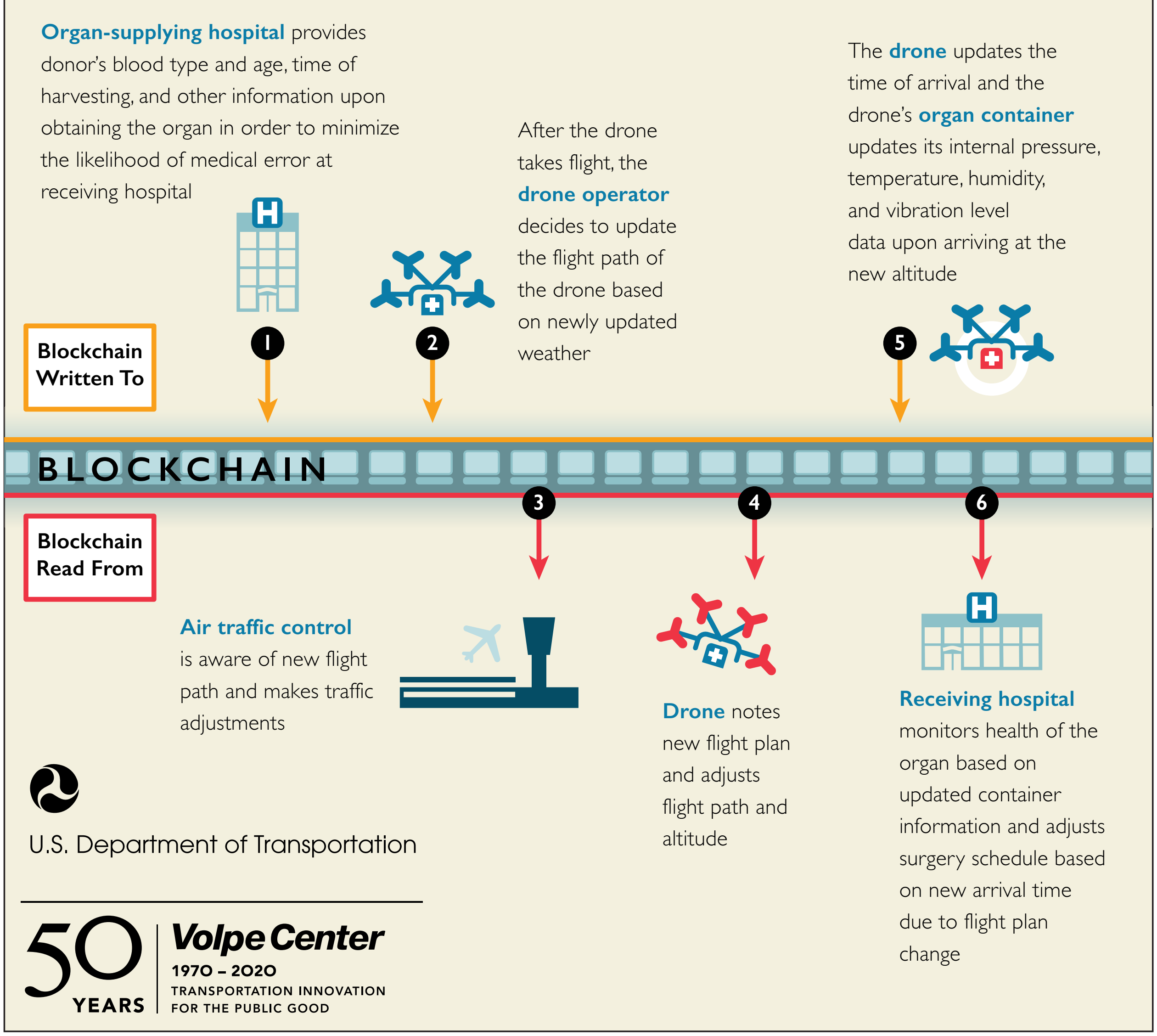
Information stored on the blockchain	Actors that need to view some of the data on the blockchain	Actors that need to contribute data to the blockchain
• Position	• ATC • Operator • Hospital (demanding)	• Drone
• Intent	• Drone • ATC	• Operator
• Drone status	• Operator	• Drone
• Organ	• Hospital (demanding)	• Hospital (supplying)
• Container	• Hospital (demanding) • Hospital (supplying) • Operator	• Drone

For example, using "intent," the drone operator could add a new route (based on weather changes for example) and the drone and ATC could see the flight path/flight plan change. Other details of these relationships can be seen in the figure.

In this case study, not only is a range of valuable information readily available, but it is also trusted, which is critical in both aviation operations and medical procedures, especially with the added complexity of a rapidly evolving, sensitive, and time-critical sequence as would be the case for an organ transfer by drone.

Blockchain/UAS Case Study Example

The different actors and their actions or types of data needed in the case of a route and altitude adjustments due to a change in weather for the organ transfer by drone.



Issues and Future Efforts

Future drones show much promise in a wide range of industries, while the lack of an onboard pilot and the inherent level of automation make trust a significant issue in their widespread acceptance and integration. In addition, the use of AI may require regulations: uniform rules that go beyond industry best practices. Blockchains might be part of successful and effective regulation, ensuring that machines operate in a trustworthy manner through the use of monitoring via a blockchain-protected recording of their activity.

> *"The next phase of the aerospace industry will include commercial aircraft, helicopters, and many different kinds of drones in all shapes and sizes. For drones to have equitable access to airspace, the industry will require reliable and immutable data to ensure accountability and trackability."*
>
> —**Jeff Thompson**, CEO of Red Cat **[25]**

Novel tasking such as drone logistics services, automated business-to-business delivery, high-altitude pseudo-satellite drones **[32]**, medical deliveries as seen in Europe and Africa, UAS-based warehousing, drones as a service, counter-UAS, and air taxis readily demonstrates the hopeful future of UASs. With these increasingly diverse UAS applications and operations comes increased risk, some of which may be mitigated with the use of blockchains.

Appendix A: How Blockchains Actually Work

While the benefits of using a blockchain are well known, how blockchains create a list that can be seen and added to but not changed may not be so clear.

Basically, each new entry on a ledger is a block of information, copies of which exist on multiple computers. A hash (a mathematical process that takes data of any size or type and maps it to a sequence of individual fixed-size values) is performed on each block of information. The output of the hash function produces a number (which is also referred to as a hash) that acts as a key. This key becomes the first entry in the next linked block so going back later and changing the contents of the earlier block would also change its key, which would affect the first entry in the next block and therefore its key, and so on. This dependent connection of block-content-derived hashes ensures the integrity of the chain. An elegant description from a defense-industry publication [19] describes the blockchain process:

> *"So what is blockchain technology? At its core, a blockchain is a distributed ledger for recording transaction data. A ledger is a recorded list of transactions. Traditional paper-based ledgers include consecutive pages where each line records a transaction and when the page is full, the process repeats on the next page. With many blockchains, each block is like a page. Transactions get verified by a consensus mechanism specified by the blockchain protocol. Validated transaction data is written into a block and time-stamped. When the block is full a new block is created. Unlike traditional ledgers, when a block is filled, the system creates a hash value, which is just a random [looking] number generated by an algorithm based on the contents of the block. This hash value is then written as the first entry in the new block, thereby "chaining" together the blocks, hence the term "blockchain." If someone ever attempts to change an entry in a prior block, the hash value would no longer match what was written into the subsequent block and that attempt would be deemed invalid. In part, this is how blockchain creates immutable records. Only validated transaction data is recorded and time-stamped, and this data cannot be altered."*

This process results in a list that is immutable (i.e., unchanging; this is enabled by the hashing of a block's contents along with the linking of the blocks by writing that hash to the next block); distributed (i.e., storing copies of the blockchain at multiple locations and under the control of multiple entities; this avoids single points of failure or the need to rely on and trust any single authority); transparent (i.e., depending on the level of desired privacy, the data on a blockchain can be visible to all interested participants); and auditable (i.e., any transaction is stored in a serial, time-stamped, immutable manner that facilitates auditing and reporting) [19].

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