Land Forces Academy Review
Vol. XXIX, No. 3(115), 2024

THE IMPACT OF BLOCKCHAIN ON CRITICAL TRANSPORT INFRASTRUCTURE – THE CASE OF AVIATION

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ABSTRACT

Critical Infrastructures produce critical goods and services for society and cover a wide range of sectors according to the governance frameworks in place in the United States, in the European Union (EU) and in EU Member States including Romania. Aviation is a particular case for the critical transport infrastructure, with a high degree of technical complexity, economic productivity and complex supply and production chains. Blockchain or Distributed Ledger is an already famous digital emerging technology with the possibility of disintermediating numerous system processes, thereby reducing costs, increasing security and reducing risk in a world where cumbersome and expensive intermediaries are required for trust in all sorts of transactions. This article provides a brief overview of the critical air transport infrastructure and of the blockchain technology, traces the possible uses of blockchain in aviation, gives real world examples and concludes with recommendations for practitioners moving forward.

KEYWORDS: blockchain, critical air transport infrastructure, aviation, economics, resilience

1. Introduction

Air transport is a vital element of the globalized world, providing the transport of people, good and equipment safely and quickly in almost any area of the world. Even though far more goods are transported by sea, the value of goods transported by air is also very high, because air transport occupies the trade segment for time-sensitive (or perishable), low volume, low weight, high value density items. Therefore, while only 2-3% of cargo volumes are transported by air each year, air freight accounts for 35% of cargo value (Turner, 2021). The rapid transport of people makes the global tourism industry possible and also the high degree of interconnectedness that facilitates global migration, business travel and family relationships. Globally, IATA (2024) states that air traffic at the end of 2023 represented 94.1% of air traffic in 2019, marking an almost complete recovery from the coronavirus pandemic that devastated international travel. Year-on-Year growth was 36.9% between 2022 and 2023, with December 2023 being 25% above December 2022 and 98% of December 2019 traffic. Many countries have important domestic air travel and freight markets, but international traffic was

DOI: 10.2478/raft-2024-0045

at 88.6% of 2019 levels in 2023. To this, we can add the importance of air transport capabilities to military operations, especially when it comes to rapid deployment and supply chains, which means that the resilience of the associated infrastructure is of the utmost importance.

This shows that air transport is not only a big business, but a vital part of the world economy. This article traces the systemic interpretation of air transport as a branch of the Critical Transport Infrastructure (CTI), namely Critical Air Transport Infrastructure (CATI). Our approach is based not on traffic according to passenger kilometer revenue, as in the IATA model, but in describing the assets, infrastructures and resources that enable the CATI to function at a high level of security and economic efficiency. CATI is one of the most complex and technology intensive sectors of Critical Infrastructures (CI) (Vamanu et al, 2016). CI are socio-technical systems encompassing technical elements, facilities, assets, distributed machinery, communication links but also organizations operating them, and whose disruption or destruction would cause significant loss of human life, material damage, loss of capability and loss of confidence (Jungwirth et al, 2023). CATI is particularly vulnerable due to the high complexity of its components systems and infrastructures and the risk of catastrophic damage should anything occur, which is why resilience through security-conscious digitalization is a priority for the sector (Bucovetchi et al, 2019).

This systemic view enables us to analyze the potential role of Distributed Ledger Technology (DLT) or blockchain in opening up new areas of growth, efficiency or value creation, as well as resilience and security enhancement. By necessity, this perspective is mainly economic and civilian, but many blockchain applications for CATI are also relevant for the Armed Forces, just as the technology tree and critical infrastructures partly overlap. For instance, DLT technologies can make complex logistics chain more robust to interference and to specific concerns such as proliferation issues and sanctions busting. Human error and intentional data sabotage can be prevented through DLT, increasing resilience However, the innate conservativeness of the defence sector and the necessity to rely on proven technologies will delay adoption until the impact on the civilian CATI sector has been measured, especially from a security perspective, beyond doubt. In the interest of space, we will not present a detailed literature review of the blockchain technology, its types, and definitions. It suffices to say that the operating principle for DLT is in widely distributing a database and validating changes to it with all or most of the network participants through the use computationally intensive methods (Dinu & Vasile, 2023) (though now there are methods such as proof-of-stake and proof-of-authority that require much less energy or computing power than the first generation blockchains (Baboi, 2023). This allows a widespread, anonymous yet trustworthy validation method for any number of operation types that can be reduced to ledger consultation and modification through the exchange of tokens (Vasile & Dinu, 2021). The natural initial application consisted of financial products, especially cryptocurrencies, where the tokens are the money itself, and subsequent DLT projects have financialized their tokens to drive an economy of interest that brings enough nodes and computing power to make their blockchain viable. However, blockchain today can be used in the running of smart contracts, in the tracing of product origin for logistics, in decentralized marketplaces, in the validation of credentials and much more (Vasile & Dinu, 2021; Dinu & Vasile, 2023). Though less spectacular, the systemic impact they may have in case of widespread adoption can be much greater.

Our research shows Blockchain applications can have an extensive positive impact on a number of different CI sectors, transport included.

2. The Critical Air Transport Infrastructure

Figure no. 1 shows a detailed breakdown of an air transportation hub with critical infrastructures, key assets and key resources, highlighting also important aspects related to economic and security governance.

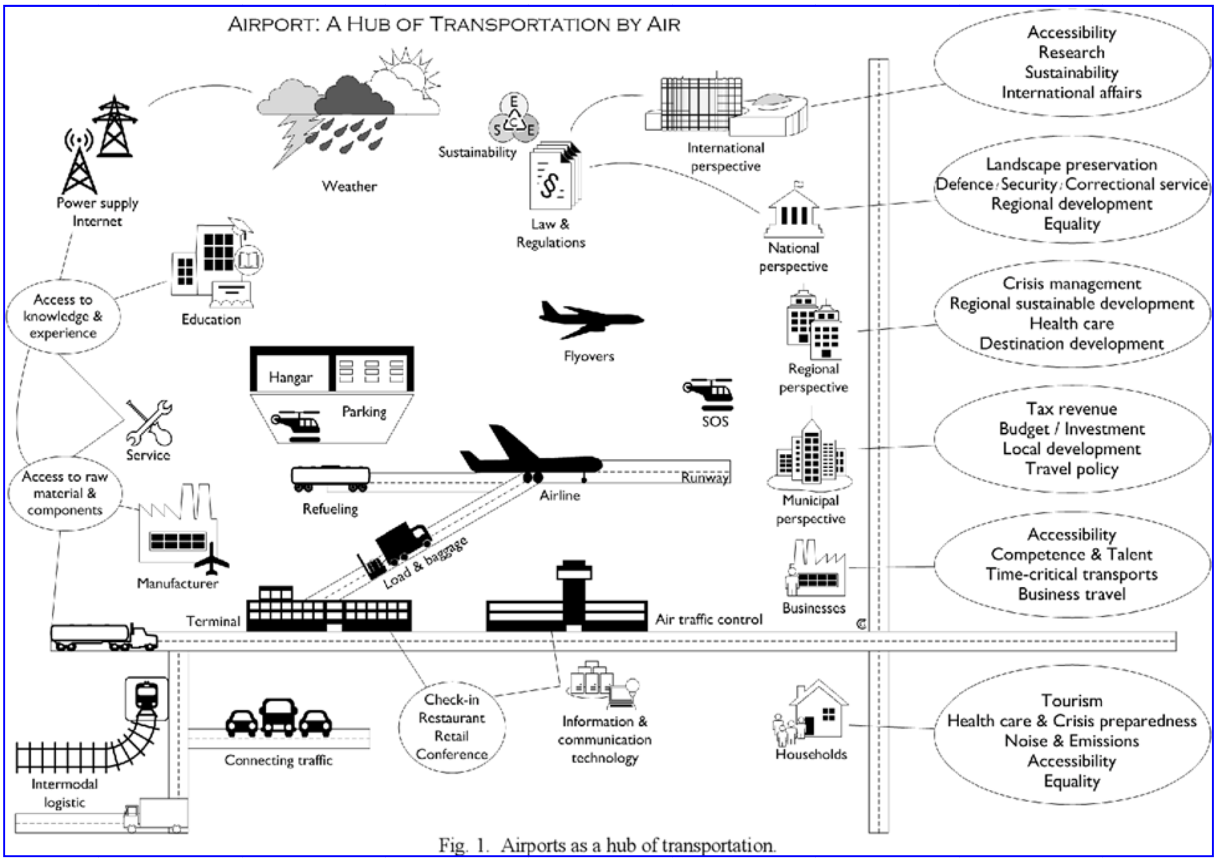

Figure no. 1: *An airport-centered perspective of the air transport infrastructure* (Source: Große, 2019)

Vamanu et al. (2018) adopted a more expansive view of the transport infrastructure in their seminal work on the transport of dangerous goods, encompassing not just the multimodal logistics hubs, but also the transporters themselves, the key supply chains on which they rely for fuel and parts and the underlying ecosystem of trade underpinned by commercial relations which ensures the constant demand for the critical goods transported by the CTI and the critical services it actually produces.

Figure no. 2 shows an attempt at a simplified systemic view of CATI, that is adapted to our research on blockchain applications. It uses critical assets and critical infrastructures based on the functions required for CATI functioning, from maintenance and supply to customer services.

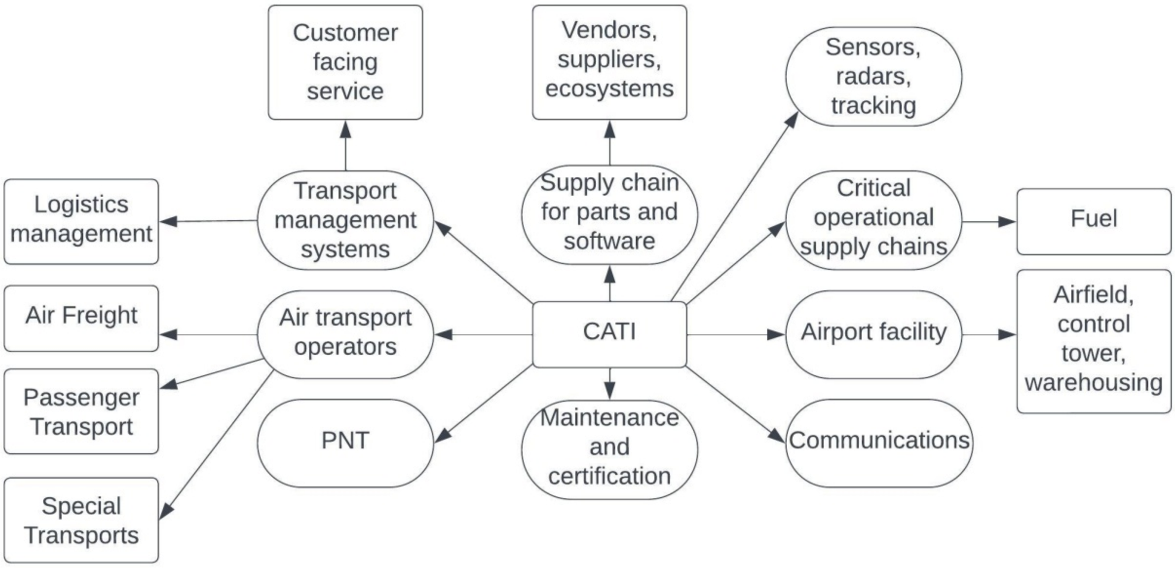

Figure no. 2: *A systemic view of Critical Air Transport Infrastructure*
(Source: Authors)

CATI provides critical goods and services necessary across long value chains encompassing manufacturing, transport, data gathering and processing, communications, finance and more which are necessary for the running of the globalized economy's flows of people and goods. Ultimately, it is also inextricably linked to security and defense issues. Much of the associated infrastructure of CATI is dual-use – aircraft (and parts) manufacturers produce also military-grade equipment and much of the technology and knowledge is applicable to both area; airports and airfields are often dual-use as well, hosting separate but nearby military facilities; civilian CATI is also useful for deployments and standard military transports, as part of military mobility facilitated by civilian infrastructures, whether road, rail, port or air. The disruption or destruction of CATI would, according to the definition, cause significant loss of human life, material damage and second and third-order effects especially of a financial or logistical nature (UNSC, 2017). It would also, as seen in the war in Ukraine, disrupt military operations. Therefore, the issue of novel and emerging technologies being adopted across CATI also has an important security and defense dimension (Alicea, 2022) and their impact on resilience, whether positive or negative, is of significant importance to planners and regulators.

3. Blockchain Use in CATI

The more expansive definition of CATI that we use, including our systemic perspective from Figure no. 2, the more uses for blockchain we can find. However, we must be wary of treating it as a "miracle technology" and, as is the case often in the tech sector, evangelizing for its use across the entire value chain, even where not appropriate or actively harmful or dangerous. Figure no. 3 presents IATA's take on a decision tree for the adoption of blockchain technology in the air transport industry (rather than the wider infrastructure). We can see that this decision tree is based not just on the technical suitability of blockchain as a solution, but also the presence of already trusted intermediaries that would be displaced by blockchain solutions, indicating a level of conservatism in the industry as a whole.

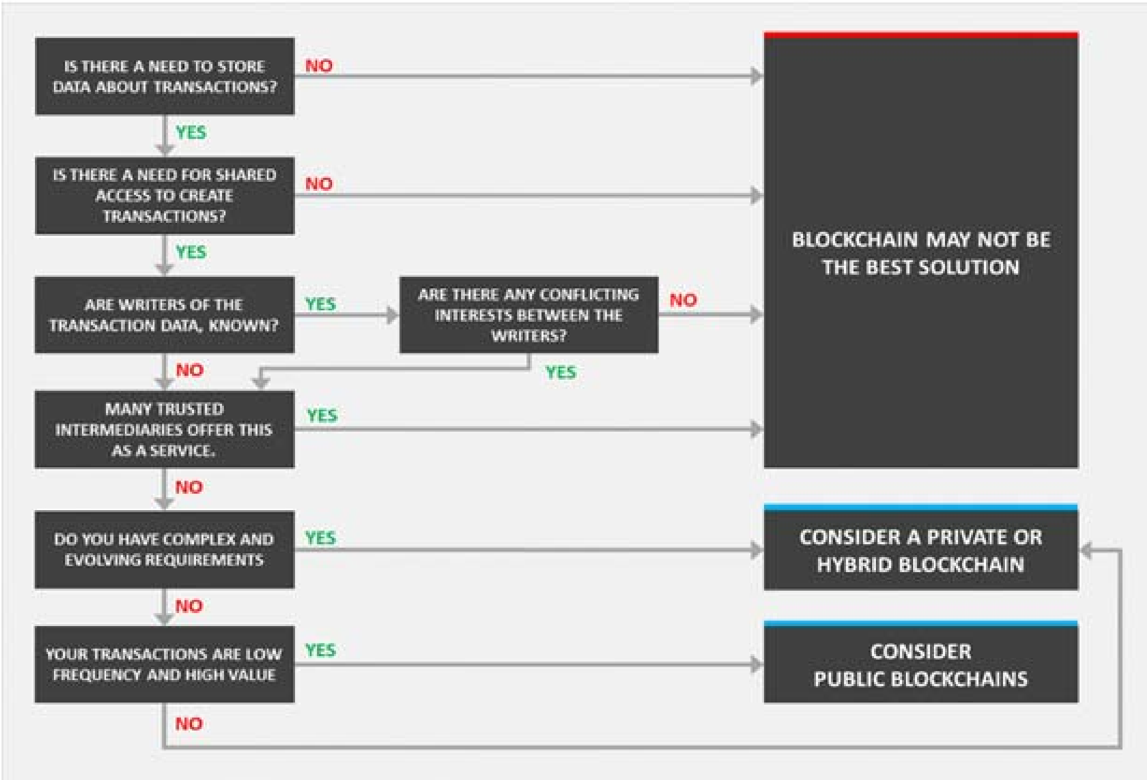

Figure no. 3: *Decision tree on adopting blockchain technology in the air transport industry*
(Source: IATA, 2018)

As a general rule, blockchain applications can be used in any operations which require a ledger to store information and which can be resolved through transaction style resolution mechanisms. Such processes often require trusted depositaries and intermediaries, which blockchain technology displaces through the use of the distributed ledger and algorithmic methods to ensure integrity. This range of solutions encompasses both public and private blockchains, and offers a wide range of options regarding governance, from financialization of tokens and "proof-of-work" algorithms, to non-financialization and "proof-of-authority" algorithms (Baboi, 2023). This simple arrangement, at least on the surface, enables a wide variety of blockchain applications, some of them in critical or sensitive fields:

- Tokenization – the development of digital assets and digital twins of real assets;
- Smart contracts – machine-executed agreements without intermediaries, especially in the paid-procurement area;
- Provenance and proof-of-origin – tracking the origin of goods and specialty products, in order to control for quality, conformity with environmental criteria, conformity with tax and other regulations and more;
- Certification and validation – the storage, verification and deployment of certificates in various fields, addressing either people, goods or processes (Vasile & Dinu, 2021; Dinu & Vasile, 2023);
- Digital identification – addressing either access management to critical facilities, or simple organizational issues such as customer data protection, privacy during duty-free purchase validations which require identification as a traveler and more.

Figure no. 4 contains a list of concrete blockchain applications. We can observe that some of them are valid also for the defense sector or are relevant to security processes.

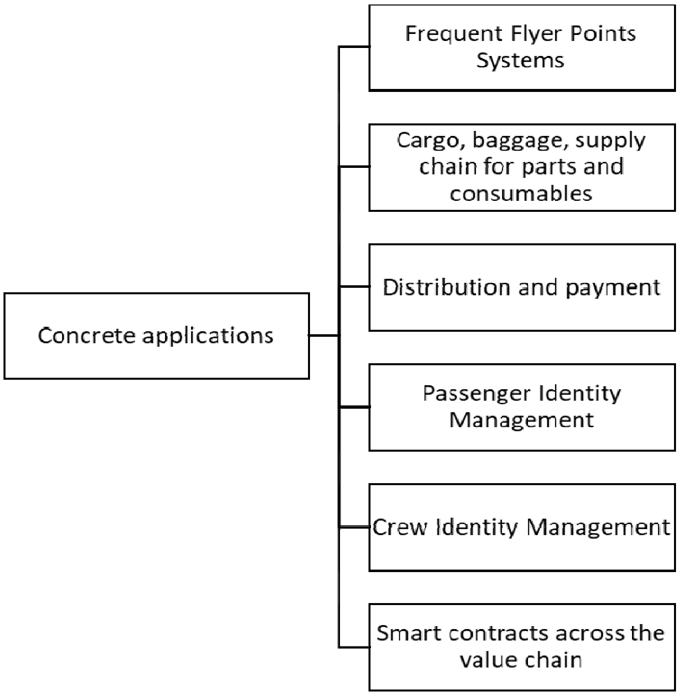

Figure no. 4: *Concrete blockchain applications in CATI*
(Source: Authors)

As seen in Figure no. 5, there are also barriers in the way of blockchain adoption in CATI. The first is the scalability of relevant blockchain solutions. Blockchains work best when they are used in the widest possible network, to ensure lower costs, safety from blockchain manipulation by having as many nodes as possible and compatibility of systems across the value chain (Stoica, 2023). This presents a coordination problem for the industry which, as we will see in the next section, has tried to be addressed by IATA through its own framework developments in blockchain, both for financial and systemic interest. The second is the issue of governance, referring to the legislative vacuum regarding the use of blockchain especially in critical processes, raising the specter of liability for using unproven technology should something go wrong. This regulatory uncertainty acts as a brake on blockchain adoption, though this is steadily being eroded directly, through companies applying blockchain first in safer areas, developing competencies and knowledge internally and becoming more comfortable with it, as well as indirectly, through their own consumption of goods and services with a blockchain component in the value chain (for instance, the logistics of the purchase of consumables for a CATI facility). The cost of transactions is also an issue in the absence of scale in the blockchain network or depending on the technology being used. Possible users would frown on slow or expensive blockchain transaction resolution, which is why many new blockchain products prioritize speed and cost, exploring also alternatives that minimize the latter (cost being not just the potential cost of the tokens, but also of the infrastructure and energy for algorithmic resolution which is ultimately priced into the token for private blockchains). Volatility and operational efficiency are related issues, referring to the issues plaguing early blockchain products, especially where their ecosystems are located in proximity to unregulated financial markets, leading to volatility in tradeable token cost or to unforeseen slowdowns in the network functioning as "miners" (professional algorithm solvers) switch en masse from one network to another chasing higher gains for their computing power. Many of these issues can be solved through the design of the blockchain, but often at the cost of scalability, upgradeability or even security (especially in systems with low node numbers, such as "proof-of-authority" ones can be (Baboi, 2023).

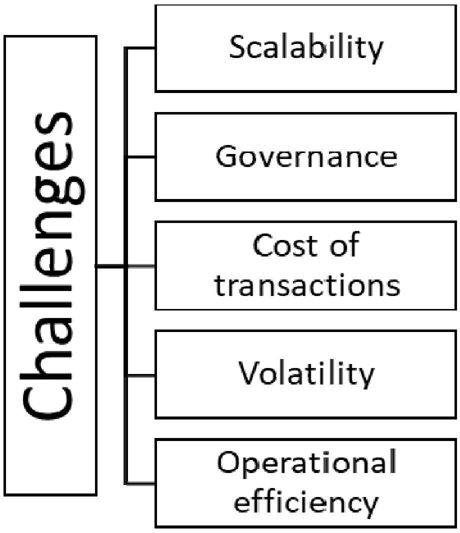

Figure no. 5: *Challenges to blockchain adoption*
(Source: Authors)

4. The Current State-of-the-Art

Blockchain use is in its infancy across CATI, but spectacular growth is foreseen across the air travel industry component of it, with growth from 420 million dollars yearly in 2020 to an estimated 1.4 billion dollars in 2025, which is a compound annualized growth rate of around 27%, denoting rapid growth (Figure no. 6).

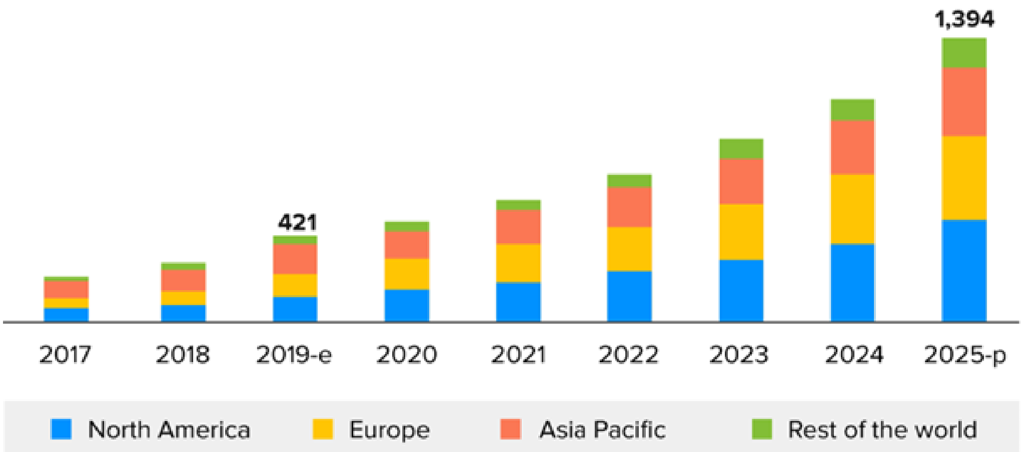

Figure no. 6: *The blockchain market in aviation by region in million USD*
(Source: Srivastava, 2023)

There are two main vectors for blockchain adoption in the industry. The first is piecemeal adoption by individual companies deploying individual products, often in a start-up paradigm. Table no. 1 presents a list of start-ups in the blockchain for aviation sector and describes their product.

Table no. 1

Start-ups in the blockchain for aviation sector

Service	Details
Aeron	Aviation safety through pilot flight logs
Loyyal	Marketing and customer incentives
Ozone	Secondary marketplace with alternative distribution of products/services
Sita FlightChain	Shared ledger on flight information with participation of delegated authorities
TravelBlock	Alternative to the traditional Global Distribution System (GDS) between airlines, hotels, car rental companies, and travel agencies
TravelChain	Open source Blockchain envisaged to be managed by all market players across the travel industry players.
Tripbit	TripBit Smart cryptocurrency for travel is proposing a mechanism to facilitate payment across the travel industry
Trustabit	Compensation for cancelled or delayed flights through Smart Contracts which issue vouchers automatically to passengers
Winding Tree	Distribution and inventory management for the travel industry, with flights and hotels in its scope
Company-based frequent flyer systems	Singapore Airlines KrisFlyer Frequent Flyer Program, Brussels Airport BRUcloud, Air France KLM aircraft maintenance
Others	Boeing has patented a Blockchain-based anti-GPS spoofing system

(Source: Data adapted from IATA, 2018)

This approach maximizes innovation and competitiveness, as companies vie to find or develop useful blockchain applications. However, it leads to a fragmented market, with problems related to scaling solutions for a tightly interconnected global market and coordinating for regulatory purposes.

The second vector is a top-down approach where a credible authority creates and promotes a blockchain ecosystem and makes it more attractive by addressing directly the fear of uncertainty exhibited by certain categories of actors. IATA is attempting to fulfill this role in the aviation sector, by trying to develop a blockchain on which to build an entire ecosystem of apps consciously modelled on the application marketplace of Apple, the technology company.

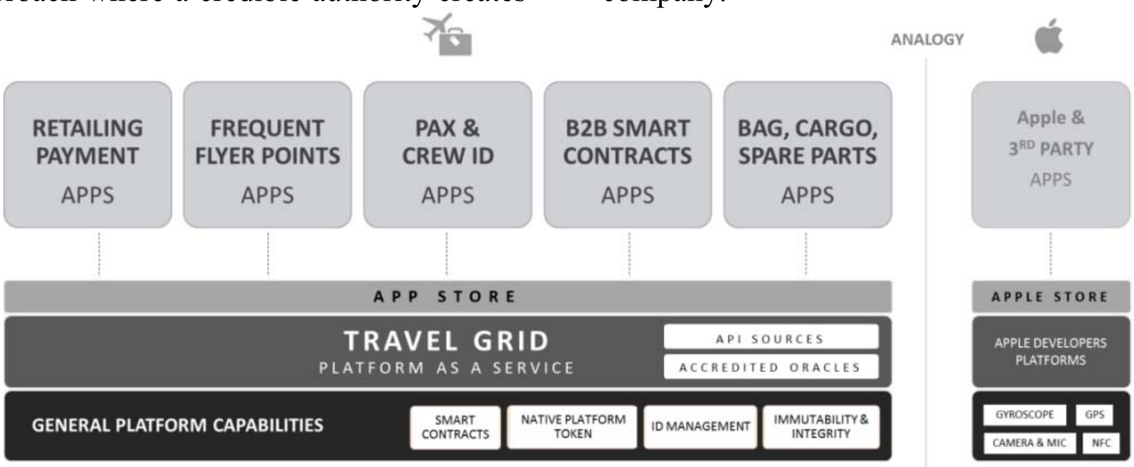

Figure no. 7: *The Travel Grid platform of IATA*
(Source: IATA, 2018)

Figure no. 7 presents IATA's Travel Grid platform, developed by the IATA Financial Development Working Group, which also handles Digital Finance, and the various types of apps that it can support, correlating well with Figure no. 4. IATA solves the scalability problem by building the ecosystem from the start, with API support for other developers and user entities throughout the ecosystem. IATA's own institutional credibility serves to blunt the effect of uncertainty on the willingness of companies to adopt blockchain solutions. The IATA Digital Certification Authority is expected to use it for:

- Identity management of entities (e.g. travel agent ID);
- Facilitating integrity of content (e.g. integrity of the airline offer);
- Availability of the certification verification platform.

The stakes are very high, since rapid adoption of blockchain can help facilitate the 754 billion dollar/year market for industry procurement and settlements (IATA, 2019).

Poleshkina (2021) has a wider vision of how its ecosystem would function in the context of systemic adoption, as seen in Figure no. 8.

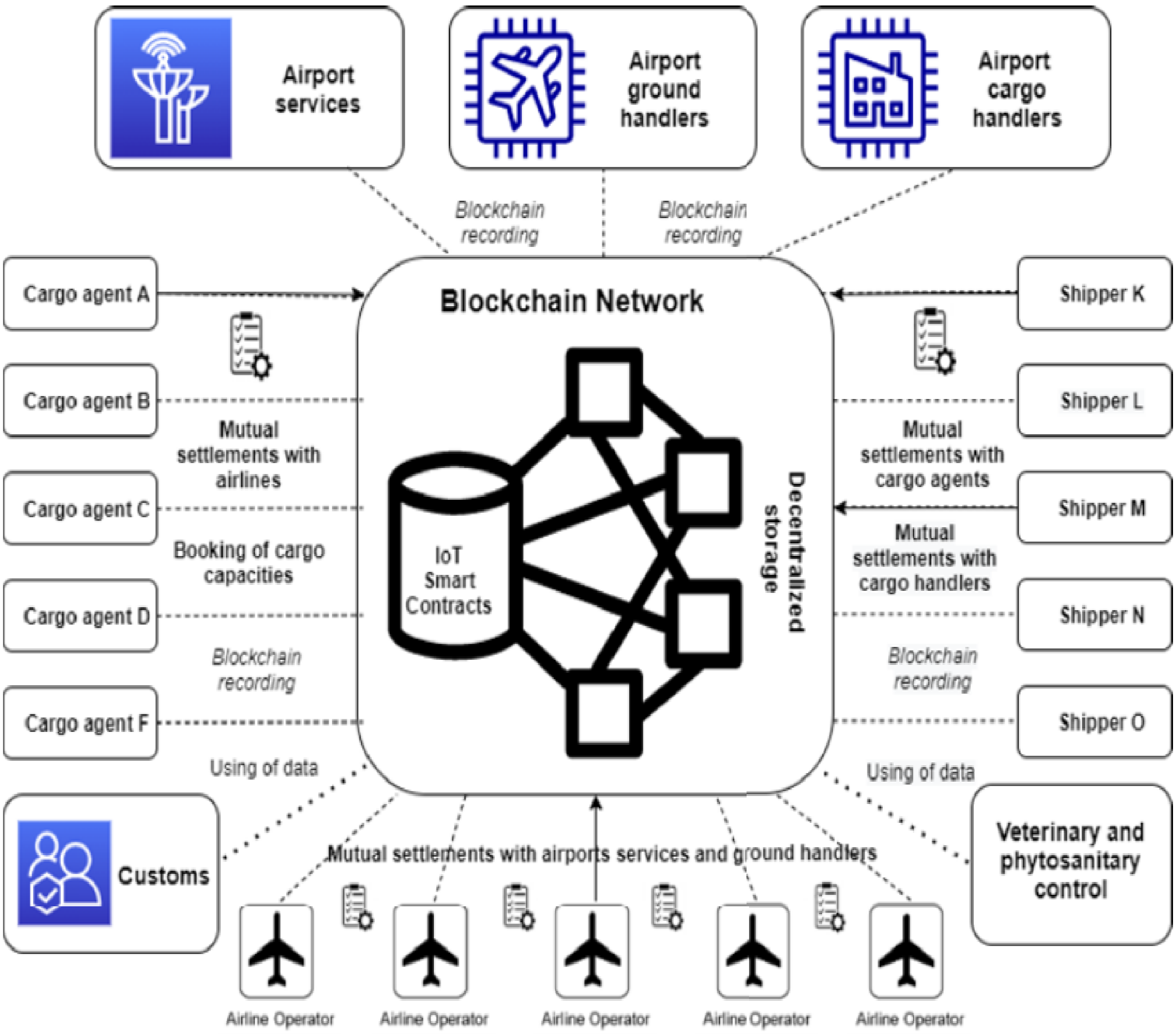

Figure no. 8: *How a dedicated blockchain network in aviation would work*
(Source: Poleshkina, 2021)

The pandemic shock on the air travel industry delayed IATA's plans to launch its blockchain ecosystem and allowed the more resilient, decentralized solutions to move to the fore. However, in an industry which is very cost conscious, the advantages of blockchain make it likely that there will be a renewed push to maximize savings and efficiency gains through a coordinated adoption of a blockchain ecosystem that is developed by a trusted authority, such as the IATACoin system proposed by IATA (started in 2014, pilot project launch in 2018).

Figure no. 8 does not map completely to the CATI defalcation presented either in Figure no. 1 or the one we developed in Figure no. 2, because it is related to the area of expertise and authority of IATA. Manufacturers and providers of maintenance and upgrade services can also benefit from blockchain adoption, as can the area of coordination/interface with other critical infrastructures sectors, from food and water to public administration and energy.

In the context of blockchain normalization and mainstreaming, the development of new products and technologies that address the initial weaknesses of blockchain solutions, and the erosion of reticence on the part of actors motivated by the need to be more effective, secure, efficient, and cost-conscious, it is likely that blockchain solutions will become ubiquitous across the CATI system-of-systems and across value chains. This means that the defense sector will also be exposed to blockchain products and services, even as it also adopts blockchain directly especially in complex logistics such as aircraft maintenance and the tracking of parts.

5. Conclusions

Blockchain technology has moved beyond cryptocurrency applications in the financial sector and has reached the level where systemically relevant applications in fields such as logistics, decentralized platforms, access management, digital ID and others are not only possible, but highly desirable and competitive. The critical air transport infrastructure is an area where, prior to the pandemic, there was a visible concerted push to develop a comprehensive blockchain solution ecosystem for a host of issues. The process is still ongoing, though the ambition has been scaled back following the financial shock of the pandemic. However, blockchain solutions offer great potential for CATI and the aviation industry in particular, and the nascent blockchain start-up ecosystem around it is proof of the potential, as is the very rapid growth of the market (from low levels).

Eventually, the applications of this digital emerging technology will also reach the defense sector, both directly and indirectly. This article described the challenges to blockchain adoption and delineated the main use cases, while also presenting the current state of the art. Future research will need to address the systemic impact of blockchain adoption in terms of resilience, fragility, information circulation (or opacity) and regulation (Georgescu & Cîrnu, 2019). Many issues are not visible right now because of the early stage of adoption, especially in the defense sector. But the drive for efficiency and cost savings makes blockchain adoption inevitable, the only question is whether it will be safe and sustainable.

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