The ADAPT Project: Adaptive and Autonomous Data Performance Connectivity and Decentralized Transport Network

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ABSTRACT

The ADAPT project started during the most critical phase of the COVID-19 outbreak in Europe when the demand for Personal Protective Equipment (PPE) from each country's healthcare system surpassed national stock amounts. Due to national shutdowns, reduced transport logistics, and containment measures on the federal and provincial levels, the authorities could not meet the rising demand from the health care system on the PPE equipment. Fortunately, the PPE production capacities in China have regained (and expanded) their available capacities through which Austria now can get the demand of PPE to protect its citizens.

ADAPT develops an adaptive and autonomous decision-making network to support the involved stakeholders along the PPE supply chain to save and protect human lives. The ADAPT decentralized blockchain platform optimizes supply, demand, and transport capacities between China and Austria with transparent, real-time certification checks on equipment, production documentation, and intelligent decision-making capabilities at all levels of this multi-dimensional logistic problem.

CCS CONCEPTS

• **Computer systems organization** → **Peer-to-peer architectures**; • **Applied computing** → **Transportation**.

KEYWORDS

Logistics, transportation, decentralization, blockchain, personal protective equipment

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1 INTRODUCTION

With the outbreak of COVID-19 in December 2019, the world has seen a global pandemic capturing the global health care systems, economies, private lives, and families, as well as the global supply chains of all industries. Consequently, the World Health Organization (WHO) released together with China a joint investigation report conducted in Wuhan, China [20] and the World Economic Forum (WEF) has initiated the COVID Action Platform calling all stakeholders to protect lives and livelihoods. Meanwhile, governments (all over the world) were struggling to secure the needed supplies for their national health care systems. Based on the world's economic lockdown, the global community had entered a stage of national me-first initiatives for acquiring personal protective equipment (PPE). WHO [19] identified four strategy pillars to conquer the global shortage of PPE and allow humanity to overcome the current infection and death rates, especially when looking at the importance of a (fully) functioning health care system (in each country): (1) increase on the industries' production output on PPE; (2) minimize the need for PPE; (3) ensure rationalized and appropriate use of PPE; (4) coordinate PPE supply chain management.

The ADAPT project focuses on the fourth pillar by researching and developing a novel blockchain-based architecture to optimize the supply, demand, and transportation capacities between China and Austria with transparent, real-time certification checks on equipment and production documentation. ADAPT aims to provide decentralized decision-making capabilities at all levels of this multi-dimensional logistic problem with an economic and environmental impact analysis throughout the whole supply chain.

The collaboration of ADAPT with national, federal, and provincial organizations revealed several organizational issues within the global supply chain of medical equipment supplies:

- Austrian health care system connection to Chinese production supplies suffers from the severe time zone and language understanding barriers.
- Production of some Chinese factories is quickly oversubscribed, while other sites operate at half of their capacity.
- Transport systems follow federally coordinated air transport capacities, which often cannot meet the consumption rates and needed quantities.
- PPE certification standards and equipment control are time-consuming and need manual coordination, quality assurance, production documentation.
- Organizations' capital cash flow is slow due to lengthy PPE quality control and transport verification cycles.

2 STATE-OF-THE-ART

2.1 Blockchain for Transport and Logistics

Blockchain technology has emerged in the transportation and logistics industry to solve more efficient and cost-saving business operations. Blockchain enables the coordination of documentation tasks on a shared distributed ledger, ensures trustworthy data across the transportation ecosystem, and provides a scalable, immediate solution for authentication and tracking by design [8]. For example, shippers can post unique timestamped loads recorded and verified by the blockchain with preserved integrity.

Tracking in transportation and logistics is limited to the delivery performance and relates to the vehicle performance within a fleet. In CarFax (https://www.carfax.eu/), blockchain can help authenticate information on the vehicle's maintenance history. In contrast to CarFax, blockchain requires no middle broker for storing and validating information for buyers and sellers. Helo et al. [10] proposed a pilot cloud-based portal for real-time tracking and tracing logistics and supply chains.

Blockchain further enables transparency in the supply chain. Abeyratne et al. [1] reviewed the state-of-the-art and example applications, discussed the potential of technology, and proposed a vision for the future blockchain-ready manufacturing supply chain. Some supply chains are already using blockchain technology [7, 21]. For example, UbiMS start-up is the world's first patented cloud-based platform that reinvented the global supply chain process using blockchain for connecting multiple providers of goods with worldwide consumers. UbiMS is a shared supply chain infrastructure for small and medium enterprises, modeled as a three-dimensional globally interconnected e-marketplace and e-supply chain process for communication and distribution of material goods.

2.2 Logistic Supply Chain Automation through Smart Contracts

Smart contracts coded through the blockchain and self-executed upon meeting certain conditions can reduce costs and eliminate the need for administrative steps, representing around 20% of the overall transportation costs. Casado-Vara et al. [5] combined smart contracts with a multi-agent system to improve the current logistics system's organization security and distribution times. ShipChain (https://blog.shipchain.io/) is one of the first start-ups that used smart contracts in maritime logistics to track goods from leaving the factory until customer delivery. Process automation allows stakeholders to purchase digital SHIP currency tokens to pay the cargo and execute transactions on the platform, enabling information sharing and platform transparency.

2.3 IoT-Blockchain Enabled Logistics Supply Chain Assurance, Auditing, and Monitoring

Sweetbridge (https://sweetbridge.com/) platform provides distributed protocols that integrate artificial intelligence, distributed ledger technology, and the Internet of Things (IoT) to improve the efficiency of settlement between parties throughout the supply chain in the freight and trucking industry. These protocols use decentralized inter-enterprise resource planning to perform continuous data assurance, auditing, and real-time control monitoring. The IoT sensors in trucks and other shipping vehicles can help shippers and transportation companies detect the space used in cargo and determine individual freight costs stored in the blockchain.

Peloton uses blockchain to store and validate the data exchanged among multiple freight vehicles forming a platoon and improving fuel efficiency and safety. Malik et al. [15] argue that blockchain cannot support the trust and reliability of data concerning the quality of physical commodities and the trustworthiness of supply chain entities. They provide an automated framework to associate trust to each supply chain event based on the trust of the participants and the quality of the commodity.

2.4 Blockchain and Cybersecurity in Connected and Automated Transportation

An increasing number of research works aim to overcome the challenges of large data storage, which results from connected and automated vehicles, especially vehicles in the platoon. The intelligent management and data protection in the entire system, especially when responding in real-time, equally attract industries and academics [11]. Blockchain has already proven to be an effective technology for decentralized distributed storage and security management with great advantages. As a result, several research studies are dedicated to investigating its applications and effectiveness in connected and automated vehicles [17].

Saltanat et al. [17] investigated the use of blockchain to improve cybersecurity by establishing secure and reliable communication among vehicles. The authors developed a tracking and recording system of vehicles' status (e.g., speed, acceleration) using the fast Exonum blockchain platform (processing up to 9000 transactions per second). Data input and acceptance confirmation of transactions is carried out using an elliptic curve digital signature algorithm.

Jiang et al. [12] investigated the extension of blockchain technology for adaptation in transport networks using theoretical modeling and performance analysis of the vehicular communication systems. To this end, the authors defined a blockchain structure of connected and automated vehicles.

Hexmoor et al. [11] proposed a novel adaptation of blockchain technology for protecting the privacy and security of platoon members and the security of data dissemination. The authors identified

and adopted key protocols for a distributed cryptographic authentication system among the platoon vehicles.

2.5 Federated Blockchain Alliance for Logistics

The Australian blockchain start-ups TBSx (https://tbsx3.com), DB Schenker (https://www.dbschenker.com/), and DP World Australia (https://www.dpworldaustralia.com.au/) formed in 2017 a blockchain consortium to counteract the global counterfeit goods industry, protect global supply chains, and help companies to restore consumer trust in supply chains. The Blockchain in Transport Alliance (founded in 2017) with more than 500 members from 25 countries comprises companies, organizations, and individuals from across the transportation, logistics, supply chain, freight, technology, and blockchain areas. Its goal as a member-driven organization is to drive new technologies among the transport, freight, logistics, and other related industries. Consequently, the alliance pushes the adoption of blockchain and embraces a common standard, education, and collaboration. The leading global shipment management software solutions provider, CargoSmart, announced in 2019 the execution of Global Shipping Business Network services agreements with maritime industry operators, such as CMA CGM, COSCO Shipping Lines, PSA International, and Shanghai International Port Group. The goal is to provide a blockchain platform for all shipping supply chain participants to support collaborative work and develop solutions through trusted and secure data exchange platforms.

2.6 Federated Optimization and Decision Making for Logistics

The optimal management of distributed resources is one of the central problems for the previous decades and the current economy. Logistics and transportation context is traditionally addressed via the Vehicle Routing Problem (VRP) [14], which targets the optimal delivery over the collection routes from one or several depots to several geographically scattered cities or customers, subject to various additional resource constraints. This problem plays a prominent role in the fields of physical resource distribution and logistics [14, 22]. Determining the optimal solution to a vehicle routing problem is NP-hard [22], limiting the scales of optimally solvable problems using conventional techniques of mathematical programming and software like SCIP [9] and CPLEX [4]. Designing simpler controllers via structural decomposition emerged in the past decades to achieve more tractable and less computationally demanding control structures. The basic optimization approach over the planning horizon is to solve a centralized MILP or MINLP problem using direct, heuristic, and meta-heuristics methods. However, unbalanced centralized optimization quickly becomes impractical for large-scale systems due to combinatorial explosion, which introduces huge computational and communication overheads, especially in the context of data-intensive scenarios [13]. Therefore, hybrid schemes can deal with large-scale problems given their capabilities to divide a complex problem into several less-complex sub-problems. The open question to investigate is how to define the static and dynamic relations between these controllers and groups of controllable agents using smart contracts. The ADAPT project bridges the gap between distributed, decentralized, and hierarchical control strategies in the context of smart contracts, expected to enable nearly optimal control systems performance in large-scale environments. The decision-making distributed among multiple nodes in the decentralized system exploits locality principles while balancing the performance and enabling high scalability.

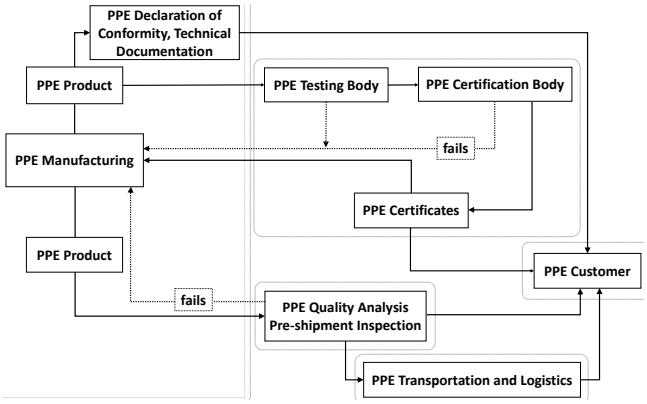

Figure 1: ADAPT medical product certification and global supply chain.

3 PPE PRODUCTION CERTIFICATION AND TRANSPORTATION

Figure 1 depicts the ADAPT medical product certification and global supply chain, further detailed in this section.

PPE manufacturing. PPE manufacturers are responsible for technical documentation and conformity assessment of the product, compliance with technical regulations and standards, traceability, and safety [6]. The ADAPT solutions contribute to efficiency control, traceability, and confidence-building throughout the sustainable value chain.

PPE product. ADAPT focuses on PPE such as FFP2 masks, FFP3 masks, single-use medical rubber gloves standard and surgical masks under regulation (EU) 2016/425, and rapid antigen tests required during the pandemic.

PPE declaration of conformity technical documentation. The EU type-examination certificate issued by the notified body is part of the declaration of conformity with the producer's obligation to comply with the underlying standards and trace the products. The monitoring of the type conformity by the notified body relies on the quality assurance of the production process (module D) or internal production control in product checks monitored at random intervals (module C2) [6]. The technical documentation includes, for example, the description of PPE, design, manufacture, operation, functioning, the purpose of use, risk analysis and risk assessment, as well as internal and external test reports, standards, and process descriptions [6].

PPE testing body. The third-party testing body has laboratory facilities and conducts tests. The testing body is independent of the producer or the testing product (EU Commission. 2016 [6]).

PPE certification body. Public authorities notify certification bodies active in the public interest and accountable to the national

authorities. As third-party certification bodies, they carry out necessary activities in line with the requirements of the conformity assessment procedure based on the applicable technical harmonization legislation and issue certificates [6].

PPE certificates. The certification mark issued by a certification body indicates a tested representative product sample that meets the requirements of a published standard. Additionally, the product is in a certification program with additional requirements, such as an initial factory audit, periodic inspection, or testing activities. The certification body owns the certification marks and grants authorization to use them to third parties. A European conformity (CE) mark with a four-digit number indicates assessment by an independent third party.

PPE quality analysis pre-shipment inspection. Pre-shipment inspection is important quality control within a supply chain to secure production compliance with the order. The buyer, supplier, and sometimes the bank agree on an independent inspection company that examines the conditions. For example, checks usually occur on quantity, quality, documentation, packing, test reports, and compliance with the importing country's standards.

PPE transportation and logistics. The ADAPT model maps the existing international transport network and compares different supply chains to optimize costs, delivery time, calculate the CO_2 footprint, and optimize it logistically. In addition, real-time data collected to determine consumption, acceleration, and deceleration patterns create models for different vehicles and traffic networks.

PPE customer. The ADAPT logistics model allows stakeholders (customers) to compare supply chains, improve efficiency, and reduce CO_2 emissions. Stakeholders are healthcare institutions, companies, government agencies, importers, and wholesalers, who need PPE equipment and related medical devices such as antigen testing. The blockchain-based certification tool hinders incorrect certificates and saves time when verifying. An intelligently, economically, and sustainably planned logistic supply chain offers additional efficiency.

4 ADAPT ARCHITECTURE

This section presents the ADAPT architecture design displayed in Figure 2, focusing on the decentralized blockchain-based PPE transportation and logistic network, followed by the autonomous transport and supply chain decision making.

4.1 Decentralized PPE Transportation and Logistic Network

ADAPT aims to create an open and agile interface using underlying blockchain technology to simplify the integration and federation of fragmented PPE stakeholders (e.g., logistic service and asset providers, PPE certification, and infrastructure resource providers). This enables transparent and decentralized PPE transportation and logistic networked infrastructure and services.

ADAPT develops and deploys a blockchain-as-a-service platform called ADACHAIN to federate and orchestrate the decentralized PPE transportation and logistics supply chain. ADACHAIN uses a

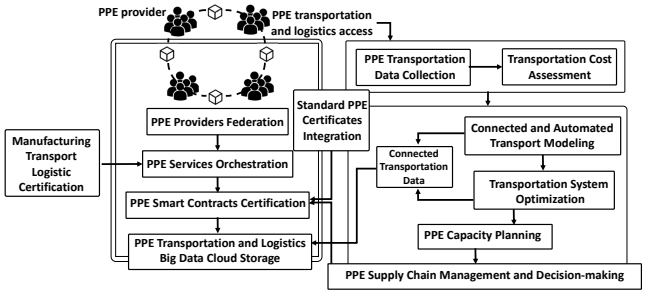

Figure 2: ADAPT architecture: decentralized PPE transportation and logistic network (left), and transportation characteristics (right).

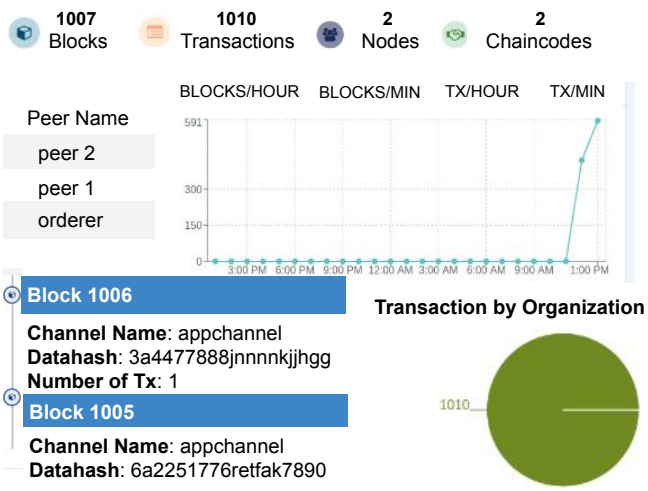

Figure 3: ADACHAIN hyperledger explorer visualization.

hyperledger fabric permissioned blockchain that offers higher availability and transaction throughput for time-critical PPE services than public permissionless blockchains like Ethereum.

Figure 3 shows the current implementation of the ADACHAIN using hyperledger explorer. The interactive visualization interface depicts the deployed PPE transportation and logistic supply chain blockchain network with over 1000 transaction executed across two networked stakeholders represented as nodes. Figure 3 shows two additional chaincodes representing smart contracts that initialize and manage certification standards and conditions by processing PPE transactions during the supply chain lifecycle. ADACHAIN offers several decentralized PPE transportations and logistic networked services, described in the following paragraphs.

PPE provider federation. ADACHAIN creates a blockchain consortium to federate multiple PPE providers in a decentralized network and maintain consistency, accountability and traceability of offered PPE services. Additionally, ADACHAIN facilitates the integration of third-party authentication providers to verify new PPE providers who join the network, providing them with a unique identity. Additionally, ADACHAIN designs and evaluates fault-tolerant consensus algorithms to achieve agreement in soft real-time among

different PPE providers in the permissioned blockchain network. This feature is crucial for successfully developing large-scale transportation and logistic services, as they deal with multiple and frequent streams of the supply chain. Finally, PPE providers in the consortium own and maintain the blockchain seamlessly coupled with game-theoretic heuristics that validate the transaction history for every provider to maintain the same federated truth and improve collaboration.

PPE services orchestration. ADACHAIN uses Docker Swarm to orchestrate pluggable and modular PPE supply chain services. The inbuilt features of Docker Swarm such as high availability, scalability, load balancing, service discovery, and rolling updates enable addressing the time-critical issues of decentralized PPE supply chain services (e.g., logistic, transportation, and certification), including automatic repair and recovery of time-critical blockchain services during system failures using a persistent storage service.

PPE smart contracts certification. ADACHAIN provides a generic smart contract adaptation interface that aggregates and combines the standardized certification requirements and conditions for verified and authenticated execution of PPE transportation and supply transactions. All stakeholders in the decentralized network verify the validity of every shared PPE supply chain transaction, which allows beneficiaries to define conditions on required PPE quality and certification standards through smart contracts.

Cloud storage for PPE transportation and logistics. ADACHAIN uses GlusterFS for the persistent storage of common certificate credentials needed by the PPE services in addition to the transaction ledger databases. This network-attached storage offers high-performance storage support and helps address high availability, resilience, auto re, pair, and automatic recovery of the decentralized logistic services during system or infrastructure failures. Additionally, ADAPT provides a distributed cloud-based big data storage of shared large data items with efficient indexing and traversals, as blockchains are inherently decentralized, not distributed. As all participating nodes in the network must maintain a copy of the blockchain while ensuring the same version of the truth, this becomes important. The blockchain only contains transaction logs about the fingerprints of the data stored in the cloud to reduce replication and network throughput.

4.2 Autonomous Transport and Supply Chain Decision-Making

ADAPT stores, integrates, and secures the vehicular disseminated data (within a platoon) through the ADACHAIN blockchain platform depicted in Fig. 2 (right) and described in the next paragraphs.

PPE transportation data collection. ADAPT maps the current transportation network and analyzes the collected data and the degree of co-modality on national and regional levels in Austria and China. The vehicles equipped with On-Board Diagnostic (OBD) dongles collect data related to fuel consumption, acceleration, and deceleration patterns, for forming different analysis models.

Transportation cost assessment. The analysis of the collected data concerning cost and other measures for sustainable transport enables the comparison of transportation modes between China and Austria, such as air, rail, and waterways. The results of this analysis bring important suggestions for efficient transport.

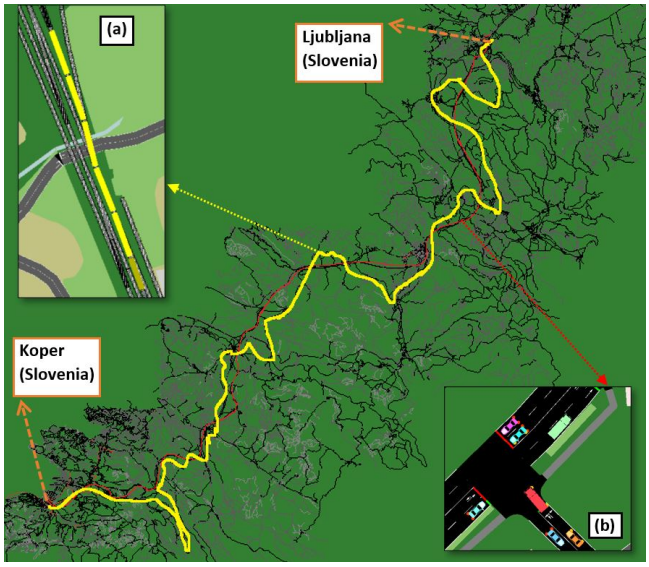

Figure 4: Traffic network visualization of 100 km, with the rail route (a) in yellow and lorry route (b) in red.

Connected and automated transport modeling. ADAPT models connected and automated technologies such as platooning, aiming at reducing fuel consumption and CO_2 emissions using the open-source Simulation of Urban Mobility (SUMO) simulation package [2]. Fig. 4 presents a part of the current simulated network, with container ships arriving at the port of Koper (Slovenia) from Tianjin (China). The red line shows the road network traveled by Lorry24-40t from Koper to Tattendorf (Austria), while the yellow line depicts the railroad from Koper to the Rail Freight Center Vienna South. To better depict, analyze and implement the platooning of vehicles, ADAPT uses the Veins open source vehicular network simulation framework [18] for vehicular communication, which relies on the OMNeT++ (https://omnetpp.org/) discrete event simulator. The integration of Veins, OMNeT++ and SUMO simulators enables autonomous vehicles to cooperate using wireless communication and exchange position, speed, and acceleration data.

Transportation system optimization. ADAPT targets the improvement of mobility models for connected and automated vehicles (e.g., platooning). The SUMO simulation relies on the cooperative adaptive cruise control model that enables platooning without considering vehicular communication. We explore the extended model considering further options to achieve and maintain an efficient and sustainable connected and automated transport network.

Connected transportation data. ADAPT uses the ADACHAIN blockchain platform to store speed, acceleration, and position-related data of connected and automated vehicles. It further aims to reproduce the type of road or driven scenario in a lab-controlled environment using 3DCoAutoSim simulation [16] to visualize the road network and traffic demand on national levels. The 3DCoAutoSim simulation platform mimics vehicle-to-vehicle communication from

a driver-centric perspective [3], extended to include automated capabilities and reproduce cooperative driving assistance systems.

PPE capacity planning. An integrated assessment method analyses the impacts of case-specific solutions, measuring the impact of the pertinent independent variables on the dependent ones. Communication technology and automated driving systems link trucks. The front truck in the platooning leads the vehicles, and following vehicles react to changes with less fuel consumption, improved efficiency, and a lower carbon print. The road network will be traceable and the simulation linked to the main blockchain sharing data platform. Machine learning techniques such as data augmentation and feature engineering for training and noise filtering will predict arrival times to suppliers and clients. This approach helps to alleviate potential data irregularities that might adversely affect the prediction process. The cross-continental, multi-modal, and extensive transportation network between China and Austria adds unforeseen complexity and difficulties during the different phases.

PPE supply chain management and decision-making. Distributed and autonomous decision-making gives the human stakeholders an optimized solution calculated in real-time while considering the changes in the supply chain's regional, national and global levels. The researched control mechanisms for distributed, autonomous decision-making allows the overall system to capitalize on the parallel cyber-physical system structure and form an adaptive, responsive and evolutionary IT network architecture.

5 CONCLUSIONS

We presented the design taken by the ADAPT project towards a novel set of decentralized, resilient, and globally sustainable services for an optimized PPE supply chain. We highlighted PPE production, certification, and transportation requirements through a pilot use case during a COVID-19 pandemic. Additionally, we briefly discussed relevant state-of-the-art technologies and advancements related to automation, auditing, and monitoring PPE transport and logistics in a global and federated supply chain environment. To realize its goals and mitigate challenges, ADAPT develops a blockchain-as-a-service platform called ADACHAIN to simplify integration and federation of fragmented PPE stakeholders and orchestrate time-critical PPE services. ADAPT provides secured and immutable storage of PPE transport, logistics, and certification data across the ADACHAIN blockchain platform. ADAPT utilizes the stored data to optimize capacity planning of PPEs, transportation costs, and sustainable and certified solutions for global PPE supply chain management and decision-making. Future works aim to validate the ADAPT architectural design by integrating diverse medical supply chain use cases other than PPEs. This will enable ADAPT to establish a large-scale and decentralized global supply chain network and live-test ADACHAIN platform with an increased number of stakeholders. The ADAPT project started in March 2021 and expects to achieve its prototype in 2022.

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