DAV White Paper

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***Abstract*— A cryptocurrency to fuel the next era of global transportation: Decentralized Autonomous Vehicles (DAV). DAV is a computer network that will ultimately connect self-driving vehicles (such as cars, trucks, rovers, and drones) to everyone on that network, enabling them to discover, communicate, and transact using a token. Users can pay for the use of any of those vehicles with a token to get a ride or pick up and deliver a package. People who own those vehicles or the charging stations on the network can earn tokens for the services they provide. Users can have an entire network of self-driving vehicles at their fingertips to bring them anything, or to take them anywhere, with one token. Even in today's transportation market, and during the transitional period before autonomous transportation reaches mass adoption, the decentralized transportation network and its underlying technology can create a variety of economic opportunities such as decentralized, on demand, manned, rides and deliveries.**

CONTENT

I. Executive Summary

The Internet is a network of computers, but it wasn't the first one; there were many computer networks prior to the Internet (for example, AOL, CompuServe, and Prodigy). What enabled the Internet to emerge and overtake the isolated silos that preceded it was decentralization. The Internet introduced a set of protocols specifying how data should be packetized, addressed, transmitted, routed, and confirmed as received, and, in doing so, it eliminated the need for a central authority that controls the network. This model provides rich opportunities for developers to build useful applications, for businesses to create value, and for people to participate in a vast and ever-growing network that is not owned or controlled by a central monopoly.

The automotive and transportation industries are currently undergoing their biggest revolution since the invention of Henry Ford's assembly line in 1908. The booming "sharing economy" is shaking up industries from office space and music to transportation. In addition to an emerging sharing economy, technology advances will soon make autonomous vehicles an integral part of our daily lives. As these trends converge, the movement of goods and people will take a completely new shape. Vehicles will be akin to packets of data, programmatically sent from origin to destination.

As with computer networks of the past, current transportation networks are being formed as isolated silos. Google, Lyft, and Uber are only a handful of the companies working on autonomous transportation, but they are all building their solutions using the same closed platform model AOL was using back in the 1990s. Autonomous drone and robotics companies have also begun to emerge and, similarly, their networks are proprietary, closed and non-inclusive.

In this paper we are laying the foundations for a decentralized transportation infrastructure that will have built-in incentives for all the different participants: consumers, businesses, software developers, hardware makers, maintenance providers, insurers, and arbitrators. A transportation infrastructure that is open-source and free to evolve, based on open and unified protocols, is highly scalable and has no single point of failure.

II. Converging Trends

A. On Demand / Passenger Economy

A report published by London-based RethinkX, an "independent think tank," estimates that as "driverless cars" become more common, people will continue the increasing trend of moving from car ownership to opting for "on demand" autonomous electric vehicle services.

This could save a family more than $5,600 per year, equivalent to a wage raise of 10% for the median American household, resulting in an additional $1 trillion dollars per year in Americans' pockets by 2030, according to the report.

With the elimination of the need for a driver, hundreds of millions of hours will be unleashed annually as drivers become passengers in vehicles that provide improved safety and a better transportation economy.

Research by Strategy Analytics finds that autonomous vehicle driving technology will enable a new “Passenger Economy” worth US$7 trillion in 2050.

The “Passenger Economy” will increasingly drive change across a variety of industries, disrupting vehicle ownership with “Mobility-as-a-Service.” This will accelerate emerging use cases, which also extend to transportation and delivery businesses.

- Consumer use of a range of “Mobility-as-a-Service” offerings will account for US$3.7 trillion, nearly 55% of all revenues.
- Business use of “Mobility-as-a-Service” will generate US$3 trillion in revenues, roughly 43% of total revenues.
- Emerging applications and services will account for US$203 billion in revenues.

As these commercial activities increase, we see a huge opportunity for large-scale adoption and growth of the sector through the enabling of drones, autonomous vehicles, robots, and charging stations to communicate and trade with each other.

B. Cost Reduction

Fierce competition has resulted in cheaper, more reliable, and more capable vehicles than those that existed just a few years ago.

One type of autonomous vehicle that has seen accelerated growth in the mainstream is the commercial drone. The best consumer drones are now being deployed for commercial use, often with few or no modifications. “Just as with smartphones, people who enjoyed playing with consumer drones realized it made sense to take them to work too,” says Jonathan Downey of Airware.

Cost reduction doesn’t stop with drones; self-driving cars need to be able to see the world around them. One way they do this is by using Lidar, a sensor attached to the top of a car that spins and shoots out lasers to create high-resolution maps of the car’s surroundings. Just a few years ago, a top-of-the-line Lidar system cost over $75,000. Alphabet-owned company Waymo has slashed the price of Lidar by 90%, according to their CEO, John Krafcik.

C. Emerging Use Cases

Whether we look at companies like Starship Technologies in Estonia and Dispatch in California, who have developed wheeled-cooler-sized drones that are making deliveries on footpaths, or Unsupervised.ai, the French startup that uses a drone that has legs and resembles a dog for “last 50 meter” deliveries, it is clear that the innovation being undertaken is broad in scope and global in scale.

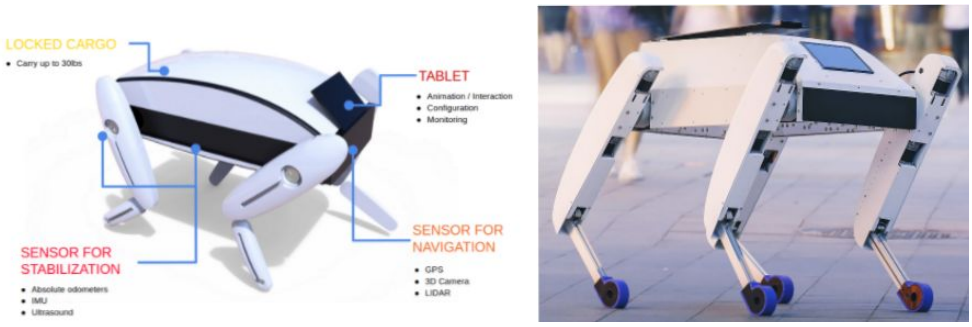


Fig. 1 - Aida, last mile autonomous delivery by Unsupervised.ai

Last-mile delivery represents 55% of the cost of a delivery today, due to manually taking a single parcel into the delivery destination, as opposed to driving a vehicle laden with a large volume of packages to near the destination. Companies are already developing hybrid systems for “integrated last mile” delivery, such as trucks that can arrive in a neighborhood and deploy both flying and wheeled drones.

We already see companies like Flytrex executing deliveries with autonomous drones in Iceland for an Icelandic online marketplace called Aha.

Fig. 3 - FlyTrex, autonomous drone delivering for Aha in Iceland

Companies like EHang in China have already tested drones that carry people in the air through Dubai. These flying passenger drones are expected to be commercially deployed in the coming years. Other companies, such as Airbus, Uber, and Kitty Hawk, have proposed similar flying-car drones.

Fig. 4 Passenger drone prototype

In Geneva, an urban area, AirMap (which manages drone traffic) and Skyguide (which manages manned aircraft) worked together with other companies to successfully demonstrate the first-ever live demonstration of drone airspace services in Europe.

Autonomous vehicles allow us to reimagine a whole range of transportation, personal vehicles, ride-hailing, public transportation, and logistics.

With a focus on shared mobility and access to fleets of vehicles, rather than a personal ownership model, people will be able to experience these technologies sooner.

Waymo has “self-driven” over 3.5 million miles on the road, across 20 US cities. In Phoenix, Arizona they are already inviting people to take part in their early passenger program.

A fully self-driving fleet now offers accessibility, safety, and flexibility and frees up time and space in the vehicle to do what you want.

Fig. 6 - Waymo, self driving vehicle

D. Legal Commercial Use

The flood of consumer drones and autonomous vehicles have forced regulators to push through legislation to allow commercial development and use.

The Federal Aviation Administration (FAA) has a blanket federal restriction on commercial drone operators. All commercial drone operators must apply for a “333 exemption” from the FAA before doing business, register their aircraft online with the FAA for $5, and receive a certificate of authorization (COA) or other FAA authorization.

The following heat map from AirMap, the airspace management company, shows that 461,120 recreational drones and 8,416 commercial-use drones had been registered with the FAA by the end of May 2017.

Fig. 7 - Heatmap of recreational and commercial drone registrations, FAA 2017

Many other countries have followed the FAA's regulatory lead, which is clearing commercial drones for takeoff worldwide.

With technology for autonomous vehicles continually developing, state and municipal governments are addressing the potential impacts of autonomous vehicles on the road.

Each year, the number of states considering legislation related to autonomous vehicles has gradually increased. In 2017, 33 states have introduced legislation, while that number stood at 20 states in 2016.

The National Conference of State Legislatures (NCSL) has a new autonomous vehicles legislative database, providing up-to-date, real-time information about state autonomous vehicle legislation that has been introduced in the 50 states and the District of Columbia.

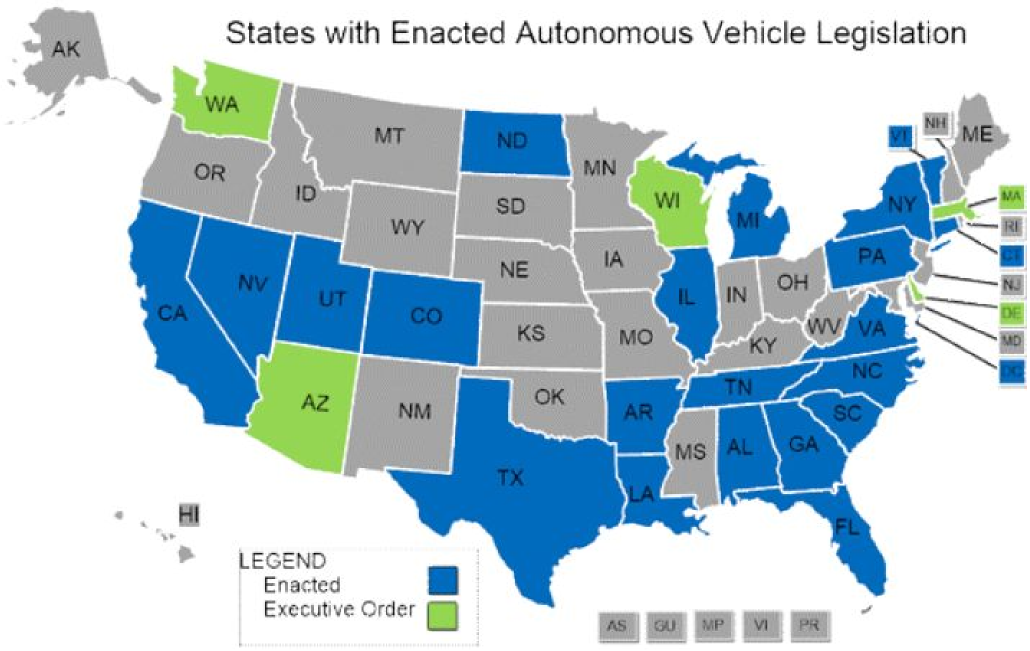


Fig. 8 - States with enacted autonomous vehicle legislation

Switzerland, Iceland, and Tanzania already allow autonomous drone delivery operations, and from 2018 Japan will permit them as well.

E. Open Source Vehicle Technology

A large number of autonomous vehicles are being developed as open-source projects by developer communities, as well as by commercial companies. These projects introduce new ways to design and build autonomous cars, drones, robots, and even underwater vessels.
In the autonomous car space: Open Source Car Control (OSCC[1]) provides developers with a collection of firmware and hardware designs for computer control of their autonomous development vehicles. Apollo[2] provides an open, reliable, and secure software platform for its partners to develop their own autonomous driving systems through on-vehicle and hardware platforms.

In drones and other UAVs: DroneCode[3] is an open-source platform for Unmanned Aerial Vehicles (UAVS), and Paparazzi UAV[4] is an open-source drone hardware and software project encompassing autopilot systems and ground station software for multicopters/multirotors, fixed-wing, helicopters, and hybrid aircraft.
In other robotics spaces: ROS[5] is a collection of libraries that aim to simplify the task of creating complex and robust robot behavior across a wide variety of robotic platforms, and OpenROV[6] is a low-cost submarine/underwater drone hardware.

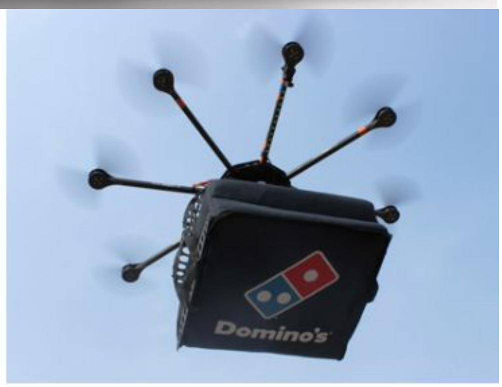
F. Token Economy

Blockchain technology has opened new possibilities for the recognition and exchange of value. We are now entering a time when applications may be built on top of blockchain technology and in doing so also create industry-specific economies and ecosystems.
This white paper proposes a way to leverage this significant economic paradigm shift by building a blockchain-based, global, and completely open-source technology stack that enables cooperation between members of the new transportation economy and the financial tools to incentivize network growth. The network becomes more useful as more users join and the demand for the tokens increases; this helps create incentives for early adopters who are vital for the creation of an active and growing ecosystem.

III. Problem/Solution

A. Problem

Today, large corporations have already begun experimenting with fleets of autonomous vehicles: Domino’s pizza delivery robots, Amazon’s Prime Air drones, Waymo’s autonomous taxis, and Baidu’s open-source self-driving cars are all leading the way towards fully autonomous transportation systems.



As these organizations employ armies of software developers in their attempts to create the first fully autonomous vehicles, they need to resolve issues revolving around perception, localization, decision making, and more. Additionally, autonomous vehicles require charging, maintenance, and docking infrastructure.

Centralization and narrow economic interests restrict the pace at which transformative technologies can be released and adopted by the market, as the key players are focused on dominating their own isolated networks, and not on creating a collaborative infrastructure that is more efficient and has higher potential for more diverse use cases in the long run.

A lack of incentives to collaborate across various value chains stifles the pace of progress in the sector. An open-source platform that is inclusive and permissionless provides economic incentives for multiple participants to join the network and enjoy its future growth in a way that allows for much more rapid scaling.

B. Solution

By open-sourcing the DAV technology stack and decentralizing protocols around identity, discovery, mission flow, and payments, provided through a modular UI, DAV enables cooperation. New players can enter the market, creating distributed value and growing participation in the transportation economy. A decentralized open source network means that players can independently take action in response to unfilled or poorly filled market needs.

C. Creativity at the edges

What's efficient about open-sourcing network technology is that it pushes innovation to the edge, giving more participants control over the pace and direction of innovation, and fueling creativity. Simplicity at the center allows for complexity at the edge.

Innovative applications and services will emerge as autonomous vehicle services scale and evolve, just as the Internet brought new businesses and business models into existence.

DAV's open-source technology stack, protocols, and UI solve problems through enabling cooperation, positioning the DAV network as a platform for independent innovation at the edge.

IV. The Internet of Transportation

A. Statement

Drones, cars, trucks, and even shipping boats are only some of the autonomous vehicles that will soon enter the mainstream. The DAV technology stack was created to make this ecosystem a reality by enabling true cooperation between autonomous vehicles, service providers, and users.

B. *Challenge Creating A Network*

For an efficient, fast-scaling shift from the existing transportation sector into the autonomous vehicle transportation sector, a huge support network must be put in place.

This autonomous vehicle network must include a large number of AVs, spread out all over the target area. Many parking spots must be designated for all of these AVs to park when they are not flying or driving around. Charging stations must be placed over a large geographical area. And finally, a network of supporting services, such as repairs, rescue, cleaning, and more must be put in place.

C. *Purpose*

The purpose of the DAV cryptocurrency is to incentivize a community-built autonomous vehicle infrastructure and build an autonomous vehicle platform that is commercially viable and essential for cooperation. The DAV network enables the distribution of tokens across all groups of network participants, and the growth of the network benefits all network members.

IV. 1. Internet of Transportation Participants

A. *Consumers*

Pay tokens in exchange for on-demand transportation of people and goods, and other services provided by DAVs.

B. *Providers*

1) *Vehicle Providers:* Earn tokens by making their vehicles available for on-demand missions of transport and delivery.
2) *Infrastructure Providers*: Earn tokens by providing docking, charging, battery replacement equipment.
3) *Service Providers:* Earn tokens by providing maintenance services for vehicles and locating and retrieving lost or damaged DAVs, according to recent GPS coordinates.
4) *Manufacturers*: Earn tokens by assembling and selling open-source DAVs using prefabricated parts, open-source plans, and open-source software.
5) *Insurance Providers:* Earn tokens by offering data-driven insurance policies on demand for people, DAVs, and parcels on selected routes and types of missions.
6) *Arbitrators*: Independent dispute resolution providers earn tokens by settling disputes directly through smart contracts on issues involving damaged goods and proof of delivery.
7) *Software / Hardware Developers*: Participate in the development of the open-source platform in exchange for bounties, as well as build their own custom services for accessing the DAV network.

V. Technical Functionality

The DAV network, as a developer-centric platform, creates SDKs for popular development platforms and APIs. It actively encourages developers to take part, making it easy for any developer to participate and contribute within their domain of expertise. The technology behind the DAV network is a stack of open-source software with a developed UI for simple interaction, which enables a truly autonomous, fast-scaling transportation system.

A. Identity

The identity stack enables users and devices to authenticate themselves to other network participants. Each DAV entity has its own identity. These entities might be a person looking to purchase transportation services, a rooftop charging station for drones, a driverless car, an insurance service, or even a group of several cargo drones controlled by a single system.

B. Discovery

Decentralized discovery provides the tools for different DAV identities to discover each other in a decentralized way. It represents the difference between a world where introducing a vehicle to a new environment requires building a support structure around it (e.g., charging and service stations, parking, etc.) and a truly connected world where any autonomous vehicle can operate in any environment, consuming services around it as the need arises.

C. Communication

DAV’s decentralized communication allows direct communications between two or more DAV participants using a common communication protocol. It is the key to facilitating most types of operations within the DAV network and enabling different entities from different manufacturers to communicate with each other, for example vehicles and charging stations.

D. Mission Flow

To enable an exchange of services between two or more parties, DAV offers a communication protocol designed to ease each step of the mission flow – from the initial statement of need through bidding, service fulfillment, and eventually payment.

E. Payments

The DAV token is a core component of the DAV stack and was created to enable secure, trustless transactions between two or more parties.

VI. DAV Technology Stack

The DAV stack is composed of five main components, each providing one piece of the puzzle needed to enable a decentralized autonomous vehicle ecosystem.

The five decentralized components are:

- Identity
- Discovery
- Communication
- Mission Flow
- Payments

VI. 1. Decentralized Identity

Each entity using the DAV network has its own pseudonymous identity, known as a DAV Identity. These entities might be a person looking to purchase transportation services, a rooftop charging station for drones, a driverless car, an insurance service, or even a group of several cargo drones controlled by a single system. These pseudonymous identities are uniquely identifiable and non-ephemeral, while still providing a degree of anonymity.

DAV Identities are stored and tracked in a decentralized way on the blockchain and can only be manipulated through a predetermined interface. This interface ensures strict access control over who (or what) can manipulate and use each identity. For example, only a user possessing the private cryptographic key that matches a given Identity's wallet can assign a human-readable name to that Identity or sign a smart contract on its behalf. On the other hand, the history of past transactions, which is stored within each Identity, can only be added to by authorized mission contracts and cannot be manipulated in any way by the user.

Unlike many other blockchain solutions, which can be completely trustless, transacting in the physical world presents additional elements that cannot be wholly encapsulated within a digital contract. In other words, while it is possible for a smart contract to know when a financial transaction has completed, knowing whether a physical package was delivered with a scratch is trickier.

DAV offers three tools for dealing with counterparty risks: a public transaction history, third-party arbitrators, and third-party insurers.

As a network of pseudonymous identities, DAV exposes the history of each Identity's performance, while also offering anonymity for it. (In other words, you can know how many successful missions a drone completed, but not who that drone is or who owns it.)

Each Identity holds within it a ledger detailing the complete history of transactions conducted by that Identity, along with their outcome. This essentially creates a permission-based access control, allowing anyone to access the full history of each Identity's transactions, while strictly limiting write permissions.

By evaluating the outcomes of an Identity's transactions over time, we can construct a clear image of its trustworthiness and the level of risk each party assumes in the transaction.

By combining both decentralized identities and a decentralized transaction history, we can achieve a decentralized system that not only exposes the full history of successful transactions, but one that does not allow an Identity to disavow or hide negative ones. DAV offers a system of full transparency and strict access control.

The nature of pseudonymous identities means that, by design, they are not tied to a real-world identity. A single legal entity or person can create multiple pseudonymous identities to represent themselves. This makes the system potentially prone to so-called sock puppets – identities created with the sole purpose of hiding past negative behavior. This issue affects all online communities where the cost of generating new pseudonymous identities is low. The user behavior that emerges in such communities, and what we expect to see among our users, is that users tend to trust and value vendors with a long history of successful transactions while considering transactions with new vendors riskier. For example, in online freelancing sites such as Upwork and Elance, veteran users with many positive ratings are able to charge a premium over new unknown users. Similarly, when evaluating bids for services over the DAV network, a potential buyer might look at a seller's history as an important criteria, and not just go for the lowest bid.

The need for a third party to decide on the outcome of some transactions opens the gate for introducing arbitrators (serving either as oracles or as additional signatures in a multisignature contract) into the system. These parties can provide their services and help facilitate transactions, resolve disputes, and increase user trust in the system. For example, when a dispute arises between a buyer and a seller, a third-party arbitrator might require a physical Proof of Delivery before signing off on a delivery. DAV's initial proof of concept demonstrates a third-party arbitrator service like this provided by the mission planning service.

Support for arbitration does not need to be built into the system (other than support for multisignature contracts supporting a refundable arbitrator fee). It represents an emergent behavior that is supported by the DAV stack.

Arbitrators are DAV Identities like any other, with their own transaction histories. They provide this service just like any other service provided on the network (i.e., an arbitration service is no different from a charging service from a technical standpoint). Some of these services can be automated (and often provided free of charge), such as being an additional key-holder in a multisignature contract, or providing a third-party verifiable Proof of Delivery, such as requiring the receiver of a package to enter a code to unlock a delivery box. Others might require human intervention (and payment of a fee). The fee can take the form of either a refundable deposit from either or both parties, or be deducted from the value of the transaction.

Not all transactions necessarily require the inclusion of a third-party arbitrator in the contract.

An Identity's transaction history can be used to determine a transaction's counterparty risk and act as a signal for both parties when deciding whether to include a third-party arbitrator or not.

The element of risk from unforeseen events and bad actors opens the gate for third-party insurance providers to offer a valuable service to the DAV network. Much like arbitrators, insurance providers implement the logic and tools for providing the insurance service and offer their services using the same DAV tools as any other service providers (i.e., a request for an insurance goes through the same channels as a request for a charging service). Thanks to DAV's decentralized nature, insurance providers have access to the full history of transactions completed by all the parties involved in a transaction (as well as their own history they may have saved in their own proprietary systems, such as their history with each party) and can use that data to estimate the level of risk and adjust the insurance premium.

While each DAV Identity is uniquely identified by a cryptographically generated hash, which is instantly recognizable to computers, this hash does not present a very human-friendly interface. By attaching a unique avatar to each Identity, generated using its cryptographic hash as the seed, DAV Identities gain an additional degree of recognizability and user-friendliness. This identifiability is enhanced by allowing an optional, unique, human-readable name to be assigned to an Identity using the DAV Naming Service, a service inspired by the Ethereum Domain Name Service[7].

Note that the concept of a DAV Identity is separate from a wallet. A certain identity can be connected to one wallet one day and a different one the next. This disassociation enables different emergent behaviors within the DAV network. For example, the owner of an autonomous charging station may sell that station to another person, without the buyer losing that Identity's transaction history, by changing the wallet it is attached to (and most likely generating new cryptographic keys required to control that station). Another example is a timeshare-like ownership of a drone by a group of people controlled by a multisignature contract that changes the wallet based on days of the week.

VI. 2. Decentralized Discovery

One of the most transformative aspects of DAV is the ability for autonomous vehicles to discover each other, as well as service providers and clients around them.

Decentralized discovery represents the difference between a world where introducing a vehicle to a new environment requires building a support structure around it (e.g., charging and service stations, parking, etc.), and a truly connected world where any autonomous vehicle can operate in any environment, consuming services around it as the need arises.

DAV implements this decentralized node discovery using a peer-to-peer protocol that is based on Kademlia[8] DHT (the same algorithm used by Ethereum's node discovery, as well as popular peer-to-peer protocols such as BitTorrent).

In Kademlia, each node is assigned a 160-bit opaque ID. Kademlia's lookup algorithm locates a node through a series of hops, with each successive hop converging closer in XOR distance to the lookup target. This enables node lookups with logarithmic difficulty and has been proven to scale remarkably well.

In DAV, each node in this peer-to-peer network represents a single DAV Identity and is identified by a unique ECDSA public/private key pair. This is separate from the key pair used to identify wallets on the blockchain (in fact, a DAV Identity may switch between different wallets without changing its public/private key). Unlike in Kademlia, node IDs within DAV's network carry with them extra function, as they take the form of a cryptographic hash of an ECDSA public key (*kpublic*), and all outgoing messages are signed using the matching private key (*kprivate*). The authenticity of any message received can be verified using that signature and public key. This ensures that malicious actors cannot pose as other nodes and forge messages (an attack known as a Spartacus attack) and creates a common identifier between the on-blockchain and off-blockchain representations of each identity.

This protocol enables general-purpose data transport and an interface for applications to communicate via a peer-to-peer network. This sits at the heart of DAV's decentralized discovery, as well as enabling its decentralized communication.

An interesting aspect of DAV is that its building blocks allow one to build discovery as a service on top of the DAV stack, as shown by our proof of concept Mission Control server. This allows for some interesting possibilities, such as allowing existing ride-hailing companies to operate their own network of autonomous vehicles, within their own app, while still enjoying DAV's other benefits, such as access to a network of token holders, service discovery, and more. Another example might be a discovery service listing only charging stations that have been verified by a third party to exclusively use renewable energy sources.

This flexibility is integral to DAV's philosophy and is supported by its modular nature.

VI. 3. Decentralized Communication

Decentralized communication is key to facilitating most types of operations within the DAV network. This communication can be divided into two groups: on-blockchain communications and off-blockchain communications (peer-to-peer communications).

On-blockchain communications take the form of messages that are communicated through events emitted by smart contracts (e.g., a transfer event when tokens are transferred between parties), as well as messages communicated by the entities using the network to the smart contracts (e.g., a state update sent by a drone to the mission contract as part of the intra-mission communication). These two types of communications should be quite familiar to anyone experienced with DApps.

Off-blockchain communications occur directly between two nodes, as well as following the publish/subscribe pattern wherein an entity publishes a message to *nsubscribers* that have shown an interest in messages that match certain attributes (also known as content-based message filtering). An example of the latter type of message would be an electric vehicle broadcasting (i.e., publishing) a need for a battery changing station that matches certain attributes (e.g., geographical location, plug type). This message would reach all the matching stations (i.e., subscribers). In response, charging stations may respond directly with a bid (as described under Decentralized Mission Planning and Coordination), an example of direct communication between two nodes.

DAV's peer-to-peer publish/subscribe system is based on an extension to Kademlia that is based on the Quasar[9] algorithm. We are working to improve on a few of the issues identified in Quasar, namely latency, advantages to peers in close XOR distance rather than geographical distance, and the ability for nodes to refuse to relay messages when it is advantageous to them to do so.

VI.4. Decentralized Mission Flow

Allowing autonomous vehicles and services to discover each other and communicate with each other are only the first steps in creating an autonomous ecosystem.

To enable a successful exchange of services between two or more parties, DAV offers a communication protocol designed to ease each step of the mission flow – from the initial statement of need through bidding, service fulfillment, and eventually payment.

These steps are executed off-blockchain using peer-to-peer communication and are governed and enforced by a number of smart contracts on the blockchain.

VI.4.1. Need

The story of each mission begins with a DAV Identity (a buyer) that requires a service broadcasting a request for that service. At its core, that buyer is defining a need. This Need is then broadcast to all DAV entities that are able to provide that service. As an example, let's take a person looking to ship a package to a friend who lives in the city. That user broadcasts a Need to deliver a package of a certain size from coordinate α to coordinate β at a certain time. In turn, a drone looking to deliver that package might broadcast its own Needs, such as a charging station within 500 m of coordinate β and a robot able to do the "last mile" of the delivery from a rooftop landing station to the second floor of the building at coordinate β.

The message containing the Need includes a number of fields, which are mandatory to all Need messages, as well as a payload with additional details specific to the type of service requested (e.g., package weight, number of passengers, etc.)

VI.4.2. Bid

The second part of the mission flow is the Bidding process. Any Identity (a seller in this case) listening to incoming Needs can respond with a Bid to fulfill that Need. The Bid is sent directly to the buyer and, like the Need, includes a few mandatory fields common to all Bids, as well as a payload containing additional details relating to the specific type of service. For example, a drone responding to a request for a ride might include the price for completing the mission, an expiration time for the Bid, the drone's current location, estimated time of pickup, estimated time of delivery, and additional details like whether it requires a third-party arbitrator to sign the contract.

Note that the entire flow is asynchronous. The drone from the previous example might receive the Need and, before sending its Bid, broadcast its own Need asking for Bids from insurers to insure the delivery. Once the drone receives a Bid from insurers, it can calculate the total cost of the delivery and make its Bid for the delivery job. Only once it is awarded the delivery job will it sign the insurance contract. Note that in this example, the drone is both a buyer and a seller of services.

VI.4.3. Contract Signing

Once the buyer has received a few Bids and has made a decision based on the Bids' details, as well as on the Identities and transaction histories of the sellers, a smart contract can be signed between the relevant parties.

DAV smart contracts support transfer of DAV tokens once a mission concludes successfully (verified by signatures from both parties, external oracles, or multisignature contracts involving third-party arbitrators), refunds, staking tokens for insurance, and more.

As part of the DAV's developer-centric platform, DAV will develop tools to enable third-party developers to create domain-specific multi-step contracts to be used on the DAV network.

VI.4.4. Intra-Mission Communication

While not a mandatory step of all mission flows, intra-mission communication using DAV's Decentralized Communication protocol allows a transfer of data and state messages. This can be extremely useful on-blockchain, such as in multi-step mission contracts, as well as off-blockchain, allowing direct communication between buyers, sellers, and oracles.

For example, a multi-step smart contract between a drone and a client looking to ship a package can be updated as the mission progresses through various steps (travel to pickup location, pickup, travel to destination, etc.) This on-blockchain data can later be used by another contract that was created to insure the transaction.

Another example might be intra-mission communication between vehicles establishing collaborations to decrease the number of empty trips [10].

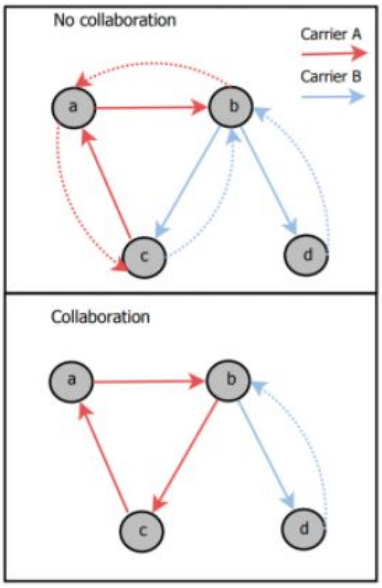


Fig. 10 - Example: Collaboration between vehicles decreases the number of empty return trips from four to one

VI. 4.5. Contract Resolution

Smart contracts may contain a number of conditions, which can lead to one of several resolutions. This differs from contract to contract, but the most common scenario occurs once a mission has been completed successfully: the two parties both send a message to the contract indicating their satisfaction, which is immediately followed by a release of funds from the contract to the seller.

VI. 5. Decentralized Payments

DAV's Decentralized Payments contracts are a core component of the DAV stack that enable secure, trustless transactions between two or more parties.

At the heart of the Decentralized Payments is the DAV token. The token is fully ERC-20 Token Standard[11]-compliant. It implements the ERC-20 token interface, with a few additions that extend its functionality for the unique needs of the DAV network, as well as deal with a few of the known security issues of ERC-20 tokens.

While tokens can be transferred directly between wallets using the DAV token contract alone, mission contracts use a specialized contract to gain additional functionality when making payments between DAV Identities. This contract serves as the glue between an Identity and the DAV token, providing additional features, such as paying for missions using an account's own tokens balance, as well as promotional incentive tokens received from an ecosystem member.

In addition to the specialized functionality it enables, the payment contract also keeps track of which Identities hold incentive tokens, as well as a whitelist of identities that can receive incentive tokens.

VI. 5.1. Payments Using Incentive Tokens

When a DAV buyer that holds incentive tokens attempts to pay a seller that has been whitelisted to receive incentive tokens by the incentive creator, payments will be made first from the incentive tokens balance of the buyer (with certain limitations, as described below).

Incentive tokens are real DAV tokens held in a separate wallet. When the DAV Foundation or other ecosystem members decide to incentivize a seller (e.g., a charging station) it sells Ethereum and buys DAV tokens, depositing those tokens in the incentive token wallet. Next, it assigns those tokens to potential buyers (e.g., electric vehicles) of that seller's services using the *addIncentiveTokens*() function. Finally, it uses the *createIncentive*() function to add that seller's Identity to the incentive whitelist, allowing buyers to pay that seller with incentive tokens. When creating an incentive, a limit is also placed on the maximum number of tokens that a seller can receive, as well as the maximum percent of each transaction that can be paid for with incentive tokens.

An example of this structure would be a charging station manufacturer incentivizing homeowners to buy and place charging equipment in their driveways. If the equipment and installation costs of each station is 100 DAV, the manufacturer may whitelist each of these new charging stations to receive up to 100 DAV in incentive tokens, virtually guaranteeing that the homeowners cover their initial costs.

VII. Fueling a New Ecosystem

DAV is committed to the the success of its platform, its token, and to the success of the economy and its participants who are building and deploying the next generation of autonomous vehicle transportation and infrastructure.

To help grow the Internet of Transportation and jumpstart the network effect, the foundation will actively incentivize early adopters in select cities, establishing favorable market conditions and lowering barriers to entry. DAV cities will be designated by the foundation based on the following criteria:

- Autonomous-vehicle-friendly regulation
- Financial incentives from local EDOs (i.e., economic development offices)
- Viable use cases and populations of early adopters
- Deployment of UTM[12] for integrated airspace management through e-registration, e-identification, flight planning, geofencing, airspace authorization, flight tracking, and live telemetry services

DAV tokens will be distributed as part of a DAV incentives program, which will provide bounties directly to consumers and enthusiasts in DAV cities, to autonomous transportation services, and/or to autonomous vehicle companies for purchasing services from within the transport economy, such as charging or maintenance.

By deploying a predefined portion of its capital this way, the foundation aims to seed sustainable transport economies of participants and help jumpstart city-wide network effects. However, while doing so, the following potential pitfalls will be addressed:

A. Origin of Incentive Tokens

When approaching the challenge of deploying large amounts of DAV tokens, using the foundation's DAV reserves would be unfair towards token holders, as the receivers of those tokens are expected to liquidate many of these tokens to cover operational expenses involved with providing the services purchased. That would mean that, by design, an influx of "free" tokens would be poured into the market, potentially to be sold at large quantities. As a balancing factor, the DAV Foundation will only fund the DAV Incentives program using DAV tokens that it has purchased on the markets at market price, using the foundation's ETH reserves that were allocated specifically for this purpose.

B. Destination of Incentive Tokens

Another issue to be resolved is avoiding the recipients of incentives tokens to sell them on the market instead of using them to buy services from DAV ecosystem providers. To help make sure that incentives tokens are properly utilized, they are embedded with a list of allowed Identities before being distributed. So, in each DAV city where incentives are to be distributed to help jumpstart the market, relevant provider Identities will be updated, and incentives tokens will only be transferred to these addresses.

While the limitations on incentives do require a temporary period of centralized growth management, this does not have an impact on the long-term architecture of DAV as a completely decentralized platform.

VIII. Risk Disclosure

The following are risk factors in relation to the DAV network business in general:

- The DAV token may be significantly influenced by digital currency market trends, and DAV value may be severely depreciated due to non-DAV-related events in the digital currency markets.
- International laws and regulations may render the DAV trade impossible.
- The ownership of DAV tokens may fall under new and unpredicted taxation laws that could erode DAV benefits.
- The positions and plans outlined in this white paper may be altered as the project progresses.

IX. Future Work/Roadmap

The core team behind DAV will work with the community to continuously document, publish, and open source proof-of-concept releases, in which each iteration will be more daring than the previous in terms of adding new autonomous vehicles and participants, as well as smarter functionalities, across longer distances and in more countries.

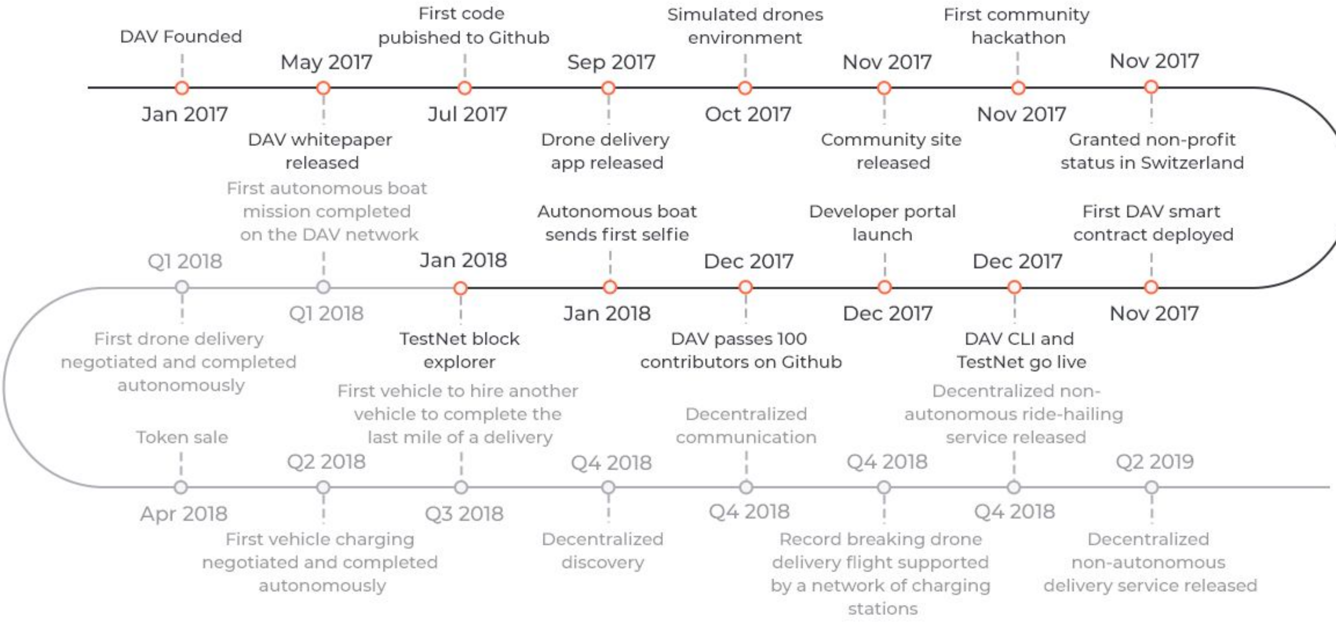


Fig. 11 - Future Work & Roadmap

Our major milestones for development and go-to market are:

- MVP #1 - World's first autonomous vehicle to autonomously bid for delivery services, complete them, and get paid using a cryptocurrency directly to its own wallet.
- MVP #2 - World's first autonomous vehicle to pay for its own battery replacement using cryptocurrency and take off to complete its delivery mission.
- MVP #3 - World's first autonomous vehicle to pay another autonomous vehicle (robot) using cryptocurrency for completing the last mile of a delivery mission.
- MVP #4 - Longest drone delivery flight ever, flying cross-country using the support of multiple DAV battery-changing stations along the way.
- Additional Development - Add support for robotic vehicles, cars, and marine vessels.

X. Conclusion

At the critical convergence of autonomous transportation technology and blockchain technology, DAV's open-source decentralized identity, discovery, mission coordination, and payments enable users, service providers, maintenance providers, third-party developers, and investors to become part of a new economy and monetize the transportation system of tomorrow.

Change is coming, and the opportunities are numerous. Just as the Internet enables P2P transfer of information, and as blockchain enables P2P transfer of value, the DAV network enables P2P transfer of physical objects.

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