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TITLE:

A Systems-Level Technology Policy Analysis of the Truck-and-Drone Cooperative Delivery Vehicle System

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ABSTRACT:

This paper concerns a systems-level assessment of the truck-and-drone cooperative delivery system and its integration into urban environments. The analysis is grounded in an assessment of the regulatory environment currently applicable to truck-and-drone logistics, with a particular focus on the state of small unmanned aerial vehicle regulation in the United States. This is followed by a broad discussion of the social, environmental and operational implications of such a system deployed at scale and its potential impact on society. The paper concludes with an appraisal of the compatibility between today's relevant regulation and the evolving truck-and-drone system technology. A proposal for an adaptive regulatory framework to guide the safe, responsible development and deployment of this emerging technology is then proposed that suits the technology's various stakeholders; citizens, municipalities, relevant regulatory bodies and logistics firms.

KEYWORDS:

Last-mile, urban, logistics, delivery, drone, unmanned aerial vehicle, truck-and-drone cooperative, flying sidekick, regulation, technology policy

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Abstract

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Acronyms

B-VLOS	Beyond Visual Line of Sight
DOT	Department of Transportation
E-VLOS	Extended Visual Line of Sight
EPA	Environmental Protection Agency
EU	European Union
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FMCSA	Federal Motor Carrier Safety Administration
FRA	FAA Reauthorization Act
GDPR	General Data Protection Regulation
GPS	Global Positioning System
NAS	National Airspace
NASA	The National Aeronautics and Space Administration
NHTSA	The National Highway Traffic Safety Administration
NTIA	National Telecommunications and Information Administration
PAR	Planned Adaptive Regulation
UAE	United Arab Emirates
UPS	United Parcel Service
UTM	Unmanned Aircraft System Traffic Management
VLOS	Visual Line of Sight

1 Introduction

In the past decade, the logistics industry has experienced substantial growth and its fair share of technological disruption. Particularly in urban settings, consumer demand for same-day or two-hour delivery has ballooned and companies have struggled to meet demand without incurring substantial "last-mile" delivery costs. The "last-mile" can be loosely defined as the last few stages of a parcel's delivery chain process, which usually happens in the congested neighborhoods of today's megacities. Whilst shifting consumer expectations have played a pivotal role, a symbiosis of trends has driven immense growth in "last-mile" delivery operations, including intensifying urbanization, increased purchasing power of the global middle class, the rise of new digital business models, and advancements in delivery vehicle and routing technologies. For example, from 2014-2019, e-commerce sales nearly tripled globally, translating to an expected growth in "last-mile" delivery demand of 78% by 2030 (Clement 2020).

The "last-mile" in a delivery chain is vitally important to firms because it constitutes a disproportionately large share of the parcel delivery cost to a customer, particularly in urban areas. From the perspective of a logistics firm, this problem currently represents an opportunity to differentiate one's product from other logistics specialists but also capture more commercial customers that previously managed their own logistics operations in-house. Amazon, United Parcel Service (UPS) and FedEx, among others, are investing heavily in new operational models, technologies, and scientific brain-power to address their urban logistics woes. Whilst the "last-mile" problem is a global one, much of this investment is being allocated to projects in the United States. Whilst firms will face a multitude of barriers in extrapolating any innovations to different countries and use-cases, the problem and the ideal outcome is the same; what can differ is the solution. With this in mind, this paper will focus solely on the state of the "last-mile" in the United States, with a handful of allusions to international enterprise.

1.1 Trends in Last-Mile Logistics

Although the final step in a typical delivery chain, the "last-mile" is a significant contributor to negative sustainability externalities associated with urban logistics more broadly, be it economic, social or environmental. In today's megacities, the face of urban "last-mile" logistics has changed. An industry that used to be an peripheral part of daily life has morphed into delivery vehicles being double parked, their drivers up against the clock to meet demanding time-window commitments and bicycles racing between congested traffic to deliver a meal before it cools. This transformation is for the worse, but the outcome is not inevitable.

Key "last-mile" players are looking to integrate a host of small solutions to achieve the larger objective of efficient urban logistics. We are already seeing aggregated demand solutions such as parcel lockers and public drop-off points being deployed – an ironic reflection of traditional logistics operational models prior to the e-commerce boom. Two-tiered solutions such as these are becoming more common in today's megacities as large parcel trucks becoming increasingly ill-suited to navigate today's dense suburban neighborhoods. The truck-and-drone (T&D) cooperative system is an innovative extension of such two-tiered systems that utilizes two separate vehicle technologies, a truck and an aerial drone, simultaneously. Whilst it offers increased flexibility and operational efficiency, these systems often require an inter-disciplinary systems-level strategy to achieve these gains at scale.

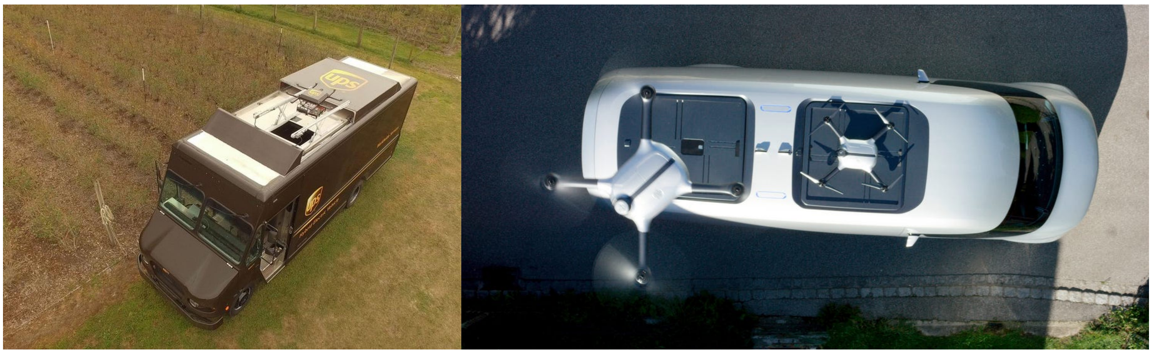
The T&D cooperative system, elaborated upon in Section 1.2, is one of numerous emerging technologies being espoused by logistics players globally. Whilst some defend pure-play drone operations, others look to more conventional e-bikes or less conventional autonomous sidewalk robot vehicles to address growing "last-mile" costs. In general, we can expect the future of the "last-mile" to look like an assorted mix of these technologies and operational models depending on the good being delivered, city, demand base, logistics firm and, of course, regulatory environment. Nonetheless, we can expect a diversification of solutions away from traditional direct parcel delivery services in the next decade.

Finally, the digital dimension of urban logistics should not be overlooked. Data collection lies at the heart of current and future "last-mile" operations, particularly in safety management and route optimization. The privacy, safety and security concerns surrounding future drone operations is undoubtedly warranted and should play a central role in future regulatory frameworks. As logistics firms seek out innovative ways to improve their bottom line, citizens and lawmakers alike should realize their vested interest in guiding the transformation of "last-mile" operations in the direction of sustainability and social responsibility.

1.2 The Truck-and-Drone Cooperative System

As mentioned earlier, one technology that has received substantial public attention in the past decade is the delivery drone. Unmanned drone deliveries were tested by the Swiss Postal Service as early as 2015 and medical supplies have been delivered to hospitals as a commercial service across Rwanda since 2016 (Landhuis 2018). Whether naysayers acknowledge it or not, commercial drone operations are here and with the multitude of drone designs and use-cases, commercial operations will take a variety of forms. Whilst drones are a promising delivery mode since they can avoid ground-based traffic and achieve nearly on-demand delivery, they are severely constrained by their flight range and cargo capacity. To surmount these constraints, a new T&D cooperative technology has recently emerged. This technology lies at the center of this paper. The T&D system is theoretically more efficient than the truck-only delivery mode since packages can be outsourced to drones to make deliveries in tandem with the driver. These drones, fixed to the top of the truck when not deployed, would be dispatched when they are requested and retrieved again at another predefined location along the truck's route. The drone would then switch its batteries with spares being charged by the vehicle ready for its next dispatch order. In a way, it is an aircraft-carrier-esque approach to drone delivery operations.

Existing logistics route optimization models show that a T&D cooperative vehicle can achieve substantial cost-savings when benchmarked against either truck-only delivery or drone-only delivery models (Salama & Srinivas 2020, Moshref-Javadi, Lee & Winkenbach 2020, Moshref-Javadi, Hemmati & Winkenbach 2020). T&D deliveries are particularly promising in affluent rural areas were distances are far by road but not by air and consumers are willing to pay a premium for speed. Moreover, integrating drones in the delivery process is particularly fruitful if a relatively small number of highly constrained customers otherwise complicates the truck-only route (Winkenbach 2019).More generally, whilst logistics firms are mainly motivated in addressing the "last-mile" bottleneck to improve operational efficiencies, municipal leaders should also see the value in more efficient "last-mile" operations for the sustainability, productivity and livability of their cities. Whilst the literature addressing the policy implications of drone-only delivery is rich, the T&D cooperative vehicle has only been studied on a technical routing level. This paper will seek to take a more holistic systems-level policy and regulatory perspective to analyze the implications of this specific emerging technology, the T&D cooperative system in the context of



(a) UPS Prototype (Forrest 2017) (b) Matternet-Mercedes-Daimler Prototype (Korosec 2016)

Figure 1: Prototype truck-and-drone cooperative delivery vehicles.

"last-mile" logistics. Additionally, this paper will attempt to detail an adaptive regulatory framework for the future of the T&D cooperative system.

2 Current Regulations

2.1 Drone Regulations

Although this paper discusses the unique T&D technology and the potential regulations that could encapsulate its commercial operations, the most interesting and consequential dimension of the T&D system is the drone. In this sense, much of this paper will focus on how drones are being integrated into logistics operations and regulatory frameworks. Currently, a dichotomy exists in drone regulations. On the one hand, there are lawmakers who seek to make it easier for businesses to harness the efficiency gains that stem from drone use which, in turn, would benefit society more broadly. On the other hand are lawmakers who want to outlaw all commercial (and, if possible, personal) drone use for privacy concerns and concerns about terrorism, vandalism or human safety because of the dangers associated with either frequent cargo-loaded drone flights or ill-disciplined hobbyists.

The Federal Aviation Act of 1958 established the Federal Aviation Administration (FAA) and made it responsible for the control and use of navigable airspace within the United States. The FAA created the National Airspace (NAS) to "protect persons and property on the ground, and to establish a safe and efficient airspace environment for civil, commercial, and military aviation". The most relevant existing FAA regulations that apply to drones are housed in the FAA Part 107 Drone Regulations, which went into effect on August 29, 2016 (Rupprecht Law 2019). Whilst this set of regulations is vast and applies to various types of drone operations, be it commercial, private or public, the most constraining regulations relevant to commercial T&D delivery are noted below:

1. Air carrier operations are strictly not allowed. Air carrier means any United States citizen undertaking by any means, directly or indirectly, the supply of air transportation. This is obviously a non-starter for commercial drone delivery but the FAA has granted numerous exemptions and waivers on a case-by-case basis for firms to test equipment and operational models (§ 107.31 Part 107 FAA 2020).

2. The drone must be flown within Visual Line of Sight (VLOS) of the pilot in command. This is very constraining for operators and the industry is pushing for regulations to permit Extended Visual Line of Sight (E-VLOS) and eventually, Beyond Visual Line of Sight (B-VLOS). Figure 2 depicts the differences between these terms (§ 107.19 Part 107 FAA 2020).

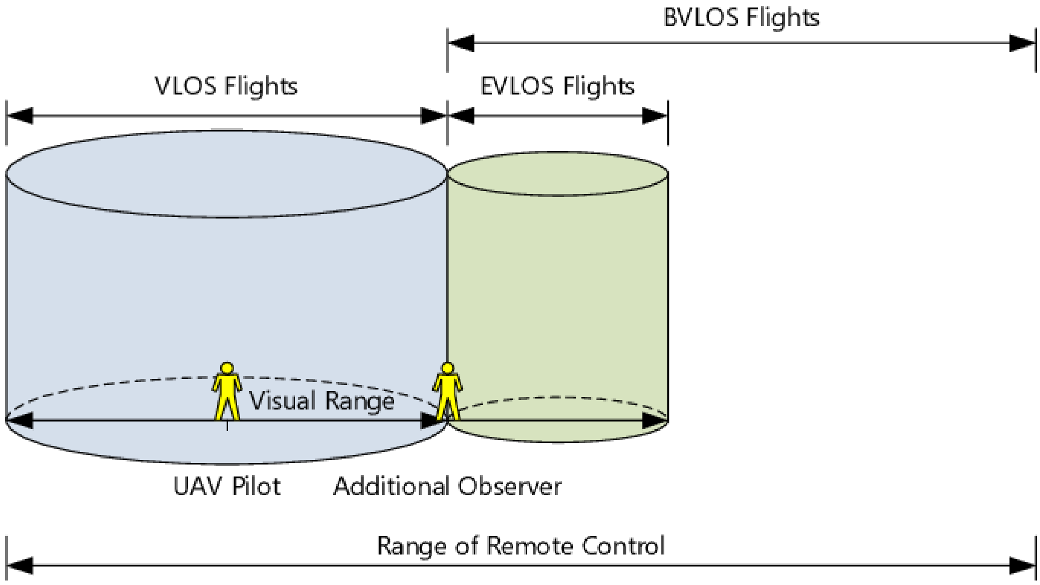


Figure 2: Visual line of sight terminology illustration. (Woo et al. 2018)

3. A drone operator is mandatory for drone flight i.e. the drone cannot be autonomously flying. Furthermore, there is a strict one-to-one relationship between operator and drone. Note that waivers have been granted that null this requirement for test purposes. (§ 107.35 Part 107 FAA 2020).

4. Drones cannot be operated from a moving vehicle to transport another person's property for compensation hire. This is another evident non-starter for the T&D system. Compromise is possible in how a firm operates a T&D system; for example, drones could be launched only when the vehicle is stationary. (§ 107.25 Part 107 FAA 2020)

5. Drones cannot be operated over a non-participating person, property populated with people or a moving vehicle, again another non-starter for urban drone delivery operations (§ 107.39 Part 107 FAA 2020).

6. The drones cannot be operated in Class B, C, D, or E airspace without an authorization or waiver. These classes are depicted in Figure 3.

7. Unless under a 107 waiver, if the drone is to be considered under Part 107, it must weigh under 55 pounds and remain under a 400 feet altitude ceiling (Woo et al. 2018).

These regulations are highly limiting for commercial drone delivery, let alone the T&D system. There is a second dimension to drone regulations, and that is state and local drone regulations. Whilst the FAA allows some flexibility when it comes to creating and implementing drone regulation at local levels, it advises states and municipalities not to stray

Figure 3: Airspace classification schematic. (FAA Safety Team 2020)

too far away from their operational guidelines. For instance, states are not allowed to restrict airspace directly (e.g. restrict drones from flying in certain areas) but since the FAA does not oversee trespassing or privacy regulations in this domain, localities have asserted their authority through these channels. This balance between national versus local drone regulation will be discussed further in Section 4.2.

In the U.S., March 15, 2017 signified the most resolute effort yet by Sen. E. Markey (D-Mass.) and Rep. P. Welch (D-Vt.) to introduce federal legislation to regulate drones. It actually took the form of a drone privacy framework. Entitled the Drone Privacy and Transparency Act of 2017, the proposed regulations suggested three methods to safeguard personal privacy threatened by drones: 1) require every person or firm seeking to use a drone for commercial purposes to obtain pre-authorization to operate the drone. This entails providing certain information about where, when, and for what purposes the drone will be flown, and whether it will collect, sell, or otherwise use personal information about any individuals; 2) require the FAA to publicly disclose this information on the Internet and 3) ban any use of drones by law enforcement personnel without a warrant (Hall 2017). Whilst it was never enacted, this piece of legislation signals to industry stakeholders the general intentions of Congress active members – the issues that face drone delivery, and even more so for the T&D system, extend far beyond the mere operational regulations.

2.2 Last-Mile Regulations

In the context of the T&D system, last-mile-specific regulations that address the manufacturing, design, maintenance and, most importantly, operational constraints that need to be considered are virtually non-existent. The T&D system is too novel to be regulated and too unlikely a "last-mile" solution for municipalities or federal bodies to draw up regulatory frameworks. Many suggest that the first step is to achieve fully-fledged commercial drone delivery first before extending newly drafted frameworks to accommodate the T&D system. This seems the most likely case for three reasons:

1. It is obvious that before the T&D system can be considered feasible from a regulatory standpoint, the drone should be a successfully integrated technology in its own right.

2. Logistics firms interested in the T&D system will undoubtedly need to prove the technical viability of their drone technology first. They will then need to understand the constraints of their drone technology and whether these limitations could be addressed by the T&D system for their target consumer markets. Simply, the T&D system is a tool that extends a drone's capabilities. Its purpose and, therefore, regulatory requirements are intrinsically tied to that of a drone.

3. A framework for the T&D system will not look drastically different to that for drone-only operations, except for additional amendments and constraints. This paper posits that these future edits will be the more difficult comply with than expected for T&D operators since they are likely to be more local in scope. This paper posits this for two reasons: a) from existing computational models, the T&D system is proving only economically viable in certain geographic scenarios, namely affluent suburban and rural areas with technology-centric consumers in generally wealthy countries with robust lower-airspace regulations. In this way, local regulations are likely to be more consequential for T&D system deployment than national regulations; b) because these edits will be local in scope, logistics firms will struggle to comply with a heterogeneous mix of different local regulations. There is also a danger in cities implementing 'revenue-seeking' regulations, since this technology is not only very advanced, but likely to target affluent neighborhoods with the ability to absorb additional T&D related fees. This will discussed further in Section 4.2.

More broadly, we can expect key "last-mile" players to be more involved in the regulatory process than they have been historically. This is because this is the first time the FAA will be involved in regulating the logistics industry, other than freight airline operations, and will likely look for stakeholder input. The FAA has been testing the waters in the last few years by offering a variety of exemption grants to certain operations beyond Part 107. One example of this is the offering of B-VLOS waivers for certain users, namely public safety management which include law enforcement, emergency response, and national defense. The logistics players know this and will likely establish partnerships with such service providers (Peterson 2019). This allows them to 1) test their hardware, software and operational strategies; 2) establish working relationships with the governing regulatory bodies and 3) solidify their reputation and secure endorsements as a safe drone operator. This will likely dominate future regulatory trends for last-mile drone delivery. We can also expect to see more of the cavalier "move fast and break things" attitude that the tech giants bring to the scene; an unexpected taste of disruption for the legacy players in the industry.

3 Implications of the Truck-and-Drone Cooperative System for Society

The T&D system emerged out of the limitations of the key disruptive technology in the logistics space: the aerial drone. Whilst the term "drone" can denote many types of vehicles, both aerial and ground based, it most commonly refers to the aerial quadcopter: a quad-rotor vehicle capable of approximately 20-30 minutes of flight time and a flight range of anywhere between 1-6 miles, depending on the configuration. The T&D cooperative system was designed around the quadcopter drone, since its value proposition as a system is extending the effective range of a delivery drone. The T&D system therefore necessitates vertical take-off and landing capabilities that fixed-wing drones cannot perform but rotor-based designs can.

Drones exhibit traits that are desirable in today's e-commerce-centric consumer market. With a relatively low operating cost, an eco-friendly energy system and high transit speeds in congestion free aerial highways, drones meet the demands of on-demand "last-mile" logistics. But in their current state and with restrictive operational regulations in place, their full value in logistics has not yet been realized. Currently, a single delivery operator is strictly bound to operate a single drone and the drone must remain in E-VLOS (see Figure 2). Economically feasible commercial drone operations would require both a one-to-many relationship between operator and drone and for B-VLOS operations to be permissible. Otherwise, regulations would require operators to remain alongside the drone as it delivers the package, not an economically viable operational solution. We can expect to see commercial drone operators lobby for these regulations to be revisited. Until then, they will invest in drone automation, computer vision, and digital security technology in preparation for when the restraints of regulation loosen.

We can also expect to see a certain level of ground-vehicle technology progression, with a particular focus on reliable launch and retrieval mechanisms. As will be mentioned later in this paper, the truck serves as a mobile ground control system for the drone, and will therefore need to integrate into future lower-airspace management frameworks and security protocols. Whether such a lower-airspace management system is an extension of existing static, the hub-and-spoke air-traffic-control tower, or a novel many-to-many air-traffic-management system, T&D delivery firms will need to rapidly become proficient in, and potentially lead, future airspace management and integration procedures. Finally, in the long term, we expect to see autonomous driving technology integrated into these trucks. This is because the key cost driver in "last-mile" delivery is the labor cost of the driver. Without truck automation, cost savings associated with the T&D delivery system are limited to delivery efficiency improvements as the drone diverts workload away from the driver and performs deliveries in tandem. Whilst autonomous technology is already on the radar for most logistics players and conceptually integrated into the T&D concept, this paper will not focus on it for three reasons: 1) whilst integrating autonomous technology into the T&D system makes theoretical sense, the complexities of operating a number of drones remotely from a moving vehicle will definitely require human input over the next decade or two; 2) regulating autonomous driving technology is notoriously complex and beyond the scope of this paper and 3) there remains a gaping flaw in how autonomous technology will be utilized in urban logistics. This is the "last-fifty-feet" conundrum. How will firms get the package from the autonomous vehicle to their customer's front porch or up ten flights of stairs? This issue has not been resolutely addressed in literature, in part because automation in logistics is still conceptual in scope. The T&D cooperative system is already, and will shape up to be, an assemblage of different technologies – aerial drone hardware, autonomous driving and computer vision software, multi-tiered delivery operations, and critical wireless connectivity – that will be deployed in and amongst the most dense urban populations to date. In addressing the technology and policy questions, the question is, where should one start?

3.1 Safety

Delivery drones pose a variety of safety dangers both to bystanders and property below, not to mention other aerial vehicles. Whilst there are a variety of safety implications associated with drone delivery operations, with bodily harm or personal injury being but a small subset of these (discussed later in Section 3.2), this section analyzes the safety implications of urban T&D operations from the perspective of how to integrate such operations into the NAS. This is a vitally important question to address before the real economic benefits and "last-mile" efficiencies of drone delivery can be realized. The main goal here is to minimize the risk of direct or indirect collisions between a drone and other aerial vehicles, high-rise objects and objects on the ground. The other safety considerations will be discussed in the latter sections about legality, liability & insurance (Section 3.2) and security (Section 3.4). As mentioned earlier, a decision has to be made whether the current lower-airspace air traffic management network will maintain the current hub-and-spoke architecture or adopt a more decentralized autonomous many-to-many design. Today, we have the former, which involves human operators based at airports managing a handful of aircraft each. It's worth noting that the current operating cost of the air traffic control system in the U.S. was $9.34 billion in 2016, or about $1,000 per commercial flight. As a point of comparison, the current average hourly operating costs of an drone vary from $75 to $500 per hour (Kuhn 2017). This suggests that the current air traffic control network will not suit the cost structures drone delivery firms need to achieve and would not be able to manage the soaring volume of drone flights.

To offer a sense of how difficult integrating drones into the NAS will be, Figure 4 shows the various airport airspace boundaries just in the city of Phoenix, Arizona. The red lines demarcates areas were drones are currently not permitted to fly under FAA Part 107 regulations. It is obvious that this is not ideal for drone delivery service providers. If such stringent airspace restrictions remain, commercial drone operations will struggle to get off the ground to serve a large portion of their total available markets excluded. Integrating drones in the NAS is a behemoth of a problem. There is discussion around whether drones should remain limited to class G airspace, as shown in Figure 3. This could allow for air traffic control to be kept separate on these lines. For instance, there would be a single air traffic control protocol and management system for larger manned commercial aircraft in classes A, B, C, D, and E and a separate low altitude high-volume-enabled system for drones operating in class G. Whilst this could work, aircraft will undoubtedly cross these boundaries by mistake. Engineering the interface between these systems for such an eventuality will be difficult. With that said, in the short term, this future is plausible, although it may not be ideal.

This lower-airspace decentralized automated air traffic management system is often referred to as Unmanned Aircraft System Traffic Management (UTM). Whilst this paper could go into the architecture of such a system and its pros and cons, it seems beyond the scope for now. What is important is that these systems currently do not exist but are being developed by a variety of stakeholders, from The National Aeronautics and Space Admin-

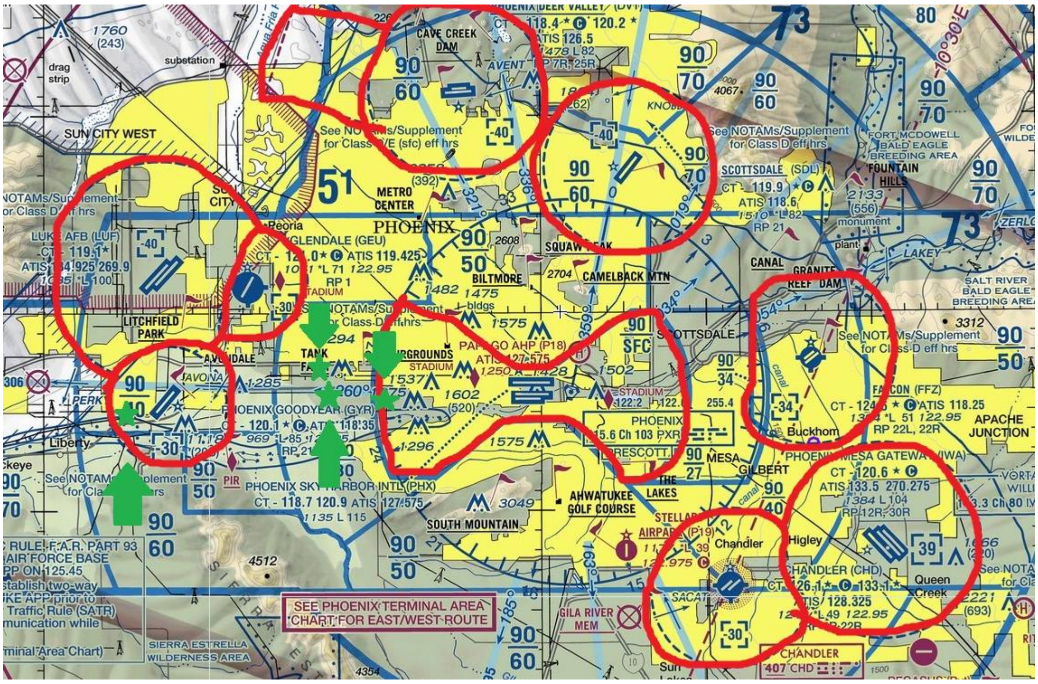


Figure 4: Greater Phoenix region feasible drone operations airspace diagram (Rupprecht Law 2019).

istration (NASA) to Airbus to smaller aviation players like Leonardo in Italy. Another spanner in the works is where the drone is launched and controlled from. In the case of the T&D system, these may coincide, or they may not. How UTM systems deal with aerial vehicles launched from moving trucks is a question that remains unanswered. As one can see, there is much room for improvement and development. We are, therefore, likely to see a lot of change over the years, which will require regulatory authorities like the FAA to remain up to date and vigilant, highlighting the need for the adaptive framework discussed in Section 4.

3.2 Legality, Liability & Insurance

As one frames the legality, liability, and insurance issues of the T&D system, a number of legal concerns come into play. The most consequential liability issues stem out of drone commercial operations, particularly in urban settings. Current FAA regulations make the distinction between three types of drones: 1) public use (operated by public entities in service of the public. This could be firefighters, emergency response or law enforcement), 2) recreational use (hobby-related, private drone operations with weight and altitude limitations), or 3) commercial use. Whilst the legality, liability and insurance concerns extend across these three types, this paper only focuses on the implications for the T&D system, and therefore the third type, commercial drone use. With this said, technological advances have meant that drone purchase costs are decreasing and we are experiencing a leveling out of drone technology across the range of drone platforms, whether they are designed for hobbyists, public, or commercial operators. The implications of this are that the FAA's current set of regulations are quickly becoming redundant and ill-suited for the current drone landscape. Whilst this is an issue that remains to be analyzed, it is both an artifact of the lack of preemptive regulatory action and the adaptive regulatory framework currently being employed by the FAA to address commercial drone deployment.

The issue of liability in drone operations is of critical importance to the manufacturers, operators, regulators and bystanders involved in the drone-delivery process. In general, the following liabilities would apply to commercial drone delivery operations:

1. Bodily injury: defined as the harm caused to the person's body if a drone is involved in a direct collision with a person.

2. Property damage: defined as damage inflicted on a piece of property either directly or indirectly caused by a drone. Indirect property damage is particularly applicable in low-altitude urban T&D drone operations. As an example, fire damage caused to a piece of property because a drone collided with power lines would fall under indirect property damage liability.

3. Personal injury: in addition to bodily injury, personal injury includes invasion of privacy of people, buildings or trade-protected images. Of chief concern is the invasion of personal privacy. Addressing these concerns necessitates the regulatory body responsible, the FAA, to secure the process used by drones for collecting, processing, storing and utilizing data collected. Regulating data privacy is not the FAA's forté and so we can expect this to be a regulatory obstacle for mass commercial drone operations in the future.

4. Third-party liability: this pertains to liability involved in contracted partnerships in drone operations, whether it be at the manufacturing level or lower down the operational supply chain.

In the U.S., these liability laws are firmly in place but may need to be extended to encapsulate the possible eventualities inherent to low-altitude aerial vehicle flight or urban aerial logistics. But beyond liability, there are several legal areas that could be implicated, namely data protection, privacy, personal liability, insurance, intellectual property, commercial export, nuisance and trespass law. The current state of these legal concepts and how they apply to the T&D system will now be assessed. Whilst the majority of these legal areas are easily translatable to the T&D system, this paper will focus on how the privacy and trespass law frameworks could evolve to meet the challenge of T&D system.

As has been discussed earlier in the section about current FAA drone regulations (Section 2.1) in today's world, any commercial drone operator needs the FAA 333, 44807 and Part 135 parcel transportation exemptions before any delivery operations can take place. These allow for 1) the drone operator to fly the drone for commercial reasons 2) the drone to be flown for commercial reasons and 3) the drone to carry packages exemptions before any delivery operations take place respectively. The issue here is that this exemption process is very ad-hoc and can lead to conflicts with local drone regulations and act as a barrier to commercial enterprise more broadly (Rupprecht Law 2019). Moreover, many drone operators have gone through the tedious process of obtaining these exemption only to find that the exemptions grants do not apply to every foreseeable use-case that their test or full-blown operations entail and that, simply, they operate their drones illegally – this has implications for insurance. It is against the law to insure an illegal activity and so in the event of a big loss, the insurance company can easily deny coverage, or be itself liable. Not only is this exemption process very ad-hoc but many states, counties, municipalities, federal lands and individual cities have drone-related laws in place that make the insurance-operator relationship all the more flawed and unlikely. The T&D cooperative system is especially at a loss here because of the extended liability issues associated with moving ground and aerial vehicles working in tandem in urban settings. In general, lessons from the current state of patchy insurance coverage warrant a more standardized licensing approach to commercial operations permits.

The final dimension to the insurance issue for the T&D system is the fact that there is little to no historical data available for insurance firms to utilize and all parties involved have little experience in what it takes to implement such a system. Measuring, classifying and pricing the risks that come along with the T&D system will be very difficult for insurance companies, especially as the technology evolves and the use-cases shift. In general, this paper posits that insurance coverage will be offered in the following stages (Nichols 2016):

1. The early study period: in this period, insurance companies work to understand the technology and its likely evolution. Either in close collaboration with key T&D players or with keen oversight, the insurers will begin to understand and quantify the risks involved.

2. Apprehensive period: the preceding period may startle some insurance players as they realize the scope of the risks involved. This may not be helped by T&D players becoming more aggressive to test their product and potentially face social, economic, product-specific or political setbacks that morph into negative PR. In this period, insurers who bought into the concept early on will look to maintain or minimize their positions.

3. Maturing phase: increased understanding of the risks involved and a more established enterprise solidifies insurers' trust in the T&D concept. Insurers begin to utilize traditional tools, for instance in-depth risk analysis or customized coverage to reasonably price the T&D product prior to its scaling. The T&D system will likely be championed by a few larger logistics players, making the job of insurers more straightforward whilst minimizing risk of unprofessional deployment procedures.

Insurance is undoubtedly another barrier to the T&D system and will require much more work and attention from all the parties involved, the insurance companies to navigate irresolute regulations and understand the technology, the drone operators to gain access to reasonable insurance policies and the FAA to ensure commercial drone deliveries happen safely.

3.3 Privacy

There are growing concerns regarding the personal privacy of both bystanders and customers on the receiving end of a T&D delivery. Privacy concerns are not unique to the T&D delivery system since it is low-altitude drone operations that are the cause for concern. Regardless, these concerns are undoubtedly warranted. As an autonomous drone (or piloted drones for that matter) are launched from the T&D system, their array of cameras and sensors will need to continuously monitor their surroundings to avoid collisions with tall structures or other low-altitude aerial objects.

As mentioned in Section 3.2, there are a variety of legal, liability and insurance related issues with autonomous drone operations in urban areas. Reducing the potential for legal liability may motivate companies to record, store and even review every moment of a drone's flight. This presents a whole host of privacy issues. For one, should a firm's employee have the right to view imagery or video captured by the drone in flight? Would this potentially constitute as trespassing or invasion of personal privacy? Additionally, should drone operators be able to utilize the data a drone collects for other commercial purposes or to sell it onto another paying entity? At certain altitudes, drones are silent and nearly invisible; with a single pass over, a drone could estimate how large your home is, how many cars you own or how many people live in your household – all valuable data to any ambitious commercial retailer. Similarly, just as Apple contends with pressure from national agencies to disclose stored data on iPhones seized from criminal suspects, drone companies will need to contend with similar requests to share aerial data with such agencies. Whether or not law enforcement employ drones in-house or purchase data from commercial drone operators, the specter of "Big Brother" surveillance is emerging.

The question, do you own the airspace above your house, is one that has has persisted since the 1946 *United States versus Causby* case, in which a chicken farmer sued the U.S. government for flying military planes at such low altitudes over his home that his chickens were literally frightened into committing suicide (Legal Information Institute 1946). The U.S. Fourth Amendment protects citizens from unreasonable search and seizure, particularly in areas where they can expect a certain level of privacy, namely their home or the curtilage of their home. But whilst one can expect privacy under the Fourth Amendment, objects, activities or statements that are exposed in plain view are not subject to the same privacy entitlements. This is why the Fourth Amendment has never required passers-by to shield their eyes when passing by a home (Brenner 2005). This begs the question, which interpretation of the Fourth Amendment should drones be subject to?

The European Union (EU) is ahead of the U.S. when it comes to enacting data privacy regulations. In 2016, the European Commission and the Council of the European Union approved the General Data Protection Regulation (GDPR), instituted on 25 May, 2018

(Voigt & Von dem Bussche 2017). One key facet of the GDPR is its purpose to "return control" to EU citizens over their personal data. And one key dimension of the GDPR is that personal data is considered significant and 'sensitive' to the private citizen if that data reveals information about that individual's racial or ethnic origin, political opinions, religious or philosophical beliefs, trade-union membership, genetic makeup or biometric, health or sexual characteristics (Hoffmann & Prause 2018). For drone operators, the following excerpt applies:

> "the controller shall be able to demonstrate that the data subject has consented to the processing of his or her personal data and the data subject shall have the right to withdraw his or her consent at any time." (Article 7, GDPR)

The GDPR makes a distinction between the "data subject", the "controller", and the "processor" in data collection processes. In future "last-mile" T&D operations, the lines between these stakeholders will become blurred as vehicles become autonomous, the software engineers responsible reside in remote locations and operations become more complex as they vary in implementation and integration into different urban societies. This is an interesting issue for which traditional firms and the new competition on the block, namely Amazon (Amazon Air), Alphabet (Google Wing), and Uber, may have different approaches to. This underscores the need for an adaptive regulatory framework and will be further discussed in Section 4.

One possibility is that logistics firms will try to solve the privacy issue via intricate terms and conditions contracts with their customer directly. How firms address the privacy concerns of all other citizens whose privacy they breach on the way to that customer is another question. They may find an operational solution, like flying higher or ensuring the drone's downward facing cameras are off until the drop zone. It could also come down to an operational tax that compensates bystanders, an idea which is discussed in Section 4.2. Will these provider-customer contracts be extended to also include liability waivers? It will likely depend on the operator and the municipal and national regulations in place.

3.4 Security

A drone is like any other wireless device in that it can be hacked. In particular, hijacking via Global Positioning System (GPS) spoofing is a security threat without a clear solution today. Spoofing is when an un-encrypted communication link is infiltrated by a counterfeit GPS signal by a malign actor. To conduct a spoofing attack, the external actor simply broadcasts a fake GPS signal with higher signal strength than the true GPS signal. One unavoidable danger here is that military units around the world have invested heavily in datalink disruption methodologies such as GPS spoofing since they are often effective and economical anti-drone weapons. The trickle-down effect of this investment into private hands could render commercial drone delivery in a precarious situation and subject to a variety of serious security confrontations. Again, regulatory bodies and the regulations they enact should be aware of this, and in particular, be able to understand how the tech-saavy and traditional logistics players alike will attempt to tackle this issue.

An additional but slightly ambiguous security issue exists in the limited radio frequency spectrum used by drones to communicate with their ground control system, which, in the case of the T&D system, the truck. Increased demand for spectrum amongst mobile broadband providers has made it difficult to secure a dedicated radio frequency spectrum for commercial drone delivery operations. In some cases, it has been shown that drones have been unable to fly due to the excessive levels of conflicting cell signals in the surrounding airspace (Mohl 2016). Furthermore, a mobile ground control system such as a truck would likely necessitate operation outside of a firm's firewall and thus be more vulnerable than a centralized ground control office. Moreover, the truck could be subject to physical assault and hijacking. Such assaults are not uncommon with today's delivery trucks; a T&D truck loaded with packages, drones, batteries and high-tech computers will be an even more attractive target.

Spectrum access and reliability are issues in-part because the FAA and the Federal Communications Commission (FCC) have not collaborated beyond The FAA Reauthorization Act of 2018 (FAA 2018). This Act required the FAA, the National Telecommunications and Information Administration (NTIA), and the FCC to submit a report to Congress on which frequencies should be dedicated to drone operations. The outcome was a small band of frequency allocated specifically to what was defined as 'amateur' drone operation. This bandwidth still serves as the only permissible set of frequencies a drone operator can use regardless of use-case and will not be nearly enough to support future commercial drone operations. So depending on the radio technology deployed, a commercial drone operations that have received the exemption grant from the FAA are likely operating in violation of The FAA Reauthorization Act of 2018 since the allocation of the frequency band is for recreational use only (AMA 2016). The FCC has not pursued actors violating the regulations suggesting they are content with the current regulatory situation. Granted, such cross-body regulation can be difficult, particularly with an inter-disciplinary configuration such as the T&D system, but this seems to be an example of where technological advancement has exceeded regulatory foresight and collaboration.

3.5 Certifiability

This section addresses the certification process of the T&D system. Focusing first on drones, all aerial vehicles flown in the U.S. are regulated by the FAA. An important part of such regulation is ensuring the vehicle's airworthiness. This actually comprises a variety of issues, from manufacturing and design to maintenance and operations. The current FAA regulations that apply to drones, FAA Part 107, only include details on operational guidelines and nothing on the other issues. These standards are typically in place to ensure the safety of the general public, in part by reducing the risk of midair collisions between aircraft and of ground impact, and can take various forms. For example, they can be based on accident risk studies or based directly on different components of the drone design. The current commercial aircraft regulation is a blend between the two with more emphasis on the latter. The latter is typical in mature industries since it requires less general testing of the vehicle either by the manufacture of the FAA, but is harder to achieve with nascent technologies. The former will likely be part of future drone airworthiness certification processes, but a balance will have to be found such that this testing process does not drive up manufacturing costs or delay innovation cycles. If there is one thing the FAA can learn from Boeing's 737 MAX 8 situation, it is that enabling self-certification can go wrong.

It is worth noting that just as there are a variety of commercial aircraft designs being operated for a variety of commercial reasons, we can expect the same to occur in the drone space. Even today there are a number of different drone designs – the quadcopter, the tilt-wing, the lift-and-push and the fixed-wing – each likely to require different certification processes and set of operational regulatory restrictions regardless of whether a risk-based or component-based airworthiness certification process is followed.

When it comes to the T&D cooperative system however, certification will have to extend to both the drone, the van and the system together. Focusing now on the van, it is worth noting that the current FAA 107 regulations that address drones also include a statement about vehicles:

> "No person may operate a small unmanned aircraft system [(drone)] ... from a moving land ... vehicle unless the small unmanned aircraft is flown over a sparsely populated area and is not transporting another person's property for compensation or hire." (§ 107.25 Part 107 FAA 2020)

This represents the FAA's take on the T&D system and is a non-starter for T&D delivery operations in urban settings. Focusing more generally on vehicle regulations however, in the U.S., a vehicle is typically regulated by the The National Highway Traffic Safety Administration (NHTSA), the Department of Transportation (DOT) and the Environmental Protection Agency (EPA) to guide the vehicle's design and emissions respectively. Additionally, when it comes to freight vehicles, the Federal Motor Carrier Safety Administration (FMCSA) also has a major say in vehicle certification. FMCSA involvement depends on the vehicle size. The NHTSA will undoubtedly have a role to play in regulating autonomous technology, vehicle cyber-security and inter-vehicle communication in the T&D system, but it is still unclear how the NHTSA, the FMCSA, the DOT, the FAA and the FCC will need to collaborate to achieve safety in the link between the drone and truck in the T&D system. Just as an example of how this inter-disciplinary technology will cause regulatory headaches... with which regulatory body do the cyber-security issues sit? As mentioned earlier, we are already seeing poor regulatory management between the FAA and FCC with the spectrum bandwidth issues drone firms are facing – what can we expect when three regulatory bodies draft an inter-disciplinary set of regulations for the T&D system? One of the pioneering players in the T&D system space, Matternet, a startup based out of The Bay Area, has already faced pushback on its T&D product, evident by how it have reinvented itself, at least in the short term, as a drone company providing drone-only hardware to logistics players like UPS. Simply, it has faced difficulty in lifting their T&D product off the drawing board – others will as well.

The final dimension to certification is to determine how closely should the FAA work with the private sector. The FAA has already instituted a working task force, the FAA Drone

Advisory Committee, whose thirty-five members represent a variety of drone stakeholders, from research and private industry to retail and government. This is definitely a step in the right direction and the value of such a committee will be discussed in more detail in Section 4.

3.6 Noise

While urban communities tend to tolerate public safety helicopter flights (such as for medical or emergency operations) they historically been opposed frequent non-essential helicopter use in urban environments. This is, in part, because of the low frequency and clear community value of public sector helicopter use. Other than cost, the noise concern has always limited how much any commercial helicopter urban aerial mobility operation can grow. Only deliberate municipal regulation has allowed small helicopter transportation services to surface in places like New York and Sao Paulo. When it comes commercial drone use and the concomitant noise issue, these concerns will likely still apply. Estimating the impact of noise on a society is non-trivial from both a technical and social level. But we can be assured that the public will likely benchmark the noise impact of drone delivery services with only other low-altitude aerial vehicle they know, helicopters. Compared to helicopters, drones emit a more high-pitched noise that may be perceived as incessant, since a drone can remain at low altitudes for an extended period of time whilst helicopters typically perform fleeting pass-overs. It is this characteristic – the acoustic profile of the drone in use – that will dictate how it is received by urbanites.

Estimating noise levels emitted from low-altitude commercial drone operations is non-trivial from both a technical and social level. This is because little data and research exists that characterize the acoustic profile of drones or how the public would respond to such frequent noise disturbances. Furthermore, drones are likely to undergo substantial design adjustments as firms learn more about their demand base and their operational and regulatory constraints. But whilst analyzing drone noise pollution on a quantitative level may be a difficult and futile exercise, there are a variety of qualitative insights one can make to guide future regulatory and commercial decisions. For one, it is not exactly the amount of noise pollution that matters but rather the annoyance factor. This comprises of the pitch, frequency, length of time and variability of the noise that matters. Furthermore, whilst considering the acoustic profile of a single drone is important, the network noise profile will likely be what the public actually notice. For instance, commercial drone operations will emit fleeting high pitched noises for a bystander on the ground, but at the network level, the impact could be made worse if drones are launched frequently. Furthermore, drones flying overhead at high speeds will mean that, from the ground, their noise will sound highly variable. This means that they will be more noticeable than other urban background noises.

Drone network design will play a pivotal part in municipal and commercial strategy to minimizing the negative externalities of drone noise pollution. For example, literature suggests that a highly decentralized drone launch and retrieval network would reduce the overall noise footprint since drones would spend less time in the air and travel shorter distances to their destinations (Lohn 2017). When it comes to the T&D system, this does not apply, but it becomes easy to see how the T&D system could actually exacerbate the overall noise impact. Recall that one reason the T&D system is valuable for efficient "last-mile" logistics is that the driver is able to outsource some delivery work to the drone. Particularly in urban settings, these stops are incredibly costly for logistics firms since much of the driver's time is spent finding a parking spot. Moreover, if they cannot find one, the drivers often double park and the firm foots the traffic violation penalty. This goes to say that T&D operations will likely be highly integrated into suburban and urban areas. From a noise perspective, this means that drones will be launched and retrieved in and amongst built up residential and commercial environments. Drones on a T&D system will therefore interface with their surroundings more directly, making their noise impact all the more noticeable and patent.

This provides some food for thought for future regulation designed to minimize the local noise impact of T&D operations. FAA regulations already contain strict noise limits for general aerial vehicles but not for drones specifically. But since drones will exhibit unique flight profiles and operational use cases, this paper posits that comprehensive drone-specific noise regulations would be a necessary addition to FAA Part 107 or as a stand-alone noise framework for low-altitude aerial vehicles. Whilst regulation can provide a hard limit on drone noise emissions, municipalities and will need to deploy a mix of regulatory constraints to address the noise issue. Any strict noise limit (measured in decibels measured from the ground from a specified altitude at a specified angle of perception) will drive innovation to reduce the overall noise footprint of drone specifically but it may not address the network noise effects. The converse will be true if lawmakers take a more action-orientated (soft-law) regulatory approach to drone noise regulation; much work could go into optimal network design whilst actual drone acoustic profiles could be neglected. A balance between quantitative and action-orientated regulation is undoubtedly desirable.

When it comes to the T&D system for instance, regulation can enforce that drones are not launched or retrieved in dense urban areas and instead offer structure to where and how drones can be launched. The proximity of a T&D drone launch to its final destination could also be part of the framework to minimize drone flight time. Furthermore, regulation could attempt to limit the overall number of drones operating in a certain area, and could also enforce no-fly times of the day. Regulation could also offer a cruise altitude lower-bound, above which the noise as perceived from the ground is deemed acceptable. This is the currently strategy to manage urban helicopter noise pollution. These regulatory tools all run antithetical to the value proposition of the T&D system, so regulators have a fine line to tread if they are not to not to kill the system's commercial value but also protect citizen's living quality.

3.7 Sustainability

One final implication of the T&D system relevant to society is the environmental impact of such a system. This is a non-trivial topic since drone configurations continue to vary, as do their applications. In general, however, there are some broad-based factors that will have an impact on how sustainable commercial drone operations are. These are the size and weight of the drone and its cargo, the distances being traversed, the battery technology onboard, the cruise speed and altitude, the drone's production process, broader drone life-cycle considerations, electricity generation practices in the vicinity, warehouse energy consumption and how the warehouse network is designed (Stolaroff et al. 2018). There are many variables at play. Furthermore, they are all potentially subject to regulatory constraints and, therefore, malleable to deliberate policy guidance but also changeable over time.

The literature is relatively rich, albeit awash with operational, regulatory, and performance assumptions to constrain this problem. But across the board, there is consensus in literature that if deployed deliberately, small drone logistics services delivering small payloads over short distances could almost half CO_2 emissions as compared to the same set of demand being served by a traditional ground-based diesel delivery vehicle. These results depend on a variety assumptions, from energy generation in the area not being coal based to warehouse networks being optimized to minimize energy consumption in drone flight to battery technology improving in the coming years. Findings also suggest that as drone size, distance, and payload weight increase, these savings do not scale linearly but rather drone emissions tend towards that of a typical diesel ground vehicle (Stolaroff 2018). In both standard commercial drone logistics and in T&D operations, emissions saving stems from the general reduction of deploying under-utilized ground-based vehicles (Chiang et al. 2019). This is particularly relevant in rural areas where distances traversed by ground-based vehicles are longer than by an aerial drone and demand is not easily consolidated into single vehicles. With regards to the T&D system specifically, drones will likely reduce the number of stops a single vehicle will have to make, allowing the vehicle to remain in motion for longer periods of time and reducing fuel wasted looking for parking. In this way, the T&D system will likely beat both truck-only and pure drone logistics emissions metrics. One caveat specific to the T&D system is that if the drone, or its batteries, are to be recharged whilst the vehicle is out in the field, certain energy transfer and storage inefficiencies could arise that negatively impact the overall sustainability of the system.

3.8 Sources of Critical Uncertainty

Each of these implications discussed above, from safety to sustainability, pose different sources of uncertainty. From public sentiment to how lawmakers develop their regulatory strategies, there are numerous factors that impact the future of the T&D system and its deployment. In each of these section above, the key uncertainties were highlighted. Some final sources of uncertainty are considered here, with a particular focus on those which have direct implications for lawmakers and the regulatory outlook.

Discussed briefly above, one key source of uncertainty lies in how drones will be integrated into the existing airspace management systems and traffic flows. For instance, substantial private-sector investment is going into developing a novel multi-vehicle air-traffic control system that minimizes the human element and enables decentralized traffic management. Conversely, much work has gone into empowering local drone autonomy, powered by on-board computer vision and collision algorithms that reduce the need for continual ground-to-air traffic management. Whilst the future solution will likely be a mix of the two approaches, cities and countries will undoubtedly take different approaches to manage commercial drone operations based on whether they have a robust air-traffic management framework to deploy or not. If they do not, we can expect a continual patchwork of policies that restrict drone operations substantially, similar to what we are currently seeing in the U.S. today. Whilst this need not be detrimental necessarily, since regulators can learn from different regulatory tests to build an adaptive regulatory framework, such an approach will slow innovation cycles and time-to-market for bullish T&D logistics firms. This is because, considering the current state of computational power and drone collision avoidance capabilities, a fully-fledged air-traffic management system is the most robust way to integrate drone operations at scale in the near future. There have been numerous instances to date that show how easily and often drones stray into no-fly zones and put many commercial airlines and their passenger's lives at risk. If regulators are bullish, they will likely see further instances of hazardous drone operations that put lives at risk and impact societies negatively in all the ways this paper has highlighted, via noise, privacy or legality encroachments for instance. These regulators will be forced to reel back their bullish strategies and revisit how they regulate the supporting air-traffic management infrastructure around drone operations again, delaying technological deployment in the process.

How the nascent T&D technology evolves over time is also a cause for regulatory concern. For instance, drone configurations are continuously being conjured up and redesigned. This underscores the value of the FAA's deliberate approach to regulating drone operations as this paper details in Section 2.1. And as drone designs evolve, as will the T&D system since it is inherently designed around the drone. This will force regulators to keep both their drone-specific regulation and T&D regulations up-to-date, requiring increased collaboration between the regulatory bodies involved. From a regulatory perspective, enacting task-force teams within each body that are dynamic and can convene more frequently would be valuable, akin to the FAA's Drone Advisory Committee but across the regulatory bodies involved.

Finally, uncertainty exists when one poses the question, what does scaled T&D delivery mean for labor in the logistics industry? Specifically, should lawmakers look to ensure humans are an integral part of T&D operations? In the case of the T&D, having a human driver is a straightforward decision since there are major regulatory hurdles to overcome before we see autonomous vehicles on the ground, let alone autonomous delivery trucks launching autonomous drones. The decision here then is, should regulation enforce firms to devote extra hands to manage T&D operations either en-route as 'drone operators', at the distribution center as remote controllers of T&D operations, or not at all? Of course, there are risks and value associated with each one of these scenarios. Whilst this paper is not in the position to measure the precise trade-offs between these scenarios when it comes to the safety, economic or operational feasibility of each, one can posit that regulators will arrive at different conclusions based on a number of factors: 1) existing safety laws specific to commercial drone operations; 2) how these laws evolve going forward; 3) the overall national or municipal sentiment towards labor policy and 4) how firms and regulators calculate the trade-off between potential job loss with work outsourced to the drone and job creation in roles such as 'drone operator', 'drone flight engineer' or 'T&D operations manager'. In the short term, these last two point will not be very consequential since large-scale T&D operations are still beyond the horizon. In the long-term, however, this is a trade-off that we will likely see across many industries being disrupted by autonomy and will undoubtedly manifest itself as a source of uncertainty in "last-mile" delivery as well.

4 Future Regulations: A Proposal for an Adaptive Regulatory Framework

In this section, this paper discusses final considerations of T&D regulatory framework and what an adaptive regulatory framework could look like. Before tackling any proposals, it is worth reflecting on how the current framework is structured and, importantly, what its merits are. As mentioned earlier, the FAA has established the Drone Advisory Committee as a focal point of stakeholder input and regulatory collaboration. This committee represents a broad range of industries and is undoubtedly necessary if the U.S. and the FAA are going to remain on-par with the global drone innovation curve. At this moment, no participating member has expressed interest in the T&D cooperative system, so as a concept, it is currently under-represented at the regulatory level. Moreover, the FAA's exemption-centric approach to enabling commercial testing allows them to maintain a certain level of innovation speed. And although it means higher costs for both industry and the FAA, it also allows them to manage safety on a case-by-case basis.

4.1 Adaptive versus Static Regulation

Adaptive regulation offers several potential advantages over so-called static regulation. It is not uncommon for static policies to yield ill-suited and over- or under-regulated frameworks over time that impart their own set of negative externalities and consequences. The overarching goal is to reduce policy errors and countervailing risks, improve net benefits to society, minimize public or industry frustration and, in the best case, incentivize future technological innovation in the industry being regulated or other industries. Additionally, adopting an adaptive regulatory mindset can help overcome some political impasses since policy adoptions occurs in stages with promise to revisit and revise policies again in the future (Bennear & Wiener 2019). Particularly in the age of rapidly evolving emerging technologies, the concept of adaptive regulations has received much attention, in part, because it helps regulatory bodies keep apace with the technologies.

Adaptive regulations do have their drawbacks, namely cost to the regulatory body. These costs can also extend to the industry more broadly since there is intrinsic value in stable regulations; it requires industry to spend less on keeping up to date with the latest policy changes and allows firms to better develop their product lines and operational strategies.

Furthermore, frequently revisited regulation opens the door for commercial interest groups to lobby their cause at each of these policy revisions. The concept of Planned Adaptive Regulation (PAR) adds value to the general concept of adaptive regulation in that, from the outset, the regulatory framework was designed to be adaptable (McCray et al. 2010). Formal learning into the process is central to the concept of PAR. This would require a periodic evaluation of the situation, which itself would involve data gathering, input aggregation and policy redrafting. Some questions here are, 1) how frequent the intervals for evaluation and revision should be? 2) what characteristics and metrics valuable to measure in assessing the state of T&D operations and their societal impact and how does one incorporate them into the decision making process? 3) how does one define the counterfactual baseline to compare how a policy is performing over time and whether it needs updating? 4) how does one measure and evaluate the cost-benefit analysis associated with using an adaptive regulatory framework? Some of these questions can be answered by singling out quantifiable outcomes from the various implications of the T&D system discussed in Section 3 and keeping track of their evolution in time. For instance, from the perspective of noise regulation, the FAA could initiate surveys of public aerial noise perception in certain regions. In these regions, the FAA could independently survey municipal and national aviation regulations and understand the relationship between certain regulatory constraints and societal impact. These insights could then inform the next iteration of regulation. And finally, a counterfactual baseline could be the results of a public aerial noise perception survey beyond that geographic region as a control experiment.

Most commonly, adaptive regulatory tools take the form of structured opportunities for analysis of a policy performance by the regulator and an oversight or advisory committee, in this case of drone regulation the FAA Drone Advisory Committee is well positioned as a forum to aggregate data on the industry performance and stakeholder opinions. Interestingly, one method to ensure these periodic committee meetings are effective in instituting iterative policy amendments is to mandate review and revision. This mandate could be for a specific time frame, for instance the likely innovation cycle of the T&D system, after which this mandate could be revisited. This underscores the level of collaboration needed in an adaptive regulatory process. Moreover, the analyses and regulatory revisions will be much more outcome-centric than form-centric. Simply, this means that regulatory language is more concerned with avoiding a certain outcome than stating specifications that industry must meet. This is immediately familiar when perusing the FAA Part 107 guidelines.

Soft law mechanisms are another tool that could be employed in the pursuit of adaptive regulations. Typically defined as regulatory arrangements that create substantive expectations but are not directly enforceable. Examples of soft law instruments are informal guidance, industry self-regulation, best-practice guidance, codes of conduct, and third-party certification and accreditation (Eggers et al. 2018). Soft laws allow regulators to rapidly adapt their policies on a case-by-case basis and better collaborate with industry. This paper posits that the FAA's current regulatory approach is already teeming with soft law policies given the case-based approach it's pursuing, particularly in the drone delivery space. Finally, as mentioned earlier in the certifiability section (Section 3.5), risk-based methods for sizing outcomes could help regulators better understand how to segment their policies and which parts to adapt iteratively.

4.2 Federal versus Regional Regulatory Oversight

As mentioned earlier, the local versus national regulatory oversight discussion is an important one in the context of drone delivery and even more so for the T&D system. This section will discuss the pros and cons of each before analyzing how finding the right balance is important to achieve a successful adaptive framework.

4.2.1 State and Local Regulations

The value of state and local regulations should not be understated, particularly in the context of an emerging technology such as the drone and the T&D system. Importantly, local regulations are typically more adaptable and better at keeping up with rapid technological evolution. Since technology does not evolve evenly across a nation, nor is the economic opportunity of such a technology symmetric, local regulation lends itself to effective decentralized management of a nascent system like the T&D system.

There are downsides associated with depending too heavily on local regulations. For one, there is always a risk that municipalities enact 'revenue generating' regulations that are not aligned with national values. There is much discussion around whether commercial drone operations should be charged a type of tax that accounts for the negative externalities they impart on the bystanders they do not serve. This tax could account for the fact that drone delivery operators are utilizing a public good, the lower airspace, for commercial gain. What if these firms decided to utilize data gathered during these flights as well? Moreover, this tax could fund the public services commercial drone operations would likely cost a city, for example fire fighting in case of an accident or health workers in case of bodily harm. However, such a tax could easily be passed onto the consumer if instituted at the operational level. A potential alternative could be to institute such a fee at the licensing level for a set period of time. This way, a commercial drone delivery license takes the form of an investment, for which a company can build long-term strategies around. This way, the fee would more likely be borne by both the firm and consumer over a longer period of time. Granted these could be valid reasons for establishing an operations tax on drone delivery, especially for an intricate system like the T&D. The FAA will undoubtedly find a balance in how much autonomy they grant local legislatures. Finally, there is a risk that local legislatures lack the technical competence to adequately regulate an advanced multi-disciplinary system like the T&D. This could lead to a patchwork of ill-suited regulatory frameworks that will mean death by a thousand papercuts for firms in the T&D delivery space.

4.2.2 National Regulations

National regulation is often valuable when a certain level of standardization is required in a maturing industry. This facilitates industry development and scaling, marking the beginning of the cycle in which firms evolve to meet consumer demands and society benefits from prescient legislation. Contrary to the cons of local regulation, national regulation may also be necessary when the technology is very complex and multi-disciplinary, requiring a certain level of technical competency to achieve sound regulatory objectives. Finally, if the technology constitutes a national security in some form, national regulation may be called upon to incentivize industry development and investment. This is not entirely the case with the T&D system. With that said, with the current state of U.S.-China relations, there is the potential for drones to be considered a security vulnerability since 70% of all drones globally are currently manufactured by Chinese drone behemoth, DJI (Borak 2018).

In broad terms, the FAA, until now, has acknowledged that a blend between local and national regulation best suits the nascent drone industry. The concept of preemption is rare in aviation law, however there is one vital exception; the Airline Deregulation Act of 1978. The Act prohibits states from enacting laws "related to a price, route, or service of an air carrier that may provide air transportation." Moreover, Congress asserts "exclusive sovereignty of airspace of the United States," and "exclusive authority for regulating the airspace above the United States with the [FAA]" (Mark J. Connot 2016). In this sense, any state law that stands in the way of any FAA drone regulations also stands to be preempted. Note that the FAA Part 107 regulations do not actually include a preemption provision and instead opted for addressing preemption issues with a case-specific analysis. This highlights the FAA's efforts to adopt an adaptive regulatory framework that is able to learn from state and local regulatory requirements. However, the FAA does acknowledge that a patchwork of differing flight regulations will soon conflict with their ability to provide standardized and consistent air passage; this is a clear trade-off that the FAA is currently navigating.

To highlight the federal stance on this trade-off, it's worth discussing the bill entitled the FAA Reauthorization Act (FRA) of 2016 which specifically addresses federal preemption in the context of drone regulations. In paraphrase, the FRA proposed to establish federal preemption rights relating to the 1) general vehicle specifications and flight path characteristics 2) operations and 3) pilot certification processes. This bill stated that state and local laws outside of these set realms, including common-law issues, would not be preempted by the FAA. Whilst the FRA was not passed by Congress, it is nevertheless interesting to analyze in the context of this paper since it sets a precedent for how the FAA is approaching the local versus state discussion, and more importantly, its iterative approach to drafting that regulation.

5 Conclusion

This paper frames the novel truck-and-drone cooperative system beyond a technical or operational analysis that literature has offered thus far. The broader societal implications of key "last-mile" logistics firms pursuing this technology are considered and the regulatory prerequisites are discussed. Current regulations that are relevant to the T&D system are first presented followed by an in-depth dive into the various potential repercussions urban citizens could experience if such a system were to be deployed at scale. The safety, security, legality, liability, insurance, privacy, certifiability, noise, and sustainability issues that remain unresolved are then discussed, whilst other important topics such as the operational or aerial navigation questions that regulators and municipalities need to answer were omitted. The paper finishes by discussing the pros and cons of adopting an adaptive regulatory framework for the T&D system. Whilst avoiding specific proposals on what this framework would look like, various tools that both local and the federal regulatory bodies could utilize to reap the benefits of an adaptive framework were touched upon.

It is worth noting the other shortcomings of this paper. As stated above, a specific regulatory framework for the T&D system is not proposed in part because the technology remains novel and largely untested to date – developing a practical framework would be as much speculation as concrete guidance. Furthermore, the technology policy issues of the T&D system revolve around the drone and encapsulate the main questions that would determine the economic, social and political viability of such a system and therefore should be addressed first by all the stakeholders involved. As mentioned in the "last-mile" regulations section (Section 2.2) the T&D system and the regulatory framework to guide its deployment will likely be an extension of those applicable to commercial drone delivery. Even today we see a glimpse of this overlap in FAA Part 107 which already bars drones from being launched from moving vehicles. Collaboration amongst the host of federal regulatory bodies which have stakes in the T&D system, namely the NHTSA, the FMCSA, the FCC, the DOT, and the FAA will be vital and may prove a significant barrier to the technology's commercial success. It has already proven so for the first players in the T&D space. Other shortcomings include the insufficient discussion about the integration of drones into the NAS and the distinction between upper- and lower- navigable airspace. Whilst there has been significant investment in this space, in part, because existing aviation players want to see the existing antiquated air traffic control system updated, it remains unclear what the path forward is for drones, not to mention for the T&D system. In both ground-based and aerial operations, the T&D system will likely face a heterogeneous mix of regulatory constraints. These will come from municipalities, which may pose operational but also more socially-motivated constraints, the FAA, the FCC, the NHTSA, and the FMCSA. Whilst this does not mean the future of the T&D system is unlikely, it will undoubtedly be difficult. The final shortcoming of this paper lies in the fact that is has solely focused on the U.S. situation, without much reference to cases internationally. There is much to learn from the approaches other countries and organizations have taken to spearhead advanced urban transportation technologies in their cities. For instance, the EU has lead the field in drafting data privacy legislation, even pertaining to drone operations. Other countries like the United Arab Emirates (UAE) have taken a more experimental approach. Such prompt regulation enables industry to begin improving hardware, corporate strategy and operational models, but not without the risk of implementing poor policy that may come back to bite down the line. Nonetheless, a comparative case-study analysis of how the T&D system would fair in a variety of regulatory scenarios, whether this analysis be international in scope or U.S.-centric, would illuminate the regulatory nuances of such a system.

Whilst the future of the T&D system in the "last-mile" remains uncertain, we can be sure that the "last-mile" problem is here to stay and the key players will continue to conjure up iterations of this technology or entirely new concepts in search of a competitive edge. The technology policy question will remain central in this space. But when there is a problem, there is an opportunity – the United States, its citizens and the logistics industry are in a strong position to capitalize on it.

References

AMA (2016), 'UAS operators must comply with FCC rules'. [online], [Accessed 6 April 2020].
URL: *https://amablog.modelaircraft.org/amagov/2018/06/13/uas-operators-must-comply-with-fcc-rules/*

Bennear, L. S. & Wiener, J. B. (2019), Adaptive regulation: Instrument choice for policy learning over time, Technical report, Draft Working Paper.

Borak, M. (2018), 'World's top drone seller DJI made $2.7 billion in 2017'. [online], [Accessed 6 April 2020].
URL: *https://technode.com/2018/01/03/worlds-top-drone-seller-dji-made-2-7-billion-2017/*

Brenner, S. W. (2005), 'The fourth amendment in an era of ubiquitous technology', *Miss. LJ* **75**, 1.

Chiang, W.-C., Li, Y., Shang, J. & Urban, T. L. (2019), 'Impact of drone delivery on sustainability and cost: Realizing the UAV potential through vehicle routing optimization', *Applied energy* **242**, 1164–1175.

Clement, J. (2020), 'Global retail e-commerce market size 2014-2023, statista'. [online], [Accessed 6 April 2020].
URL: *https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/*

Eggers, W., Turley, M. & Kishnani, P. (2018), 'The future of regulation'. [online], [Accessed 6 April 2020].
URL: *https://www2.deloitte.com/us/en/insights/industry/public-sector/future-of-regulation/regulating-emerging-technology.html*

FAA (2018), 'FAA reauthorization'. [online], [Accessed 6 April 2020].
URL: *https://www.faa.gov/about/reauthorization/*

FAA Safety Team (2020), 'Alc-42: Airspace, special use airspace and TFRs, classes of airspace'. [online], [Accessed 6 April 2020].
URL: *https://www.faasafety.gov/gslac/ALC/course$_c$ontent.aspx?cID = 42sID = 505preview = true*

Forrest, C. (2017), 'UPS tests drone delivery, launching UAV from top of truck'. [online], [Accessed 6 April 2020].
URL: *https://www.techrepublic.com/article/ups-tests-drone-delivery-launching-uav-from-top-of-truck/*

Hall, S. (2017), 'The drone privacy and transparency act of 2017: Overdue or over-reaching?'. [online], [Accessed 6 April 2020].
URL: *https://www.jdsupra.com/legalnews/the-drone-privacy-and-transparency-act-42426/*

Hoffmann, T. & Prause, G. (2018), 'On the regulatory framework for last-mile delivery robots', *Machines* **6**(3), 33.

Korosec, K. (2016), 'Here's why Mercedes is betting on drones and self-driving robots'. [online], [Accessed 6 April 2020].
URL: *https://fortune.com/2016/09/07/mercedes-vans-drones-matternet/*

Kuhn, K. D. (2017), Small unmanned aerial system certification and traffic management systems, Technical report, RAND.

Landhuis, E. (2018), 'Medical cargo could be the gateway for routine drone deliveries'. [online], [Accessed 6 April 2020].
URL: *https://www.npr.org/sections/health-shots/2018/03/10/592059175/medical-cargo-could-be-the-gateway-for-routine-drone-deliveries*

Legal Information Institute (1946), 'United States versus Causby et ux.'. [online], [Accessed 6 April 2020].
URL: *https://www.law.cornell.edu/supremecourt/text/328/256*

Lohn, A. J. (2017), 'What's the buzz?: The city-scale impacts of drone delivery'.

Mark J. Connot, J. J. Z. (2016), 'Everybody wants to rule the world: Federal vs. state power to regulate drones'. [online], [Accessed 6 April 2020].
URL: *https://www.foxrothschild.com/content/uploads/2016/09/Air-and-Space-Lawyers-Connot-and-Zummo-Everybody-Wants-To-Rule-the-World-Federal-v.-State-Power-To-Regulate-Drones.pdf*

McCray, L. E., Oye, K. A. & Petersen, A. C. (2010), 'Planned adaptation in risk regulation: An initial survey of US environmental, health, and safety regulation', *Technological Forecasting and Social Change* **77**(6), 951–959.

Mohl, J. N. (2016), A risk analysis of unmanned aircraft systems in the National Airspace system for utility applications, PhD thesis, Massachusetts Institute of Technology.

Moshref-Javadi, M., Hemmati, A. & Winkenbach, M. (2020), 'A truck and drones model for last-mile delivery: A mathematical model and heuristic approach', *Applied Mathematical Modelling* **80**, 290–318.

Moshref-Javadi, M., Lee, S. & Winkenbach, M. (2020), 'Design and evaluation of a multi-trip delivery model with truck and drones', *Transportation Research Part E: Logistics and Transportation Review* **136**, 101887.

Nichols, G. (2016), 'Drone deliveries? it all depends on the insurance'. [online], [Accessed 6 April 2020].
URL: *https://www.zdnet.com/article/drone-deliveries-it-all-depends-on-the-insurance/*

Peterson, K. (2019), 'UPS flight forward attains FAA's first full approval for drone airline'. [online], [Accessed 6 April 2020].
URL: *https://pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType =PressReleasesid=1569933965476-404*

Rupprecht Law (2019), 'Drone delivery – 3 big legal problems'. [online], [Accessed 6 April 2020].
URL: *https://jrupprechtlaw.com/amazon-drone-delivery-3-major-legal-problems-amazon-prime-air/*

Salama, M. & Srinivas, S. (2020), 'Joint optimization of customer location clustering and drone-based routing for last-mile deliveries', *Transportation Research Part C: Emerging Technologies* **114**, 620–642.

Stolaroff, J. (2018), 'Future of energy: Is drone delivery good for the environment?'. [online], [Accessed 6 May 2020].
URL: *https://www.smithsonianmag.com/innovation/drone-delivery-good-for-environment-180968157/*

Stolaroff, J. K., Samaras, C., O'Neill, E. R., Lubers, A., Mitchell, A. S. & Ceperley, D. (2018), 'Energy use and life cycle greenhouse gas emissions of drones for commercial package delivery', *Nature communications* **9**(1), 1–13.

Voigt, P. & Von dem Bussche, A. (2017), 'The EU general data protection regulation (GDPR)', *A Practical Guide, 1st Ed., Cham: Springer International Publishing* .

Winkenbach, M. (2019), 'Commentary: Drone-delivery projects must look beyond the hype'. [online], [Accessed 6 May 2020].
URL: *https://www.wsj.com/articles/commentary-drone-delivery-projects-must-look-beyond-the-hype-11574875675*

Woo, J., Whittington, J. & Arkin, R. (2018), 'Urban robotics: Achieving autonomy in design and regulation of robots and cities', *Available at SSRN 3145460* .

§ 107.19 Part 107 FAA (2020), '14 cfr § 107.19 - remote pilot in command.'. [online], [Accessed 6 April 2020].
URL: *https://www.law.cornell.edu/cfr/text/14/107.19*

§ 107.25 Part 107 FAA (2020), '14 cfr § 107.25 - operation from a moving vehicle or aircraft.'. [online], [Accessed 6 April 2020].
URL: *https://www.law.cornell.edu/cfr/text/14/107.25*

§ 107.31 Part 107 FAA (2020), '14 cfr section 107.31 - visual line of sight aircraft operation'. [online], [Accessed 6 April 2020].
URL: *https://www.law.cornell.edu/cfr/text/14/107.31*

§ 107.35 Part 107 FAA (2020), '14 cfr § 107.35 - operation of multiple small unmanned aircraft.'. [online], [Accessed 6 April 2020].
URL: *https://www.law.cornell.edu/cfr/text/14/107.35*

§ 107.39 Part 107 FAA (2020), '14 cfr § 107.39 - operation over human beings.'. [online], [Accessed 6 April 2020].
URL: *https://www.law.cornell.edu/cfr/text/14/107.39*