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Miguel A. Figliozzi
Portland State University, figliozzi@pdx.edu

Chad Tucker
Portland State University

Polina Polikakhina
Portland State University

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Drone Deliveries Logistics, Efficiency, Safety and Last Mile Trade-offs

Miguel A. Figliozzi [1], Chad Tucker[2], Polina Polikakhina [3]

[1, 2, 3] Portland State University, USA
{figliozzi@pdx.edu, chtucker@pdx.edu, ppolina@pdx.edu}

Abstract. Unmanned aerial vehicles (UAV) or drone last mile deliveries are receiving a lot of attention from startups and big companies like Google, Amazon, and UPS. Around the world there are already examples of successful small scale delivery operations utilizing drones. Despite all the hype and excitement around this topic, there is surprisingly little research done on understanding the capabilities and technical tradeoffs among drones that are currently available in the market. The goal of this paper is to survey currently available multicopter drones and analyze them in terms of their potential for last mile and last yard deliveries. Novel data and linear relationships among multicopter payload, take-off weight, and energy efficiency are presented. A novel contribution of this research is the discussion of tradeoffs among UAV logistical capabilities, sustainability, safety, and last yard delivery constraints.

Keywords: UAV (drone), last mile - yard deliveries, payload, energy efficiency, economies of scale, safety

1. Introduction

From filming movies or researching a pod of whales to delivering medication or delivering an explosive payload, Unmanned Aerial Vehicles (UAVs) are increasingly being utilized for a wide range of tasks. Since 2002, when the Predator drone was first used by the U.S. military in Afghanistan [1], drones have become smaller and cheaper, making it feasible for people to imagine alternate uses for UAVs, like delivering freight. Since 2011, big names such as UPS [2], Amazon [3], and Google [4] have thrown their hat into the UAV delivery ring, while other lesser known companies, such as Matternet and Zipline, have actually started delivery service in Rwanda, Australia, Switzerland, and Bhutan. UAVs have become a popular topic of conversation and an exciting source of speculation around how they might change the status quo of many businesses.

UAVs that deliver cargo are already in operation in several different countries. Mostly, these UAVs were specifically tailored to meet the specific demands of the job or service. For example, in Rwanda, there is a great need for life-saving blood medicines in the rural parts of the country, but the road infrastructure is very poor. A company called Zipline has started using fixed-wing autonomous drones to deliver these medicines via parachute faster than any other kind of transportation available [5]. In Switzerland, the Swiss Post and Matternet are in the final stages of testing the use of drones to transport medications and lab samples between two hospitals in Lugano, a town in southeastern Switzerland near the Italian border [6]. The two hospitals are only about 1.5 km apart from each other in the middle of the town, but the roads take delivery vans along a circuitous 12 minute route. Drones would make hospital deliveries much faster and much cheaper. Even in the United States, the FAA (Federal Aviation Administration) has allowed a company in Virginia to test the effectiveness of drones delivering medical supplies to low-income rural areas in the Appalachian foothills from mobile medical vans [7]. Some recent reports forecasts that consumer preferences are likely to push new business models and delivery systems where drones are likely to have a major role in future last-mile logistics systems [8, 9].

The academic literature has already documented the advantages that UAVs can provide to deliver medicines in remote locations [10]. Other researchers have analyzed UAVs potential applications and challenges for smart city applications such as data collection [11] and some authors have focused on the regulatory barriers that can preclude large UAV deployments [12]. The logistics services company DHL has identified higher last-mile efficiency, reduction of accidents, and faster deliveries as key potential UAV benefits; key potential challenges associated to UAVs are security, privacy, congestion, and regulatory concerns [13]. UAVs may also present clear benefits in terms of sustainability and CO_2e emissions for rural deliveries but the sustainability of drones for urban deliveries are affected by several factors such as customer density, ground vehicle efficiency, and delivery route characteristics [14]. For small payloads and speedy deliveries, UAVs may be competitive with ground vehicles especially in remote areas [14]. Some of the existing literature compares the capabilities of an UAV against the current method of performing a certain task, while others compare UAV's particular components, such as propulsion systems and orientation sensors. For example, a recent 2017 paper [15] surveys UAV technology and their subsystems (frame, propellers, motors and batteries, payloads, and data processing) with a brief discussion of potential applications in spraying of liquids, and logistics.

Although there is a lot of excitement about how drones could change how freight transportation networks are designed and operated, there is very little research on the actual capabilities of the products that are currently on the shelf. The main goal of this research is to analyze, based on a survey state of the art UAVs, main capabilities and limitations of UAVs in the freight industry. As discussed throughout the paper, the potential is high but currently the limitations are serious in terms of capabilities and unsolved problems for urban deliveries such as the tradeoffs among UAV logistical capabilities, sustainability (in terms of energy consumption and CO2 emissions), and safety concerns. To the best of the authors' knowledge, the topic of this research is novel and the contributions of this paper are unique and timely. Next section describes the data collection methodology and key multicopter capabilities. Section 3 shows graphs and relationships among UAVs payload, take-off weight, and energy efficiency followed by a discussion of safety and regulatory constraints in Section 4. The paper ends with conclusions and a discussion of future research avenues.

2. METHODOLOGY and INITIAL COMPARISONS

To obtain the data for the different UAV models, the researchers conducted an extensive internet search of UAV manufacturers and their products. They utilized information published on their websites along with downloadable material such as user manuals, technical specifications, and press releases. Though most information was obtained this way, some specifications were procured through consumer tech reports or online retailers. In some cases, customer service was contacted to request additional information. Unfortunately, not all manufacturers posted all the relevant logistical data needed for a proper analysis. For instance, few manufacturers provided hovering times and most manufacturers did not provide detailed technical specification regarding battery chargers or recharge times for the battery. In some cases, there was also a lack of detailed performance data that is useful for the freight industry, e.g. flight times, flight range with different levels of payload, or the number of cycles a battery can be recharged before replacement. The researchers analyzed data from 21 UAVs currently available in the market. In addition, researchers try to prioritize the inclusion of multicopter UAVs that cover the range of existing capabilities, sizes and prices.

The scope of the search was limited to multicopter drones that can potentially deliver in both urban and rural areas. Fixed wing drones were excluded from the search because currently only copters have the capability of hovering and delivering products in tight spaces (required in urban areas); fixed wing UAVs typically cannot land or take-off vertically. Single copters can hover, i.e. similar to helicopters, but were not included in the search because these aircrafts tend to be larger and the size of the propeller and blade made them unsafe for areas without a large clearance (more discussion about this issue in a later section). The search is also restricted to multicopters or multi-rotor drones because this type of aircraft can hover but also have higher stability and maneuverability which made them more suitable to navigate tight spaces or to fly near humans and/or valuable property. In addition, drones with engines that are not electric were not included; noise and pollution problems are likely to hinder urban deployments. Internal combustion engines are mostly used in larger UAVs, and a later section discusses issues associated with size and noise limitations.

Finally, this is a rapidly evolving and still "young" industry, without clear standards yet. Focusing only on electric multicopter drones allows for a more in-depth discussion of state of the art drone delivery capabilities within a reasonable paper length. The lack of standardized data from manufactures provided a major challenge in terms of data presentation. Hence, instead of presenting data in tables that includes each model, each topic is discussed in terms of observed trends, the typical value (median) and ranges found (25th and 75th intervals). Next section presents a more detailed discussion of energy consumption and economies of scale.

2.1. Speed, Flying Times, Ranges and Payloads

In shipping, speed is a key logistical consideration. The higher the speed, the faster the cargo can be delivered. Most speeds are in the range of 16 to 20 meters per second (35 to 45 miles per hour). The range of speeds is more than

adequate for urban areas considering that UAVs may travel more direct aerial routes and are not affected by ground road congestion.
Most available flying times are in the range of 20 to 30 minutes. Flying times are mainly restricted by battery constraints. Flight range is heavily dependent on a multitude of factors, such as battery efficiency, battery size, payload size, weather, topography, and whether it is flown within line-of-sight (LOS), autonomously, or remotely. Battery constraints and limited flying times determines that the typical range of current multicopters is between 15 and 35 kilometers (roughly 10 and 22 miles). The practical range should be less than the maximum range stated by the manufacturer. In practice, the UAV operator has to provide a margin of safety and some factors like headwinds can dramatically increase energy consumption. Hence, a drone with a stated maximum range of 35 kilometers may only serve customers within less than a 14 kilometer (8.7 mile) radius (assuming that is uses 80% of the theoretical range). Heavier payloads also reduce the range. For example, a drone may be able to fly 25 kilometers with a 2 kg. payload but only 20 kilometers with a 3 kg payload. The maximum payloads surveyed ranged from 1.8 kg to 6.4 kg. (4 to 14 lbs). As a reference, Amazon's future delivery service limits itself to 2.3 kg (5 lb) [16] and Google promises a maximum payload of 2.7 kg (6 lb) [17]. There is a clear trend linking the size and weight of the drone with its maximum payload capacity. As the drones increase in size and weight there is also an increase in the amount they can lift. As later discussed, there is clear link between battery capacity, battery weight, and payload capacity.
The practical range of drones will determine not only the service area of delivery but also the amount of infrastructure needed to serve an area or to achieve a particular level of service, e.g. Amazon's 30 minute or less policy. A shorter range would require more, closely spaced nodes at which drones could recharge, whether those were mobile vans, warehouses, or simply a charging station that was part of a charging network.

2.2. Battery/Energy

Batteries are primarily lithium based (also lithium polymer) though a few UAVs use lithium-ion batteries. Batteries are typically composed by several cells. Battery capacity ranges from 2700 mAh to the Vader HL's 40,000 mAh battery pack. The typical battery amperage was almost 10000 mAh. Voltages are typically between 22.8 and 11.4V. Battery energy ranges typically between 200 and 70 Wh though some longer range drones like the MD4-3000 can have a battery with over 750 Wh.
Batteries are a major component of the weight of a drone. In small drones the battery can be heavier than the maximum payload. In larger drones the battery can weigh as much as 80% of the maximum payload. Battery technology is a key constraint for UAV performance, typical lithium based batteries used in available drones have an energy density that ranges from 190 to 175 wh/kg.
Recharge time will be an important factor in freight delivery logistics. The longer it takes to recharge a battery, the longer a drone sits on the sidelines being unproductive. Long recharge times might prompt a business purchase more drones or more batteries to be able to maintain an ever-ready drone fleet. The majority of the drones had longer recharge times than flight times, sometimes as much as 500% longer. Recharge times are also affected by the type of battery charger used. Faster recharge times require more expensive chargers. Recharge times tend to increase with battery size but they also are a function of the recharger type.

2.3. Size and Weight

In general, larger drones have a higher payload and heavier drones a longer range (more and heavier batteries). The typical payload/takeoff-weight ratio ranges from 0.33 to 0.20 and the battery/takeoff-weight ratio typically ranges from 0.30 to 0.25 (see Table 1). Heavier drones tend to be larger (longer diagonal measurement). The average size across the diagonal is 1,045 mm not including the propellers, with a typical range from 1485 to 350 mm. The typical takeoff weight is approximately 4 kg but longer-range drones have a takeoff weight of 10 kg or more.

Table 1: List of weights and diagonal sizes for selected drones (not including propellers and blades)

UAV Model	*UAV Weight (grams)*	*UAV diagonal size (mm)*
Spark	300	170
Mavic PRO	734	335
Sky Tech	1250	470
Skyranger	2400	559
Inspire 1	2845	581
Aibot X6	3400	1485
Inspire 2	3440	605
Mavrik X8	3650	821
AR180	5400	1800
Alta 8	6200	1325
AR200	9100	2200
Matrice 600	9613	1133
MD4-3000	11000	2788
Vader HL	16400	1320

2.4. Costs

There is a wide range of costs, small multicopters cost a few hundred dollars and the most expensive multicopters cost over $20,000 each. The wide range is explained by the different capabilities and the cost of the batteries. The batteries and the charger can be as expensive as the cost of the drone itself (everything but the battery). Table 2 presents a table with reference prices, though these values should be use with caution because they change frequently and also because many drones can be customized and different features may be added or removed (e.g. charger, additional batteries) and some costs like shipping or taxes vary significantly by state or country.

Table 2: List of costs for selected drones

UAV Model	*UAV Cost**
Bebop 2	$349
Phantom 3 Standard	$499
Spark	$499
Sky Tech	$649
Mavic PRO	$999
Phantom 4 Advanced	$1,199
Phantom 3 Pro	$1,499
Inspire 1	$1,999
Mavrik X8	$3,096
Inspire 2	$4,147
Matrice 600	$4,999
Vader HL	$14,795
Alta 8	$17,495
Aibot X6	$23,269

* This value is approximated and provided just to give a rough estimate (see main text).

2.5. Safety

There is a concern about the risk of a UAV malfunctioning in mid-air, falling from the sky, and damaging property or injuring people. The drones surveyed range in weights from 1.25 kg (2.76 lb) to 33 kg (72.75 lb), though if their maximum payloads are included then these weights increase to the Sky Tech weighing 3.25 kg (7.17 lb) and the MD4-3000 weighing 16 kg (35 lb) and flying at 20 m/s (45 mph).
A recent report commissioned by the FAA [18] indicates that three vehicle characteristics may contribute to fatal drone collisions: kinetic energy, ignition sources based on vehicle power systems, and vehicle rotating components. The kinetic energy is proportional to the takeoff-weight and the square of the aircraft speed. Drone batteries, motors, and potential cargo may increase the severity of the crash because they dense objects. The propeller blades attached to quadcopter drones can slice skin and blade guards may better protect people [18].

2.6. Operational Limitations

Most drones can operate with headwinds of less than 10 meters per second. Hence, current drones cannot be reliably deployed in windy areas. The operating temperature ranges typically between -10° C and 45° C, hence, drones cannot be deployed in extremely hot or cold areas. Finally, remote controller maximum transmission distance is typically far less than the maximum flying range. Though this limitation can be overcome by configurating UAVs with more expensive sensors and communication devices.

3. The Impact of Economies of Scale

This section highlights some trends, mostly linear, among payloads, takeoff weights, and energy consumption. Figure 1 shows a remarkably linear relationship between payload and takeoff weight.

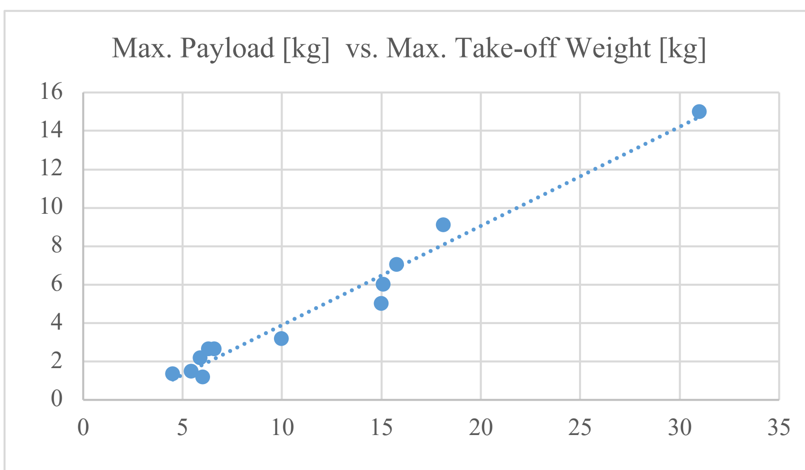

Figure 1: Payload and Take-off Weight Relationship

The second graph displays the relationship between energy efficiency, in watt-hour per kilometre, and takeoff weight. Takeoff weight is clearly correlated with UAV size. Figure 2 shows a steady increase of energy consumption as a function of takeoff weight.

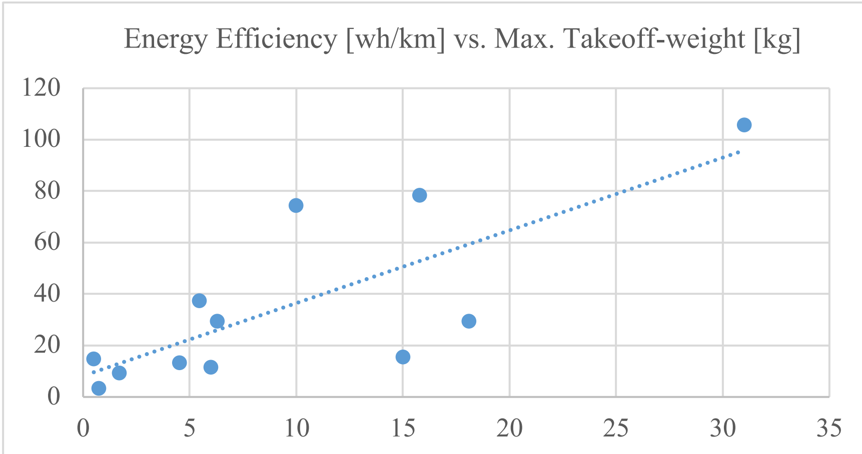

Figure 2: Energy Efficiency and Takeoff-weight Relationship

The third graph displays the relationship between energy efficiency, in watt-hour per kilometre, and maximum payload weight in kilograms. Figure 3 shows a steady increase of energy consumption as a function of payload.

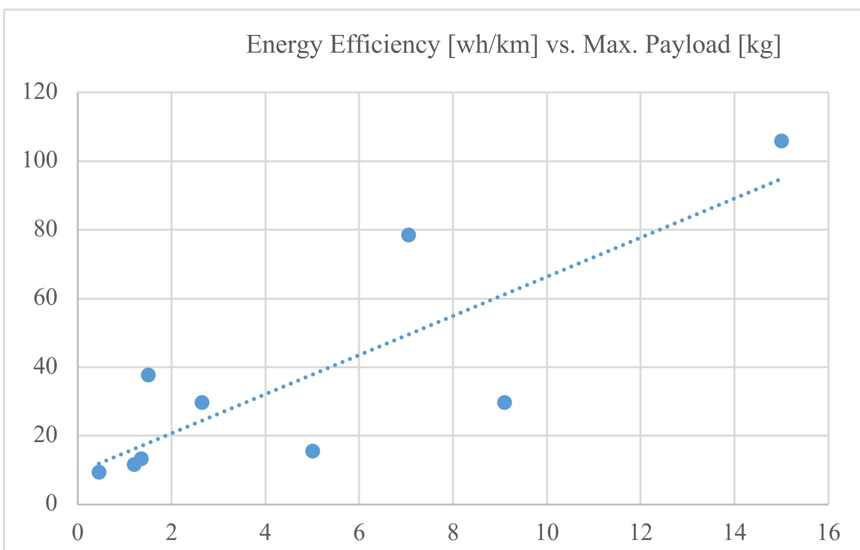

Figure 3: Energy Efficiency and Max. Payload Weight Relationship

Finally, energy consumption per unit of payload [wh / km-kg] shows a negative relationship. The strength of the relationship is somewhat similar to the relationships found in Figures 2 and 3 but with a negative sign. Hence, the efficiency in terms of energy consumption (and emissions) increases as the payload increases. From a logistical viewpoint, lower energy consumption per unit of cargo and distance travelled [wh / km-kg] clearly implies the benefits of economies of scale. However, the benefits of economies of scale are opposed by increased safety risks as discussed in the next section.

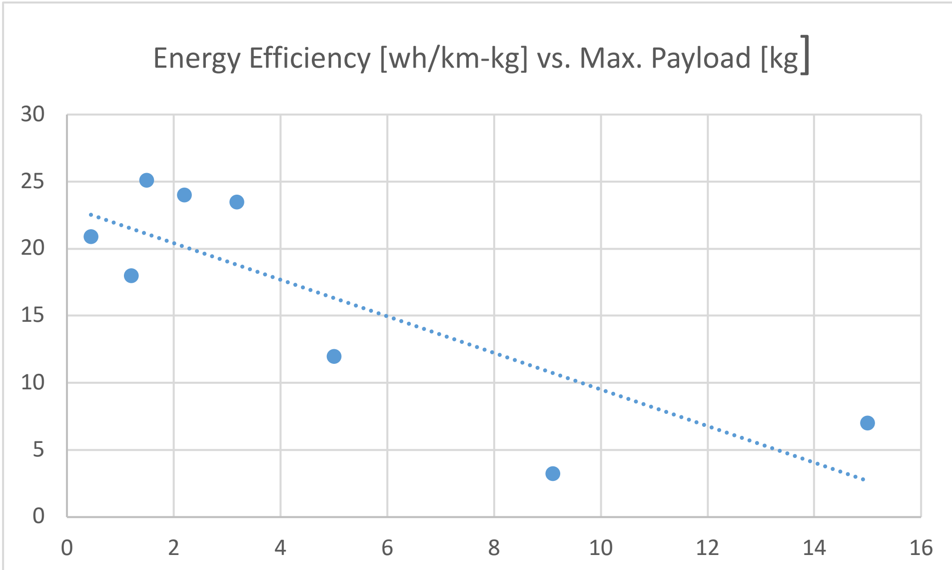

Figure 4: Energy Efficiency and Max. Payload Weight Relationship

Energy efficiency is a key factor because at the moment battery technology is a constraint that restricts capabilities and substantially increases UAV delivery costs. Drone range with current battery technology allow the delivery of small packages (less than 3 kg) within a service area with a 9-mile radius; this service area is sufficient to cover most of the population in a mid-size city like Portland, Oregon, in the USA. If battery energy density doubles in the near future, drone range can be extended to serve a service area with a 18-mile radius; this radius is sufficient to cover most of the population in the New York metropolitan area.

4. Safety and Regulatory Constraints

In 2016, the Federal Aviation Administration (FAA) issued restrictions on the non-recreational use of unmanned aerial vehicles which effectively prohibited freight delivery using drones in the USA [24]. Some restrictions do not affect the drones surveyed (400' maximum altitude, 45 m/s (100 mph) maximum land speed). However, other restrictions prevent any business from currently utilizing drones in a freight delivery service. For example, drones must be flown using VLOS (visual line of sight) at all times which would greatly reduce the size of the service area, especially in forested hilly terrains or dense areas with skyscrapers, and reduce the economic benefit of not having a human pilot in the UAV. Furthermore, the communication range of most of the surveyed drones is shorter than the theoretical flying range. Hence, a VLOS mandate further restricts the range for most drones currently available in the market.
According to 2016 FAA rules, drones must not be flown over populated areas, less than 400' from any structure, when visibility is a less than three miles, and reduced daytime visibility. These restrictions allow freight to be delivered in rural environments over short distances and on very clear days. The 25 kg (55 lb) weight limit, which includes payload, does affects only one of the drones we surveyed, the Vader HL, most are well under that limit. In summary, most of the available multicopter drones' basic capabilities, e.g. speed, altitude, and payload; do not violate FAA's restrictions. However, restrictions governing where/what the drone can fly over, how it can be piloted (beyond line of sight or autonomously), and how far it can fly from its origin severely limit UAVs business and geographical scope.
The FAA is partnering with NASA to study when drones can be used in U.S. National Airspace and in what capacities [25]. NASA is working on an air traffic management system for drones similar to what exists for today's air traffic, except that the UAV air space resides mainly within altitudes from 200' to 500'. This is critical to ensure that the digital aviation infrastructure that would be designed to organize the many different paths of the UAVs prevents drones from crashing into one another or flying into a restricted zone. Other countries where regulation is more "relaxed" are likely to see more progress. In Australia, a commercial operator can procure a Remotely Piloted Aircraft Operator Certificate and operate within 15

meters of a non-company person but requesting their consent first. Also, the Australian certificate enables the operator to apply for permission for other flight procedures such as night flying and Beyond Visual Line of Sight flying [19]. In September 2016, the Australian government reduced the kinds of commercial operations that would require a remote pilot's license or operator's certificate, making it easier to utilize drones in certain circumstances [26]. In the UK, drones weighing 7 kg or less including maximum payload are allowed to fly in all airspaces including those around the busiest airports over "congested areas" [20][27]. In the UK, drones are regulated into three groups according to their mass and the potential harm that can result from a midair malfunction. For example, the heaviest category, 150 kg or higher, is regulated at the same level as manned aircraft [28].

Privacy, safety, and noise are issues that may problematic in urban areas though not a major (or so important) problem in rural areas. A privacy backlash may restrict the flying space in urban areas if some neighbours do not allow unannounced or unauthorized aircrafts over their properties.

Safety is also a major concern, different kinds of problems could result from thousands of drones zipping through the sky. Not only is there potential for collisions to power lines, buildings, and monuments resulting in property damage, but also the more important risk to people. Falling from the sky or crashing at maximum speed could be fatal. For a drone to be allowed to fly within 15 meters from a non-company person, the Australian government required that it be fitted with a kind of motor redundancy that would prevent it from falling from the sky [19]. In the UK, any flight that will go over a populated area must submit a "safety case" that includes the potential Kinetic Energy Limits that a free-fall from 400 feet high or that a collision at maximum speed would create [20]. In addition to danger from a system malfunction, there is also the threat of people using it as a terrorism device. In response, some American manufacturers have created multicopter drones that can seek and capture enemy drones with netting [21].

Finally, noise is another aspect that can be subject to regulation. There is a concern in populated areas of added noise pollution coming from drones flying nearby. A few drone manufacturers state the noise level of the aircrafts as a function of distance or flying speed. In general, noise levels increase with the size of the drone and with the proximity to the aircraft. According to one study the movements from hexcopter and quadcopter style UAVs can emit decibel levels in the low to mid 70s, which is about as loud as a vacuum cleaner or "living room music." [22]. There is ongoing research by NASA to lessen the noise pollution emitted by drones by improving propeller technology. One way being explored is by having each propeller rotate at varying speeds, which prevents the collective whines of the propellers from amplifying themselves [23]. That particular kind of technology, though, is not available on the market yet.

5. Last yard Constraints

An often overlooked problem in UAV delivery discussions is the issue of the last yard of the delivery. Though UAVs aerial paths avoid ground congestion and last mile delivery problems associated to truck parking and unloading, there is a major challenge in terms of the last yard of the delivery process. Urban last yard deliveries are likely to require landing pads or delivery stations as well as safe spaces for takeoff and landing (some companies are discussing dropping or parachuting packages). For single home or unit dwellings the cost implications of the last yard delivery infrastructure are not yet clear. As discussed in the previous sections, there are clear tradeoffs between UAV size, efficiency, safety, and size of the last yard infrastructure.

For multiunit building, rooftops are a largely under-utilized urban area that, if retrofitted properly, could become prime delivery nodes for the building (whether it was condominium, a business, or a factory). Provided a suitable structure could be built that would protect the packages from the elements as well as proper retrofits that would ensure the safety of people retrieving (or dropping off) their packages, rooftop delivery zones would also keep the items secure from theft. Coupling these landing pads with rooftop charging stations throughout a downtown area means that the UAVs would be capable of longer flight distances or larger payloads. This kind of network would offer up a viable complementary freight delivery option to that on the ground level. There are start differences between last yard constraints and possibilities when comparing single home versus multiunit dwellings or buildings. Last yard costs and constraints may limit the size of the UAVs and therefore limit their efficiency and competitiveness.

6. Conclusions

This research presented novel data and linear relationships among current multicopters payload, take-off weight, and energy efficiency. A novel contribution of this research is the discussion of tradeoffs among UAV logistical capabilities, sustainability (in terms of energy consumption), safety, and last yard delivery constraints. The data shows that there are clear economies of scale in terms of energy consumed per unit distance travelled and per kilogram of payload delivered. Based on our comparative analysis range, payload, size, and cost are positively correlated and tend to increase together. Unfortunately, potential safety, noise, and last yard constraints also increase as drone capabilities and size increase.

The survey seems to indicate that currently available UAVs can fill a delivery service niche in sparsely populated areas with a low number of customers and density. In rural areas, the regulatory landscape and last yard delivery constraints are also more relaxed. The majority of existing applications for delivery drones have been in rural areas, e.g. rural Africa, the Appalachian mountain villages or islands near a mainland. In rural areas the economic benefit brought about by reducing the cost of a driver to visit remote customers are obvious but in this environment UAV range is a key consideration.

UAVs for package delivery have a lot of potential to improve logistics productivity and reduce environmental externalities such as trucking diesel engine pollution. However, safety concerns and last yard constraints are likely to limit the benefits that can be achieved through economies of scale. Future research efforts can compare UAVs and ground vehicles in terms of safety and last mile efficiency.

It is expected that multicopter UAV technology, capabilities, and costs will improve substantially in the near future [29]. Hence, there are still many areas to research and model in terms of UAVs costs, markets, potential benefit, and supply chain impacts [30].

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8. References

1. Sifton, John. “A Brief History of Drones.” *The Nation*, 7 Feb., 2012. https://www.thenation.com/article/brief-history-drones/
2. Stewart, Jack. “A Drone-Slinging UPS Van Delivers the Future.” *Wired,* 21 Feb, 2017, https://www.wired.com/2017/02/drone-slinging-ups-van-delivers-future/
3. Anderson, M. Amazon Seeks FAA Approval to Test Delivery Drones Outdoors, The Seattle Times. 11 July 2014. Web accessed on 25 Nov. 2014 and Amazon Prime Air UAV logistics program https://www.amazon.com/b?node=8037720011
4. Madrigal, Alexis C. “Inside Google’s Secret Drone-Delivery Program.” *The Atlantic.* 28 August, 2014. https://www.theatlantic.com/technology/archive/2014/08/inside-googles-secret-drone-delivery-program/379306/
5. “Making Instanat Deiveries Across Rwanda.” *Zipline.* Accessed on 7/31/2017. http://flyzipline.com/now-serving/index.html
6. “Drones in logistics: Transporting goods by airmail.” *Swiss Post.* Accessed on 7/31/2017. https://www.post.ch/en/about-us/company/innovation/swiss-post-s-innovations-for-you/drones-in-logistics.
7. O’Donnell, Jayne; Ungar, Laura. “First FAA-approved drone delivery brings medical supplies to rural Virginia.” *USA Today,* https://www.usatoday.com/story/news/nation/2015/07/17/faa-drone-medical-supplies-virginia/30296025/. Accessed 31 July, 2017.
8. Joerss, M., Schröder, J., Neuhaus, F., Klink, C., & Mann, F. (2016). Parcel delivery–the future of the last mile. McKinsey & Company.
9. Lee, H. L., Chen, Y., Gillai, B., & Rammohan, S. (2016). Technological Disruption and Innovation in Last-Mile Delivery. STANFORD VALUE CHAIN INNOVATION INITIATIVE
10. Thiels, C. A., Aho, J. M., Zietlow, S. P., and Jenkins, D. H. (2015). Use of unmanned aerial vehicles for medical product transport. Air medical journal,34(2), 104-108.
11. Mohammed, F., Idries, A., Mohamed, N., Al-Jaroodi, J., and Jawhar, I. (2014, May). UAVs for smart cities: Opportunities and challenges. In Unmanned Aircraft Systems (ICUAS), 2014 International Conference on (pp. 267-273). IEEE.
12. Boyle, M. J. (2015). The race for drones. Orbis, 59(1), 76-94.

13. Heutger, M., Kückelhaus, M. (2014). Unmanned Aerial Vehicles in Logistics: A DHL Perspective on Implications and Use for the Logistics Industry.
14. Figliozzi, M. A. (2017). Lifecycle modeling and assessment of unmanned aerial vehicles (Drones) CO2e emissions. Transportation Research Part D: Transport and Environment, 57, 251-261.
15. González-Jorge, H., Martínez-Sánchez, J., & Bueno, M. (2017). Unmanned Aerial Systems for Civil Applications: A Review. Drones, 1(1), 2.
16. "Amazon Prime Air." *Amazon,* 31 July, 2017. https://www.amazon.com/Amazon-Prime-Air/b?node=8037720011.
17. Hsu, Jeremy. "Google Dreams of Drone Food Delivery for Six Dollars." *Discover,* http://blogs.discovermagazine.com/lovesick-cyborg/2016/12/10/google-dreams-of-drone-food-delivery-for-six-dollars/#.WYAvbfnyu9J. Accessed 31 July, 2017.
18. Arterburn, David, Mark Ewing, Raj Prabhu, Feng Zhu, David Francis, and Pei-Sung Lin. UAS ground collision severity evaluation. (2017).
19. "Operations between 30m and 15m – non-company personnel." *Australian Government: Civil Aviation Safety Authority,* 31 July, 2017, https://www.casa.gov.au/standard-page/operations-between-30m-and-15m-non-company-personnel
20. Safety and Airspace Regulation Group. *Unmanned Aircraft System Operations in UK Airspace – Guidance.* Sixth Edition, 31 March, 2017. http://publicapps.caa.co.uk/docs/33/CAP%20722%20Sixth%20Edition%20March%202015.pdf
21. Nellis, Stephen. "Drone-catchers emerge on a new aerial frontier." *Reuters.com.* *http://www.reuters.com/article/us-usa-drone-hunter-idUSKBN16S1IT.* Accessed on 31 July, 2017.
22. "Comparitive Examples of Noise Levels." *IAC Acoustics.* 2017. http://www.industrialnoisecontrol.com/comparative-noise-examples.htm.
23. "Ten-Engine Electric Plane Completes Successful Flight Test." *NASA.* 30 April, 2015. https://www.nasa.gov/langley/ten-engine-electric-plane-completes-successful-flight-test.
24. Federal Aviation Administration. *"Summary of Small Unmanned Aircraft Rule (Part 107)."* 21 June, 2016. https://www.faa.gov/uas/media/Part_107_Summary.pdf
25. "First Steps Towad Drone Traffic Management." *NASA.* 19 Nov, 2015. https://www.nasa.gov/feature/ames/first-steps-toward-drone-traffic-management
26. "Gaining your remote pilot license (RePL) and RPA operator's certificate (ReOC)." *Australian Government: Civil Aviation Safety Authority*. https://www.casa.gov.au/aircraft/standard-page/commercial-unmanned-flight-gaining-your-remotely-piloted-aircraft-pilot. Accessed on 31 July, 2017.
27. "Introduction to Airspace." *NATS.* http://www.nats.aero/ae-home/introduction-to-airspace/. Accessed on 31 July, 2017.
28. "An Introduction to unmanned aircraft systems." *Civil Aviation Authority.* https://www.caa.co.uk/Consumers/Unmanned-aircraft/Our-role/An-introduction-to-unmanned-aircraft-systems/. Accessed on 31 Aug, 2017.
29. Floreano, D., Wood, R. J. (2015). Science, technology and the future of small autonomous drones. Nature, 521(7553), 460-466
30. Wright, C., Rupani, S., Nichols, K., & Chandani, Y. (2018). White Paper What should you deliver by unmanned aerial systems? JSI Research and Training Institute.