A COST ANALYSIS OF AMAZON PRIME AIR (DRONE DELIVERY)

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Abstract

This paper estimates the costs of the Prime Air delivery system proposed by Amazon.com, Inc. that uses drone technology to deliver packages to customers' doorsteps. The paper sets forth a benefit-cost analytical framework to examine the labor-saving technology of the drone system by modeling the Prime Air system in Chattanooga, TN. The model addresses FAA regulations, drone design, logistics, and related factors to predict how Amazon might set up and operate the drone system. Cost savings per package delivered of one-third or more relative to ground delivery, exclusive of R & D costs, seem feasible.

Key Words: cost-benefit framework, drone delivery system, new technology

JEL Classification: D29, L62, O18

Introduction

In December of 2013, Amazon President Jeff Bezos proposed that in a few years Amazon would use drones, or Octocopters, to deliver packages to a customer's doorstep. Critics of Bezos and skeptics expressed concerns. No one besides Bezos himself and perhaps others within Amazon knew details regarding the proposed drone delivery system. Commercial drone operation in the US was and is illegal! Certainly, drone technology would provide Amazon the opportunity to expand transportation and delivery service in a way previously only imagined. As Paul Misener, Amazon Vice President of Global Public Policy, commented, "one day, seeing Amazon Prime Air will be as normal as seeing mail trucks on the road today, resulting in enormous benefits for consumers across the nation" (Amazon.com, 2014).

A key advantage Amazon claims over other online retailers is the speed at which it sends out a package for delivery. The company created and held this advantage with massive investment in fulfillment centers across the country. Amazon now operates a fulfillment center within five miles of most metropolitan areas (Davis, 2013). In 2013, Amazon had over 10 million Amazon Prime Members - loyal customers that buy frequently from the online retailer and for a yearly fee receive free shipping and other benefits. This number is projected to increase to 25 million by 2017 (McCorvey, 2013). How has Amazon created such a customer base? Fast delivery. Within 2.5 hours of an order being placed, the package has been shipped. Amazon accomplishes this

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speed through an efficient packaging process enhanced by the close proximity of its fulfillment centers to consumers. These fulfillment centers are equipped with Kiva Robotics Systems which are programmed to retrieve and move items around the warehouse (Wohlsen, 2014).

Over the last few years, with delivery costs rising as a result of rising gas prices, Amazon's profit margins have shrunk. Amazon currently relies on FedEx, UPS, and the postal service to deliver its packages. By switching to drone delivery, Amazon cuts out this delivery-service middle man to complete an order all the way to the customer's doorstep. This will replace the cost, including profit, in current UPS and FedEx charges for delivery. Amazon gains the opportunity for additional profit or to lower a customer's cost.

Drones also reduce labor costs by replacing much of labor's role in ground delivery. The only human labor required will be for operational management and drone maintenance.

Literature Review

Little written literature exists regarding the commercial use of drones for package pick-up and delivery. Instead, most published research regarding drones focuses on aerial surveillance: to survey for oil fields, to take aerial views of properties, for mapping and general surveying, and to search for missing persons (Laing, 2014).

Kharchenko and Prusov (2012) divide the various uses for drones into three groups: safety control, scientific-research, and commercial. They highlight commercial photography and surveillance uses, but do not consider cargo delivery. They also identify specific requirements needed in the structure of an Unmanned Aviation Complex (UAC) or drone station: the unmanned aircraft itself, control stations (management) of unmanned aircraft and the antennae system, software and systems for monitoring of the unmanned aircraft, communication means (earth/air and air/earth) for air-traffic control and unmanned-aircraft payload, terminals of data processing, landing system, launch system and systems for re-charging, maintenance equipment and the support of the unmanned aircraft and its systems, and systems of storage and transportation of unmanned-aircraft.

Kharchenko and Prusov note that as drone usage becomes more popular, problems may arise in the use of airspace and the "allocation of frequency range for unmanned aircraft control and data transfer from the [aircraft] to the earth and vice versa."

Peter Tatham (2009) addresses the uses of drones (UAVS) in providing aerial surveillance and reconnaissance.[3] He emphasizes the importance of timeliness of delivery in disasters, concluding that drones can lead to earlier and better quality aid to areas suddenly struck by a disaster. Tatham writes that "the [drone] cost/hour is similar to a manned aircraft, and less than a helicopter; [UAVs] require less launching/landing area; can operate at low levels in cloud(s) and medium precipitation conditions that would not be allowed or safe for manned aircraft" and have greater endurance levels (Tatham, p. 65). He has no doubt that in the coming years, the cost of UAVS will decrease. In his analysis, Tatham compares the costs of operating a fixed-wing light aircraft, helicopters, and UAVs and finds that UAVs are less expensive to obtain and operate considering capital cost, operating speed, and mission cost.

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[3] Throughout this paper various acronyms are used in reference to drones: UAV (Unmanned Aerial Vehicle), UAS (Unmanned Aircraft Systems), and sUAS (small Unmanned Aircraft Systems).

History and Regulations

The Federal Aviation Administration (FAA), under operational control of the Department of Transportation, maintains legal authority over all US airspace (FAA.gov, History). Though the use of drones for private use has not been regulated, the FAA has restricted their commercial use – drones must be flown below 400 feet and may not enter airspace within a mile of airports.

In 2012 Congress passed legislation that required the FAA to open US airspace to the use of commercial drones in the next five years by "develop[ing] a comprehensive plan to accelerate the integration of civil unmanned aircraft systems into the national airspace system" no later than September 20, 2015 (FAA Modernization and Reform Act of 2012, Section 332). The FAA may grant companies permission to operate drones in US airspace prior to this completion date (Sec. 333). Therefore, each US business that wishes to use drones for commercial purposes must submit an application for exception to the FAA and be granted special permission. A business seeking exception must provide drone specifications (such as size, weight, flight speed, etc.) so that the entity's drone model may be approved to fly.

As of August 4, 2015, the FAA has granted 1,008 exemptions under Section 333 (FAA.gov, News and Updates). Restrictions placed on a drone operator include obtaining "a regular pilot's license, pass an aviation medical check, be assisted by a spotter, request permission two days in advance, and limit flights to less than 35 mph and below 300 feet" (Cooper, 2015).

Amazon wants to begin testing drones in Seattle, WA, near its headquarters and existing facilities. Since Washington is not one of the six approved test sites (Alaska, Nevada, New York, North Dakota, Texas, and Virginia), the company must seek special FAA permission (Walker, 2014). Indeed, to comply with current regulations, Amazon shot its demo video - required for FAA permission - outside the United States where permission to fly was not required.

On February 15, 2015, the FAA released proposed rules for integrating small, commercial UASs into US airspace. The proposed parameters for commercial drones include:

- UASs must weigh less than 55 lbs. and fly at a maximum speed of 100 mph and a maximum altitude of 500 ft. above ground level.
- UASs must remain in sight of operator, in daylight hours only, and not over a person (cannot fly over people).
- UASs cannot operate near airports.
- Pilots/Operators of UASs would be required to: pass an initial aeronautical knowledge test at an FAA-approved knowledge testing center as well as a recurrent test every 24 months, be vetted by the Transportation Security Administration, obtain an unmanned aircraft operator certificate with small UAS rating, and be at least 17 years old.

The full extent of the rules and regulations may be found in a 195-page document on the FAA's website. Of particular importance are the requirements of operational sight and flight occurrence only during daylight hours. If these rules are approved, Amazon will have to modify its system to operate within line of sight (a maximum of 3 miles), use individual operators, and fly drones only during daylight hours. In March 2015, the FAA approved Amazon's first exemption request for drone testing, but by that time, the drone Amazon was proposing to test had become obsolete (Janson, 2015).

With these latest drone requirements and the lag in approvals, critics say that the FAA is causing drone development in the US to lag behind countries such as China, Canada, and Australia. These three countries are among the first to allow the use of commercial drones (Canada has only granted experimental permits). Zookal, a textbook rental company based in Australia, has partnered with Flirtey (a startup tech company) to develop a drone system to deliver textbooks. Using an app to deliver within a 2-kilometer (1.24 mile) radius, Zookal hopes to begin solving the problem of delivery logistics and saving time and money just as Amazon proposes to do in the US (Mckenzie, 2013). Flirtey's chief executive, Matt Sweeney, claims that, as the program realizes with economies of scale "we expect to see long term reduction of costs in delivery and a strong environmental benefit with the reduction of vans on the roads doing deliveries." (sUSA News, 2014). Just recently Flirtey made drone-delivery history. Partnering with Virginia Polytechnic Institute (VPI) and the FAA, Flirtey performed the first officially-approved US drone delivery on July 17, 2015. The drone delivered much needed medical supplies to a free clinic in rural Virginia (Ackerman, 2015).

Flirtey is also working with New Zealand to implement Airshare, "a hub for UAV information, which will allow commercial operators to log their flights to ensure maximum safety" (Lim, 2014). China is working on a drone based postal system and Dominos in Europe is testing the use of their "Domicopters" to delivery pizzas to a customer's door (Smith, 2013).

Theory and Operation

Amazon will set up its drone system only in cities where it will be expected to increase efficiency and profitability. For example, the drone system would be costlier and less profitable in a low density/low population city versus a high density/high population city. Urban areas with denser and larger populations of customers are expected to provide scale economies not available in a city such as Chattanooga, TN.

If Amazon succeeds in its venture to use drones for commercial delivery in the US, it may gain a research and development (R&D) advantage as well as reductions in future developmental miss-steps through learning by doing while gaining consumer favor as an innovator. Though these advantages may fade over time giving way to competition, Amazon will have gained in technological leadership, preemption of assets, and buyer switching costs (Lieberman, 1988).

Amazon's fulfilment centers serve as a median location where the cost of transporting many packages to the fulfillment center is traded-off against the cost of individual package delivery. The general location of fulfillment centers located on the outskirts of a city works well with the use of a few drone stations located strategically around the city.

We use details about 8th and 9th generation drones revealed in Amazon's letter to the FAA in the model. Each drone will weigh less than 55 pounds, fly at speeds of up to 50 miles per hour, carry packages of 5 pounds or less, and carry packages within a ten-mile radius of a drone station. Traveling at 50 miles per hour, this radius is travelled in 12 minutes:

$$\frac{50\text{ miles}}{1\text{ hour}} = \frac{50\text{ miles}}{60\text{ minutes}} = \frac{10\text{ miles}}{12\text{ minutes}}$$

Thus, a drone flies a maximum round trip in 24 minutes. Allowing an additional 6 minutes for flight acceleration and deceleration, loading and unloading of packages, and flight ascent and descent, a drone delivers a package to a maximum distance and returns in 30 minutes (24 minutes of flight time + 6 minutes of extra time). Assuming the average flight radius is 7.5 miles, the elapsed time is 24 minutes (9 minute flights to and from the delivery site plus 6 minutes).

The drone is pre-programmed for each flight, giving it the capability to fly to a customer and back without a human operator. A series of computer codes transmitted from the drone station to the drone direct it to its destination.[4] Human labor will monitor flights and perform maintenance tasks. One employee should be able to monitor multiple flights at once just as an air-traffic controller does with commercial passenger planes.

Amazon has petitioned the FAA to run test flights at heights up to 400 feet (approximately the height of a 40 story building). Drone expert Missy Cummings (Gross, 2012) estimates that the drones will have to fly at 300 feet or higher to prevent human interference. In our model, the drone first ascends to an altitude of 400 feet. It then flies at altitude on a set path. Upon reaching the destination coordinates, the drone descends, lands and releases its package, and then retraces the flight pattern back to the drone station.

Various extraneous factors, for instance, poor weather conditions such as snow, rain, and sleet, may have an effect on the system's efficiency. Missy Cummings theorizes that drones will be equipped to fly in light rain or snow, but nothing heavier, because precipitation obscures the sensors (Gross, 2013). Of course, if precipitation is too heavy for drone flights, it would slow or render ground delivery unsafe. Either way, weather may cause flight delays during periods of heavy precipitation.

Drones could increase operational hours of delivery by enough to make up for weather delays. FedEx and UPS deliver 11 hours daily, typically 8 am to 7pm, Monday through Friday. With the necessary legislation in place, Amazon could go to 24 hours a day drone operations or, more realistically, operate 12 hours per day and Monday through Saturday (or even Sunday). A drone of course flies above road delays such as construction, detours, accidents, traffic, etc.

We model drone delivery to Chattanooga, Tennessee. This facilitates identification and inclusion of various factors. Chattanooga is a relatively "average" size with population of 171,279 and over 470,000 living in the Chattanooga Metropolitan Statistical Area, a population density of 1,267 people per square mile (City-Data.com, CEC-ICMC 2007). The altitude of the area ranges from 1,800 feet in the valley where the downtown area sits to 2,300 feet on suburban Signal Mountain. Parts of the metropolitan area (East Ridge) cross into Georgia with density that ranges from 149.88 to 3,134.06 people per square mile. See Figure 1.

Because the metropolitan area spills into Georgia, legal permission to fly drones is needed from both Tennessee and Georgia. Chattanooga averages of 120 days of rainfall per year. The likelihood of a thunderstorm or moderate rain occurring on a day with precipitation is 61% (WeatherSpark.com). Because drones have trouble operating in moderate rain or thunderstorm conditions, the drones are likely to experience flight delays 73 (120 times 0.61) days per year.

On its peak delivery day (November 26, 2012), Amazon centers worldwide shipped over 306 items per minute (Cheredar, 2012). Assuming that just 1/4 of those packages were shipped in the US, then more than 3.9 million of the packages were shipped in the US for an average of 0.0122295 packages per person.[5] If this average is applied to the Chattanooga area population of 470,000, then approximately 5,748 packages were shipped that day in Chattanooga.

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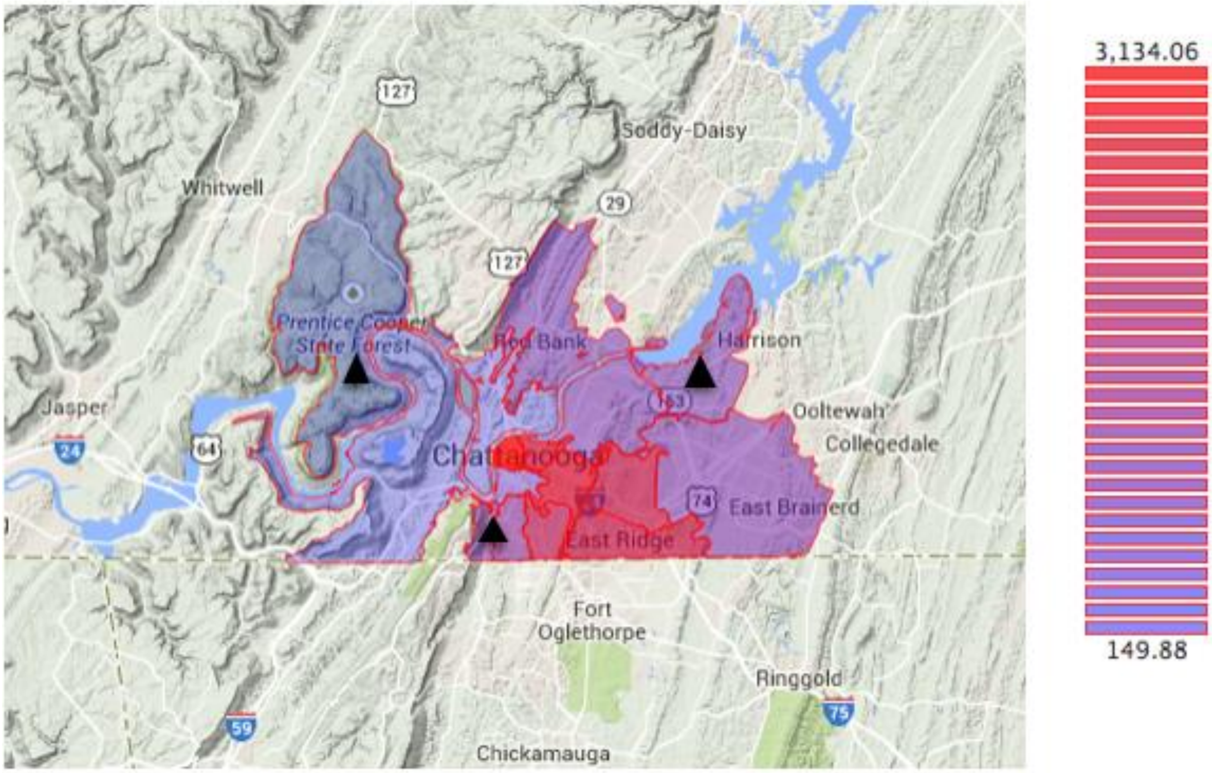
[4] Drones are commonly referred to as small unmanned aircraft systems or "sUAS". The sUAS are equipped with additional programming such as anti-collision technology to prevent the drone from flying into obstructions. The drones are also programmed with basic safety protocols. Should communication be lost between the drone station and the drone, the drones are programed to return to a secure location (Amazon.com).

[5] The number of packages delivered by Amazon on an average day is not available.

Figure 1: A map of the population density of Chattanooga



(Map and data from zipatlas.com)

On the busiest day of the year, 4,943 packages (= 5,748 packages x 86% representing the % of total packages of 5 lbs. or less (Cheredar, 2012)) are potentially delivered by drones to the Chattanooga area. Amazon drones operating round-the-clock (three 8-hour shifts) would need to deliver 205 packages hourly to achieve this total. With the average of 2.5 trips per hour (= 60 minutes divided by 24 minutes/trip), 82 drones are needed every hour. So each of the three drone stations needs 28 drones in constant operation, while another 28 drones are charging for the next shift. To provide a reserve against the risk of running short on drones, each station needs 7 reserve drones (estimated 25% of drones in operation) to be available on its busiest day and for backup during repairs or malfunctions. Hence, each of the three stations requires 63 drones for Amazon's busiest package day of the year or a total of 189 drones for the Chattanooga area.

If stations operate 12 hours per day instead of 24, which better accommodates business and residential hours to accept delivery, then the numbers for the busiest day become: 412 deliveries per hour require 165 drones in operation. Per station, this is 55 operating, another 55 charging, and

18 (25% of 55 drones) in reserve. Thus, 128 drones are needed per station for a total of 384 drones in Chattanooga. This is the maximum for peak periods. During non-peak periods, deliveries can be accomplished by operating fewer drones or fewer hours.

How will a drone "know" exactly where to land? The idea of having "helipads" for the drones to land and drop their package has been put forth. Other ideas such as an app with GPS locating ability would "call" the drone to the person's phone. Either way, Amazon must find a way to program specific coordinates that are deemed "safe landing spots". These could be strategically located throughout the city where a drone will land, drop off the package, and resume flight (Gross). Customers then pick up their packages from this specific location rather than at their door. Delivery to a customer's doorstep raises the legal issue of permission for Amazon drones to land in public areas.

Costs and Benefits

Drones range in cost from a few hundred dollars to millions of dollars. We assume that a drone costs between $3,000 to $5,000 ($1,000 to $3,000 for the drone and $2,000 for software and maintenance) with an average cost of $4,000 per drone (Keeney, 2015). This mandates an initial capital investment of $756,000 (189 drones) for 24 hours per day operation, or for 12 hours per day operation, $1,536,000 (384 drones). We assume that operating costs for personnel, loading, and monitoring will be approximately the same per package for truck as for drone delivery.

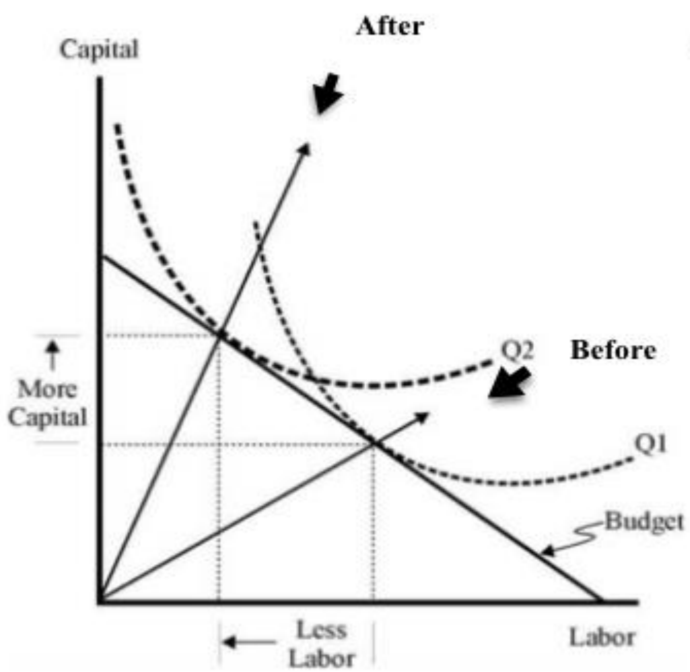
Amazon's drone technology is a labor-saving/capital-using technology as drones replace labor and trucks with more specialized capital and labor in the production delivery services. See Figure 1. Introduction of drone technology switches production from isoquant Q1 to isoquant Q2, replacing labor with capital and increasing the capital to labor ratio. Figure 1 shows the new technology (isoquant Q2) changing the input mix from labor intensive to capital intensive. Amazon's application of drones to package delivery accomplishes by substituting drones for trucks. Each truck requires a driver whereas the drone is guided by transmitted computer codes plus labor for flight monitoring. One drone operator will monitor multiple drones.

John Swope (2015) analyzes UPS delivery cost. He assumes that a UPS driver makes $25 an hour delivering packages, 10 hours a day. After factoring gas and tolls, though not truck capital or maintenance cost, the cost of delivery-by-truck comes to around $30 an hour. Swope also found that, according to a UPS driver forum, a driver delivers up to 250 packages per day. The average delivery cost per package equals:

$$\frac{\text{Cost of driver}}{\text{\# of packages delivered}} = \frac{\frac{\$30}{\text{hour}} \text{x} \frac{10 \text{ hours}}{\text{day}}}{\frac{250 \text{ packages}}{\text{day}}} = \frac{\$1.20}{\text{package}}$$

This excludes Amazon's cost of getting packages to the UPS center, fuel and other transport costs, and fringe benefits or any other contractual costs.

Figure 1: Labor-Saving Innovation



Alternatively, Swope estimates that maintenance and other costs will average $4,000 over the five-year lifespan of a drone. Using this information, the cost per package delivered with 24 hours per day service can be calculated. First, the total packages delivered over five years is

$$\frac{4943 \text{ packages}}{\text{day}} \text{x} \frac{6 \text{ days}}{\text{week}} \text{x} \frac{51 \text{ weeks}}{\text{year}} \text{x } 5 \text{ years} = 7{,}562{,}790 \text{ packages.}$$ [6]

Total cost for drone delivery 24 hours per day with 3 shifts equals:

$$\frac{\text{Capital Cost} * \#\text{ Drones} + \text{Delivery Cost} * \#\text{ Drones}}{7{,}562{,}790 \text{ packages}} = \frac{\text{Cost}}{\text{package}}$$

$$\frac{\$4{,}000 * 189 + \$4{,}000 * 189}{7{,}562{,}790 \text{ packages}} = \frac{\$0.200}{\text{package}}$$

For 12 hours per day operation the cost per package delivered is:

[6] These numbers allow for no Sunday operations and operating 51 weeks per year to account for major holidays.

$$\frac{\$4{,}000 * 384 + \$4{,}000 * 384}{7{,}562{,}790 \text{ packages}} = \frac{\$0.406}{\text{package}}$$

Or, allowing for some reduction to $3,000 of maintenance and other cost per drone per 5 years as a result of a drone delivering fewer packages on average:

$$\frac{\$4{,}000 * 384 + \$3{,}000 * 384}{7{,}562{,}790 \text{ packages}} = \frac{\$0.355}{\text{package}}$$

These costs per package are for the busiest or "most efficient day" delivery. Still the drone cost per package delivered is one-third or less of the UPS delivery cost. And that $1.20 cost excludes vehicle cost. The future price of a drone is likely to decrease due to economies of scale in drone production as their commercial use expands. On the other hand, the drone costs per package delivered increase on less busy days. Nevertheless, delivery of one-half as many packages per day, only increases the 12 hour per day operation cost to about $0.80 – still a one-third cost saving of $0.40 per package before any concurrent reduction in maintenance or other operating costs.

There are additional drone costs such as: setting-up and running the drone delivery stations, the investment in research and development, and lobbying the FAA. Other costs include: buildings and land associated with the drone stations, computers and monitoring software systems for drone flights, computer technicians and drone monitors on site, robotics engineers for maintenance and upgrades to drones on site, utility costs of running the building, logistics management team to oversee operations, potential insurance and legal fees associated with drones, and potential air and/or radio frequency rights for drones, etc. There is also the potential for legal costs in some of the following situations: drones are found operating in unauthorized airspace, drones are shot down by civilians, a drone lands in an unauthorized space, etc.

Drone delivery itself is a novelty. Many persons within range of drone delivery are likely to be excited by the very idea of receiving a package delivered by drone. Another advantage will be shorter delivery response time. The time required for drone delivery will almost certainly average less time than driving. Currently, customers are faced with a decision between driving to a store to buy the product and waiting several days for delivery to their door. With drone delivery, the customer receives the product without the drive and just a minimal wait. It is also possible – perhaps likely – that longer range drones flying from a metropolitan station will reduce delivery cost to rural areas.

Table 1 compares drone versus truck issues and costs. We have considered drone-delivery as changing comparative labor and capital costs. The Table clarifies that other proprietary costs exist - some of which are "historically" fixed for trucks.

Conclusion

Amazon has much to gain if the drone project becomes operational. Amazon stands to gain a strong competitive advantage over both online and physical retailers. The quick delivery and initial novelty of drone delivery should increase business. Although the logistics of the drone delivery system remain a mystery to those outside of the inner workings of Amazon, our analysis demonstrates that it has a cost advantage of one-third or more per package over ground delivery.

Table 1: COMPARISON OF AMAZON TRUCK VS. DRONE DELIVERY

CAUSE/ISSUE:	TRUCK	DRONE
Operating Hours/Week	55	72
"Traffic" Delivery Delays	Roadway Construction,	None - use Anti
	Traffic Accidents	Air-Collision Techno.
Weather Delays	Snow, Very Heavy	Moderate Rain
	Rain	to Thunderstorms
Legal	Comm. Driver's	Pilot's License (FAA)
	License (CDL)	Other FAA Regs.
COST FACTORS:		
Labor/Delivered Package	$1.20	?
(excludes fringe benefits)		
Capital & Maintenance[1]	?	$0.36
Fuel/Package	?	?
City Station (Building & Land)	?	?
Drone Sub-Stations	Roadway Provided	?
(Building & Land)	by Government	
Research & Development	None/Previously	?
Computers, Software &	None/Previously	?
Technicians for Drones		
Drone/Truck Insurance &	?	?
Related Legal Fees		

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