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Forecast of the Commercial UAS Package Delivery Market

The economics of using commercial UAS for package delivery are so compelling, companies in the package delivery market will either need to adopt this new disruptive technology or face declining market power in the face of a new industry model.

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Executive Summary

This is the first in a series of papers we will publish on the future of the commercial unmanned aerial systems (UAS) industry. This initial paper deals with issues of size and scale so those engaged in the public policy process can see the industry's potential. *Size* refers to how big the industry may grow. *Scale* refers to how big it is with regard to existing systems. A third important element is speed, which refers to how fast the system can grow.[1]

Follow-up papers will examine additional issues related to infrastructure, as well as UAS and autonomous cars. In addition, we will look at how UAS will impact energy usage and the environment. These concerns come together as part of a greater whole.

Herein we introduce what we consider the fundamental axiom of all UAS commercial economic analysis: UAS is a disruptive technology.

Disruptive technologies are new ways of doing things that disrupt or overturn traditional business methods and practices. When it comes to unmanned aircraft systems (hereafter referred to as UAS), the term is appropriate.

In December 2015, the Federal Aviation Administration (FAA) issued regulations requiring every UAS owner to register any UAS weighing between .55 and 55 lbs. More than 1 million small UAS were registered in the United States in the first 18 months of the program; roughly 100,000 were registered for commercial use, according the FAA. This comprises four times the current fleet of manned aircraft, including commercial and general aviation. The FAA forecasts project that the commercial UAS fleet will grow to 500,000 by 2021.[2]

In September 2016, FAA issued the Small UAS Rule (Part 107), which requires commercial operators of UAS to earn a Remote Pilot Certificate (RPC). More than 40,000 UAS pilots were certified for commercial operation in the first 10 months. FAA projects that RPCs will range from a low of 211,000 to a high of 422,000 by 2021.

Businesses from a variety of industries, including construction, utilities, real estate and agriculture, are already using this technology to dramatically change their operations. But perhaps no UAS use has so captured the media's attention and public imagination as UAS package delivery.

This paper seeks to explore how we might expect UAS to impact – and disrupt – the future of the delivery and logistics industry in the United States. Additionally, this paper outlines technical and regulatory steps needed in order to make UAS package delivery a reality. Finally, we begin

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[1] A number of commentators use the term *elasticity* for how fast the system can grow. Because this term has a precise economic meaning, we have chosen *speed* in its place.

[2] *FAA Aerospace Forecast 2017-2037*, adjusted to June 2017.

the discussion on ways policymakers and regulators can address these needs. Our main conclusions are:

- The fundamental premise for autonomous vehicle economic analysis is that UAS are a disruptive technology.
- The area where commercial UAS will create the biggest disruption is in last-mile package delivery to homes and small businesses.
- The impetus for this change is a major downward reduction of delivery costs to as little as $1.00 per delivery.
- Our most pessimistic forecast for package delivery estimates more than 8 million operations per day within 20 years.
- Our optimistic forecast estimates 86 million package deliveries per day within 20 years.
- The economic annual savings to logistics companies will be at least $2 billion for our pessimistic forecast and for our midrange forecast (50 million daily operations) of $10 billion.
- Autonomous and beyond visual line of sight flight operations are necessary conditions for this disruptive technology to commence.
- If there are limitations on UAS delivery from things like airport buffers, weather, high rise apartment's buildings and so forth, the potential market for UAS delivery is so large that none of these limitations will seriously impede the economic attractiveness of this business.

The cost estimates we use are very preliminary and we invite a healthy discussion of these initial efforts.

In addition to the above, we carefully examine some of the constraints of UAS package delivery implementation, including weather and irregular operations, high-rise apartments, county taxation and other matters. Our initial work in these areas is exploratory, but illustrates there are data available to foster an intelligent discussion. Furthermore, our exploratory analyses help better define the topics that require further investigation. For example, there is an absolute need for operational standards and testing, including the boundary conditions under which different UAS platforms can perform in different weather.

Much needs to be done with UAS standards before UAS package delivery can begin. We suggest research that can be conducted using readily available data. This will address many of the problems posed by questioners of UAS delivery. We also discuss the critical need for a science- and data-based regulatory system rather than simply trying to adopt the legal-based regulatory systems that have evolved in other areas.

The issues relating to air traffic management (ATM) of such a large number of forecasted daily package delivery operations require attention at the policy level. One point seems certain: Congress is unlikely to have the money needed to build this system. What are the alternatives? Is this a blessing in disguise? What will the operational budget be? What is the business plan to maintain operations and replace and build out new systems? The questions we need to address seem endless. One point is very clear: The new UAS traffic management system (UTM) will bear little resemblance to the current ATM system. This system will be different not only in the size and scale, but also in its business operations.

There is potential for new industries to grow, but growth rests on the assumption that regulations will appear at the proper times and be structured such that this nascent industry can thrive. While the potential is real, the necessary conditions for growth rest on the ability to move rapidly towards autonomous operations. In addition, there are necessary conditions for the platforms such as they will need to be ultra-safe and secure with digital identification. They will need to be connected to the UTM and be authenticated with contingencies planned and mitigated such as the ability to operate under GPS degraded or cell-degraded conditions.

One subject of considerable interest concerns the various business models companies may use for package delivery: As many of 14 or more different models may emerge. These will be explored in detail in another paper.

The reality is the predicted economic impact for commercial UAS will not occur until beyond visual line of sight operations are functional. Those using visual line of sight operations will experience a small positive economic impact, but the biggest markets are dependent on beyond visual line of sight and autonomous operations.

Beyond visual line of sight and autonomous operations are the necessary conditions for this disruptive technology to commence.[3] Regulations for line of sight operations have provided a good beginning, but the economic impact is miniscule compared to autonomous operations. The problems are the costs of the technology and the costs imposed by the regulatory environment.

Anything that increases costs is counteractive to a disruptive technology. When costs are minimal, UAS achieves its maximum capability. Therefore, a corollary to the fundamental economic axiom of commercial UAS is that its economic potential is limited until UAS can reach autonomous operations. Short-term solutions such as daisy chaining, where multiple

[3] Even though package delivery will be autonomous, dispatchers will still be at the controls in the case of an emergency.

observers on the ground ensure the UAS will not collide with other objects, is not a solution because it increases rather than decreases the cost function. Disruption requires continual cost decreases.

All of this requires more investment in analytics and intelligent software. Simply being able to perform remote sensing is insufficient if the software cannot interpret what is seen and then generate solutions. All we are doing now is taking first steps; the real heavy lifting is before us.

This paper will proceed in the following manner. First, we will develop the concept of a disruptive technology and give additional reasons why UAS fits in this category. Next, we will develop our methodology for the forecasts. Three alternative forecasts will be given: optimistic, pessimistic and an averaging of the two. The future lies somewhere in this range. In addition to the forecasts, we will spell out the conditions under which the forecasts will or will not be realized. We will also examine some of the criticisms leveled at the concept of UAS package delivery. These include the economics of package delivery. What are the costs of a company using UAS to make deliveries? It is reasonable to assume that if UAS costs are higher than current delivery methods (UPS, FedEx, DHL, etc.), the industry will not begin. We accept this proposition and will argue herein that delivery costs via UAS will be significantly lower. Not only will the costs be lower, but the convenience of UAS package delivery will minimize the fixed schedule of the current system, allowing delivery at the convenience of the customer rather than the fixed schedule of the delivery driver. In addition, we will examine other issues such as local regulations, weather, urban density, and other problems.

This paper will conclude with a discussion of relevant policy issues raised by the size and scale of our forecast. In making these forecasts, we state the implicit assumption that all technological and safety issues relating to last-mile delivery with a UAS are addressed.

Disruptive Technologies

It is our contention that commercial UAS is a disruptive technology. This axiom is fundamental to all commercial UAS economic analysis.

In this section, the concept of a destructive or innovative technology will be developed. Generally speaking, disruptive technologies have these three characteristics:

1. They will lower costs.
2. They will open new markets.
3. They will make some products obsolete.

Clayton Christensen provides an explanation of a destructive or innovative technology:

> "As companies tend to innovate faster than their customers' needs evolve, most organizations eventually end up producing products or services that are actually too sophisticated, too expensive, and too complicated for many customers in their market.
>
> "Companies pursue these 'sustaining innovations' at the higher tiers of their markets because this is what has historically helped them succeed: by charging the highest prices to their most demanding and sophisticated customers at the top of the market, companies will achieve the greatest profitability.
>
> "However, by doing so, companies unwittingly open the door to 'disruptive innovations' at the bottom of the market. An innovation that is disruptive allows a whole new population of consumers at the bottom of a market access to a product or service that was historically only accessible to consumers with a lot of money or a lot of skill.
>
> "Characteristics of disruptive businesses, at least in their initial stages, can include: lower gross margins, smaller target markets, and simpler products and services that may not appear as attractive as existing solutions when compared against traditional performance metrics. Because these lower tiers of the market offer lower gross margins, they are unattractive to other firms moving upward in the market, creating space at the bottom of the market for new disruptive competitors to emerge."[4]

As examples of an innovative or destructive technology Christensen cites the following examples:

Disruptor	**Disruptee**
Personal computers	Mainframe and mini computers
Mini mills	Integrated steel mills
Cellular phones	Fixed line telephony
Discount retailers	Full-service department stores
Retail medical clinics	Traditional doctor's offices

Table 1: Clayton Christensen's examples of a destructive technology

Stuart Hart and Clayton Christensen give this classic definition of the necessary conditions for disruption:

[4] http://www.claytonchristensen.com/key-concepts/#sthash.Cm38d4SR.dpuf

> "The product or service must be one that initially isn't as good as those being used by customers in mainstream markets; as a result it can only take root only in new or less demanding applications among non-traditional customers."[5]

In one sense, this definition perfectly fits with the commercial UAS market. The traditional markets for UAS were defense oriented, and the products are expensive and very demanding. Military-grade UAS are very different from commercial UAS because the missions are very different. Consider the Global Hawk (Northrop Grumman) and the Predator (General Atomics). Both are made to specific guidelines with specific applications. They are made by well-managed defense contractors under pressure to sustain corporate growth rates and enhance overall profits.

Defense applications such as the Global Hawk and the Predator are manufactured to specific military requirements and require high altitudes and sensitive optics. These platforms have little to no usage in the mainstream commercial markets. Commercial UAS aren't designed for defense-oriented missions and would not be able to perform them. Thus, commercial UAS builders are able to incubate their businesses in the safety of markets that resource-rich competitors are motivated to ignore. Large aerospace firms have revenues in the billions. Small commercial UAS will do little to substantially increase these numbers. Generally, we expect large aerospace firms to watch the market and purchase those companies that have larger defense industry uses.

In this research, we examine our assertion that commercial unmanned aircraft systems will have its most disruptive effects in the areas of delivery and logistics. We will demonstrate this in a later section when we show that last-mile delivery costs of small packages are significantly lower than current delivery methods. We consider the lower costs of using UAS for last-mile package delivery a sufficient condition for expanded usage. In mathematics, a sufficient condition must be satisfied for a statement to be true. If this condition cannot be satisfied, the statement is false.[6] In other words, nobody will use commercial UAS for last-mile package delivery if it costs more or the same as current delivery methods. The necessary conditions are regulations and the necessary infrastructure is in place to allow autonomous UAS operations to develop. The necessary conditions will be a function or both government and/or industry partnerships and need to be addressed by Congress. Part of the purpose of this research is to illustrate the economic impact, which we hope will stimulate greater discussion within governmental circles to make autonomous UAS operations happen.[7]

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[5] http://integralleadershipreview.com/5851-coda-18/

[6] http://www.dictionary.com/browse/sufficient-condition

[7] Autonomous operations refer to UAS that will be flown, commanded, and controlled robotically by highly developed software.

In this section, we have developed the concept of a disruptive technology and have shown that its success is contingent on costs being lower than competitive methods. As a limit theorem to the concept of UAS being a disruptive technology, we offer this:

> *UAS disruption is at a maximum when it is totally autonomous and all costs are at a minimum.*

Autonomous operations offer the best opportunity for package delivery potential.

Companies are already developing UAS package delivery products and testing the concepts. For example:

- In March 2017, Amazon's Prime Air UAS delivered sunscreen to the company's invite-only MARS conference in Palm Springs, California. Although the order was prearranged, the delivery itself was fully autonomous.
- In December 2016, Amazon successfully tested package delivery from a warehouse in the United Kingdom with 13 minutes from click to delivery.
- In September 2016, Google and Chipotle tested burrito deliveries at Virginia Tech.
- Zipline has started medical supply delivery in Africa and by the summer of 2017, will commence delivery to Smith Island on the Chesapeake Bay, Maryland.
- Flirtey has begun carrying medical supplies in some parts of the world.
- In February 2017, UPS successfully tested a drone that launched from the top of a UPS package car, operated autonomously to deliver a package to a home, and then returned to the vehicle while the delivery driver continued along the route to make a separate delivery.

Methodology

In this section, we will describe the methodology for two different tasks. First, we will discuss how the forecasts will be performed. Second, we will explain how we derived the cost estimates. The forecast will be divided into two groups: Optimistic and Pessimistic. A third group will be an average of the two forecasts. The optimistic forecast applies the most favorable assumptions. The pessimistic forecast is the opposite and makes assumptions that few, if any, favorable assumptions will happen.

For the optimistic forecast, we use an intuitive method that assumes every package for which UAS delivery is the least cost method will be delivered by UAS. For the pessimistic forecast, we use a method called curve fitting. In this, we examine other disruptive products and use their growth curves as the basis for our forecast. We consider this pessimistic because we were forced to begin with a very small number to make the mathematics work. If we started with a larger number, the growth curve accelerated so fast that the forecast quickly became bigger than the total market size.

For cost estimating, we used a variety of methods: engineering studies, surveys, and educated guesses. For certain figures – insurance, battery life, prop replacement, etc. – we relied on surveying people who are heavy UAS users. This includes members of local user groups who referred us to more than 200 users to find 25 who met the criteria of commercial users. In certain cases, such as command and control and airspace costs, we interviewed users who are developing software to be used in these specific areas. Because ready estimates are non-existent, we made best guesses based on those interviews. In making best guesses, we treated the initial or capital costs as sunk costs and therefore not relevant to the operational cost estimate.[8] The estimate of the capital costs needed to build out the infrastructure is beyond the scope of this paper. However, how these costs are incurred and who pays for them is an interesting policy topic and deserves another paper. We invite comments from those with differing opinions about our cost estimates. As a follow up to this paper, we will do an engineering study of UAS operations, which we will share with the public at no cost.

One thing we have learned from our research is how little information we have to work with.

First, we will discuss the cost estimates because if they are higher than the current methods, package delivery using UAS will never develop.

The Economics of Package Delivery

The idea of speedy delivery services is not new. What is new is the compelling economics that may drive UAS delivery. Commercial UAS operations have lower capital and operating cost than alternative delivery methods. To verify this, consider the capital and operating costs of delivery trucks versus the cost of a UAS. But, as the volume of deliveries increases, the amount of fixed, in-place infrastructure and investment costs will increase. The unit cost of UAS package delivery will be a function of lower overall operating costs and how many deliveries can be made. As the number of deliveries increases, the unit cost will go down.

We offer the following last-mile delivery costs as a benchmark. The last-mile delivery costs for UPS and FedEx were derived from their annual reports (see Footnote 9). The calculations are based on the percentage of ground costs to air costs. As the 10-k's and 10-Q's break these out, we can obtain a ratio of ground to air. In this case, it amounts to approximately (the unweighted

[8] A sunk cost is one that has already been incurred and cannot be recovered. Sunk costs are not used in calculating marginal or operational costs.

average) 68% air and 32% ground (see Tables 2 and 3). For a typical FedEx package that costs $8.50, the ground costs are approximately $2.72. USPS does not report these costs, so the simplifying assumption is made they are similar. Hence, $2.72 becomes the benchmark. If commercial UAS can deliver at a significantly lower last-mile cost, sufficient conditions for commercial UAS last-mile delivery will be met. The operating costs for commercial UAS will be calculated in the next section.

Company	Cost	Type	On Demand
Uber	$6.00 to $10.00	One mile plus	Yes
Lyft	$6.00 to $10.00	One mile plus	Yes
UPS	$2.80		No
USPS	$2.80		No
Fed Ex	$2.80		No
Amazon Prime	$25/hour	One hour delivery	Yes

Table 2: Last-mile delivery costs

	UPS	FedEx
Ground Costs	33%	31%
Air Costs	67%	69%

Table 3: UPS and FedEx ground and air delivery costs

Cost of UAS Package Delivery

As part of our research, we conducted interviews with 25 UAS operators. Their experience and predictions closely correlated with one another to help us form an accurate picture of the commercial UAS landscape. After each initial interview, we conducted a second, more in-depth follow-up interview.

We arrived at the following calculations: The wholesale cost of an individual commercial-grade battery that can power a UAS weighing up to five pounds and for at least 10 miles is $100 when purchased in bulk (the retail price is $200 each). The battery life for each commercial-grade battery is at least 250 hours.

For commercial-grade motors that can produce enough thrust to lift a 10-pound UAS (five-pound platform and five-pound package) and travel for at least 10 miles, the cost for four motors is less than $60 for each one and the motor can be expected to last for approximately 750 hours.

The wholesale cost of a set of four commercial-grade rotors is $1. The hourly operating costs are shown in Tables 4, 5, and 6. In addition, we estimate marginal electricity costs to be approximately $.25 per trip. This may be the most difficult factor to compute because the calculation depends on how much wind and other weather factors affect the battery charge. We define the operations conservatively, using a 50-week year rather than a 52-week and to account for maintenance. The operational assumption is that each trip and recharging takes at least one hour.

Batteries					
Hours Usage per Week	**Weeks per Year**	**Usage Hours per Year**	**Number of Batteries Needed**	**Annual Battery Cost**	**Cost per Trip**
20	50	1000	4	$400	$0.40
30	50	1500	6	$600	$0.40
40	50	2000	8	$800	$0.40
50	50	2500	10	$1,000	$0.40

Table 4: Battery cost per trip

Motors					
Hours Usage per Week	**Weeks per Year**	**Usage Hours per Year**	**Number of Motors Needed**	**Annual Motor Cost**	**Cost per Trip**
20	50	1000	1.33	$80	$0.08
30	50	1500	2.00	$120	$0.08
40	50	2000	2.67	$160	$0.08
50	50	2500	3.33	$200	$0.08

Table 5: Motor cost per trip

Rotors					
Hours Usage per Week	**Weeks per Year**	**Usage Hours per Year**	**Number of Rotors Needed**	**Annual Rotor Cost**	**Cost per Trip**
20	50	1000	10	$10	$0.01
30	50	1500	15	$15	$0.01
40	50	2000	20	$20	$0.01
50	50	2500	25	$25	$0.01

Table 6: Rotor cost per trip

In calculating the air traffic user fees for an individual flight, our thought process is as follows: As the number of daily operations is in the millions, the marginal cost of an individual flight will be small. The first is the capital budget and the second is the operating budget for a high-tech organization. Because there are no benchmarks from which to compare these numbers, an estimate is difficult. However, we could be off by more than 100% and it would only impact the final number by less than 10%. In any case, we consider these approximations to be robust. We invite opposite opinions on this matter.

In addition to these cost estimates, we include system costs such as insurance, command and control operational costs, communication, labor, airspace charges, etc. Each of these is an unknown cost and is estimated to be in the $.01 to $.02 per unit range. These incremental costs may add to our hourly operating cost estimate.

The battery charges are based on a national average electricity cost (unweighted at $.12 per watt). There is the cost of machinery to do these tasks, but we are unable to estimate these costs. The calculations also assume a five-mile trip without mid-trip refueling (see Table 7).

System Item	Cost
Insurance	$0.02
Command and control	$0.02
Communication	$0.02
Labor	$0.02
Maintenance	
Batteries	$0.40
Motors	$0.08
Rotors	$0.01
Electrical	$0.03
Battery recharging	$0.24
Airspace charges	$0.10
Total Hourly Operating Costs	$0.94

Table 7: Total hourly operating costs

We estimate the hourly operating costs to be at least $0.94. Given the high volume of operations expected in the future, our assumption is that as the number of operations increases and infrastructure for these operations is established, the unit cost for each unknown quantity becomes very low. They will have an effect, as all costs do, but the assumption is that they will not materially affect the estimate.

For the electrical costs (computer components), we estimate that the UAS components will last approximately one year (at least 2,500 hours) and are therefore included as a capital cost to be calculated later. We also do not include overhead because it is not an operational cost. Again, we invite comments on this.

To figure the capital cost, we need appraisals of how much large companies like Google, Amazon, and Walmart may be expected to invest in commercial UAS, as well as UAS delivery systems infrastructure, and then add these capital costs to the operational cost. As this type of information is proprietary, we used various price points and annual utilization assumptions.

The numbers are presented in Table 8. It is difficult to know how to depreciate the costs of a commercial UAS because there are no data available. Nor do we have readily available operational data to estimate the lifespan. We depreciate the coasts over one year and in addition add in replacement's costs. We believe this is being very conservative and results in some double accounting. We do this as we are simply unsure about so many different things, and this gives us a cushion. At any rate, we believe we are guilty of overestimating costs rather than underestimating them.

We are working under the following implicit assumptions. First, we assume commercial-grade UAS will fly in all types of weather conditions, with the inherent wear-and-tear it will have on each unit and its parts. We have included allowances for everything except the platform. Our working assumption is that it will require significant replacement at least once per year because of weather conditions and wear-and-tear. In essence, we expect operators will replace all components at least once each year. Therefore, we depreciate the entire platform over a one-year time frame. We look forward to more data points on this front as the commercial UAS industry develops.

Capital Cost	20 hours per week	30 hours per week	40 hours per week	50 hours per week
$1,000	$1.00	$0.67	$0.50	$0.40
$2,000	$2.00	$1.33	$1.00	$0.80
$3,000	$3.00	$2.00	$1.50	$1.20
$4,000	$4.00	$2.67	$2.00	$1.60
$5,000	$5.00	$3.33	$2.50	$2.00

Table 8: Operational capital costs

We have available two benchmarks. The first is the $2.72 we calculated earlier in this report and the second is Amazon's purported cost of last-mile delivery with USPS at $2.50.[9] In other words, for UAS to be an economic alternative to the USPS, the fully allocated cost must be lower than $2.50. As these two estimates are correlated, we will use $2.50 to be more conservative. With this as a benchmark, and using our assumptions above, we can speculate that the purchase price for a commercial UAS must be less than $3,000 (see Table 9). The economic feasible regions are highlighted in red.

UAS purchase price	20 hours per week	30 hours per week	40 hours per week	50 hours per week
$1,000	$1.94	$1.61	$1.44	$1.34
$2,000	$2.94	$2.27	$1.94	$1.74
$3,000	$3.94	$2.94	$2.44	$2.14

[9] https://www.bloomberg.com/news/articles/2015-07-30/it-s-amazon-s-world-the-usps-just-delivers-in-it

$4,000	$4.94	$3.61	$2.94	$2.54
$5,000	$5.94	$4.27	$3.44	$2.94

Table 9: Fully allocated unit cost of package delivery

The numbers in Table 9 represent our best estimates on the fully allocated cost of a single commercial UAS package delivery, assuming various different purchase prices, operating costs, and weekly hourly usage. In other words, if a large online retailer were to consider using commercial UAS delivery to a customer's home and that retailer paid $2,000 for each platform and the UAS could fly at least 50 hourly flights each week, the fully allocated cost is $1.74 per trip. If the retailer normally pays at least $2.50 per last-mile trip using other delivery methods, it saves $0.76 per delivery and has more control over its distribution channel because it has not outsourced delivery to a company like UPS or FedEx. For a company that sells millions of products online daily, the economics are hard to ignore – which is why companies like Walmart and Amazon are at the forefront of this effort. In terms of one-hour delivery options, given the higher cost of delivering a product in the $8 to $10 range, the economic benefits are even greater given the alternatives.[10]

UAS is expected to be a cheaper way to deliver small packages even when the delivery is not time sensitive. UAS delivery costs don't really change when the delivery is time sensitive, except perhaps the equipment utilization might go down slightly. Ground delivery cost, however, are much higher for time sensitive deliveries. UAS will have a competitive advantage for routine, non-time sensitive deliveries and an even bigger competitive advantage for time-sensitive deliveries.

Now consider the boundary conditions of our estimates. The only information we have is based on average costs, so basing forecasts on average cost differentials is a reasonable approach. However, there are some limits to an approach that doesn't consider the distribution of costs that underlies the averages. We'll address those limitations in the methodology and forecast discussions.

Our ground cost delivery estimate is $2.50 to 2.80. That may well be the average cost of the last-mile delivery for FedEx and perhaps it's also a good estimate for USPS as well. However, within that average is a distribution of actual costs that varies based on the characteristics of the specific delivery. For a high-rise apartment where a driver may be able to deliver many packages to many recipients with a single stop, the per-package delivery cost is lower (possibly much lower). Conversely, when FedEx or UPS delivers a package to the wilderness of Montana, the per-package delivery cost is much higher.

[10] https://newsroom.uber.com/us-new-jersey/introducing-uberrusha-reliable-ride-for-your-deliveries/. This can also be estimated using FedEx and UPS annual reports. The cost numbers are divided out between ground and air and the ratio of the two is 1/3 ground costs and 2/3 air costs. The cost of last-mile delivery is between $2 and $2.50.

The person in Montana isn't charged a higher delivery rate any more than the urban apartment dweller gets charged a lower rate. Both FedEx and UPS apparently have decided that the gains from charging everyone the same delivery cost are greater than any gains from charging differentiated costs based on the attributes of the destination. And it's not just the attributes of the destination that vary. If the FedEx or UPS delivery happens to be on a day where there are many other deliveries in the area, then their cost per delivery is less than if a delivery is on a day when there are few other deliveries in the area. It isn't just one hour delivery and same day delivery, UAS can be cheaper for other options as well. Next day delivery is a third market.

What does this mean for our estimates? The important point is that even if the average UAS delivery cost is less than the average FedEx or average UPS delivery cost, it may not be a cheaper option for every delivery. Rather, it will be cheaper for some and more expensive for others. Deliveries to high-rise urban apartments may be cheaper for ground trucks than for UAS, even if the mechanics of delivery to such apartments by UAS were solved. By the same token, some of the high-cost ground deliveries, such as to a remote home in Montana, may also be cheaper by ground truck – the distances may well exceed the capabilities of a UAS. Perhaps there are variations on this theme combining both delivery trucks and UAS. UAS costs per delivery may also vary with the specific characteristics of the individual delivery. For deliveries made by FedEx and UPS, only a portion of them can be made at lower cost by UAS. If we knew the distributions of costs for FedEx, UPS, and UAS, we could estimate the portion of truck-based ground deliveries that is vulnerable to UAS delivery. Of course, we don't have that data, so we don't know how many deliveries could be cheaper using UAS. This does damper our optimistic forecast; the number is still very large and requires a different UTM system.

While the average is an unbiased estimator of where the industry is headed, the standard deviation of this average will tell us what various different business models may develop, which in itself presents an interesting follow-up paper.

Commercial UAS Package Delivery Forecast

In this section, we will look at the future of package delivery using UAS. Of all of the possible future UAS uses, the most popular may be delivery because the economics are more favorable than other options.

The growth of commercial UAS package delivery will be dependent on the following:

1. The ability to economically serve three delivery markets:
    a. One-hour delivery
    b. Same-day delivery

c. Next day delivery

2. Proven operational reliability

3. Needed infrastructure in place

4. A business plan to fund the infrastructure and its daily operations

5. Fully autonomous operations, meaning the ability to be fully operated robotically

6. A supportive regulatory environment

We consider the above components and conditions to be vital to the success of the UAS package delivery business. We will discuss them in forthcoming discussion papers. The sufficient conditions are the favorable last-mile economics.

Scenario Analysis

In the following section, we analyze several possible scenarios in which all small packages will be delivered by commercial UAS. There are many different ways to forecast future demand for commercial application of UAS (Table 10).

Year	2020	2025	2030	2035	2040
Conversion (100%)	241	242	242	243	244
Conversion (85%)	205	206	206	207	207
Conversion (70%)	169	169	170	170	171
Conversion (50%)	121	121	121	122	122

Table 10: Package delivery via UAS under different conversion rates (in millions)

Optimistic Forecast

Our optimistic forecast is that most small packages eventually will be delivered by commercial UAS (100% conversion). There are a number of ways to calculate how many products are sold online each day. The first is to simply refer to the sites that track Amazon sales. The calculations are very simple – take the number of sales per second and multiply by the number of seconds per day and the number of days per year. Most sources estimate Amazon accounts for approximately one-third of all online sales.[11] The final step is to extrapolate Amazon's one-third to the total. Another method is to rely on online sites that estimate the total number of sales.[12] There is a very high correlation between the two. If we take the lower number (100 million) to be conservative, we have our beginning point.

More than 100 million products are sold online every day. Of these, 86% to 91% (totaling at least 86 million packages) weigh less than five pounds and can be economically delivered via UAS for 50% of the existing delivery expenses.[13] Based on this simple analysis, we believe future UAS package deliveries will number in the millions each day.

Even if only 1% to 2% of the packages sold online are delivered by UAS, the operations will dwarf the volume of flights handled by the existing Air Traffic Management system (ATM). Currently, there are more than 100,000 daily flight operations in the United States; about 40,000 commercial airline flights per day and about 60,000 general aviation flights each day. Compare this to the 86 million packages per day that we project will eventually be delivered via UAS (see Figure 1).[14] Because the volume of package delivery UAS flights will be orders of magnitude greater than for manned aircraft and because UAS flights will use airspace much different (lower altitude and not close to airports for example) than that used by commercial airline and general aviation manned aircraft, the UAS ATM system will likely be separate from, but coordinated with the ATM system for manned aircraft. The principal airspace overlap between UAS and manned aircraft which will require coordination will be the operations of medical and police helicopters.

Pessimistic Forecast

In this section, we use the fundamental axiom that UAS is a disruptive technology to make the forecast. Disruptive products all exhibit what is known as "logistic growth." This means they

[11] http://www.businessinsider.com/amazon-holiday-facts-2012-12; http://www.theverge.com/2013/12/26/5245008/amazon-sees-prime-spike-in-2013-holiday-season; http://www.inc.com/tom-popomaronis/amazon-just-eclipsed-records-selling-over-600-items-per-second.html

[12] https://founderu.selz.com/40-online-shopping-ecommerce-statistics-know/. This can also be calculated by taking Amazon's online sales and using their market share to get the final number. This information is disclosed in Amazon's annual reports, which are available publically and online. https://www.sec.gov/Archives/edgar/data/1018724/000101872416000172/amzn-20151231x10k.htm

[13] We used various sources for this number. We refer the reader to annual reports from FedEx, UPS, and Amazon. It is interesting that these numbers are so highly correlated. The numbers in this forecast report are taken from Jeff Bezos' *60 Minutes* TV interview: https://www.sec.gov/Archives/edgar/data/1090727/000109072716000053/ups-12312015x10k.htm.

[14] These numbers can be tracked at https://www.faa.gov/air_traffic/. These numbers range by season from a low of 26,000 commercial flights per day to the high of 40,000 commercial flights. The point is these numbers are small compared to what may happen with UAS.

begin to grow slowly, pick up speed, and then ultimately level off. Figure 1 illustrates this concept using data from the growth of Facebook.

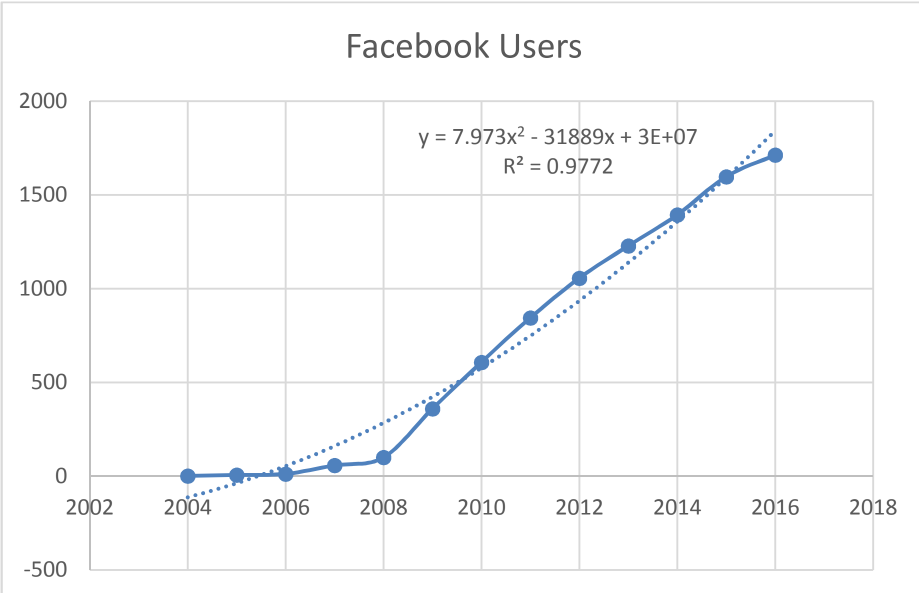


Figure 1: Facebook growth rates

The cell phone and later the smartphone changed life for people all over the world. The U.S. growth rates are shown in Figures 2, 3 and 4.

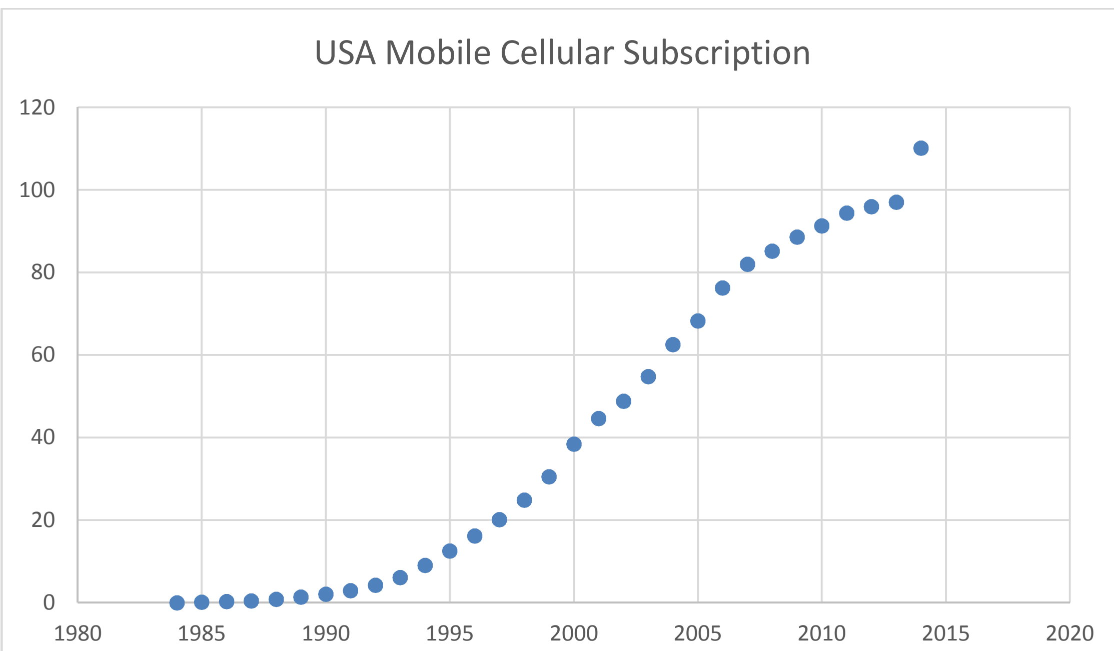


Figure 2: Cellular phone growth

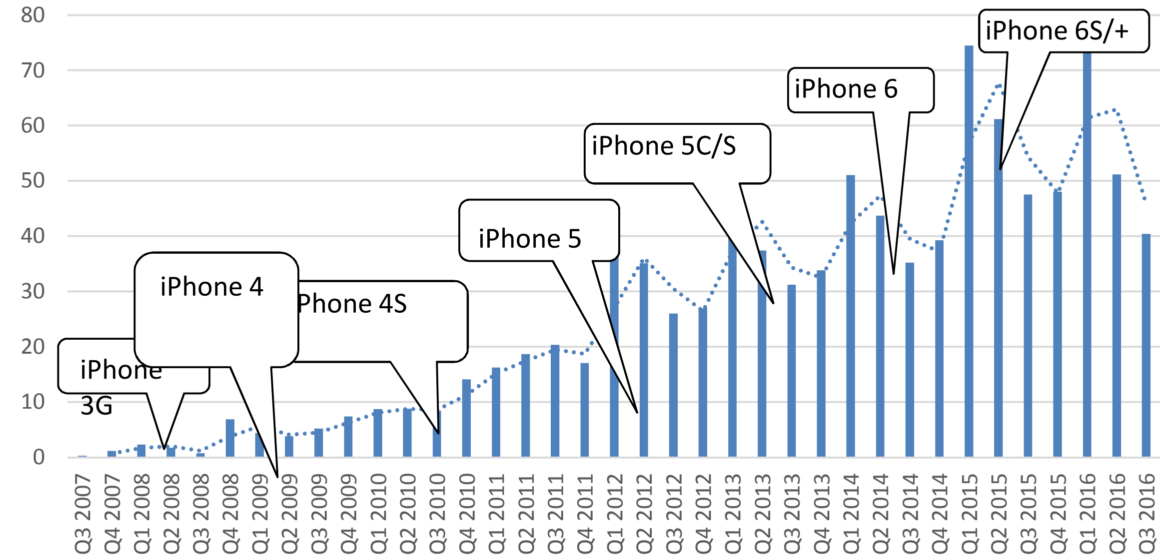


Figure 3: iPhone sales (in millions)

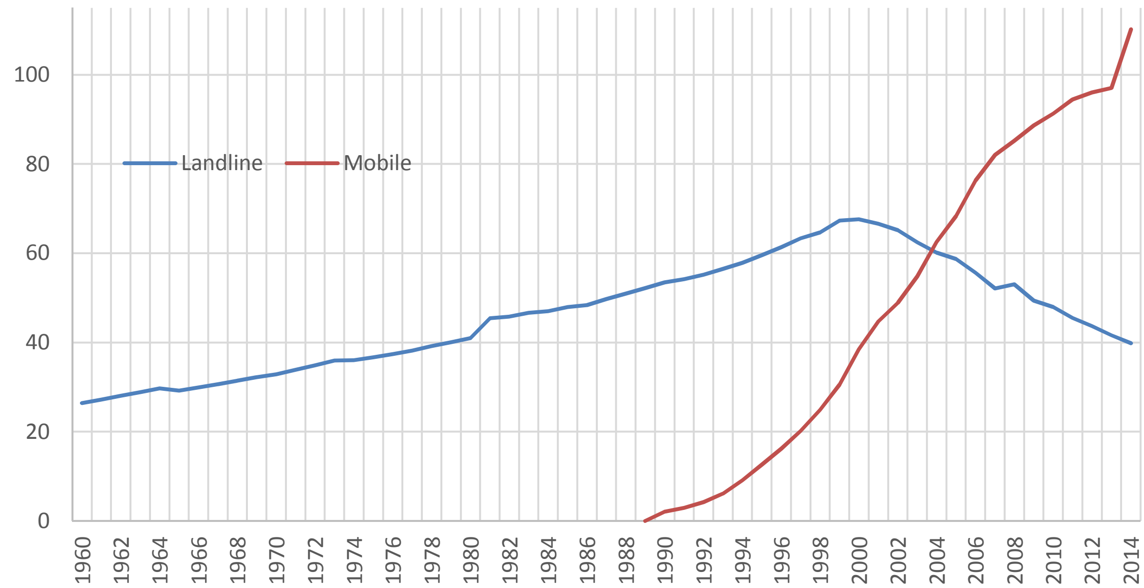


Figure 4: Subscriptions of land and cellular lines per one million people

If UAS is a disruptive technology, it will exhibit similar growth patterns. Using a conservative forecast, we begin our analysis with 10,000 operations per day as the starting point. Using very small initial starting parameters, growth starts out slowly, and then grows rapidly. The outside constraints are warehouse facilities with the ability to deliver using UAS in government-regulated airspace. We chose 10,000 operations as the base number because when numbers larger than 10,000 were used, the growth was rapid and quickly exceeded the predicted total number of package deliveries. This is why we consider this forecast highly constrained (Figure 5).

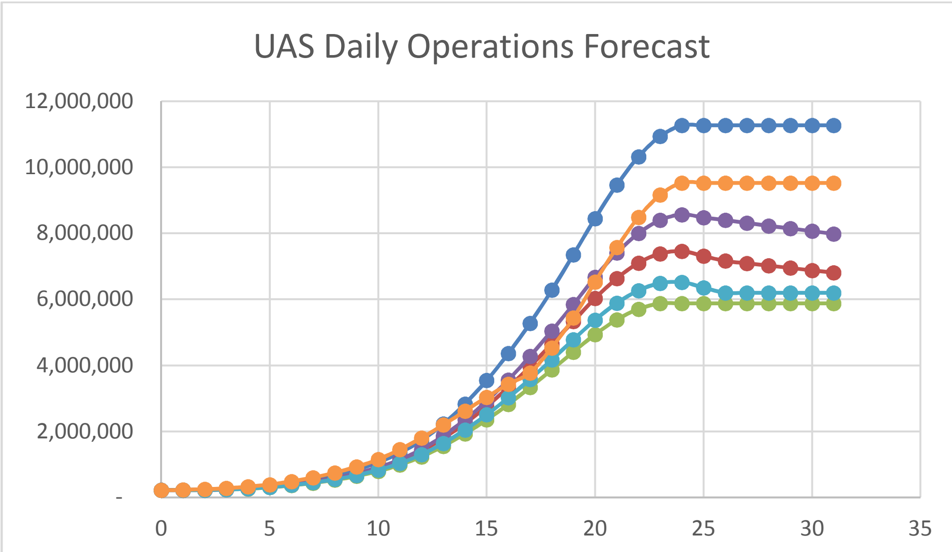


Figure 5: UAS forecast under highly constrained conditions

In Figure 5, the blue line represents UAS package delivery growth if it follows the same pattern as Facebook. The orange line represents the UAS growth curve if it mimics the growth of iPhones; the purple line shows how fast UAS will grow if it follows the growth rate of computers. The red line how fast UAS package delivery could grow when the growth rate is compared to electric cars. The aqua line follows the growth of cellular phones, and the green line shows the growth rate of the internet.[15]

[15] The growth numbers were taken from a presentation by Professor Bijan Vasigh at Embry-Riddle University.

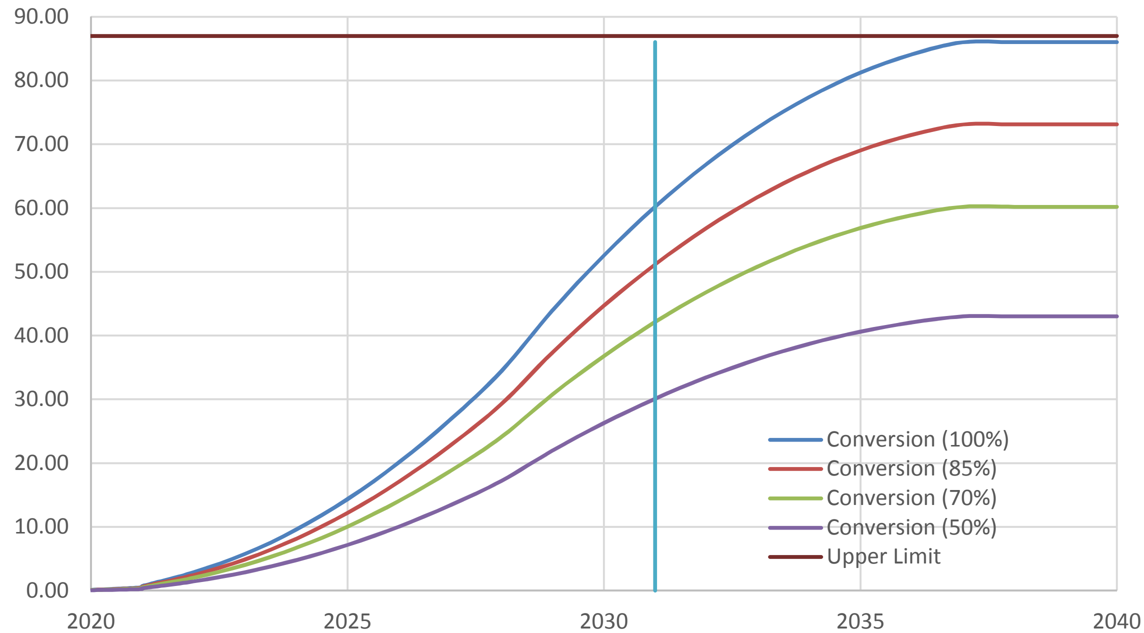


Figure 6: Projected package delivery via UAS (in millions)

It is anticipated that the growth rate for the initial years of UAS delivery will severely under-estimate the actual performance, and the intermediate years will be correct at some point much earlier in the actual forecast range. The forecast in Figure 6 is based entirely on case studies that project that UAS will grow at rates similar to other disruptive products. Even though we show years in the above figure, we have no estimate of when deliveries will begin because a number of government regulatory factors must occur before autonomous UAS deliveries can take place in the National Airspace System.

If we take the midpoint of our various simulations, the pessimistic forecast is 8 million daily operations. If we use the midpoint of the feasible solutions in Table 9 ($1.94) and compare this to the conservative benchmark ($2.50), we see an annual savings to logistics companies from a pessimistic range of (8,000,000 *0.56 *360) or $1,612,800,000 to nearly $2 billion a year for our midpoint estimate of (50,000,000*0.56* 360) or $10,080,000,000 (Figure 7).

This is the compelling economics that will drive the conversion to commercial UAS.

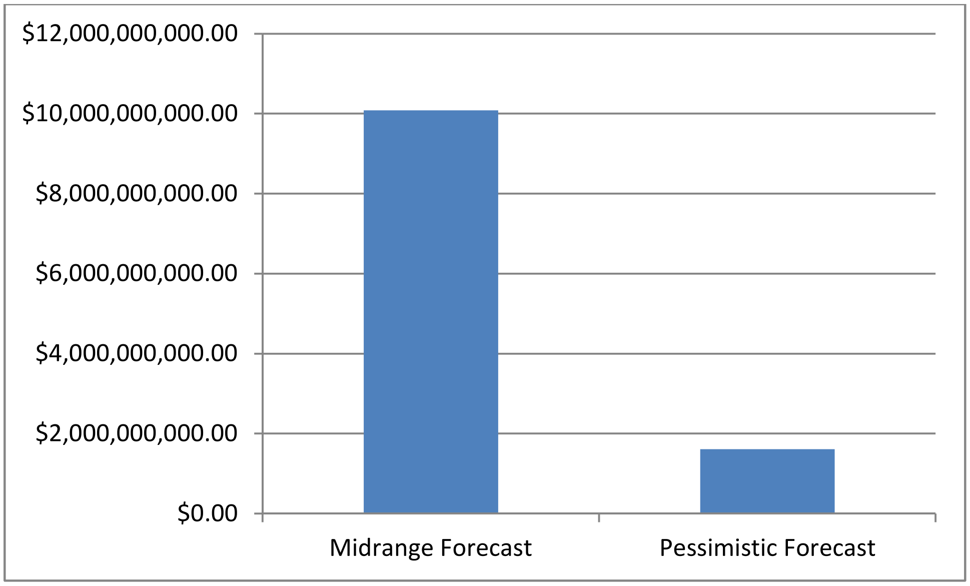


Figure 7: Economic benefits to logistics companies

The Conditions under Which the Forecasts Will Be Wrong

In this section, we perform a number of exploratory analyses. These are not meant to be conclusive, but rather suggestive. In addition, these point out areas where data do and do not exist. If nothing else, this section sets up an interesting future research agenda.

There have been a number of critics of UAS package delivery. Generally, the concerns are:

1. Weather will affect operations
2. Apartments, condos and high rises will affect operations
3. Safety concerns with commercial airlines
4. Counties will tax flights

Because some critics argue these potential problems will materially affect the ability to perform package delivery, we will examine each one to consider what impact they may have. To better understand each concern and their impact, we will present a case study using operational and other data collected at Salt Lake City International Airport (SLC). All of the data in this case were obtained from Masflight.[16]

[16] http://www.geemedia.com/products/operations-solutions/masflight

SLC: Airspace and weather analysis

The airspace surrounding an airport is a constraint on UAC package delivery. In this section, we examine the areas within the B Airspace at Salt Lake City International Airport (SLC).[17] The airport is bounded on the east and the west by mountains and to the north by lakes, giving it only two approaches. This is one of the reasons why we chose SLC – it simplifies the analysis. At the same time, a reasonable person may criticize this as an outlier. We use this as an example for illustrative purposes only. This is simply the first in a series of much-needed analytics and shows the data are readily available and can be collected for any city. Detractors may prefer to conduct their own analyses of other cities. Within the next couple of months, we will look at the top 35 markets and make this analysis publically available at no charge.

In doing this analysis, we used weather data in 10-minute increments over a three-year period ending in 2016. During the same period, we tracked each take-off and landing below 500 feet above ground level (AGL). Figure 8 shows the tracks of the take-offs and landings and their flight paths beneath the 500 feet AGL threshold.

[17] See Appendices B and C for definition of airspace terms.

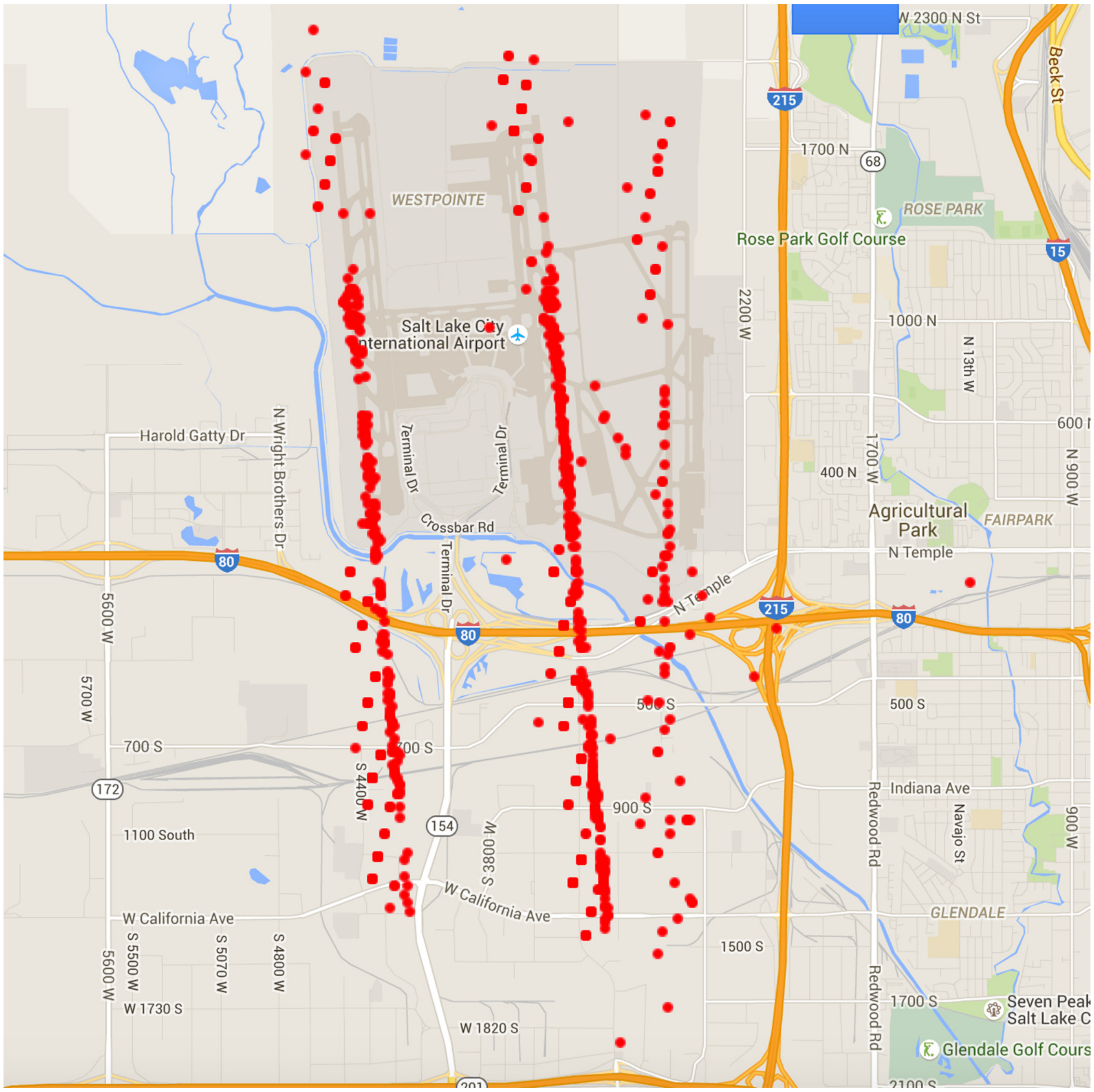


Figure 8: Commercial and general aviation flight paths below 500 feet AGL at SLC (2013 to 2016).

The left and center runways are for commercial flights and the right runway is for General Aviation. There is no housing or business to the immediate north, so we can concentrate exclusively on the south, thus simplifying the analysis. The plurality of flights are above 1820 South. Furthermore, the flights are bounded between 5600 West on the left side of the flight path and I-215 on the right side. There are no structures north of I-80 (except for the airport itself), so these areas can be easily calculated. The distance from I-215 to 5600 West is 4.0 miles and from I-80 to Route 201 (the southern most visible boundary) is 3.0 miles giving us 12 square miles.

These 12 square miles define the area where commercial UAS will be in conflict with commercial or general aviation aircraft in the entire Salt Lake Valley. This area cover zip code 84104 and has approximately 7,174 households and 1694 businesses. The only aircraft that may come in close contact with commercial UAS outside these boundaries are helicopters, which is a legitimate concern. Concerns about hobbyist UAS and commercial aircraft are another matter and outside our area of research. From this preliminary analysis, we suggest the following:

1. The number of households that lie in the direct path of landings and take-offs while the planes are below 500 feet AGL is arguably small with regard to the population of the area.

2. The number of affected houses is so small it will not materially affect the forecast.

3. The number of businesses that lie in the direct path of landings and take-offs while the planes are below 500 feet AGL is arguably small with regard to the population of the area.

4. The number of the affected businesses is so small it will not materially affect the forecast.

SLC Case Study: Impacted Airspace

If we look at the impacted area, it is obvious that this is a rounding-off error in relation to the SLC airspace. For those who wish to calculate the percentage of the Class B airspace impacted, it is a simple calculation. Think of Class B airspace as the summation of the volume of three cylinders. The cubic volume of each of these can be calculated using the formula:

Cubic volume of a cylinder = $\pi R^2 * H$

Where:

π= 3.1415926
R = radius of the cylinder
H = height of the cylinder

The cubic airspace of the airspace below 500 feet can also be approximately calculated:

Cubic airspace = (L X W X H)/2

Where:

L = length
W = width
H = height

The result is the airspace occupied by commercial and general aviation aircraft flying into and out of SLC. This airspace occupies very little of the Class B airspace and the probability of a commercial UAS colliding with another aircraft is even less because the airspaces are separated. The need for large buffer areas for commercial UAS around airports is a tad excessive and not justified by flight operations data. Making a determination of where UAS can fly based solely on airspace definitions, when the UTM will provide separation is not a legitimate safety or economic argument.

What is needed is a better understanding of the exact areas where commercial and general aviation flights may be impacted, as well as how intersecting runways and multiple approaches and landings impact the analysis. The question at hand regards an understanding of the airspace and maintaining proper safety separation.

This analysis tells us that the area impacted by commercial operations need not be a deterrent to package delivery. This area is small and concerns can be handled with procedures. Even if these airspaces were off limits to aircraft, the size of the package delivery market is not significantly impacted and the scale is unchanged.

SLC Case Study: Weather Conditions

We also examined the weather in detail, which revealed the following:

1. Over a three-year interval, there were only 27 ten-minute intervals when the wind speed was higher than 30 miles per hour.

2. There were a total of approximately 138 days when the wind speed was between 15 and 30 miles per hour.

3. Approximately 70% of the time when the wind was blowing, the wind speed was no more than 15 miles per hour.

4. Thunderstorms occurred a total of 4.6 days over the approximately 1100-day time period.

5. Over the entire time period, irregular operations accounted for 0.06% of the time.

6. We did not consider snow conditions because there is no data on how UAS operate in snow.

We do know that batteries do not perform at peak efficiency under extreme conditions, and a thorough knowledge of this subject is essential to perform regularly scheduled operations.

We wish to emphasize the following points: While citing airspace and weather as criticisms against UAS package delivery, all of these questions can be answered using data. Data to answer these questions are readily available and will positively help the UAS industry move forward. We suggest the following:

1. Weather will undoubtedly affect UAS package delivery operations. However, we believe this impact will be minimal. There may be certain areas with regular severe weather (Alaska, the Badlands, etc.), where this disruption will be greater.

2. The need to analyze weather patterns over longer periods is important for planning for future UAS operations.

3. UAS delivery will take place over a 24-hour time period, so disruptions will be short.

4. Further analysis on all major markets is needed.

5. Operating standards are needed to help identify the conditions under which irregular operations begin and end.

6. More information is needed on how weather affects battery performance. For example, UAS flights could be delayed or canceled because of wind, rain, snow, ice storms, fog, extreme cold, and other factors. Wind could exceed the performance capabilities of some UAS vehicles, snow and ice accumulation could increase its weight and decrease performance. Fog could interfere with visibility and guidance depending on the guidance technology used. Cold could impede battery performance.

Until we have better standards regarding UAS delivery and weather, it is difficult to make concrete judgments. The first steps in a research program are to determine the UAS operational boundaries.

Apartments

Some have argued that it is not practical to use UAS to deliver packages to apartments. There may be some validity with high rises in metropolitan areas like Manhattan and downtown Chicago (Table 11).[18]

City	Total New High-Rise Building Completed (2000-13)	Rank	Total High-Rise Buildings (as of 2013)	Rank
New York	281	1	2,151	1
Chicago	149	2	701	2

[18] http://www.urbanophile.com/2013/08/20/trends-in-american-high-rise-construction-by-david-holmes/

Miami	74	3	130	7
Atlanta	50	T4	134	6
Las Vegas	50	T4	96	11
Houston	38	6	174	3
San Diego	35	7	67	15
Seattle	30	8	100	10
Dallas	22	T9	116	9
San Francisco	22	T9	149	4
Boston	21	11	89	12
Arlington	17	12	47	19
Portland	14	T13	41	T21
Austin	14	T13	27	T32
Los Angeles	13	15	127	8
Philadelphia	12	T16	135	5
Charlotte	12	T16	31	29
Tampa	11	T18	28	T30
Denver	11	T18	69	14
Orlando	11	T18	27	T32
Milwaukee	10	21	40	23
Minneapolis	9	22	76	13
Baltimore	8	23	51	18
Phoenix	7	T24	34	T26
San Jose	7	T24	10	T50
High-rise = 18 stories or greater. Totals are as of June 2013.				

Table 11: Top 25 U.S. cities for high-rise building construction, 2000-13

Table 12 gives an estimate of the number of people living in apartments and condos (includes high rises).[19]

Type of Household	Households	% of U.S. Total	Residents	% of U.S. Total
Renter-occupied	43,701,738	37%	111,118,927	35%
Owner-occupied	74,506,512	63%	202,228,998	65%
Total	**118,208,250**	**100%**	**313,347,925**	**100%**

Table 12: Percentage of Americans living in apartments

Table 13 details age demographics of apartment and condo dwellers in the United States.[20]

Age Distribution	Renter-Occupied Households	Share	Owner-Occupied Households	Share
Under 30 Years Old	9,540,382	21.90%	2,900,285	3.89%
30 to 44 Years Old	14,575,260	33.45%	15,906,092	21.31%
45 to 64 Years Old	13,105,191	30.08%	33,180,350	44.46%
65 Years and Older	6,349,513	14.57%	22,651,140	30.35%
Total	**43,570,344**	**100.00%**	**74,637,864**	**100%**

Table 13: Age demographics of apartment dwellers

Approximately 35% of the U.S. population lives in apartments and condos. It is possible to subtract those in high rises by looking at population density in census records. For example, we know Manhattan has 400,000 to 500,000 people per square mile. The point is these questions

[19] NMHC tabulations of 2015 American Community Survey. Updated 10/2016. http://www.nmhc.org/Content.aspx?id=4708

[20] NMHC tabulations of 2015 American Community Survey. Updated 10/2016. http://www.nmhc.org/Content.aspx?id=4708

can be answered by looking at the data. This one requires more analysis and is beyond the scope of this paper.

Technical problems regarding package delivery are minimal. The issue is always economics. The size of the market may be affected by the number of high-rise apartments. We do not currently have data to answer this question, but the answer revolves around the issue of delivery trucks being able to deliver 100 packages at one time to a high-rise. This is an issue of convenience for the delivery company and may cast the most important vote on how deliveries are made. Deliveries of less than one hour are another issue. In addition, as was stated earlier, while the average cost of UAS delivery may be below the benchmark, the standard deviation may prove that package delivery is more efficient with trucks in densely populated areas.

We are raising more questions than we are answering currently, but hopefully, we are turning the discussion towards a data-based decision.

In this analysis, we may need to rethink what an address is (your cell phone is an address), where people can take delivery, and what time of day a customer wants to accept delivery. High rises may pose UAS package delivery problems, but those difficulties may turn out to be minimal. Hence, where a person lives may change the size of the forecast, but not the scale.

County and/or State Taxes

Every level of government, everywhere in the world always has its hand outstretched looking for more ways to collect and spend money. (Many of these subjects are legal, and therefore outside our area of expertise). In terms of the economics, the value-added proposition will be small. Neither the platform nor the delivered package will have high-dollar value. This is not like hotel and car rentals, where the dollar amounts run in the hundreds; the values are much smaller. Any charges will not justify higher than normal sales and/or gasoline tax. While end users will not want to pay these, it is doubtful this will ruin the economics of the situation. The most this can affect the cost structure is by 10% (10 cents). This amount is not enough to change the overall economics. At any rate, the lobbying that takes place around these issues will be entertaining.

Other Factors that Can Affect the Forecast

There are a number of other issues that may affect the forecasts. These include:

1. Lack of economic growth
2. Liability issues

3. Lack of regulations

4. Inability to build the needed infrastructure

5. A change in tastes due to an accident

6. Privacy and security concerns

7. Exogenous events

In this short examination, we have analyzed some of the questions regarding package delivery. We see nothing to affect the overall scale. For apartment delivery, we will need to analyze the demographics of the online buyer and make comparisons, which is outside the scope of this paper.

Technical and Regulatory Requirements

There are a number of essential technical and regulatory steps that need to be put in place before truly disruptive, autonomous beyond visual line of sight UAS package delivery can occur. Following are some of these needs.

Technical Needs

- Development of a UAS Traffic Management System (UTM) to manage the expected surge in UAS flights
- Established standards that govern the development and operation of UAS to ensure safety, efficiency, and effectiveness of operations
- Development and adoption of sense-and-avoid technologies to ensure platforms have active sensors for detecting other aircraft within their airspace
- Development of command and control centers to launch and retrieve the UAS
- Skilled labor to manufacture increasingly complex commercial UAS and service this growing sector

Regulatory Needs

The FAA’s current Part 107 regulations for package delivery permit the transportation of property for compensation or hire, provided the operator complies with all the provisions of the rule, including that the operator must keep the UAS within visual line of sight (and not from a moving vehicle); external loads must be securely attached and cannot adversely affect the flight characteristics or controllability of the aircraft; cannot be operated at night; cannot be operated over people; and the aircraft with payload must weigh less than 55 pounds at take-off.

For the UAS package delivery market to develop and thrive, the following changes will be required:

- Regulations to allow for beyond visual line of sight operations
- Regulations to allow for night operations
- Regulations to allow for flights over people
- Funding support to implement and enforce regulations, as well as build necessary infrastructure for UTM

Conclusions

In this paper, we state a fundamental axiom that commercial UAS will be a huge disruptor to the logistics industry. Our forecast ranges from a low of 8 million daily operations to a midpoint range of 50 million daily operations. This dwarfs anything currently being managed in the airspace. Even if the most pessimistic forecast is adopted, it is still a very large number. The only situation where any of these forecasts can be shown to be incorrect would be a function of no economic benefits, which is an argument we reject.

This conclusion is based on the fact that the economics of last-mile delivery are so compelling that existing companies will have no choice but to adopt this technology in order to survive and that new markets will be opened. Pizzas, milk, Slurpees, and just about any item that consumers want in a short time will be delivered via UAS.

What type of a system can be scaled to handle this much traffic? Who will manage it? What is the trade-off between automation and human interaction? Who will finance this system? What are the consequences for delivery trucks that currently do last-mile delivery? So many questions remain unanswered. They will be addressed in future opinion reports.

The quandary with moving to autonomous operations is that the commercial industry's current intellectual capital has been investing into the initial stage of visual line of sight operations. This is an unfortunate, but necessary evil. The potential economic benefits of this nascent industry are larger than anything we originally envisioned when the first UAV NAS integration study was done for AUVSI. This dwarfs anything else on the economic growth list. The financial needs are large – billions of dollars will be needed for software development to handle this amount of traffic.

Those of us who work in this business are fortunate to live in a time when such technology exists that will create this economic giant. Business, engineering, and finance need to come together to plot this growth and ensure a proper regulatory environment exists to safely handle the projected traffic. New regulatory formulas, relying on science and engineering, rather than outdated codifications of ancient technology need to be put in place. Engineers and scientists are needed. Regulations based on data must be the new norm.

Appendix A: Bios

Clinton V. Oster, Jr. is Professor Emeritus and former Associate Dean for Bloomington Programs at the School of Public and Environmental Affairs, Indiana University. His research has centered on aviation safety, airline economics and competition policy, air traffic management, energy policy, and environmental and natural resource policy. He has co-authored numerous articles and five books on various aspects of air transportation. He has chaired and served on numerous National Academy of Sciences study committees. He has served as president of the Transportation Research Forum, Research Director of the President's Aviation Safety Commission and on Gubernatorial Transition Teams for two Indiana governors. He has served as a consultant to the U.S. Department of Transportation, the Federal Aviation Administration, the National Aeronautics and Space Administration and as an expert witness for the U.S. Department of Justice. He also works as a safety inspector and accident investigator for Indycar. He holds a bachelor's degree in engineering from Princeton University, master's degree in public affairs from Carnegie-Mellon University, and Ph.D. in economics from Harvard University.

Dr. Vasigh is professor of Economics and Finance in the College of Business at Embry-Riddle Aeronautical University, Daytona Beach Florida. He has focused his research, teaching, and consulting on the theory, modeling, and application of financial instruments in transport finance. He is the author of North America's leading aviation textbooks entitled, *An Introduction to Air Transport Economics*: From Theory to Application, *Foundation of Airline Finance*: Methodology and Practices, and *Aircraft Finance*: Strategies for Managing Capital Costs in a Turbulent Industry. He has been listed as a Highly Cited faculty in aviation finance and he continues to be regularly invited to present and share his subject matter expertise at national and international symposia.

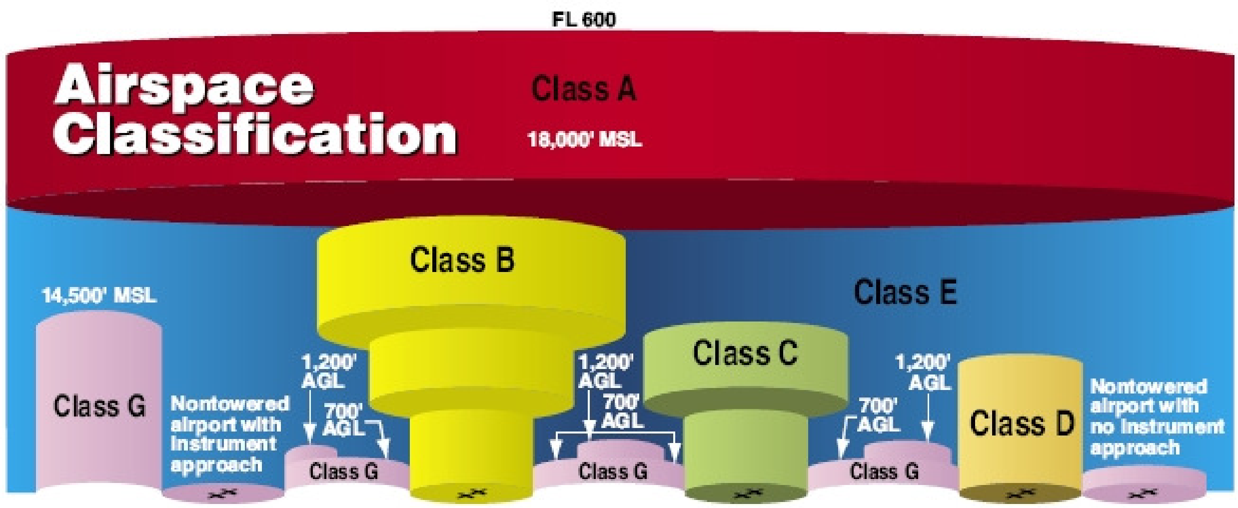
Bijan's work has led to formal collaboration with multiple domestic government agencies and foreign governments such as the International Civil Aviation Organization (ICAO), the International Air Transport Association (IATA), and NASA on a grant on "Determination of Statewide Economic Benefits of the Small Aircraft Transportation System (SATS)".

He has been interviewed and quoted by national and international news media such as The Washington Post, Wall Street Journal, NBC News, USA Today, Forbes, National Public Radio (NPR) Marketplace, Voice of Russia, El Pais (Spain), Rzeczpospolita (Poland), Trinidad Express, Cuba News, and The Guardian (United Kingdom), Bloomberg Business, among others.

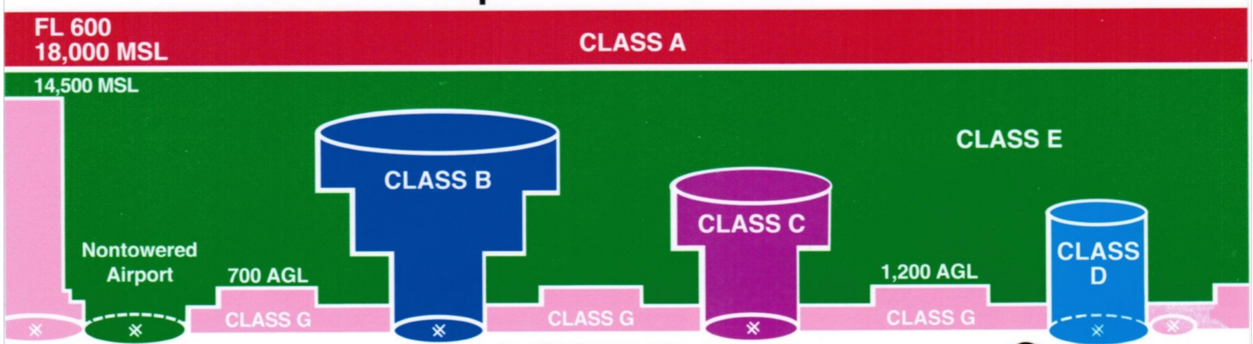
Dr. Tullinda Larsen

Dr. Tulinda Larsen is CEO and Founder of Skylark Drone Research, a Women Owned Enterprise. Skylark Drone Research specializes in applying economic principles and modeling to understanding the drone market. Economic analysis provides insight into how markets operate, and offers methods for attempting to predict future market behavior in response to events, trends, and cycles. Dr. Larsen is a private pilot, President (2016) of the International Aviation Club, past-President (2001) of the Aero Club of Washington DC, member Board of Directors, Royal Aeronautical Society, member International Aviation Womens Association, member Women in Commercial Drones, Member AUVSI, Member RTCA and served as Chairman, Regional Aviation Subcommittee, Transportation Research Board, National Academies 1995-2007. She holds a BA and MA in Economics from the George Washington University and her doctorate in Management from University of Maryland UC.

Appendix B: Airspace Diagram



U.S. Airspace Classes at a Glance



AGL - above ground level
FL - flight level
MSL - mean sea level

14 CFR Part 91.155

www.FAASafety.gov
Your Aviation Safety Web Site

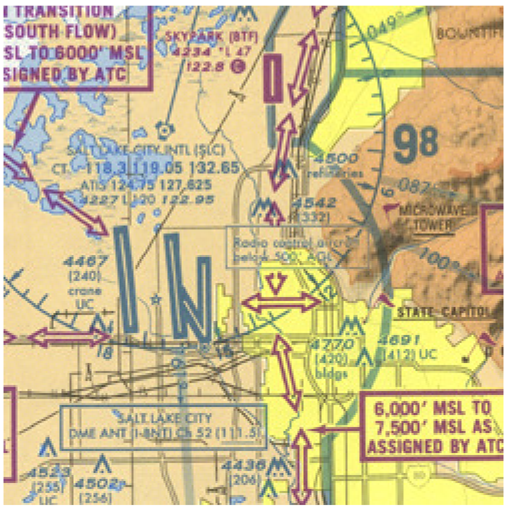
U.S. Department of Transportation
Federal Aviation Administration

Airspace Class	Entry Requirement	Pilot Certificate or Rating	Two-Way Communication	Altitude Decoding Transponder	VFR Min. Visibility Below 10,000 MSL	VFR Min. Visibility 10,000 MSL and Above	VFR Cloud Clearance Below 10,000 MSL	VFR Cloud Clearance 10,000 MSL and Above
A	ATC Clearance	Instrument	Yes	Yes	N/A	N/A	N/A	N/A
B	ATC Clearance	Private Certificate or student with endorsement	Yes	Yes within 30 nm of the class B primary airport[1]	3 miles	3 miles	Clear of Clouds	Clear of Clouds
C	VFR: Radio Contact IFR: Clearance	Student Certificate	Yes	Yes within C space and above lateral limits of C space[1]	3 miles	3 miles	500 below 1,000 above 2,000 horizontal	500 below 1,000 above 2,000 horizontal
D	VFR: Radio Contact IFR: Clearance	Student Certificate	Yes	No unless required by other airspace	3 miles	3 miles	500 below 1,000 above 2,000 horizontal	500 below 1,000 above 2,000 horizontal
E	VFR: None IFR: Clearance	Student Certificate	IFR only	No unless required by other airspace	3 miles	5 miles	500 below 1,000 above 2,000 horizontal	1,000 below 1,000 above 1 mile horizontal
G	None	Student Certificate	No	No unless required by other airspace	Day: 1 mile Night: 3 miles	5 miles[2]	500 below 1,000 above 2,000 horizontal [2]	1,000 below 1,000 above 1 mile horizontal [2]

[1] An altitude decoding transponder is required above 10,000 MSL.
[2] When flying 1,200 AGL or below: DAY: 1 mile visibility clear of clouds; NIGHT: 3 miles visibility, 500 below, 1,000 above, 2,000 horizontal.

02/11

Appendix C: SLC Class B Airspace [21]



For an expandable version of this map go to the footnote below.

[21] https://www.faa.gov/air_traffic/flight_info/aeronav/productcatalog/vfrcharts/terminalarea/