An Introduction to The Economics of Flying Beyond Visual Line of Sight (BVLOS)

Darryl C. Jenkins

Drone Economics, LLC.

Author Note

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Correspondence concerning this article should be addressed to: Darryl Jenkins at airjenkins@aol.com

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Abstract

This paper explores the necessary conditions for Beyond Visual Line of Sight (BVLOS) drone operations and the concept of a single pilot controlling multiple drones simultaneously. These two factors are crucial for many segments of the commercial drone industry to achieve profitability and long-term sustainability. While the paper introduces these factors, it also acknowledges that the sufficient conditions are entirely dependent on regulatory frameworks. However, the rapid advancement of technology in this industry makes the realization of the discussed concepts highly probable.

For BVLOS operations to become profitable, several factors must align. The paper delves into these factors, highlighting the evolving role of pilots over the next decade. Although there will still be a pilot in command, their responsibilities will undergo a drastic transformation. The economics of BVLOS revolve around cost reduction and revenue maximization. Rather than training more pilots, the key to success lies in leveraging sophisticated software that minimizes the need for human intervention.

Drones have already begun to revolutionize industries by enabling closer, more cost-effective, and automated aerial inspection and data collection. However, most current commercial and public safety drone applications are limited to flying within the visual line of sight (VLOS) of the pilot or ground observers. This constraint significantly hinders the full economic potential of drone services. The paper presents and defends the fundamental axiom that the economics of commercial drones begins with BVLOS operations. Furthermore, it introduces and discusses nine essential laws governing the economics of commercial drone BVLOS operations.

Key words: BVLOS, economies of scale and scope, One to N flying, fundamental economic laws

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Introduction

Expanding drones into routine BVLOS operations promises immense economic upside across major industries. Technological innovations now allow specially equipped drones paired with advanced software to fly more autonomously over far longer ranges. Missions can span hundreds of miles collecting imagery, sensor data, and carrying cargo across restricted, hazardous, or previously inaccessible terrain. The economics of delivering these solutions scales favorably.

As regulators continue opening airspace access and infrastructure for managing BVLOS improves, entirely new drone use cases become financially viable. Vast linear infrastructure like pipelines, railroads, power lines and bridges snake thousands of miles but have been enormously expensive to inspect thoroughly until now. Current VLOS operations within these market segments are not sufficient to scale and significantly reduce costs. Remote area delivery services, enhanced border security and police operations, detailed land management mapping efforts, and sophisticated commercial data analytics stacks will finally take off economically speaking through advanced BVLOS activities.

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Realizing this full potential depends on the drone industry maturing to meet escalating BVLOS operational demands at affordable pricing. Pilots need upgraded training and credentials for spatial orientation. Command and control systems must evolve for managing extensive fleets efficiently across broad stretches of sky. Sensors, battery technology, weatherized airframes and night operation capabilities require enhancement as well.

The economics clearly suggest the upside for increasingly autonomous drones traversing hundreds of miles in unfettered flight is monumental. As regulations and maturing technology lower barriers, expect BVLOS drone adoption to achieve escape velocity growth. The following section explores the financial factors and use cases driving this expansion in detail. While the FAA is doing more with waivers, the industry is still a long way from profitability, and more is needed. As wide scale BVLOS operations are currently unavailable, this paper is future looking.

Disruptive Technology

Disruptive technologies are innovations that significantly alter the way industries or markets operate, often by displacing established market leaders and transforming the way people live and work. These technologies typically start off as inferior to existing solutions in terms of performance or features, but they offer unique benefits such as simplicity, convenience, or lower costs. As disruptive technologies mature and gain market share, they can have a profound impact on the cost structures of industries and the prices paid by consumers.

One of the key characteristics of disruptive technologies is their ability to drive down costs over time. Initially, these technologies may be more expensive than established solutions due to the research and development costs associated with bringing them to market. However, as adoption increases and economies of scale come into play, the costs of production and implementation tend to decrease significantly. This cost reduction can be attributed to factors such as improved manufacturing processes, increased competition, and the spread of knowledge and best practices.

As costs fall, disruptive technologies become more accessible to a wider range of users, further accelerating their adoption and impact. This phenomenon can create a virtuous cycle, where increased demand leads to even greater cost reductions, making the technology even more attractive to potential adopters. Over time, the cost advantages of disruptive technologies can become so significant that they completely reshape the economic landscape of industries, forcing established players to adapt or risk being left behind.

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Economies of Scale and Scope

This section discusses the economic concepts of scale and scope and are vital to understanding all the concepts in the chapter. In assessing the financial viability underpinning specialized commercial drone business models, two pivotal intertwined economic concepts stand paramount influencing potential sustainability – economies of scale and economies of scope. Together these correlated forces describe how per-unit costs behave as production volume and operational breadth expand, with immense implications determining ultimate profitability prospects separating successful ventures from unsuccessful participants across this intricate emerging industry.

Economies of scale refer specifically to the economic advantages where per-unit production costs for a firm decline as total output grows larger thanks to that enlarged scale. This reflects efficiencies around fixed initial research, platform development and infrastructure investments getting spread across greater numbers of saleable units - driving down breakeven pricing. Basically, aggregated volume production allows amortizing upfront fixed expenses over more items – meaning firms that can scale up market share save money through expansion dividends impossible for smaller firms lacking equivalent output volumes over which to distribute incurred costs (see Figure 1).

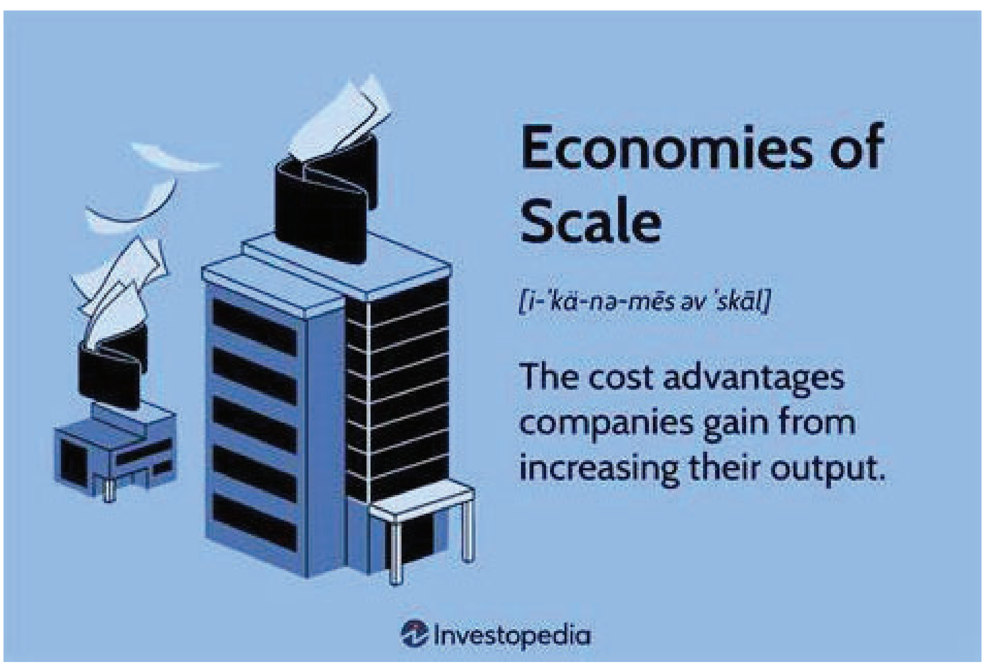

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Figure 1: Economies of Scale [1]

A drone manufacturer able to sell 1,000 units of a specialized camera payload for example can distribute associated non-recurring engineering, certification, factory calibration, and production start-up expenses across those 1,000 payloads - enabling competitive market pricing and profits unworkable selling just 10 payloads which lack volume scale sufficient to recoup those fixed costs. Service companies enjoy parallel benefits leveraging fleets, analytics software, and insurance over large numbers of mission hours. Scale drives lower nominal costs.

While closely related, economies of scope distinctly describe economic advantages where a company produces/offers a wider range of related products or services thereby lowering individual item costs through operational synergies. This means cost efficiencies materialize from "scope" diversification itself as increased breadth allows leveraging common components, expertise, supply chains and platforms across an array of applications – essentially cross-subsidizing through resource fungibility where focused specialty firms lack flexibility spreading investments broadly (see Figure 2).

Figure 2:Economies of Scope[2]

For drone service operators this proves equally crucial as specialized aircraft, sensors, data links and other hardware can get redeployed on diverse customer missions from agriculture to energy to public safety once acquired - defraying individual application costs impossible for niche suppliers concentrating on targeted singular industries alone. Scope synergies multiply portfolio value.

In both scale and scope contexts, commercial drone economics prove uniquely sensitive to expansion factors driving down or raising per-item/per-hour costs because specialized vertical equipment, inspection expertise, and advanced flight logistics prohibit casual commoditization. Only operators leveraging scale production volumes or scope application synergies sustain

[1] Economies of Scale Types - Search Images (bing.com)
[2] Economies of Scope Example - Search Images (bing.com)

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against competition absent those flexibility advantages innate to fragmentation. In financial projections analysts must consider implications from potential fleet scaling and transferrable reusability determining ultimate competitiveness. Gearing up output volume or operational breadth offers sustainability - staying small invites revenue erosion absent serious differentiation.

Fundamental Axiom and the Laws of Drone BVLOS Economics

The fundamental axiom of drone economics states drone economics on a large scale, begins with BVLOS operations. We believe this axiom applies in general, but not specific terms.

The Fundamental Axion of BVLOS Drone Economics:

Drone Economics begins with BVLOS.

From an economist's perspective, the drone industry begins with the advent of Beyond Visual Line of Sight (BVLOS) operations. While Visual Line of Sight (VLOS) drones have proven useful for a variety of applications, such as aerial photography and short-range inspections, they are inherently limited in terms of their range, autonomy, and scalability. In contrast, BVLOS drones, which can operate independently over long distances without direct human supervision, offer the potential for significant economies of scale and scope that can transform the economics of the drone industry and unlock a wide range of new use cases and business models.

Several factors contribute to the economies of scale in BVLOS drone operations. First, the ability to operate drones over longer distances and for extended periods allows operators to serve a larger geographic area and customer base with a single drone, reducing the need for multiple drones and operators. Second, the increased autonomy of BVLOS drones enables them to execute missions with minimal human intervention, reducing labor costs and increasing operational efficiency. Finally, the standardization and automation of BVLOS drone operations allow for more consistent and predictable mission outcomes, reducing the risk of errors and increasing the overall reliability of drone services.

The economies of scale achievable through BVLOS operations have the potential to fundamentally reshape the drone industry and its role in the broader economy. By reducing the cost of drone services and expanding their reach and capabilities, BVLOS operations can open new markets and applications that were previously uneconomical or impractical. This could include large-scale

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infrastructure inspections, long-range cargo delivery, precision agriculture, and remote sensing for environmental monitoring and resource management.

Moreover, the economic benefits of BVLOS drone operations extend beyond the direct cost savings and revenue opportunities for drone operators. The widespread adoption of BVLOS drones has the potential to drive significant productivity gains and cost efficiencies across a wide range of industries, from transportation and logistics to construction and energy. By providing faster, cheaper, and more flexible solutions for data collection, asset monitoring, and service delivery, BVLOS drones can help businesses optimize their operations, reduce their costs, and improve their competitiveness.

From an economist's perspective, the drone industry begins with the advent of BVLOS operations, which offer the potential for significant economies of scale that can transform the economics of the drone industry and unlock a wide range of new use cases and business models. By reducing costs, expanding capabilities, and driving productivity gains across multiple sectors, BVLOS drones have the potential to become a major catalyst for economic growth and innovation in the years ahead.

There are at least nine fundamental economic drivers underpinning the viability and growth of BVLOS drone operations. These include:

1. Drones designed for Beyond Visual Line of Sight (BVLOS) operations will be significantly more expensive than traditional Visual Line of Sight (VLOS) quadcopters.
2. The role of AI software will take on increasing importance.
3. The core value of BVLOS drones derives from enhanced data capture (imagery, sensor data) and logistics (transport, delivery) efficiency.
4. For BVLOS drone operations focused on non-logistics use cases, the greatest value lies not directly in the aerial data capture itself, but rather the sophisticated analysis and insights extracted from the torrents of imagery, topological and other sensor data accumulated across expansive flights.
5. The key value proposition is the post-processing algorithms and analytical techniques applied to rich drone-gathered datasets that ultimately enable superior decision-making, risk detection and predictive modeling across industries from agriculture to insurance.
6. Certain market opportunities are only financially viable given the expanded operational radii enabled by BVLOS. Delivery, surveying, security, and agricultural use cases rely on beyond line-of-sight ranges making otherwise unprofitable jobs feasible.
7. Shifting one pilot from operating a single drone to coordinating many drones reduces per-unit labor costs while enabling each pilot to generate higher total revenue.
8. Increased altitude expands visible range significantly, enabling wider area data capture and reduced need for imaging overlap. This drives higher resolution insights paired against operational costs and hardware capabilities.
9. As flight scales change so do business models and the end customer. BVLOS markets dynamics changes substantially.

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BVLOS Economic Law #1: Drones designed for Beyond Visual Line of Sight (BVLOS) operations will be significantly more expensive than traditional Visual Line of Sight (VLOS) quadcopters.

We start out with this as it is so important. To justify their higher cost, BVLOS drones must be built with more robust and durable components, enabling them to withstand the rigors of extended missions and harsher environmental conditions. Furthermore, to achieve economic viability, these drones should be designed with a longer lifespan in mind, allowing their initial costs to be amortized over a period of seven to ten years, which is considerably longer than the typical lifespan of consumer-grade VLOS quadcopters.

One of the issues with VLOS, is there are no operational economies of scale. No matter how often a task is performed, it must be short lived due to battery constraints. Because of this, costs remain constant over time and destroys the disruptive nature of the service. While there are many VLOS markets, and these will have their own life, many will also be lost to BVLOS due to economies of scale.

A hardened drone is one with significant redundancy and a platform made to withstand various weather conditions. BVLOS drones represent a significant advancement in drone technology, enabling longer-range missions and more autonomous operations. However, these capabilities come at a higher cost compared to traditional Visual Line of Sight (VLOS) drones, such as consumer-grade quadcopters. The increased costs associated with BVLOS drones can be attributed to several factors, including more advanced sensors and onboard processing systems, ruggedized designs to withstand harsh environmental conditions, and the need for reliable long-range communication links.

Given the substantial upfront costs of BVLOS drones, it is essential to consider their economic viability over an extended period. To justify the investment, these drones must be designed and built to last, with a target lifespan of seven to ten years. This longevity allows the initial acquisition costs to be amortized over a more extended period, making the investment more financially feasible for organizations and businesses seeking to leverage the benefits of BVLOS operations.

To achieve this longer lifespan, BVLOS drones must be engineered with durability and maintainability in mind. This involves using high-quality, robust components that can withstand the wear and tear of regular use, as well as designing the drones in a manner that facilitates easy maintenance and repairs. Additionally, the software and firmware of these drones should be updatable and adaptable to keep pace with evolving technologies and changing mission requirements over their extended service life.

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In addition to the drones themselves, a robust command and control center is crucial for the successful operation of BVLOS drones over their extended lifespan. The command-and-control center serves as the central hub for monitoring, managing, and directing the drones during their missions. It must be equipped with reliable, high-bandwidth communication systems to maintain constant contact with the drones, as well as advanced software for flight planning, real-time data processing, and decision support. The command-and-control center should also be designed with redundancy and failsafe measures in mind to ensure continuity of operations even in the face of technical issues or external disruptions. Investing in a well-designed, durable command and control center is essential for maximizing the long-term economic benefits of BVLOS drone operations.

By building BVLOS drones with a target lifespan of at least seven to ten years, manufacturers and operators can help ensure that the upfront costs are effectively amortized over time. This approach not only makes the adoption of BVLOS drones more financially attractive but also encourages the development of more sustainable and long-lasting drone solutions. As the use of BVLOS drones continues to expand across various industries, from agriculture and infrastructure inspection to public safety and logistics, the importance of designing these drones for long-term economic viability will only continue to grow (see Figure 3).

Initial Cost	**Depreciation in Years**	**Annual Cost**
$250,000	3	$83.333
$250,000	4	$62,500
$250,000	5	$50,000
$250,000	6	$41,667
$250,000	7	$35,714
$250,000	8	$31,250
$250,000	9	$27,778
$250,000	10	$25,000
$250,000	11	$22,727
$250,000	12	$20,833

Figure 3: Annual Cost of Capital Expenditures

One of the key strategies for reducing the unit costs of Beyond Visual Line of Sight (BVLOS) drone operations is to maximize the utilization rate of the drone fleet. A high utilization rate refers to the proportion of time that a drone is actively engaged in revenue-generating missions, as opposed to being idle or undergoing maintenance. By ensuring that BVLOS drones are consistently deployed on a high volume of missions, operators can spread the fixed costs of drone ownership, such as capital expenditure and overhead, across a larger number of flight hours, thereby reducing the cost per mission.

There are several ways in which BVLOS drone operators can achieve a high utilization rate. One approach is to focus on serving a diverse range of customers and applications, rather than relying on a single use case or industry vertical. By diversifying their customer base, operators can minimize the impact of seasonal or cyclical fluctuations in demand and maintain a more consistent stream of missions throughout the year. This can involve actively seeking out new market opportunities, developing customized solutions for different industries, and building a flexible and adaptable drone fleet that can accommodate a wide range of mission requirements.

Another strategy for increasing utilization is to optimize the scheduling and routing of BVLOS drone missions. By carefully planning and coordinating the deployment of drones, operators can minimize downtime and ensure that each drone is efficiently utilized. This may involve the use of advanced scheduling software and algorithms that can dynamically assign missions to available drones based on factors such as location, battery life, and maintenance status. By streamlining the mission planning and execution process, operators can reduce the time and cost associated with each flight and maximize the number of missions completed by each drone.

In addition to optimizing the utilization of individual drones, BVLOS operators can also achieve cost efficiencies by leveraging economies of scale. As the size of the drone fleet grows, operators can spread fixed costs such as infrastructure, software development, and training across a larger number of units. This can lead to lower unit costs and improved profitability, particularly for operators that can achieve a high level of standardization and automation across their fleet.

However, it is important to note that achieving a high utilization rate for BVLOS drones also requires significant investments in infrastructure, maintenance, and support services. Drones must be regularly inspected, serviced, and updated to ensure optimal performance and reliability, and operators must have access to a robust network of charging stations, maintenance facilities, and spare parts. The costs associated with these support services can be substantial, and operators must carefully balance the benefits of increased utilization against the ongoing expenses of fleet management.

Achieving a high utilization rate is a key strategy for reducing the unit costs of BVLOS drone operations. By maximizing the proportion of time that drones are actively engaged in revenue-generating missions, operators can spread fixed costs across a larger number of flight hours and improve their overall profitability. This requires a focus on diversifying customer bases, optimizing mission scheduling and routing, and leveraging economies of scale. However, operators must also carefully balance the pursuit of high utilization with the need for robust maintenance, support services, and compliance with safety and regulatory requirements. By striking the right balance and continuously optimizing their operations, BVLOS drone operators can unlock significant cost efficiencies and drive the widespread adoption of this transformative technology (see Figure 4).

Annual Cost	Annual Hours Flown	Hourly Cost
$25,000	350	$71.43
$25,000	450	$55.56
$25,000	550	$45.45
$25,000	650	$38.46
$25,000	750	$33.33
$25,000	850	$29.41
$25,000	960	$26.32
$25,000	1050	$23.81
$25,000	1150	$21.74

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$25,000	1250	$20.00

Figure 4: Hourly Unit Costs

BVLOS Economic Law #2: The role of AI software will take on increasing importance and will ultimately be more important than the platform.

The platform is merely a delivery mechanism. The platform is only partially a function of where the value is created. The role of artificial intelligence (AI) software in (BVLOS) drone operations is becoming increasingly critical, and its significance is expected to surpass that of the drone platform itself soon. As BVLOS missions become more complex and autonomous, the AI software responsible for guiding the drones, processing data, and making decisions will play a central role in determining the success and efficiency of these operations.

One of the key reasons for the growing importance of AI software in BVLOS drones is the need for real-time decision-making in dynamic environments. During BVLOS missions, drones must be able to navigate autonomously, adapt to changing weather conditions, avoid obstacles, and respond to unexpected situations without human intervention. Advanced AI algorithms, such as machine learning and computer vision, enable drones to process vast amounts of sensor data, identify patterns, and make split-second decisions to ensure safe and effective operation.

Moreover, AI software plays a crucial role in enabling BVLOS drones to perform complex tasks and gather valuable insights. For example, in precision agriculture, AI algorithms can analyze high-resolution imagery captured by drones to identify crop health issues, optimize irrigation and fertilization strategies, and predict yields. In infrastructure inspection, AI software can automatically detect and classify defects, such as cracks or corrosion, in bridges, pipelines, or wind turbines, saving time and reducing the risk of human error.

As the capabilities of AI software continue to advance, it is expected to become the primary differentiator in BVLOS drone solutions. While the physical drone platform remains important for ensuring reliable and durable operation, the AI software will be the key driver of mission performance, data quality, and overall value generation. This shift towards software-centric solutions will likely lead to a greater emphasis on developing and refining AI algorithms specifically tailored for BVLOS drone applications.

The growing importance of AI software in BVLOS drones also presents new challenges and considerations. Ensuring the reliability, security, and transparency of AI algorithms will be critical to building trust and acceptance among regulators, operators, and the public. Developers will need to prioritize robust testing and validation processes to ensure that the AI software can handle a wide range of scenarios and edge cases, while also being resilient to potential adversarial attacks or data manipulation attempts.

Furthermore, the increasing reliance on AI software in BVLOS drones will require a new set of skills and expertise within the drone industry. Operators and maintenance personnel will need to be trained not only in the physical aspects of drone systems but also in understanding and troubleshooting AI software components. This will likely drive demand for interdisciplinary talent, combining knowledge of aeronautics, robotics, computer science, and data analysis.

The role of AI software in BVLOS drone operations is poised to become more important than the drone platform itself. As BVLOS missions become more autonomous and data-driven, the performance and capabilities of the AI software will largely determine the overall effectiveness and value of these solutions. While this shift presents new challenges and requirements, it also opens up exciting opportunities for innovation and growth in the drone industry. By prioritizing the development and integration of cutting-edge AI software, BVLOS drone manufacturers and operators can position themselves at the forefront of this transformative technology trend.

BVLOS Economic Law #3: Value Creation

The drone industry is entering a transformative era propelled by advancements across two frontiers - enhanced aerial imagery through better pixel capabilities and the ability to rapidly deliver products to consumers' doorsteps. Drones today are equipped with high-resolution cameras and sensors that can capture strikingly detailed visual data from the skies, analyzing everything from crop health to the progression of construction projects through sophisticated pixels. However, the practical use cases of drones extend beyond just data gathering. Advanced logistics functionalities like longer flight times, heavier payload capacities, and integrated mapping/GPS systems now allow drones to facilitate timely last-mile delivery operations. Whether it's a retail giant like Walmart transporting a new pair of shoes or a medical warehouse delivering urgently needed pharmaceuticals, drones integrated with inventory and logistics networks promise delivery speeds and efficiencies hitherto unheard of without dependence on roads. While pixels have dramatically expanded the reconnaissance and analytical abilities of drones, rapid logistics promises to unleash their disruptive potential in sectors relying on the movement of goods. With both facets maturing in tandem, drones are transitioning from visual tools to becoming integral components of automated, aerial delivery infrastructure.

BVLOS drones has unleashed promising new value creation opportunities across various industries. Underpinning this potential is the ability of BVLOS technology to enormously expand data capture and logistics capabilities compared to existing methods. From agriculture to insurance to commerce, drones promise leaps in informational and operational efficiency even as technological and regulatory vehicles for their capabilities are refined. The key to realize is that while drones themselves represent a fascinating new technology, the true value comes from their role as enabling platforms. Specifically, these remote piloted and autonomous aircraft vastly expand the timely accessibility of hard-to-reach locations for data gathering or delivery activities. By offering a means to access places people or ground vehicles cannot reach, they provide a window into minimizing uncertainty and expanding operational reach in fields ranging from crop health analysis to search and rescue to transport. The value is not necessarily in the drones themselves, but in the otherwise unavailable vantages and connections they facilitate.

On the information side, this means massively expanding both the volume and geographical spread of image and sensor datasets firms can leverage to minimize uncertainty. For example,

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insurers and underwriters are exploring how small but expansive BVLOS drone fleets might enable faster, higher resolution assessments of disaster-stricken properties remotely. Not only could this speed claims processing for clients by weeks, it also cuts claims processor labor costs. What one analyst could slowly examine on foot now gains multipliers in speed and scope thanks to airborne eyes, with only the cost and safety assurance of a drone operator at the helm. This better mitigates financial uncertainties for insurers while improving disaster responsiveness for policyholders (see Figure 5).

Figure 5: Drone inspecting a car accident[3]

Similarly, industries like mining, construction and agriculture lean on drone observation for functions from site engineering planning to crop pest identification. As drone cameras cover more ground at higher resolutions than inspectors traversing sites manually, both topographical and nanoscopic insights of sites are enhanced. This adds value through planning efficiencies, but also improved yields as threats to output are caught and contained earlier based on automated drone sweeps not possible previously. In vast field crop applications, where complete manual inspection is implausible, this enables entirely new preventative measures enhancing harvest reliability and abundance. Expanding pilots' visual range and frequency of these operations amplifies advantages.

On the logistical side, BVLOS introduces entirely new transportation connectivity options benefitting both commerce and society. Delivering everything from life-saving medical supplies to consumer packages in hard-to-reach locales enables markets otherwise lacking accessibility. Just as cell phones introduced communications where landline infrastructure could never connect profitably, drones now fill operational gaps. Last mile delivery needs from urban areas to rural

[3] drones inspecting a car accident - Search Images (bing.com)

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communities can gain flexibility from air routes ranging beyond roadways mired in traffic. This expands firms' addressable market reach while offering faster fulfilment demanded by time-conscious shoppers. Even public entities benefit, with medical drone delivery promises for enhanced rural access to defibrillators, vaccines, or prescription refills at lifesaving speed.

While public concerns around factors like privacy, safety and nuisance shall persist around proliferating high-flying drone highways, the expansive latent demand for their services speaks to their value creative potential. Realizing this potential relies on steady advancement within still nascent drone technologies themselves and the air traffic coordination frameworks needed to enable enterprise-scale BVLOS adoption. Battery life constraints, durability limitations, software reliability and appropriate automation enabling reduction or elimination of constant pilot oversight during extended beyond line-of-sight journeys all pose surmountable but nontrivial scaling challenges in coming years. Yet as solutions emerge, so shall confidence in embracing drones among both private and public sector leaders needed to unleash their dormant economic contributions waiting overhead.

BVLOS Economic Law #4: Data capture at unprecedented scales

BVLOS drone operations are unlocking new possibilities across many industries by enabling aerial data capture at unprecedented scales. However, for non-logistics use cases, the true value lies less in the raw data collection itself and more in the sophisticated analysis and insights that can be extracted from the rich sensory inputs accumulated on these expansive flights.

In sectors like agriculture, infrastructure inspection, mining, and environmental monitoring, BVLOS drones equipped with high-resolution cameras, thermal sensors, hyperspectral imagers, LiDAR scanners, and other payload instruments can scan very large areas - hundreds or thousands of acres - in a single flight. This allows the rapid aggregation of immense datasets consisting of high-density photographic images, intricate topological maps, multispectral readings, heat signatures, and more. But without analytical techniques to process and translate this torrent of information into actionable intelligence, much of the utility is squandered (See Figure 6).

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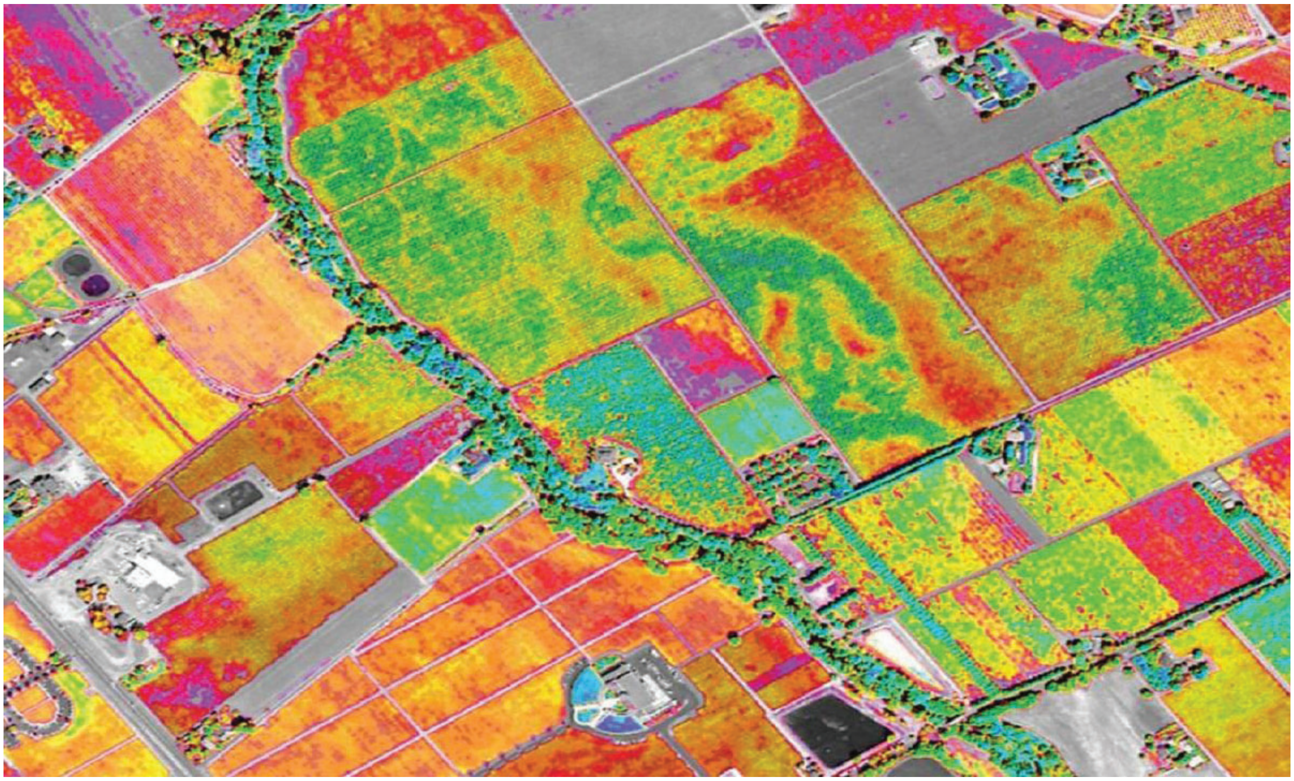

Figure 6: Hyperspectral image of a field[4]

For example, in precision agriculture, drones equipped with multispectral and hyperspectral sensors and AI-powered analytics engines can survey huindreds of farms in a single flight, analyzing vegetation health across vast acreages far faster than scouting on foot. However, for growers to respond to insights from the broad-scale aerial crop analysis and make data-driven decisions, the torrent of spectral readings and photographic imagery must first be turned into key agricultural metrics. Automated machine learning pipelines can extract plant health visualizations, yield prediction maps, variability zones, and targeted prescriptions for fertilizer, irrigation, and pesticides tailored to each individual farm. This enables rapid translation of the rich aerial inputs into actionable insights customized across the dozens of growers in the flight path.

Similarly, in solar farm inspection, BVLOS drones equipped with thermal and hyperspectral payloads can scan rows of solar panels over hundreds of acres in a single flight - but the true value emerges after analytics engines process the data to detect subtle heat signatures indicative of faulty panels and panels with abnormal efficiency issues difficult to spot through visual inspection alone. By overlaying these insights onto the GPS-tagged topological maps of the facilities, operators can rapidly pinpoint and fix problems at scale. And when monitoring critical infrastructure like pipelines, drones conduct extensive multi-sensor scans above expansive areas far more rapidly than ground patrols, augmenting static CCTV networks. Here, the key is leveraging algorithms to analyze long video segments from drone flights to automatically detect subtle anomalies - things like construction activity encroaching on rights of way, inconsistent

[4] hyperspectral iamge of a corn field - Search Images (bing.com)

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vegetation growth indicating a leak, suspicious vehicular activity, and other threats that might otherwise slip through the cracks. This enables operators to selectively review only the most concerning events versus sifting through days of tedious footage (See Figure 7).

Figure 7: Drones Inspecting Solar Panels[5]

Unlocking such use cases requires an analytics system robust enough to handle rapid streams of heterogenous sensory inputs from large-scale BVLOS missions and isolate the true signals from an immense sea of noise. Combining computer vision, edge processing, modern cloud infrastructure, and purpose-built AI/ML algorithms tailored to each industry's challenges, these insights engines automate the conversion of torrential sensor data into intelligent observations that drive real-world decisions and workflows. And over time, as rich pools of analytical metadata accumulate from hundreds of flights over farms, solar facilities, pipelines, and other sites, new opportunities emerge to find deeper connections through historical comparative analyses, predictive modeling based on identified trends, and continuously tuned machine learning algorithms. Farmers can better predict optimal harvest dates based on crop development patterns mapped over seasons. Pipeline operators can reduce false alarms by distinguishing usual vegetation factors from suspicious encroachment. Solar managers can make capital investment decisions optimized to actual - not presumed - degradation rates across different equipment.

Unencumbered by the practical flight range and endurance limits inherent to small VLOS drone operations, BVLOS unlocks invaluable new aerial perspectives. But it is the maturation of the remote sensing capabilities and analytics engines purpose-built to interpret those rich vantage

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[5] drone inspecting solar cells - Search Images (bing.com)

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points that make the intelligence actionable at scale across the industries pioneering this new frontier. It is no longer enough to just reach new heights and capture more data. To fully benefit from BVLOS drone capabilities and ROI, the information torrent must be channeled into insights through sophisticated analysis - converting raw inputs into calibrated outputs that reshape workflows.

BVLOS Economic Law #5: The Key Value Proposition

The key value proposition unlocked by large-scale BVLOS drone infrastructure is not merely expanding data gathering capacity, but rather the sophisticated post-processing algorithms and analytical techniques applied to rich drone-captured datasets that ultimately enable superior decision-making, risk detection, and predictive modeling across industries from agriculture to insurance. Simply gathering vastly more aerial imaging and sensor data through BVLOS networks absent advanced systems to parse that torrential firehose of information into actionable intelligence would serve little intrinsic purpose. While expanding raw data gathering capacity promises invaluable material to feed analysis, successfully translating that potential into profitability and sustainability for drone operators relies upon extensive interdisciplinary cross-pollination with artificial intelligence, cloud computing, and data analytical sciences.

To extract differentiation and defensibility amidst an increasingly crowded industry of longitude-latitude-timestamp data providers, BVLOS pioneers must emphasize proprietary systems integrating customized machine learning pipelines, analytics visualizations, simulation modeling capabilities, change detection protocols, and other specialized techniques to optimize post-processing software, streamline customers' decision workflows, and yield insight-revealing interpretations tailored to each use case and vertical. For example, in precision agriculture, while multispectral/hyperspectral sensors gathering aerial crop data at vastly larger scales via BVLOS provide invaluable foundations, translating those rich inputs into accelerated adoption relies upon downstream agronomic analytics engines generating smart prescription maps that farming customers can integrate into real-world fertilizer, irrigation, harvest planning operations. To produce such actionable intelligence algorithms must filter noise, isolate signal, reveal variability, render predictions - culminating in decisions not just observations.

Similarly, vast pipelines for regional solar energy producers resist adopting BVLOS services gathering thermal data on hundreds of thousands of panels absent customized machine learning to pinpoint damage, estimate production impact, and prescribe maintenance actions location-by-location to optimize yield. For industrial mega-scale cattle feedlots, raw aerial monitoring serves limited standalone utility without AI rapidly flagging behaviors indicative of illness outbreaks and modeling transmission risks, so mitigation responses protect investments at margins of pennies per animal. Across security-conscious enterprises spanning mines to mixed use

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developments encompassing billions in hard assets, beyond simply accumulating surveillance footage intelligence systems must alert BVLOS customers to anomalous patterns indicative of theft, leaks, encroachments through analytics intentionally designed to parse signal from noise amidst expansive camera fields.

Unlocking such vertical use cases and delivering defensible value atop mere longitude-latitude-timestamp datasets demands investment not just in drone fleets, but interdisciplinary artificial intelligence teams designing customized neural networks, learning pipelines, reinforcement learning protocols, computer vision models, explainability frameworks and control mechanisms purpose-built for translating torrents of unstructured sensor data into structured insights that reshape decision workflows. Further value accrues by accumulating industry-specific corpuses of benchmark training data over successive missions and shared learnings across customers to continuously refine computer vision, model reliability, explainability and accuracy over time - seeking not just reactive insights but predictive intelligence and prescriptive decision recommendations.

Architecting specialized analytics engines around tailored machine learning capabilities purpose-built for individual verticals and use cases requires extensive investment - but powers differentiation. This unlocks the fuller value propositions by not just showing customers more observational data but telling them what it means and advising data-optimized decisions amidst complexity at scopes impractical for unaided human analysis. The business sustainability and dependability for BVLOS service providers ultimately relies upon pursuing this interdisciplinarity - not just aviation capability.

BVLOS Economic Law # 6: New accessible markets and use cases enabled by BVLOS drone operations

By expanding operational radii beyond constrained VLOS limitations, BVLOS drones unlock entirely new market opportunities. Applications from agricultural insights to emergency response rely on accessing locales previously beyond economic reach. The vastly expanded ranges introduce new economies of scale and scope, fueling services unviable under restricted VLOS caps. As you go through this exercise, consider how the market size for package delivery increases as the scale of BVLOS increases. When you consider 90% of the US population is within 10 miles of a Walmart store, this example takes on added meaning.[6] Here are the calculations showing how the market size for drone operations expands drastically as the operational radius increases from 1 mile to 10 miles, using the area of a circle formula (See Figure 8):

[6] 25+ Essential Walmart Statistics for 2024 | Fortunly

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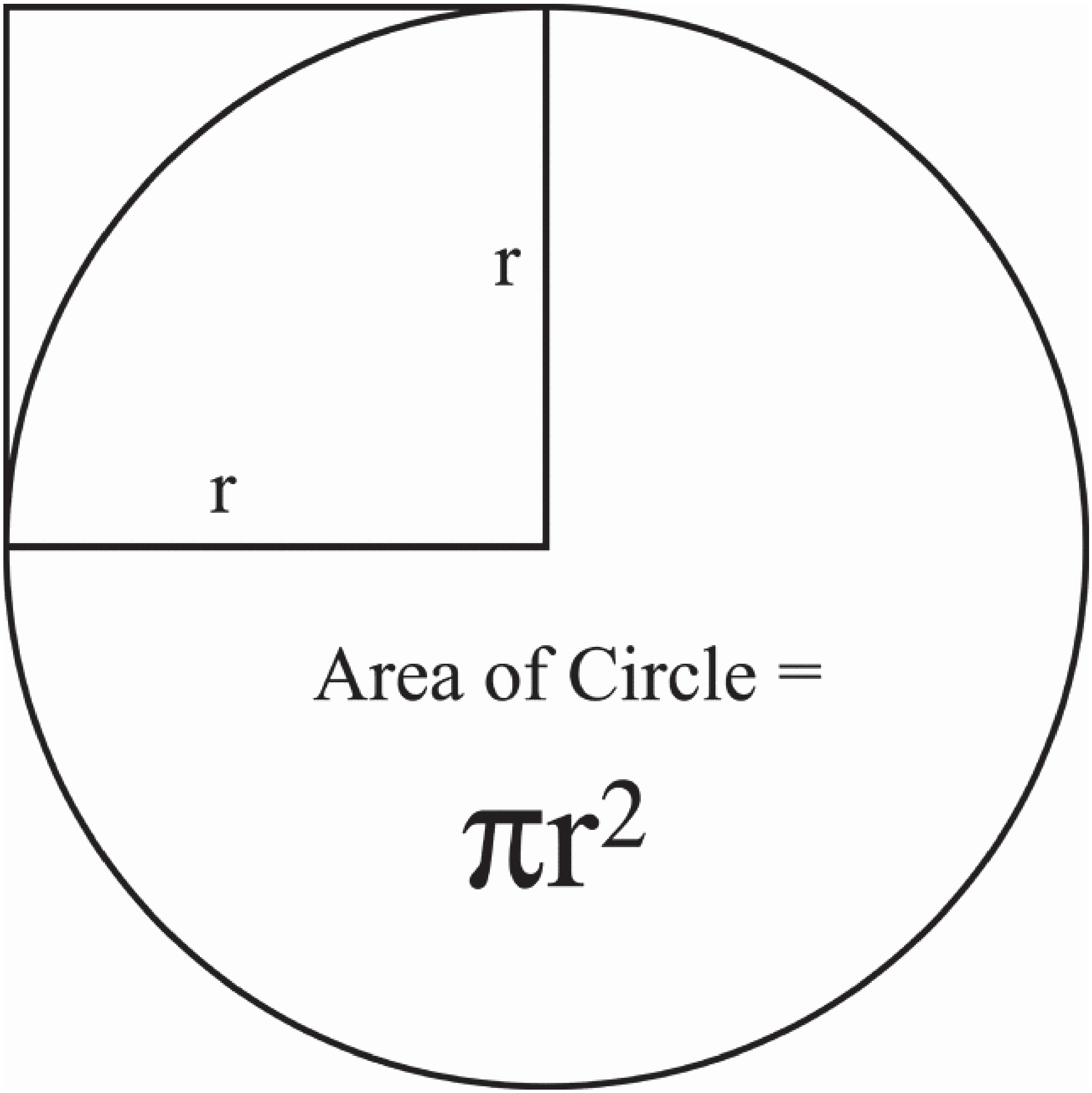

Figure 8: Area of a Circle[7]

1. Area of Circle Formula: A = πr2

Where:

A is the area

π is the constant approximately equal to 3.14

r is the radius

[7] showing how the area of a circle increase geometrically - Search Images (bing.com)

2. 1 Mile Radius

Area = π x (1 mile)2

Area = 3.14 x (1 mile x 1 mile)

Area = 3.14 square miles

So with drones only capable of a 1 mile radius the accessible market size is 3.14 square miles.

3. 10 Mile Radius

Area = π x (10 miles)2

Area = 3.14 x (10 miles x 10 miles)

Area = 314 square miles

When drones can operate across a 10-mile radius the addressable market area for drone operations rises to 314 square miles. Increasing the effective drone operational radius 10X from 1 to 10 miles expands the addressable market area by 100X from just 3.14 to 314 square miles thanks to the quadratic area of a circle geometric relationship.

This demonstrates the immense market potential unleashed when longer distance beyond visual line of sight drone operations become approved through advancing regulatory frameworks and operational capabilities over this decade. Even relatively modest linear range improvements geometrically multiply the aerial coverage and far wider market adoption possibilities from superior area access. The incremental area of coverage market size expansions going from a 1-mile drone operational radius up through a 10-mile radius is as follows (See Figure 9):

Mileage	Square Miles
1	3.14
2	12.57
3	28.27
4	50.27
5	78.54
6	113.10
7	153.94
8	201.96
9	254.47
10	314.56

Figure 9: Market size Increases as the Radii Increases

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As shown, each additional mile of incremental linear drone range, enabled by advancing BVLOS functionality, allows access to exponentially larger surface areas for coverage across infrastructure inspection, delivery logistics, security patrol, agricultural survey, and other drone industry use cases. For example, vast expanses of farmland, forests and industrial facilities have seen manual surveying and assessment costs prohibitively high, locking knowledge value left unclaimed. Drones now offer promise in cost-effectively gathering imagery, topological and sensor data at regular intervals across properties spanning thousands of acres which foot and ground vehicles cannot regularly cover. This opens avenues for monitoring crop health patterns, detecting invasive species spread, and assessing equipment integrity across territories previously unobservable at sufficient frequency. Where sampling may have occurred annually at best, weekly unmanned sweeps extract multiples more analyzable data to guide land use decisions and risk detection.

Natural disaster response similarly relies on vastly expanding quick observational range to accelerate aid. As extreme weather events from hurricanes to wildfires afflict larger swathes of territory, being able to rapidly assess damage reports and send supplies promises dramatic human impact. BVLOS drone infrastructure offers route planning and assessment intelligence unbounded by impassable debris that could trap terrestrial responders. Further, payload delivery of essential medical supplies when hospitals are cut off by storms or separated fire fronts grows more urgent than ever with climate change. Only BVLOS capacities can make reaching these sites reliably to save lives and property feasible on mass scales.

From crop health to disaster response to border security and delivery services, BVLOS drones introduce entirely new operational scopes at cost structures finally viable enough to tap latent demand. Just as past innovations from rail to refrigeration similarly shrunk operational friction enabling economic activities for the first time, so shall drones multiply market opportunities. Realization depends on advances in battery life, aircraft durability and weight thresholds as well as air traffic coordination and even public acceptance to fulfill this proliferation potential. But the promising economics underpinned by expanded accessibility to new data and operational connection opportunities beckon compellingly as enablers now accelerate.

BVLOS Economic Law #7: The Economics of Transitioning from 1:1 to 1: N pilot to Drone Operations Ratios

The conventional VLOS restriction of one pilot to one drone in flight creates an intrinsic bottleneck on revenue. A single pilot operating a lone quadcopter or rotary drone within eyesight can only collect imagery or sensor data from that tight geographic circle in real-time before needing to land and recharge batteries. Even with near 100% utilization, total flight time caps out

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around three or four hours per day optimistically due to the short flight times and the need to recharge batteries and drive to different locations. This will drastically change with BVLOS.

Conversely, trained BVLOS pilots licensed to manage multiple fixed-wing drones simultaneously can scale data collection and services provided exponentially higher. Instead of binding one pilot to just one set of eyes, advanced ground stations synthesize real-time drone telemetry, air traffic feeds, terrain maps and sensor footage from each asset simultaneously. When drones can operate for hours without direct eyes-on monitoring, one pilot overseeing a fleet of five to ten drones in staggered flight rotations essentially increases their productivity by an order of magnitude. New BVLOS economics emerge by spreading the sunk capital costs across these force multiplying factors. Consider the improvements in pilot cost per hour as we transition from one pilot per drone to one pilot per 10 drones.

Here are the calculations using a $100 per hour pilot wage:

1 Pilot: 1 Drone

- Pilot pay = $100 per hour

- Total drone flying hours per pilot hour = 1 hour

- Unit cost per drone hour = $100

1 Pilot : 10 Drones

- Pilot pay = $100 per hour

- Total drone flying hours per pilot hour = 10 hours (10 drones)

- Unit cost per drone hour = $10

  = $100 pilot cost per hour / 10 drone hours per hour

  = $100 / 10 drones

With a $100 per hour pilot wage, transitioning from 1:1 to 1:10 pilot-to-drone management ratio still reduces the unit economics by 10X - dropping from $100 down to $10 per drone flight hour. As the number of drones that can be flown safely increases, the unit costs of flying them trends towards zero as a limit function. This order of magnitude cost efficiency improvement remains highly compelling even at higher pilot salaries. It shows the immense financial upside of progressing to BVLOS systems where one pilot oversees larger drone fleets rather than just a single aircraft. The dramatically lower unit costs per flight hour promise vastly superior commercial viability potential.

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Here are the incremental unit economics per drone flight hour with the pilot getting paid $100 per hour (See Figure 10):

Number of Drones Being Flown	Pilot Cost per Hour
1	$100.00
2	$50.00
3	$33.33
4	$25.00
5	$20.00
6	$16.67
7	$14.29
8	$12.50
9	$11.11
10	$10.00

Figure 10: BVLOS Pilot Costs

With a $100 per hour pilot wage, the cost savings going from 1:1 to 1:10 pilot to drone management ratios drops from $100 down to $10 per flight hour. Enabling coordinated oversight of larger fleets via improving BVLOS systems still produces monumental cost efficiency gains regardless of absolute pilot pay. The order of magnitude unit cost reduction promises vastly superior commercial scale potential helping drones proliferate mass adoption.

The revolution lies in transitioning pilots from visual scanners to meta-data managers through superior command and control systems. Skilled BVLOS pilots then optimize and choreograph drone fleets to execute larger combined missions that were simply impossible under constrained VLOS restrictions. While unit pilot costs are going down, the ability to earn incremental revenue goes up as the pilot to drone ratio goes up from flying one drone at a time to ten.

Here are the incremental revenue calculations as pilot productivity grows from flying 1 drone per hour to 10 drones per hour, with each drone contributing $300 per flight hour (See Figure 11).

Pilot Flying number of Drones	Potential hourly earnings per pilot
1	$300
2	$600
3	$900
4	$1,200
5	$1,500
6	$1,800
7	$2,100
8	$2,400
9	$2,700
10	$3,000

Figure 11: Revenue Potential per hour per pilot.

By enabling each pilot to scale their productivity from 1 to 10 revenue-generating drones per hour, total hourly revenue potential grows over 10X from $300 to $3,000 thanks to the increased fleet oversight capabilities that advancing BVLOS systems facilitate. This order of magnitude revenue growth multiplier promises tremendous commercial upside. There will be diminishing returns to scale at a certain point given the magnitude of the various submarkets.

A strict 1:1 ratio of one remote pilot per drone is only sufficient to cover flight operations themselves. Simply keeping a drone airborne and capturing raw aerial data serves little end purpose. To transform and analyze volumes of airborne sensor measurements into usable business intelligence requires an entire backend workflow.

Additional staff becomes essential across IT, data science, engineering, mapping, reporting and more to handle elements like:

1. Data Management/Storage - Processing troves of high-res imagery and lidar models from drones
2. GIS Specialists - Creating geospatial data layers and 3D terrain maps
3. Analysts - Extracting and formatting key infrastructure insights from the drone data
4. Application Developers - Building tools to annotate images and automate workflow
5. Client Services - Packaging actionable deliverables and driving adoption

When regulation allows a single pilot to control many drones in BVLOS scenarios, generating value from the drone hardware alone is insufficient. The real ROI stems from budgeting for the human analytics horsepower behind the scenes to elevate aerial data into knowledge products that influence better decisions. The labor, supervisory, cost recovery and fatigue issues make a dedicated 1:1 BVLOS drone structure completely impractical. BVLOS economics need regulatory changes to embrace command centers where teams of pilots coordinate fleets of drones using automation aids, simulations, and advanced data systems.

The amortization and financing dilemma for expensive fixed-wing BVLOS drones poses a surmountable economic obstacle. The more yearly flight time these assets log, the quicker their immense value gets realized through actionable aerial intelligence that outweighs the sticker shock. Early drone operations have largely depended on dedicated one-to-one ratios between remote pilots and aircraft. This caps revenue generation potential for pilots while driving up operating costs considerably. However, advancing automation and regulatory enablement of BVLOS functionality promises a transition to single pilots overseeing larger fleets of drones simultaneously.

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On the cost side, the ability for properly trained pilots to coordinate multiple drones rather than just one vastly improves per unit economics. Transitioning to an operating model of one pilot capable of coordinating dozens of drones executing automated routes or data gathering missions' slashes per drone operating costs substantially. This will achieve profit break-even points on far more drone applications.

Further, aggregating more drone operations under individual pilot direction allows those personnel to generate substantially higher revenue streams as force multipliers of their expertise. Much like master train conductors, BVLOS operations shall enable master drone operators to play more strategic oversight roles while monitoring automated navigation and data capture across vast terrain. The sole scenarios when dedicating one remote pilot to operate an individual drone remains financially and operationally viable are limited to two niche cases:

1. Low-Cost Drones for Short, Visual Line of Sight Missions

Commercial pilots utilizing very basic VLOS drones for short duration flights within eyesight, such as quick property inspections or simple aerial photography, can still recoup costs with a dedicated 1:1 staffing ratio. When drone hardware remains simple and flight time is measured in minutes rather than hours, the lack of scale does not yet cripple profitability potential. As soon as more expensive hardware, sensors, licensing, insurance, or specialty pilot skills enter the picture though, the model collapses.

2. Mission-Critical Specialist Operating Solo Drone

The only other viable 1:1 scenario is that of highly specialized drone operators who take on end-to-end mission responsibility themselves. For instance, expert geospatial drone photographers who pilot drones for high resolution imaging and handle all data analysis, client reporting and application development themselves can still generate substantial revenue off operating solo aircraft. Their niche skillset, efficiency and service value sustain a 1:1 operation. Similarly for software developers piloting drones with proprietary algorithms and analytical payloads, relying on no other staff allows protecting IP sensitivities. Outside these two exceptions though, single pilot oversight even during visual line of sight flights offer no economies of scale.

Any scenario involving sophisticated drone hardware, expensive sensor and analytical software payloads, liability and regulatory compliance, and any desire to fly longer BVLOS sorties renders the 1:1 pilot-drone ratio utterly impractical from cost and utilization perspectives. Only the two above categories see financial or operational logic favor the simplistic 1:1 approach given their niche economics. For all others, transitioning to team oversight of larger drone fleets promises vastly superior cost and revenue scalability.

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Ultimately, transitioning BVLOS drone economics towards single pilot oversight of larger fleets promises exponential gains in both per unit cost reductions and revenue creating potential through force multiplication. Identifying these key economics drivers and reducing their inefficiency shall accelerate mainstream enterprise adoption as regulations enable expanded BVLOS functionality.

BVLOS Economic Law #8: Observational efficiency for drone imaging from higher altitude BVLOS operations

As drone technologies enable safer operations at expanding altitudes, their value proposition for aerial imaging gains compelling advantages. Specifically, increased flight elevation allows captured imagery to span wider geographic areas while also reducing the degree of image overlap needed to create contiguous mosaics during processing. By enhancing per-flight observational efficiency, higher vantage BVLOS drone infrastructure can exponentially escalate data productivity at even greater quality.

For example, if we increase the flight height being flown from 400 Feet Above ground level (AGL) to 3,000 feet AGL, the change in instantaneous field of view (IFOV) and coverage area per image is quite large. Instantaneous field of view (IFOV) is the angular cone of visibility from a camera at a given instant in time. It defines the ground area that is captured in an individual image frame. A wider IFOV means more ground area is covered in a single image (See Figure 12).

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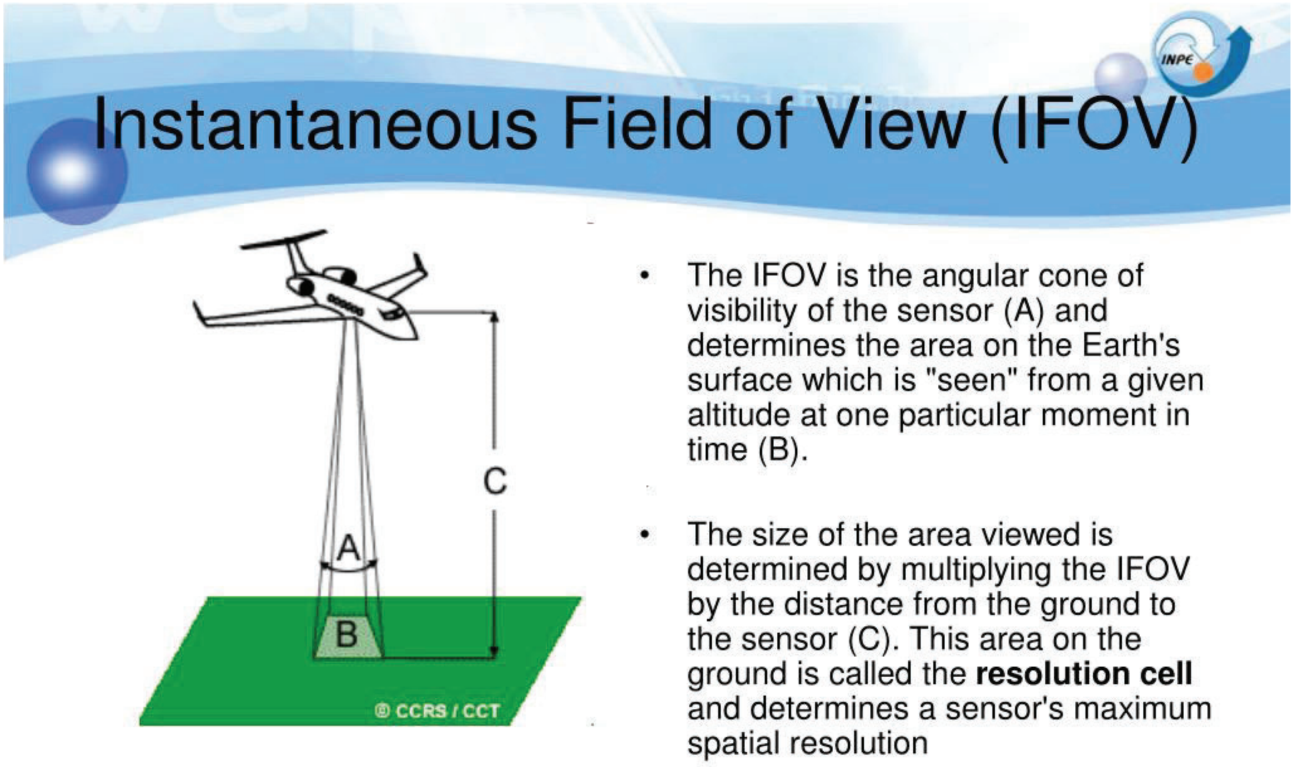

Figure 12: Instantaneous Field of View[8]

- At 400 ft AGL, the IFOV covers a relatively narrow area - let's still call it X sq ft
- At 3,000 ft AGL, the IFOV covers a much wider area. For a rough estimate:
  - As a rule of thumb, IFOV increases linearly with increase in height[9]
  - So at 3,000 ft (7.5 times higher than 400ft), the IFOV would be ~7.5 times wider
  - Thus each image covers ~7.5X sq ft rather than just X sq ft at 400 feet

The exact multiple depends on camera specifications, but the area covered by each image at 3,000 ft AGL is much larger than at 400 ft. For example, an area that takes 100 images to survey at 400 ft could be covered in roughly 13 images (100 divided by 7.5) from 3,000 ft. This allows

[8] drone Instantaneous field of view (IFOV) - Search Images (bing.com)

[9] Electro-Optical Imaging Systems (fas.org). The exact relationship is: IFOV is proportional to the tangent of the half-angle of the FOV 1. This means that as the height increases, the half-angle of the FOV decreases, and the IFOV increases proportionally.

much larger project areas to be mapped efficiently with fewer total images, but at a sacrifice of ground resolution due to being at a greater distance above the area. Altitude needs to be chosen judiciously based on coverage needed versus resolution required for the application. This allows faster sweeping of sites of interest, key for time sensitive applications like disaster damage assessment and precision agriculture field scanning. Further, expensive camera payloads can gather vastly more image data per mission as their observational range grows. This provides economies of scale on costly sensor investments by using them more actively through expanded purview. Further, added elevation enables construction of reliable imagery mosaics with significantly reduced side and front/back overlap between captured frames during missions. This overlap facilitates accurate stitching in post processing but requires additional flight time and therefore battery overhead to execute previously. The combined advantages amount to massive per unit area data generation improvements using the same piloting and imaging equipment simply elevated on appropriately certified drone airframes. Surveying sites of several square miles shifts from full day endeavors to executable in under an hour as altitude caps transition toward thousands of feet eventually. This proves compelling economics not just for commercial users like surveyors, but public sector applications as well. More regions can be assessed more quickly after disasters to coordinate response or for regular infrastructure integrity checks at heightened resolutions using the same equipment and manpower.

BVLOS Economic Law #9: As Flight Scales change so do Market Dynamics

In precision agriculture, drones equipped with multispectral sensors and AI-powered analytics engines can survey hundreds of farms in a single flight, analyzing vegetation health across vast acreages far faster than scouting on foot. However, for growers to respond to insights from the broad-scale aerial crop analysis and make data-driven decisions, the torrent of spectral readings and photographic imagery must first be turned into key agricultural metrics. Automated machine learning pipelines can extract plant health visualizations, yield prediction maps, variability zones, and targeted prescriptions for fertilizer, irrigation, and pesticides tailored to each individual farm. This enables rapid translation of the rich aerial inputs into actionable insights customized across the dozens of growers in the flight path. The sheer scale of coverage enabled by BVLOS not only unlocks new analytics use cases, but also enables business model shifts as services become viable across vastly larger geographic areas. Rather than selling piecemeal field-by-field or firm-by-firm as with most VLOS services, extensive BVLOS networks make it economical to sell annual county-wide or even statewide subscriptions to governments, cooperative extensions, industry associations, and major agribusiness conglomerates managing expansive land assets across entire regions. This same dynamic applies to infrastructure verticals, where owners of whole pipeline networks, railway systems, electrical grids and roadways become the anchor customers versus

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individual site managers. The customers are fewer but bigger. To serve and support these large regional clients, the data aggregation, standardization, analytics, and machine learning algorithms do heavy lifting behind the scenes while delivering insights customized to each customer's assets. By tapping bigger tickets at national scales, the addressable market potentials grow substantially.

And over time, as rich pools of analytical metadata accumulate from hundreds of flights over dozens of farms, solar facilities, pipelines, and other sites across counties and even states, new opportunities emerge to find deeper connections through historical comparative analyses, predictive modeling based on identified trends, and continuously tuned machine learning algorithms. Regional farm collectives can better predict optimal harvest dates based on crop development patterns mapped over seasons across participating counties. Pipeline operators can reduce false alarms by distinguishing usual vegetation factors from suspicious encroachment across wider networks. Solar managers can make capital investment decisions optimized to actual - not presumed - degradation rates across different equipment based on insights gathered from hundreds of installations. Unencumbered by the practical flight range and endurance limits inherent to small visual line of sight drone operations, BVLOS unlocks invaluable new aerial perspectives at massively expanded scales. But it is the maturation of remote sensing capabilities and analytics engines purpose-built to interpret those rich vantage points that make the intelligence actionable across industries. It is no longer enough to just reach new heights and capture more data. To fully benefit from BVLOS drone capabilities and ROI, the torrential sensor data must be channeled into insights through sophisticated analysis - converting raw inputs into calibrated outputs that reshape workflows.

The keys to unlocking this potential are:

1) Advanced aerial capture technologies like high-resolution hyperspectral imaging which can reliably gather precise sensory inputs across diverse environments and conditions.[10]
2) Scalable cloud analytics leveraging modern GPU/TPU computing to rapidly process torrential streams of aerial data into useful metadata.[11]
3) Purpose-built machine learning algorithms continuously tuned on industry-specific benchmarks to transform sensor readings into decision-ready intelligence.[12]

These pillars work in conjunction to extract the full value from BVLOS drone missions as operations shift from mere data collection confined to individual sites toward networked services delivering regional insights that cannot be achieved with traditional methods. The superior speed, cost, quality, and analytic depth ultimately enable better decisions and outcomes.

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[10] Hyperspectral imagery applications for precision agriculture - a systemic survey | Multimedia Tools and Applications (springer.com)

[11] GPTPU: Accelerating Applications using Edge Tensor Processing Units (arxiv.org)

[12] Machine Learning: Algorithms, Real-World Applications and Research Directions | SN Computer Science (springer.com)

The Promised Land of BVLOS Economics

The Promised Land of BVLOS Economics Rests on Taming Torrents of Sensor Data. BVLOS drone operations live or die based on the ability to cost-effectively manage immense volumes of aerial sensor data. Whether long distance drone missions focus on infrastructure monitoring, agricultural yield projections, environmental conservation efforts or public safety enhancement, the aircraft itself serves mostly as the ephemeral data collection vector. The true value getting extracted which justifies heavy investment in expensive fixed-wing or powered rotor drone platforms lies in downstream processing and analytics of their voluminous payload.

Generating Prescriptive Insights from Data

Pushing further beyond processing refinement brings us to the true holy grail and watershed economics promised by BVLOS innovation. Converting historically inaccessible or cost-prohibitive data flows directly into decision catalysts and automated action through advanced modeling techniques. This next level of analytical maturity unlocks substantial labor cost and risk reduction - while informing prescriptive business, operations and policy moves not otherwise apparent.

Consider our electrical grid transmission line example. Baseline analytics would accurately pinpoint component failures down to specific towers, arms or insulators driving enhanced repair crew efficiency and lowering outage impacts. But top-tier analytics solutions take this a full level deeper. Machine learning algorithms ingesting billions of data points across vast BVLOS monitoring territories uncover hidden year-over-year trends and correlations. Predictive failure signatures emerge at macro grid level. Planners enhance budgets for proactive component upgrades and vegetation clearing in grid segments exhibiting telltale high corrosion indicators. Engineers develop advanced composite materials for towers and connectors tailored to terrain prone to accelerated infrastructure decay based on environmental and operational factors. Real-time dashboards track ambient impacts of weather, load changes, voltage indicators on component stress and lifespan dynamically across the overall grid network. Renewed assets get purpose built for maximum longevity per their exact intended operating conditions. Outage levels fall while maintenance costs drop through proactive investments - all via BVLOS analytics allowing planners to monitor the massive grid territory comprehensively.

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Figure 13: Power Line Inspection before drones[13]

This hints at the sheer economic upside lurking within BVLOS sensor data waiting to be harnessed through creativity. And how advanced algorithms and AI will transform many hands-off industries as complex modeling combines streaming BVLOS sensor inputs with traditional SCADA measurements and weather data to generate powerful predictive insights and mitigation paths.

Obstacles to Overcome

Realizing this full potential depends on the drone industry maturing quickly across a few pivotal domains:

i. Automated Data Curation - open-source labels, neural nets and quality control protocols allowing drones to interpret their own data accurately while embedding key metadata for context.[14]

ii. Enhanced Fleet Operations Tools - hardware, sensors and software supporting dynamic vehicle to vehicle / vehicle to ground communication

[13] power line inspection by drones - Search Images (bing.com)
[14] Cleanlab Raises $25M Series A to Automatically Increase the Value and Accuracy of the World's Enterprise Data Used by AI, ML, and Analytics Solutions | Business Wire

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for smoother distributed missions encompassing both piloted and pilotless drone assets across vast connected skies.[15]

iii. Avionics and Control Stations- advancing reliability for severe operation scenarios spanning weather, magnetic interference, limited visibility, technical malfunctions, and adversary detection events. Reducing risk for both equipment and surroundings during abnormal scenarios.[16]

The goal is purpose-built drone technology moving beyond standardized hobbyist platforms to enable safe, advanced BVLOS use.

Conclusion - BVLOS Economics Depend Upon Mission Scale and Infrastructure Maturity

Truly realizing the immense latent value of wide area drone monitoring hinges upon maturing several pivotal supporting capabilities. Sophisticated aircraft and sensors merely provide the ephemeral means for gathering intelligence. All else being equal, the core economics boil down to infrastructure able to ingest, process, analyze, and act upon the resulting data flows across vast imagined geographies.

BVLOS drone operations promise immense capability advances once freed from the labor-intensive oversight models the industry relies upon presently. The future sees primarily pilotless aircraft managed by slim supervision teams aided by vehicle-to-vehicle collaboration, airspace automation services and resilient contingency logic. Onboard optics feed servers leveraging

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15 Ask an Expert: Capturing fleet impact from telematics | McKinsey
16 On the Reliability of Interference Limited Unmanned Aerial Vehicles | Wireless Personal Communications (springer.com)

https://doi.org/10.52202/075106-0014

scalable cloud compute rather than just storage alone. Machine learning provides the true differentiator as software derives otherwise inaccessible insights from endless petabytes of aerial intelligence. Together, the collective economics pivot drastically once these forces align at scale. But developers caution the roadmap ahead remains strewn with obstacles. Hardware gets prohibitively expensive absent commitments for large fleet orders. Advanced negotiable autonomy still faces skepticism among conservative aviation authorities. Bandwidth costs continue strangling small operators lacking bulk access to vital satcom infrastructure. Insurance products now only nibble around the risk margins of complex BVLOS operational envelopes envisioned. And the skilled labor pool familiar with optimizing enterprise drone data outputs remains shallow.

Still pioneers press ahead undaunted. The sheer magnitude of aging infrastructure requiring perpetual monitoring at continental scale simply defies traditional methods absent around the clock aerial surveillance. And exponential tech improvements rapidly tackle barriers one by one. Expect determined teams to patiently coax regulators forward while building irrefutable proof cases demonstrating the immense latent upside. Advanced BVLOS drone operations constitute an inevitably technology once key infrastructure and trust foundations solidify. Those laying the groundwork today stand well-positioned to reap substantial rewards in the coming decade.

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