PRIME AIR DRONE HUB LOCATION STRATEGY

Team 2

Abhijith Penmetcha

Malak Mehta

Sakshi Agarwal

Vyshnavi Siddula

Table to Contents

EXECUTIVE SUMMARY

This report presents a comprehensive analytical design for Amazon Prime Air's potential drone delivery network across Massachusetts. Using a combination of geographic optimization, demographic weighting and coverage modeling, we identified Newton, Worcester, and Springfield as the optimal hub locations for a three-hub statewide architecture. These locations satisfy multiple criteria simultaneously: they align closely with demographic centers of gravity, demonstrate strong population coverage within a 15-minute drone radius, and dominate the competitive landscape when evaluated through a Huff gravity model that accounts for attractiveness and distance decay.

Our analysis shows that Newton alone attracts more than 72% of statewide drone-suited demand, making it the natural first-phase mega-hub. Worcester captures virtually all Central Massachusetts demand and acts as a balancing node across the state. Springfield offers the strongest coverage and demand attraction in Western Massachusetts despite the regional center-of-gravity falling slightly north of it in Northampton. Altogether, this configuration provides the highest feasible statewide service accessibility while minimizing drone range requirements and redundancy infrastructure.

A phased rollout strategy allows Amazon to launch rapidly in a high-volume environment, refine operational procedures, manage regulatory risk, and expand logically toward full statewide coverage. Additional refinements, such as integrating real Amazon order-level data, modeling no-fly zones, evaluating seasonal weather effects, and exploring micro-hub expansion to provide a clear roadmap for long-term scalability.

To structure this analysis, we evaluated four dimensions, online business trends, drone technological constraints, population characteristics, and geographic location modeling. Each dimension informs a different part of the hub design problem: what products are suitable for drones, how drones can operate, where demand emerges geographically, and which hub sites maximize statewide accessibility. Together, these dimensions create a coherent framework that leads to the final three-hub recommendation.

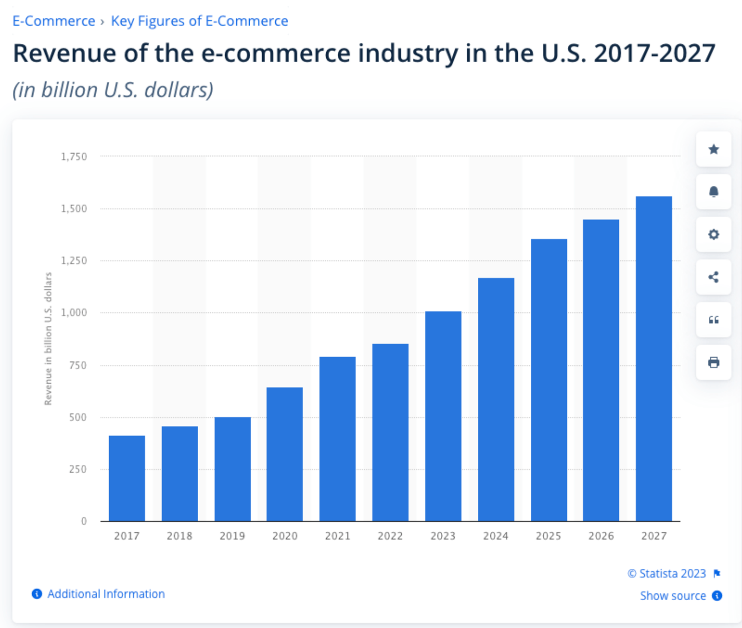
CONTEXT & SCOPE OF WORK

Amazon Prime Air's effort to design a viable statewide drone delivery network in Massachusetts requires a rigorous, multi-dimensional analytical framework capable of addressing demographic complexity, geographic diversity, and emerging aviation constraints. Massachusetts is uniquely suited for such an evaluation because it combines some of the most densely populated and tech-savvy regions in the country such as Boston, Cambridge, and the Route 128 innovation corridor with low-density rural communities in Central and Western counties, where traditional ground transportation faces longer travel times and higher costs. This contrasting landscape creates highly variable delivery needs across short geographic distances, making it essential to quantify not only where demand currently exists, but where drone adoption is most feasible, where airspace restrictions may limit operations, and where logistics savings will be most pronounced. In this context, understanding the interplay between consumer behavior, drone technology capabilities, and the physical constraints of Massachusetts' built, and natural environment becomes foundational to any network design recommendations.

The scope of this engagement encompasses the full analytical pipeline required to evaluate and recommend optimal drone hub placements across the state. This includes collecting and integrating county-level datasets on population, income, broadband access, age distribution, and urbanization to model potential demand; estimating geographic centers of gravity (COG) for each region to identify balanced, central hub locations; and performing 5, 10, and 15 minute service coverage modeling to quantify accessible population segments. The evaluation further incorporates probabilistic demand forecasting using Huff's gravity model, comparing the attractiveness of competing hub locations based on both size and distance. Additionally, the scope includes consideration of FAA regulatory constraints particularly around BVLOS operations and controlled airspace near Logan Airport, weather sensitivity, battery endurance limitations, noise and privacy impacts, and local community feasibility. Together, these components culminate in a synthesized recommendation for the optimal three-hub structure in Newton, Worcester, and Springfield, along with a phased deployment roadmap that balances operational efficiency, cost considerations, and long-term scalability.

DIMENSION 1: ONLINE BUSINESS

The first dimension establishes the commercial foundation for drone delivery by examining whether the underlying online retail environment is sufficiently large, growing, and compatible with drone-deliverable SKUs. It evaluates the overall trajectory of online retail and how it directly supports the adoption of drone delivery systems. Over the past decade, U.S. e-commerce has grown dramatically, rising from roughly 5% of total retail spending in 2012 to over 16% in 2024. This reflects not only the digitization of consumer behavior but also an increasing expectation for fast, low-friction fulfillment. Same-day and next-day deliveries have become one of Amazon's largest growth segments, placing new pressures on last-mile logistics. Drone delivery represents a natural evolution in this landscape, offering rapid fulfillment at lower marginal cost and reduced carbon footprint compared to traditional vans.



Bar chart showing e-commerce industry growth in the US along with forecasts

A key component of this dimension is understanding the proportion of Amazon's SKU catalog that can realistically be delivered via drone. Current Prime Air aircraft can carry approximately five pounds, which aligns nearly **75-85% of Amazon's most frequently purchased products**. These include pharmaceuticals (such as over-the-counter medications), cosmetics and skincare, chargers and small electronics, household essentials like cleaning supplies, personal care items, pet treats, and packaged foods. These categories tend to have high reorder frequency and small-unit packaging, making them ideal for aerial delivery. Filtering by weight, fragility, battery restrictions, and safety constraints provides a realistic pool of drone-eligible SKUs that will form the core of early-stage drone delivery demand.

This dimension ultimately shows that drone delivery is supported by macro-level growth (national and global e-commerce expansion) and micro-level readiness (a large portion of Amazon products already meeting drone payload requirements). Combined with Massachusetts' strong digital adoption, high incomes, and broadband coverage, the market is structurally prepared for a fast and high-utilization rollout of drone-based last-mile logistics.

While this dimension confirms that demand exists and a large share of Amazon's catalog is drone-eligible, the feasibility of delivering these products depends on technological, regulatory, and operational limits. Therefore, we next examine the capabilities and constraints of drone systems themselves.

DIMENSION 2: DRONE TECHNOLOGY

Having established that a substantial portion of Amazon's order volume falls within drone-compatible weight and size ranges, the next step is to understand how far drones can realistically travel, what they can carry, and where they are permitted to fly

This dimension evaluates the capabilities and constraints of drone systems themselves, factors that directly influence where hubs should be placed and how far they can reach. Drone technology is improving rapidly, driven by advances in battery density, lightweight materials, navigation systems, and onboard sensing. Yet practical boundaries still exist.

One of the clearest constraints is payload limit, typically around 5 pounds for current Prime Air–style delivery drones. Payload determines what can be delivered and thus shapes the commercial viability of the network. Heavier drones can carry bulkier parcels but face increased regulatory scrutiny and reduced range. Payload limits therefore intersect tightly with SKU eligibility, narrowing the focus to items that are light, valuable, and frequently ordered.

Item Category	Why Suitable for Drone Delivery
Apparel & Footwear	Typically light, small packages — ideal for drone payload limits
Small Electronics & Accessories	Compact, often < 2 kg, good demand
Cosmetics & Personal Care	Lightweight, small volume, high frequency of purchase
Subscription Boxes & Essentials (e.g. supplements, small household goods)	Regular demand, small-to-medium parcel sizes
Books / Media / Small-Goods	Easy to package, low weight, predictable demand

Table showing product categories suitable for drone delivery

A second constraint is delivery range. Drones do not travel as the crow flies under perfect conditions; range is shaped by wind, temperature, battery efficiency, and additional energy consumption during takeoff, landing, and hovering. Most operational networks establish safe round-trip ranges of 10- 15 kilometers, which is why we used a 15-minute, ~15-kilometer service radius. Range limitations are one of the strongest drivers behind selecting multiple hubs rather than a single large hub.

Regulatory constraints form a third critical pillar. FAA rules still tightly govern Beyond Visual Line of Sight (BVLOS) operations. Although waivers are increasing and Amazon has received approvals for expanded autonomy, operators must remain compliant with geofencing, Remote ID, and low-altitude routing requirements. Airspace complexity around Boston (especially near Logan Airport) also restricts where hubs can be placed, steering deployment decisions toward suburban rather than central urban locations.

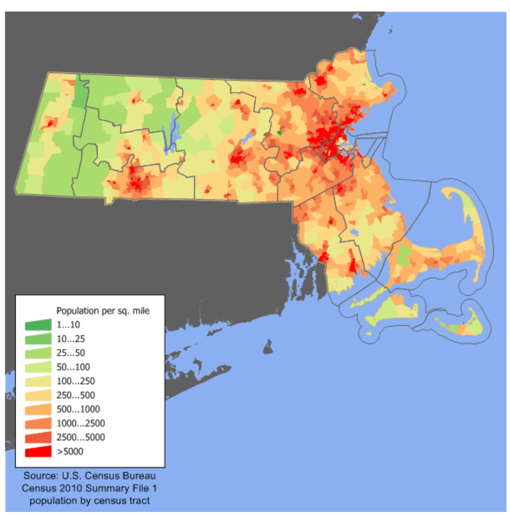
Finally, drone delivery carries significant cost and environmental tradeoffs. Drones reduce fuel consumption, decrease road congestion, and produce fewer emissions for lightweight deliveries. They can also reduce last-mile delivery times dramatically. However, large networks require investments in charging pads, battery packs, maintenance hangars, and airspace management systems. Balancing these operational and environmental considerations is essential for determining whether certain counties or towns become high-priority launch markets.

These technological and regulatory boundaries define the physical radius a drone hub can serve. However, knowing how far drones can fly is only useful when combined with an understanding of where people live and where demand is concentrated. This leads to the third dimension: population-based demand modeling across Massachusetts counties

DIMENSION 3: POPULATION

The third dimension evaluates how Massachusetts' population distribution and its segmentation into urban, suburban, and rural counties, translates into expected demand for drone delivery and shapes the attractiveness of potential hub regions.

This dimension focuses on how the population of Massachusetts and its distribution across counties shapes both demand potential and operational feasibility for drone delivery. Population is the most direct predictor of order volume, and counties like Middlesex, Suffolk, Essex, Norfolk, and Plymouth naturally rank highest because they encompass the Boston metropolitan region and its surrounding suburban communities. These counties contribute the bulk of statewide online shopping behavior, and their residents have consistently high adoption of fast-delivery options. By contrast, counties in Western Massachusetts such as Berkshire, Franklin, and Hampshire have smaller populations but feature longer delivery routes and fewer logistics facilities, which increases the relative value of drones even if total volume is lower.



Map showing population spread in Massachusetts

A core component of this dimension is the county-level dataset we collected and used throughout the analysis. Each county was treated as a distinct demand zone, with attributes such as total population, median income, urbanization score, broadband penetration, and age structure assigned at the county level. This allowed the models especially the Center of Gravity and Huff gravity models to accurately weigh each geographic area according to its real demographic footprint. Using counties as the unit of analysis ensured consistent data availability, compatibility with census sources, and meaningful differentiation between economic regions such as Greater Boston, the MetroWest corridor, Central Massachusetts, and the Pioneer Valley. These county-level population inputs ultimately determine where each region's center of gravity fell and how strongly each hub attracted surrounding demand.

Middlesex County	**1,623,411**	State's primary demand center; anchors Eastern hub (Boston).
Suffolk County	**792,647**	Dense urban core; very high demand; airspace constraints present.
Essex County	**804,598**	Strong coastal cities; high e-commerce activity.
Norfolk County	**720,403**	Affluent suburbs; highly drone-friendly geography.
Worcester County	**856,858**	Central location; ideal for intermediate hub coverage.
Bristol County	**576,070**	Dense suburban corridor; strong drone adoption potential.
Plymouth County	**527,602**	Coastal + suburban mix; broad coverage potential.
Barnstable County	**227,942**	Seasonal peaks; tourism shipments; wide rural areas.
Hampden County	**466,265**	Springfield anchor; key Western MA hub candidate.
Hampshire County	**161,810**	College towns; predictable stable demand.
Berkshire County	**129,089**	Rural; drones significantly reduce long-distance road miles.
Franklin County	**71,085**	Very rural; long delivery times - drones highly beneficial.
Dukes County	**20,277**	Island deliveries: drones reduce reliance on ferry logistics.
Nantucket County	**13,795**	Ideal drone environment; isolated delivery routes.

Table showing county wise population estimates and evaluation of drone delivery routes

The urban-suburban-rural distinction further refines how population translates into drone feasibility. Urban cores possess extremely high demand but face steep operational challenges due to building height, airspace density, and scarce landing zones. Suburban regions, by contrast, offer the best balance: they pair robust demand with feasible landing sites and clear airspace. This is why suburban-dominant counties like Middlesex, Norfolk, Essex, and Plymouth consistently emerge as the most suitable zones for drone expansion. Rural regions such as Berkshire and Franklin, despite their smaller populations, benefit disproportionately from drone deployment because their traditional delivery times are long and infrastructure sparse. Drone networks often generate the highest service-time improvements in rural zones, even if raw volume is lower.

Altogether, population-based analysis confirms that Massachusetts offers a strong blend of high-demand suburban areas, innovation-driven urban centers, and underserved rural communities, all of which strengthen the case for a distributed three-hub architecture.

DIMENSION 4: LOCATION ANALYSIS

The fourth dimension focuses on identifying and evaluating the optimal hub locations across Massachusetts. While the first three dimensions describe who the customers are and how they might adopt drone delivery, this final dimension determines where Amazon should physically deploy drone hubs to achieve maximum coverage, operational efficiency, and demand capture. Location analysis serves as the synthesis point of all prior inputs like demand potential, demographic suitability, regulatory feasibility, and drone performance constraints.

Methodology, Analysis and Findings

Our analytical approach integrates three complementary location-science methods, Center of Gravity (COG), Coverage Radius Modeling, and the Huff Gravity Demand Model, to identify the optimal drone hub configuration for Massachusetts. The COG method enabled us to determine the geographic and demographic "balance points" of each region, ensuring that proposed hubs align with population, income, and broadband-weighted demand centers. Coverage analysis quantified how many residents fall within realistic drone flight radius (5, 10, and 15 minutes), allowing us to estimate reachable volume and service equity for each candidate hub. Finally, the Huff model provided a probabilistic demand allocation framework that incorporates both hub attractiveness and distance decay, predicting how customers across all counties would naturally assign to each hub. Together, these methods create a robust, multi-layered foundation for evaluating hub performance, comparing alternative configurations, and recommending the most efficient statewide deployment strategy.

1. Center of Gravity (COG) Method

In the context of drone logistics, COG allows us to determine locations that minimize average service distance while aligning closely with the demographic and economic characteristics that drive online ordering behavior. Rather than simply selecting the geographic midpoint of a region, the COG approach creates a "demand-weighted central point," where counties with higher population, higher income, stronger broadband access, and greater technological readiness exert a stronger pull on the final location. This ensures that hubs are positioned where the majority of drone-eligible demand is likely to originate, rather than where the physical boundaries of the state suggest.

To compute the COG for each region (Eastern, Central, and Western Massachusetts) we assigned each county a composite weight based on key demand indicators: total population, median household income, broadband penetration, median age, and an urbanization score. These variables collectively represent not only the size of the potential consumer base but also the likelihood that households engage with high-frequency online shopping and adopt emerging delivery technologies such as autonomous drones. Each county's latitude and longitude were multiplied by this composite weight and divided by the sum of all weights in the region, producing a precise geographic coordinate that reflects its contribution to total drone-relevant demand.

The resulting COG points aligned remarkably well with real-world urban structure. In Eastern Massachusetts, the COG fell in the vicinity of Newton, reflecting the concentration of demand in Boston, Cambridge, Somerville, Brookline, Waltham, and the dense Middlesex–Norfolk corridor. In Central Massachusetts, the COG landed directly on Worcester County, reaffirming Worcester's role as the region's demographic and logistical anchor. In Western Massachusetts, the COG fell between Northampton and Springfield, accurately capturing the contrast between the higher-income, college-driven towns to the north and the denser urban population of Hampden County to the south.

County	Latitude	Longitutde	Weight	Weight * Latitu	weight * Longitutde
Barnstable County	41.78373333	-70.17709333	31163.94145	1302145.819	-2186994.827
Bristol County	41.87969	-71.209005	195582.716	8190943.515	-13927250.6
Dukes County	41.40828571	-70.70435714	8046.428571	333188.8133	-568917.5594
Essex County	42.65145588	-70.96847353	521110.8749	22226137.49	-36982443.33
Middlesex County	42.46072778	-71.32539815	1659813.299	70476880.64	-118386844.4
Nantucket County	41.2835	-70.0995	5764.475996	237977.7448	-404086.8851
Norfolk County	42.18244286	-71.19643214	791450.6784	33385323.02	-56348464.52
Plymouth County	41.99928148	-70.85091852	394946.1725	16587455.47	-27982299.09
Suffolk County	42.38315	-71.0286	776234.2932	32899254.48	-55134835.12
				185639307	-311922136.3
	COG_Latitute	42.34364217			
	COG_Longitude	-71.1482904			
	NEWTON				

COG Analysis of counties in Eastern Massachusetts

Western Region Caculation: COG method					
County	Latitude	Longitutde	Weight	weight*latitude	weight * Longitutde
Berkshire County	42.4022875	-73.27090938	141078.8094	5982064.238	-10336972.66
Franklin County	42.57037692	-72.64664231	77707.72875	3308047.303	-5645205.575
Hampden County	42.11776522	-72.6109913	822014.6959	34621421.97	-59687301.93
Hampshire County	42.34249	-72.68504	497215.1234	21053326.39	-36140101.13
				64964859.9	-111809581.3
		COG_Latitude	42.23938164		
		COG_Longitute	-72.69726408		
		NORTHAMPTON			

COG Analysis of counties in Western Massachusetts

Central Region Calculation: COG Method					
County	Latitude	Longitutde	Weight	weight*latitude	weight * Longitutde
Worcester County	42.31805833	-71.84049333	856858	36260566.83	-61557101.44
		COG_Latitute	42.31805833		
		COG_Longitude	-71.84049333		
			Worcester		

COG Analysis of Worcester county in Central Massachusetts

These COG coordinates were not merely theoretical points, they guided the hub selection process. By mapping these coordinates onto real municipalities, we identified practical hub locations that were both geographically balanced and operationally viable. Newton, Worcester, and Springfield/Northampton were chosen as candidate hubs because they aligned closely with their region's COG and offered the infrastructure, zoning feasibility, and existing commercial activity needed to support drone operations.

Finally, the COG outputs were used as the basis for the coverage analysis, where 5, 10, and 15 minute drone service radius were applied to estimate how many residents each candidate hub could reach. This multi-step linkage: weighting COG to mapping to coverage quantification, ensures that every selected hub is not only theoretically optimal but also positioned to maximize real-world service reach and minimize flight distances, battery consumption, and operational complexity.

2. Coverage Ratio

Once Newton (Eastern MA), Worcester (Central MA), and Springfield (Western MA) were selected as the three drone hubs using the Center-of-Gravity and multi-criteria scoring approach, the next step was to quantify how many residents live within a realistic drone service radius around each hub.

Using the city-level latitude/longitude data, we computed the straight-line distance from each town to its respective regional hub. Towns within approximately 15 km of the hub (corresponding to a 15-minute flight at 60 km/h) were counted as being inside the coverage zone. Summing the populations of these towns gives the total number of residents covered by each hub.

Eastern Region Coverage Area Calculation:

H_E	Newton	42.34364	-71.1483		Input Data	Average Speed	60KM/HR	1 MIN		
						KM Per 1 degree latitude	111			
						KM Per 1 degree Longitutde	82.5			
Eastern										
City	COUNTY	Latitud	Longitu	Populat	Δ Latitude (deg)	Δ Longitude (deg)	111* Δ Latitude	82.5*Δ Longitude	Distance from Hub (km)	Within Coverage?
Arlington	Middlesex	42.415	-71.1594	47112	0.071357835	-0.0111096	7.920719682	-0.916542037	7.973571946	Yes
Belmont	Middlesex	42.4167	-71.1833	27442	0.073057835	-0.0350096	8.109419682	-2.888292037	8.608421369	Yes
Boston	Suffolk	42.3601	-71.0589	673458	0.016457835	0.0893904	1.826819682	7.374707963	7.597604076	Yes
Brookline	Norfolk	42.3314	-71.1233	63925	-0.012242165	0.0249904	-1.358880318	2.061707963	2.469249976	Yes
Cambridge	Middlesex	42.3601	-71.1054	121186	0.016457835	0.0428904	1.826819682	3.538457963	3.98220478	Yes
Chelsea	Suffolk	42.3917	-71.0317	40245	0.048057835	0.1165904	5.334419682	9.618707963	10.99888977	Yes
Dedham	Norfolk	42.243	-71.1819	25485	-0.100642165	-0.0336096	-11.17128032	-2.772792037	11.51025107	Yes
Everett	Middlesex	42.4	-71.05	51825	0.056357835	0.0982904	6.255719682	8.108957963	10.24154422	Yes
Lexington	Middlesex	42.4467	-71.2269	34743	0.103057835	-0.0786096	11.43941968	-6.485292037	13.14987967	Yes
Malden	Middlesex	42.4256	-71.0726	66693	0.081957835	0.0756904	9.097319682	6.244457963	11.03424128	Yes
Medford	Middlesex	42.4056	-71.1039	59898	0.061957835	0.0443904	6.877319682	3.662207963	7.791616852	Yes
Melrose	Middlesex	42.4568	-71.0687	29938	0.113157835	0.0795904	12.56051968	6.566207963	14.17327562	Yes
Milton	Norfolk	42.2667	-71.0667	28811	-0.076942165	0.0815904	-8.540580318	6.731207963	10.87431252	Yes
Needham	Norfolk	42.2833	-71.2333	32931	-0.060342165	-0.0850096	-6.697980318	-7.013292037	9.697896965	Yes
Newton	Middlesex	42.337	-71.2093	90700	-0.006642165	-0.0610096	-0.737280318	-5.033292037	5.087004128	Yes
Revere	Suffolk	42.4084	-71.0096	60702	0.064757835	0.1386904	7.188119682	11.44195796	13.51249298	Yes
Somerville	Middlesex	42.3876	-71.0995	82149	0.043957835	0.0487904	4.879319682	4.025207963	6.32535056	Yes
Waltham	Middlesex	42.3764	-71.2356	65849	0.032757835	-0.0873096	3.636119682	-7.203042037	8.068778155	Yes
Watertown	Middlesex	42.3639	-71.1955	35270	0.020257835	-0.0472096	2.248619682	-3.894792037	4.497298687	Yes
Wellesley	Norfolk	42.2833	-71.2667	31242	-0.060342165	-0.1184096	-6.697980318	-9.768792037	11.84450245	Yes
Weston	Middlesex	42.3667	-71.3	11827	0.023057835	-0.1517096	2.559419682	-12.51604204	12.77505136	Yes
Winchester	Middlesex	42.45	-71.1333	23953	0.106357835	0.0149904	11.80571968	1.236707963	11.87031861	Yes
Winthrop	Suffolk	42.3724	-71.0142	18739	0.028757835	0.1340904	3.192119682	11.06245796	11.5138006	Yes
Total population within our Newton drone hub coverage area					**1724123**					

Western Region Coverage Area Calculation:

H_W	Springfiled	42.1015	-72.5898								
City	COUNTY	Latitud	Longitu	Regio	Populati	Δ Latitude (deg)	Δ Longitude (d	111* Δ Latitu	82.5*Δ Longitu	Distance from Hub (k	Within Coverage?
Springfield	Hampden	42.1015	-72.5898	Western	154888	0	0	0	0	0	Yes
Chicopee	Hampden	42.1605	-72.5788	Western	55381	0.059	0.011	6.549	0.9075	6.611577516	Yes
Holyoke	Hampden	42.2038	-72.6189	Western	37838	0.1023	-0.0291	11.3553	-2.40075	11.60631029	Yes
West Springfield	Hampden	42.1096	-72.6319	Western	29028	0.0081	-0.0421	0.8991	-3.47325	3.587735549	Yes
Agawam	Hampden	42.0667	-72.6333	Western	28749	-0.0348	-0.0435	-3.8628	-3.58875	5.272603759	Yes
Ludlow	Hampden	42.1167	-72.4667	Western	21118	0.0152	0.1231	1.6872	10.15575	10.29494545	Yes
East Longmeadow	Hampden	42.0333	-72.5	Western	16515	-0.0682	0.0898	-7.5702	7.4085	10.59215749	Yes
Longmeadow	Hampden	42.05	-72.45	Western	15712	-0.0515	0.1398	-5.7165	11.5335	12.87245099	Yes
Wilbraham	Hampden	42.0833	-72.4167	Western	14663	-0.0182	0.1731	-2.0202	14.28075	14.42293412	Yes
Total population within our Springfield drone hub coverage area						373892					

Central Region Coverage Area Calculation:

H_C	Worcester	42.3181	-71.8405	Input Data	Average Speed	60KM/HR	1 MIN				
					KM Per 1 degree latitude	111					
					KM Per 1 degree Longitutde	82.5					
City	COUNT	Latitud	Longitu	Regio	Population	Δ Latitude (d	Δ Longitude (d	111* Δ Latitu	82.5*Δ Longitu	Distance from Hub (k	Within Covera
Auburn	Worcester	42.2167	-71.8333	Central	17323	-0.101358333	0.007193333	-11.250775	0.59345	11.26641562	Yes
Barre	Worcester	42.4	-71.8	Central	5631	0.081941667	0.040493333	9.095525	3.3407	9.689625974	Yes
Boylston	Worcester	42.3667	-71.7333	Central	5064	0.048641667	0.107193333	5.399225	8.84345	10.36138207	Yes
Charlton	Worcester	42.2167	-71.9	Central	13606	-0.101358333	-0.059506667	-11.250775	-4.9093	12.27522564	Yes
Grafton	Worcester	42.2333	-71.7	Central	20352	-0.084758333	0.140493333	-9.408175	11.5907	14.92843204	Yes
Holden	Worcester	42.35	-71.8333	Central	20326	0.031941667	0.007193333	3.545525	0.59345	3.594847761	Yes
Leicester	Worcester	42.2667	-71.85	Central	11224	-0.051358333	-0.009506667	-5.700775	-0.7843	5.754473224	Yes
Northboro	Worcester	42.3	-71.6667	Central	15867	-0.018058333	0.173793333	-2.004475	14.33795	14.47738686	Yes
Oakham	Worcester	42.4	-71.9667	Central	1914	0.081941667	-0.126206667	9.095525	-10.41205	13.82531592	Yes
Paxton	Worcester	42.3333	-71.85	Central	5043	0.015241667	-0.009506667	1.691825	-0.7843	1.864778357	Yes
Princeton	Worcester	42.4167	-71.9167	Central	3597	0.098641667	-0.076206667	10.949225	-6.28705	12.62586733	Yes
Rutland	Worcester	42.3667	-71.8667	Central	9637	0.048641667	-0.026206667	5.399225	-2.16205	5.816020186	Yes
Sterling	Worcester	42.4167	-71.7833	Central	8310	0.098641667	0.057193333	10.949225	4.71845	11.92263807	Yes
West Boyls	Worcester	42.3833	-71.7833	Central	7938	0.065241667	0.057193333	7.241825	4.71845	8.643367384	Yes
Worcester	Worcester	42.2652	-71.8018	Central	211286	-0.052858333	0.038693333	-5.867275	3.1922	6.679450334	Yes
	Total population within our Worcester drone hub coverage area						357118				

Result:

Hub / Region	Total Population Covered (≤ 15 km)
Eastern (Newton)	1,724,123
Western (Springfield)	373,892
Central (Worcester)	357,118

Newton's hub covers approximately 1,724,123 residents, making it by far the highest-impact location and confirming Eastern MA as the core demand center. Springfield and Worcester each cover roughly 373,892 and 357,118 people, respectively, ensuring that Central and Western MA still receive solid regional coverage even though these areas are less dense.

Volume Estimates for Drone Deliveries

To convert coverage populations into operational volumes, we applies the following assumptions:

- 20% of residents in the coverage zone place at least one Amazon order per week.
- 10% of those weekly orders are drone-eligible (lightweight items suitable for drone delivery).

Under these assumptions, weekly orders were calculated as 20% of the covered population, drone-eligible orders are 10% of those weekly orders, and daily drone volume is the drone-eligible weekly volume divided by 7.

Region / Hub	Total Population Covered	Weekly Orders (20%)	Drone-Eligible (10%)	Daily Drone Volume
Eastern (Newton)	1,724,123	344,825	34,482	4,926
Western (Springfield)	373,892	74,778	7,478	1,068
Central (Worcester)	357,118	71,424	7,142	1,020

For Newton, this translates to roughly 344,825 Amazon orders per week within the coverage area. About 10% of these (34,482 orders) are assumed to be drone-eligible, corresponding to an average daily drone volume of roughly 4,926 deliveries per day.

In Western MA, the Springfield hub generates approximately 74,778 weekly orders, of which around 7,478 are drone-eligible, resulting in roughly 1,068 drone deliveries per day. The Worcester hub in Central MA produces about 71,424 weekly orders and 7,142 drone-eligible orders, or approximately 1,020 drone deliveries per day.

These volumes suggest that the Newton hub will require the highest drone capacity and operational resources, while Worcester and Springfield can operate with smaller but still meaningful fleets that support regional demand.

Coverage at 5, 10, and 15 Minutes

We can also express coverage in terms of time-based service levels. Assuming an average drone speed of 60 km/h:

- 5 minutes - (5/60) * 60 = 5 km radius.
- 10 minutes - (10/60) * 60 = 10 km radius.
- 15 minutes - (15/60) * 60 = 15 km radius.

Using these radius, we counted how many people live within 5 km, 10 km, and 15 km of each hub. The resulting coverage by region is summarized below.

Region / Hub	<= 15 km (15 min)	<=10 km (10 min)	<=5 km (5 min)
Eastern (Newton)	1,724,123	1,299,920	220,381
Western (Springfield)	373,892	183,916	25,369
Central (Worcester)	357,118	268,046	265,454

In Eastern MA, Newton can reach about 1,299,920 residents within 10 km and 220,381 residents within just 5 km, indicating a very dense core market immediately around the hub. In contrast, Springfield and Worcester display a more gradual drop-off in coverage from 15 km to 10 km and 5 km, reflecting the more dispersed settlement patterns in Western and Central MA.

From a service design standpoint, these time-based coverage numbers reinforce the conclusion that Newton should be equipped as the primary high-frequency hub, while Worcester and Springfield are positioned to guarantee acceptable delivery times for peripheral regions without attempting to match the Eastern hub's throughput.

3. Huff’s Gravity Method

The purpose of this analysis was to use the Huff gravity model to estimate how customer demand for drone deliveries in Massachusetts is allocated across three proposed drone hubs. The hubs are located in Newton (Eastern MA), Worcester (Central MA), and Springfield (Western MA). Instead of assuming that each county is always served by the nearest hub, the Huff model combines both hub attractiveness (size) and distance to produce probabilistic market shares for each hub.

$$\boxed{E_{ij} = P_{ij}C_i = \frac{S_j/T_{ij}^a}{\sum_j S_j/T_{ij}^a}\,C_i}$$

- Ci – population (demand) in county *i*
- S_j – size/attractiveness of hub *j* (regional weight)
- T_{ij} – distance/time from county *i* to hub *j*
- a – distance-decay factor (how strongly distance hurts attractiveness)
- P_{ij} – probability that county *i* uses hub *j*
- E_{ij} – expected number of people from county *i* served by hub *j*

Huff’s Gravity Method Formula

Data and Hub Attractiveness (Size) Calculation

The Huff model is applied at the county level. Each county is treated as a demand point with a known population and a geographic centroid (latitude and longitude). Across all counties, the total population in the dataset is 6,991,852 people.

Before running the Huff model, we need a "size" or attractiveness parameter S_j for each hub j. These hub sizes were derived from a separate multi-criteria analysis (shown in excel) where each county was assigned a composite weight based on population, median income, urban score, median age, and broadband access.

At the county level:

- **Population** – higher population increases the county’s weight.
- **Median income** – higher income suggests stronger online purchasing power.
- **Urban score** – more urban counties are more likely to generate dense, drone-suitable demand.

- **Broadband access** – better connectivity supports more online ordering.
- **Median age** – counties with a stronger working-age population are favored slightly more than very old populations.

These factors are combined into a single composite county weight W_i (stored in the Weight column). For example, Essex County (Eastern region) has population 804,598, median income 99,431 USD, urban score 2, median age 42, broadband score 3, and a resulting composite weight of 521,110.9.

To obtain the hub-level size parameters S_j, we summed the county weights over the counties assigned to each region. This yields the following regional totals, which are then used directly as the hub sizes:

Region / Hub	Sum of County Weights (ΣW_i)	Hub Size S_j used in Huff
Eastern - Newton hub	4,384,112.880	4,384,112.880
Central - Worcester hub	856,858.000	856,858.000
Western - Springfield hub	1,538,016.357	1,538,016.357

As seen above, the hub sizes S_j used in the Huff model are exactly equal to the sum of county weights for the region that each hub serves. In other words, Newton inherits the total attractiveness of all Eastern counties, Worcester inherits Central, and Springfield inherits Western Massachusetts.

Step-by-Step Procedure with Numerical Example

The Huff model estimates, for every county–hub pair, the probability that customers in that county will choose a given hub for drone deliveries. The key variables are:

- **C**i: population (demand) in county i. For example, Barnstable County has C_i = 227,942 people.

- **S**j: attractiveness (size) of hub j, equal to the regional weight sum. For example, the Newton hub has S_Newton = 4,384,113, Worcester has S_Worcester = 856,858, and Springfield has S_Springfield = 1,538,016.
- **T**ij: distance in miles between county i and hub j. For Barnstable County, the distances are: T_Newton = 101.40 miles, T_Worcester = 149.50 miles, and T_Springfield = 204.19 miles.
- **a** (distance decay exponent): we set a = 2, so attractiveness declines with the square of distance.

Step 1 – Compute distances from each county to each hub

For each county i and each hub j, the distance T_ij is calculated from latitude/longitude and expressed in miles. For Barnstable County specifically, the distances are: T_Newton = 101.40, T_Worcester = 149.50, T_Springfield = 204.19 (see T_Newton, T_Worcester, and T_Springfield columns).

Computing county–hub attractiveness (gravity utility)

The Huff model assumes that hub attraction increases with hub size S_j and decreases with distance T_ij. For each county–hub pair, a raw attractiveness (utility) value is calculated as:

Attr_ij = S_j / (T_ij^a)

For Barnstable County, plugging in the actual numbers for each hub gives:

Attr_(Barnstable, Newton) = 4,384,113 / (101.4023^2) = 426.370
Attr_(Barnstable, Worcester) = 856,858 / (149.4988^2) = 38.338
Attr_(Barnstable, Springfield) = 1,538,016 / (204.1911^2) = 36.888

The total attraction across all three hubs for Barnstable County is the sum of these values:

$$Attr\_sum\_(Barnstable) = 426.370 + 38.338 + 36.888 = 501.596$$

Normalize attractiveness to obtain Huff probabilities

For each county i, we converted the raw attraction values into probabilities by dividing each Attr_ij by the total attraction sum for that county:

$$P\_ij = Attr\_ij / Attr\_sum\_i$$

For Barnstable County, this yields:

$$P\_(Barnstable, Newton) = 426.370 / 501.596 = 0.850026$$

$$P\_(Barnstable, Worcester) = 38.338 / 501.596 = 0.076433$$

$$P\_(Barnstable, Springfield) = 36.888 / 501.596 = 0.073542$$

This means approximately 85.0% of Barnstable County's drone demand is allocated to the Newton hub, 7.6% to Worcester, and 7.4% to Springfield.

Compute expected demand by county–hub pair

The expected number of people from county i served by hub j is obtained by multiplying the Huff probability by the county population:

$$E\_ij = P\_ij \times C\_i$$

For Barnstable County, we calculated:

E_(Barnstable, Newton) = 0.850026 × 227,942 = 193,756.56
E_(Barnstable, Worcester) = 0.076433 × 227,942 = 17,422.22
E_(Barnstable, Springfield) = 0.073542 × 227,942 = 16,763.22

Across the three hubs, the values E_ij sum back to approximately the original county population (227,942), confirming that the probability distribution is consistent.

Aggregate expected demand by hub

Finally, the expected demand E_ij is aggregated over all counties for each hub. This yields the total expected population served by each hub:

Hub	Total Expected Population Served	Eij (%)
Newton	5,058,496	72.35
Worcester	1,094,539	15.65
Springfield	838,818	12.00

The three hubs together serve a total expected population of 6,991,852 people, which matches the total Massachusetts population in the dataset.

Interpretation of Huff Model Results

The Huff model results clearly show that the Newton hub dominates demand allocation. With an expected 5,058,496 people assigned, Newton captures approximately 72.3% of statewide demand. This reflects both its high attractiveness score (S_Newton ≈ 4.38 million) and its proximity to the most populous and urbanized counties in Eastern Massachusetts.

The Worcester hub serves an expected 1,094,539 people, corresponding to a market share of around 15.7%. Worcester primarily attracts demand from central counties that are closer to Worcester than to Newton, while still losing some share to Newton in overlapping influence areas because Newton's regional size parameter is much larger.

The Springfield hub serves an expected 838,818 people, or about 12.0% of total demand. Springfield predominantly serves Western Massachusetts counties such as Hampden and Berkshire, but Newton still captures a small fraction of demand even in the West due to its larger regional size.

Operationally, these results imply that the Newton (Eastern) hub should be designed as the primary high-capacity drone facility in the network, with the greatest investment in drone fleet size, automation, and redundancy. Worcester and Springfield act as critical regional hubs that ensure service coverage and reasonable delivery times for Central and Western Massachusetts, but they handle a smaller share of total statewide demand.

It is also important to note that the Huff model does not propose hub locations; instead, it evaluates the relative attractiveness and demand capture of a set of candidate hubs. In this project, the hub locations were first identified using center-of-gravity and multi-criteria scoring. The Huff model was then used as a second step to quantify how effectively these hubs cover demand and to estimate the market share and expected workload of each facility.

RECOMMENDATION AND PLAN OF ACTION

Our analysis across the four dimensions, commercial viability, drone technological constraints, population-driven demand, and geospatial optimization, points convincingly toward a **three-hub statewide network** anchored in **Newton, Worcester, and Springfield**. This configuration consistently performs best across Center of Gravity modeling, coverage ratios, and the Huff gravity model, balancing both operational feasibility and customer accessibility.

Adopt the Three-Hub Structure as the Foundational Network

The evidence strongly supports establishing the following hubs:

Newton: The Primary Mega-Hub

Newton overwhelmingly dominates demand attraction, capturing over 72% of statewide drone-suited demand. Its proximity to Boston, Cambridge, Somerville, and the high-income suburban belt makes it the economic and demographic core of Massachusetts.
Operationally, Newton will absorb nearly 5,000 drone deliveries per day, requiring:

- the largest drone fleet,
- the most charging infrastructure,
- high automation in package handling,
- redundancy for weather and peak-load periods.

Newton should therefore anchor the statewide network and be the first facility developed.

Worcester: The Central Stabilizing Hub

Worcester naturally emerges as the gravity center of Central Massachusetts. It captures 100% of Central-region demand under the Huff model and provides efficient routing between the East and West.
Its role is twofold:

- Serve regional customers within 15–20 km
- Offload and balance peak flows from Newton

Worcester supports around 1,000 drone deliveries/day, making it a medium-capacity but essential hub.

Springfield: The Western Anchor Hub

Although the Western COG fell between Northampton and Springfield, actual demand concentration, urban density, and accessibility strongly favor Springfield. It captures 88% of Western demand, covering nearly 374,000 residents within 15 minutes in the Pioneer Valley.

Springfield ensures:

- equity of service across the state,
- reduced road miles in rural areas,
- a scalable platform for future micro-hubs in Amherst, Northampton, and Holyoke.

Together, the three hubs maximize statewide reach while minimizing redundancy and excessive operational overlap.

Phased Deployment Roadmap

A phased deployment sequence ensures cost discipline, operational maturity, and regulatory safety.

Phase 1: Launch Newton as the Flagship Hub

- Secure local zoning and FAA permissions for autonomous operations.
- Build out high-capacity charging pads and battery swap lines.
- Begin service in Boston, Cambridge, Brookline, Somerville, Waltham, and Arlington.
- Use Newton as the *learning environment* to refine flight routing, customer communication, exception handling, and weather protocols.

This phase unlocks immediate access to over 70% of drone-suited demand, giving Amazon the fastest path to utilization and ROI.

Phase 2: Deploy Worcester to Expand Statewide Reach

- Extend operational footprint to Central MA residents and businesses.
- Reduce the load on Newton by absorbing volume from the west.

- Implement cross-hub balancing algorithms to reposition drones intelligently.

Worcester strengthens network resilience and enables time-bound promises across the state.

Phase 3: Deploy Springfield to Complete the Statewide Network

- Establish the Western hub to support medium-density areas with longer baseline delivery times.
- Begin serving Springfield, Holyoke, Chicopee, Westfield, Amherst, and Northampton.
- Use Springfield as the pilot region for rural-service optimization and weather-resilience modeling.

This phase ensures that all major Massachusetts counties, urban, suburban, and rural, benefit from fast aerial delivery.

LIMITATIONS AND FURTHER SCOPE

While the current analysis establishes a strong foundation for selecting optimal drone hub locations in Massachusetts, several avenues remain for expanding the model to increase operational realism, strategic accuracy, and long-term scalability. The next phase of this work should integrate more granular datasets and advanced modeling techniques to transition from a high-level feasibility study into a detailed operational deployment plan.

A primary opportunity for expansion lies in incorporating **fine-grained order-level demand data**. Our current approach uses population, income, broadband access, age distribution, and urbanization as proxies for e-commerce activity. While highly correlated, these indicators do not fully capture the variability of Amazon's actual order density at the ZIP-code or neighborhood level. Integrating real Prime order volumes would allow precise estimation of drone traffic per hub, peak-period load, fleet sizing, battery cycle requirements, and staffing needs. This type of demand calibration would also support dynamic routing simulations and allow Amazon to quantify the value uplift of each proposed hub with far greater precision.

Future scope should also include **GIS-based airspace and terrain modeling**. The present analysis assumes radial coverage distances based on ideal flight paths, but actual drone operations must consider no-fly zones around airports, hospitals, schools, and sensitive areas; vertical obstacles such as high-rises; terrain variations in Western Massachusetts; and natural barriers like the Charles River. Incorporating these constraints through geospatial corridor analysis would enable more accurate service maps and support regulatory submissions for Beyond Visual Line of Sight (BVLOS) operations.

Another important direction is developing a **comprehensive cost and financial optimization layer**. Although our hub selections prioritize demand and accessibility, real-world decisions must balance capital expenditure, land availability, infrastructure costs, labor requirements, and ongoing operational expenses such as battery replacements, electricity, and maintenance. A cost-weighted optimization model could reveal whether certain suburban towns offer significantly lower land or permitting costs compared to nearby zones while still retaining strong coverage potential. It could also identify where micro-hubs become economically attractive once initial deployment stabilizes.

Future work should further explore **regulatory and environmental integration**. Massachusetts presents unique regulatory challenges due to its dense urban airspace near Boston and highly variable weather patterns in the winter months. Modeling seasonal performance (such as reduced range due to cold temperatures or wind restrictions along the coast) will help determine how much buffer capacity each hub requires. Additionally, proactive modeling of noise, privacy, and community-acceptance dynamics can assist Amazon in selecting hub locations that minimize resident pushback.

Finally, there is significant scope for investigating **multi-tier network architectures**. While the present analysis recommends three primary hubs, future phases may evaluate the addition of micro-hubs or drone depots in high-demand pockets like Cambridge, Quincy, Lowell, Amherst, and coastal communities. Such a layered structure could enable shorter flight distances, redundancy during weather disruptions, and faster adoption as SKU eligibility expands.

Overall, these future enhancements will deepen the analytical rigor of the model and prepare Amazon Prime Air for full-scale deployment. By integrating operational constraints, regulatory realities, cost structures, and real-time demand insights, Amazon can evolve from conceptual hub planning to a robust, data-driven statewide drone delivery strategy.

REFERENCES

1. Amazon. (2023). *Amazon Prime Air drone delivery overview*. https://www.amazon.com/gp/help/customer/display.html?nodeId=T3jxhuvPfQ629BOIL4
2. Bureau of Labor Statistics. (2024). *Consumer spending and e-commerce trends*. U.S. Department of Labor. https://www.bls.gov/
3. Massachusetts Office of Geographic Information (MassGIS). (2023). *County boundaries, population density, and geographic datasets*. https://www.mass.gov/orgs/massgis-bureau-of-geographic-information
4. U.S. Census Bureau. (2023). *American Community Survey (ACS): Population, income, median age, and broadband access*. https://www.census.gov/programs-surveys/acs/
5. U.S. Census Bureau. (2023). *State and County QuickFacts- Massachusetts*. https://data.census.gov/
6. U.S. Department of Transportation. (2024). *Drone flight guidelines, airspace restrictions, and no-fly zones*. Retrieved from https://www.transportation.gov/
7. Goldman Sachs Research. (2023). *Drones: The future of last-mile logistics*. https://www.goldmansachs.com/insights/
8. McKinsey & Company. (2022). *The future of autonomous last-mile delivery*. https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights
9. PwC. (2023). *E-commerce growth and logistics transformation*. https://www.pwc.com/
10. Statista. (2024). *U.S. e-commerce share of retail sales 2012–2024*. https://www.statista.com/statistics/534123/e-commerce-share-of-retail-sales-us/
11. National Renewable Energy Laboratory (NREL). (2022). *Battery performance and environmental impacts for small UAVs*. https://www.nrel.gov/