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# Locating Electrified Aircraft Service to Reduce Urban Congestion

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**Abstract:** The relentless expansion of urban populations and the surge in e-commerce have increased the demand for rapid delivery services, leading to an increase in truck traffic that contributes to urban congestion, environmental pollution, and economic inefficiencies. The critical challenge this poses is not only in managing urban spaces efficiently but also in aligning with global sustainability goals. This study addresses the pressing need for innovative solutions to reduce reliance on truck transportation in congested urban areas without compromising the efficiency of freight delivery systems. This study contributes a novel approach that leverages electrified and autonomous aircraft (EAA) cargo shuttles to shift the bulk of air transportable freight from road to air, specifically targeting underutilized airports and establishing vertiports in remote locations. By applying data mining techniques to analyze freight flow data, this research identifies key commodity categories and metropolitan statistical areas (MSAs) where the implementation of EAA services could significantly mitigate truck-induced congestion. The findings reveal that targeting a select few commodities and MSAs can potentially decrease truck traffic, with electronics emerging as the dominant commodity category, and cities like Los Angeles and Chicago as prime candidates for initial EAA service deployment. Stakeholders in urban planning, transportation logistics, and environmental policy will find this study's insights beneficial. This work lays a foundation for future innovations in sustainable urban mobility and logistics.

**Keywords:** aircraft electrification; autonomous aircraft; autonomous trucks; eVTOL; freight forwarders; regional airports; sustainable cities; truck traffic; vertiports



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## 1. Introduction

Urban areas across the globe are grappling with the dual challenges of escalating population densities and a budding e-commerce sector. These trends have significantly increased the demand for rapid delivery services, contributing to an unsustainable surge in truck traffic on urban roadways [1]. This situation worsens urban congestion, leads to increased greenhouse gas emissions, and imposes substantial economic costs due to delays and inefficiencies in freight delivery systems [2]. As urban centers continue to grow, the imperative to find innovative solutions that can alleviate congestion while ensuring the efficient movement of both goods and people becomes increasingly urgent.

Shippers have long recognized air cargo as a vital mode of transport for time-sensitive and high-value goods [3]. Over the past two decades, the volume of air freight has doubled, highlighting its critical role in global trade and supply chain management [4]. However, the reliance on trucks to move cargo between airports and logistical centers for final delivery often compromises the efficiency of air cargo [2]. This reliance contributes to congestion around key trade gateways, including airports, seaports, and border crossings, thereby undermining the potential benefits of air freight [5].

This research proposes an approach to address these challenges by integrating electrified and autonomous aircraft (EAA) cargo shuttles into urban freight systems. EAA are emerging as a clean alternative to regional cargo aircraft that can carry thousands of pounds hundreds of miles [6]. Hence, the main idea is to incorporate EAA to connect airports and other trade gateways with multimodal logistical centers located outside of urban areas. These logistical centers can be underutilized airports and newly established regional and urban vertiports that can facilitate middle-mile and last-mile connections that utilize other modal options, including rail and trucks. This strategy aims to divert a significant portion of truck traffic away from congested urban centers.

Figure 1 illustrates the proposed concept. Unlike conventional trucks, EAA offer the advantage of bypassing ground traffic and infrastructure constraints, significantly reducing transit times for time-sensitive shipments. In comparison to high-speed rail at airport terminals, EAA provide greater flexibility in terms of deployment locations and do not require extensive infrastructure, which can be prohibitively expensive and time-consuming to construct. The expense of high-speed rail infrastructure, however, may not be as pronounced in other regions such as Europe where such modes may offer more potential to carry low-weight, high-value cargo [7]. EAA facilities will require planners to overcome the challenges of higher initial investment costs for vertiport infrastructure, the current limitations in battery technology, community acceptance, regulatory restrictions, and resistance from organizations such as labor unions. Despite these challenges, EAA exhibit a lower environmental impact through reduced greenhouse gas emissions and energy consumption, presenting a scalable solution for urban freight transport as technology advances and regulations adapt.

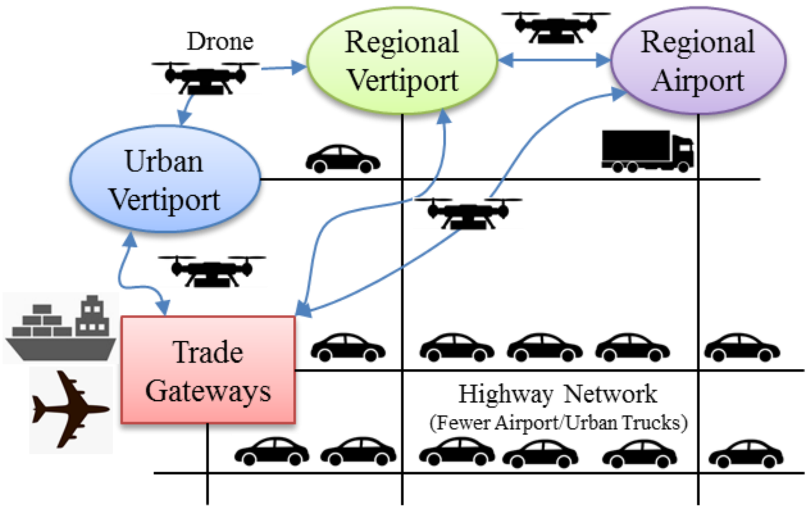


**Figure 1.** Proposed logistics to divert truck traffic away from busy trade gateways.

The adoption of EAA cargo shuttles offers a promising solution to reduce road traffic congestion, lower greenhouse gas emissions, and enhance the efficiency of air freight operations. Employing advanced data mining techniques, this study analyzes freight flow data to identify the commodity categories and metropolitan statistical areas (MSAs) that would benefit most from the deployment of EAA services. The U.S. Office of Management and Budget defines MSAs as geographical regions that consist of an urban core and the surrounding economic area; they are utilized for statistical purposes such as tracking population growth and economic trends [8].

This work contributes to the scholarly discourse on sustainable urban logistics and transportation innovation by offering a novel approach to integrating emerging technologies into existing freight systems. Planners, policymakers, and logistics companies will find the insights invaluable for developing strategies to achieve sustainable urban growth, reduce environmental impacts, and enhance the resilience of supply chains. In advancing this discussion, this work draws on the most recent scholarly academic publications and industry reports to frame the problem, articulate the proposed solution, and substantiate the potential impacts of EAA cargo shuttle deployments. This work not only addresses an immediate challenge facing urban logistics but also sets the stage for future research and innovation in sustainable transportation systems, including impacts on passenger mobility.

The structure of the rest of this paper is as follows: Section 2 reviews the literature on air freight demand, trucking impacts on traffic and the environment, the potential benefits of locating EAA hubs, and future directions to fill gaps. Section 3 describes the methodology to identify the commodity categories and metropolitan areas that would yield the biggest impact with the fewest deployments. Section 4 discusses the results of the analysis and implications for managers and planners. Section 5 concludes the research and suggests future work to inform more microscopic location selection for the proposed hubs.

## 2. Literature Review

The ongoing challenges of urban congestion and inefficiencies in freight delivery systems necessitate a paradigm shift in traditional logistics models. This literature review examines the intricacies of air freight demand, the detrimental impacts of trucking on urban environments, the transformative potential of EAA in revolutionizing cargo shuttle services, and future directions needed for adoption.

The global increase of e-commerce as well as the increased expectations for rapid delivery have propelled air cargo demand to unprecedented levels, highlighting its pivotal role in sustaining global supply chains [9]. Concurrent technological advancements in EAA, such as enhanced battery efficiency, autonomous navigation, and vertical takeoff and landing (VTOL) capabilities, offer a promising avenue to address these demands sustainably [10]. The integration of EAA into cargo operations stands to significantly reduce air freight's carbon footprint, augment operational flexibility, and alleviate the pressure on overburdened ground transportation networks [6]. Electrified aircraft promise a notable reduction in $CO_2$ emissions, noise pollution, and energy consumption compared to conventional truck freight [11]. Electrified propulsion promises to reduce noise pollution, a significant concern around urban freight operations, given the quieter operation of electric motors compared to diesel engines [11]. This transition aligns with global sustainability goals, offering a cleaner alternative that complements urban environmental initiatives.

Detailed quantitative analyses, utilizing life cycle assessment (LCA) methodologies, are necessary to fully understand the environmental benefits and trade-offs of integrating EAA systems into existing logistics networks. The unsustainable environmental, social, and economic impacts of trucks increasingly overshadow their indispensable role in facilitating last-mile delivery [1]. Trucks are major contributors to urban congestion, pollution, and infrastructure degradation, raising significant public health and safety concerns [12]. The industry's struggles with labor shortages and inefficiencies further highlight the urgent need for innovative freight delivery alternatives [13].

Without the need for runways, emerging eVTOL cargo drones can carry more than 500 kg for at least 200 km [14]. Other types of electrified aircraft that do require runways can carry much heavier payloads even farther [15]. Hence, deploying EAA cargo shuttles from underutilized airports and remote vertiports is a viable strategy to circumvent the challenges posed by conventional trucking methods. Such remote facilities could significantly diminish the need for truck movements in congested areas, leveraging EAA efficiencies to enhance freight transport operations [16]. Beyond mitigating congestion and emissions, the shift toward EAA cargo shuttles promises lower logistics costs, bolstered supply chain resilience, and expanded access to isolated communities.

While the potential of EAA cargo shuttles in alleviating urban congestion and enhancing freight system efficiency is compelling, the following are several critical areas that require further exploration to fully realize this potential:

- Comprehensive Data Analysis: A pivotal area for expansion is the broadening of data analytical frameworks to include diverse metrics such as traffic congestion patterns [17], environmental impact assessments [18], and socio-economic ramifications of EAA adoption [19]. A multi-faceted analysis will enable a refined understanding of EAA's benefits and challenges, facilitating informed decision-making.

- Technological Advancements and Regulatory Frameworks: The rapid evolution of EAA technology [6], coupled with the dynamic regulatory landscape [20], necessitates ongoing research into the operational capabilities, safety standards, and airspace management policies governing EAA. Airspace management emerges as a critical concern, necessitating clear guidelines to ensure the safe integration of EAA with manned aircraft and other drones. Regulatory bodies must develop and enforce safety standards specific to autonomous flight operations. Addressing these considerations is crucial for integrating EAA into existing urban freight systems while ensuring public safety and compliance with aviation regulations [21].
- Economic Viability and Impact Analysis: Assessing the economic implications of transitioning to EAA cargo shuttles is vital. This includes analyzing the economic interplay with trucking [22] and considering factors such as infrastructure investment [23], operational costs [24], and potential economic benefits derived from reduced urban congestion and pollution [25].
- Real-world Applications and Pilot Programs: Insights from EAA pilot programs and case studies are invaluable for bridging the gap between theoretical research and practical implementation. Initial pilot deployments emphasize the need for further research into optimizing EAA operational parameters such as payload capacity, energy consumption, and routing algorithms, to fully exploit their potential in urban logistics systems. These real-world examples can highlight operational challenges, scalability issues, and the overall effectiveness of EAA in diverse urban contexts, serving as critical benchmarks for broader adoption [26]. Strategies to address these deployment challenges include engaging stakeholders early in the planning process, phased testing and deployment of EAA services to build public trust, and leveraging public-private partnerships to fund infrastructure and technology development.
- Integration with Urban Logistics Infrastructure: The synergy between EAA and urban logistics infrastructure, such as fulfillment centers, represents a promising avenue for enhancing last-mile delivery efficiency [27]. Investigating the optimal integration of these systems can further reduce reliance on ground transportation and streamline urban freight operations.

The above literature review emphasizes the critical need to address the growing challenges in urban freight transport and the gaps in deploying innovative solutions. Addressing the identified needs and gaps is fundamental to advancing the discourse on EAA cargo shuttles and their role in transforming urban freight systems. Future research should strive for a holistic approach—encompassing technological innovation, regulatory alignment, economic sustainability, and practical feasibility—to pave the way for sustainable urban logistics solutions.

## 3. Methodology

The application of several data mining techniques was central to the methodology employed. The study employed advanced data mining techniques to analyze freight flow data, utilizing a combination of Python scripts and GIS tools for data cleaning and analysis. The input datasets are as follows:

- The freight analysis framework (FAF) data from the Federal Highway Administration (FHWA) [8].
- The commodity flow survey (CFS) geography definitions [28].

The CFS is a joint production of the Bureau of Transportation Statistics (BTS) of the United States Department of Transportation (USDOT) and the United States Census Bureau (USCB) of the Department of Commerce [29]. The CFS primarily covers shipping data from the U.S. mining, manufacturing, and wholesale sectors. The FHWA integrated shipping data from other sectors such as agriculture, extraction, utility, construction, and service to create the FAF dataset [8]. The comprehensive coverage of U.S. freight movements and the granularity of the data regarding commodity types and transportation modes motivated the choice of the FAF and CFS datasets. The authors used the most recent version of these datasets, which was version 5.5, updated in 2024. The FAF used survey data from a 2017 base year to project freight flow out to 2050. The data cleaning addressed challenges encountered in data handling, such as discrepancies in MSA codes between datasets, through meticulous text string matching and manual verification processes. This approach ensured the accuracy of the analysis, enabling the identification of key commodities and MSAs for potential EAA deployment.

A detailed description of the workflow (Figure 2) is as follows:

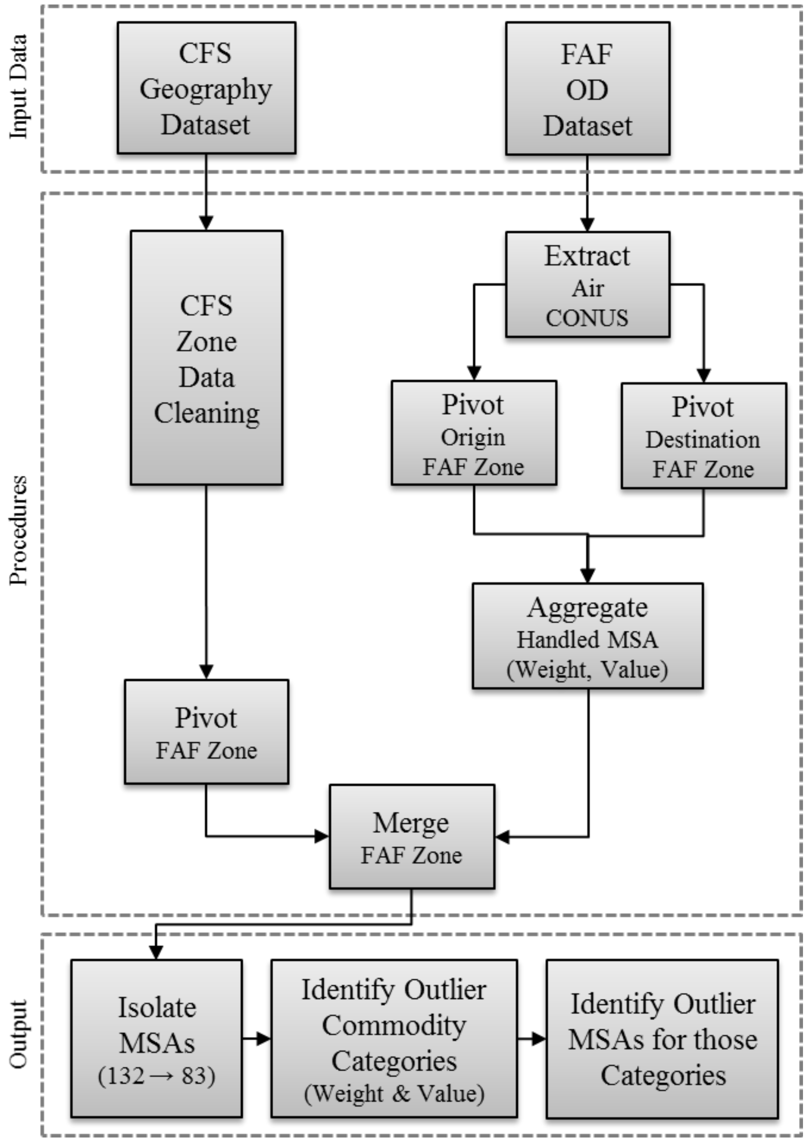


**Figure 2.** Input datasets and analytical workflow.

Initial Data Extraction from the FAF Database: The freight analysis framework (FAF) database (FAF OD Dataset) contained over 1.6 million origin–destination records of various commodity categories moved across 132 FAF zones. The procedure filtered it to extract records relevant to commodities moved by air, resulting in approximately 354,782 records. This step isolated air freight data for a more specific analysis of domestic movements among FAF zones.

Identification of Commodity Categories Moved by Air: Pivot table operations identified 40 commodity categories transported by air within the CONUS. This step helped in focusing on commodities specifically relevant to air transport.

Data Cleaning on the CFS Geography Dataset: The commodity flow survey (CFS) geography dataset underwent a cleaning process that matched area names via text strings to identify and replace 13 unique metropolitan statistical area (MSA) codes that differed from those in the FAF dataset. This step ensured consistency in geographical identifiers across datasets.

Integration with FAF Zones as MSAs: The procedure then merged the cleaned CFS dataset with the FAF dataset, identifying 83 out of 132 FAF zones as MSAs within CONUS. Figure 3 represents these MSAs as polygons, providing a geographical representation of the areas involved in the analyzed air freight movement.

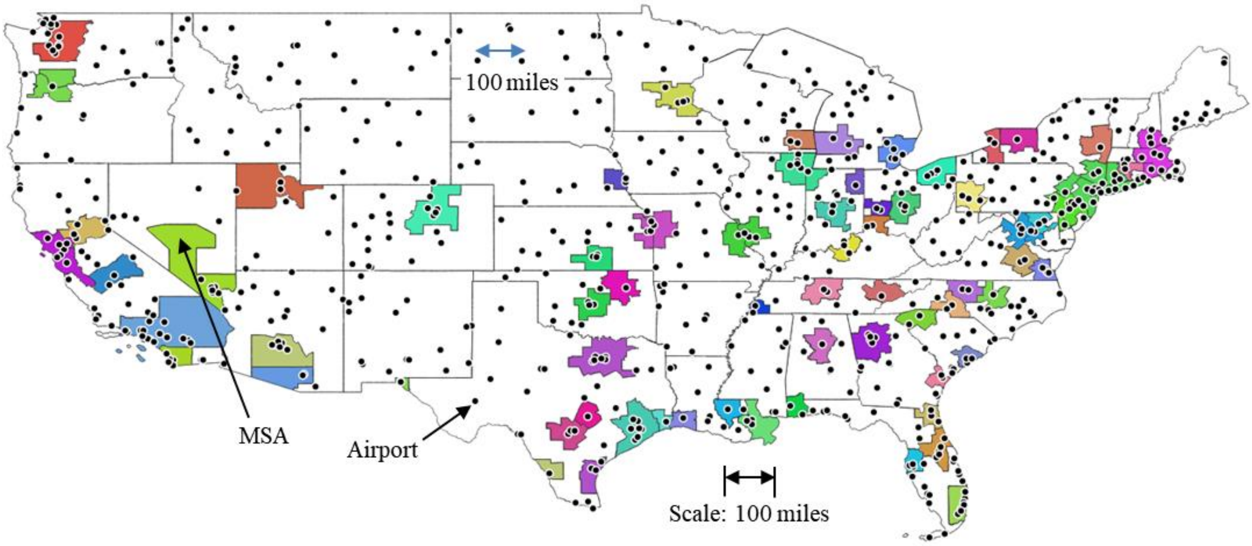


**Figure 3.** Spatial distribution of MSAs and airports.

Analysis of Weight and Value Matrices: Merging the weight and value matrices for the identified commodities and conducting a scatter plot analysis helped in identifying outlier commodity categories moved by air. This step was crucial for understanding the distribution and significance of different commodities in air freight.

Distribution Analysis through Histogram and Matrix Transposition: The procedure conducted a matrix transposition followed by a histogram operation to analyze the distribution of MSAs handling each of the outlier commodity categories. This step provided insights into the geographical spread and concentration of air freight handling capacities across different MSAs.

Ranking of MSAs and Commodity Categories: Finally, by extracting a matrix subset of outlier MSAs and outlier commodity categories, the procedure produced an ordered ranking based on weight. This ranking helped in identifying the most significant MSAs and commodities in terms of air freight volume.

Some of the FAF zones are equivalent to MSAs defined by the United States Census Bureau (USCB), and others are entire states [29]. Using a geographic information system (GIS) tool and shapefile data from the USCB to produce Figure 3 enables a visualization of the relative size and spatial distribution of the MSAs on the contiguous United States (CONUS). The figure also shows the arrangement of the MSAs relative to existing airports. This visualization and scale annotated in the state of North Dakota suggests that most airports are within 100 miles (161 km) of each other. Therefore, existing fleets of eVTOL aircraft with a 200 km range capability can already support the direct transfer of goods within MSAs without using trucks, and between MSAs with multiple hops, if needed.

## 4. Results and Discussions

Figure 4 is a scatter plot with each shaded circle representing an air cargo commodity category moved by both weight and value. The annotations point to each of six outliers; the labels include the FAF commodity category code in parentheses. The cluster in the lower left of the chart comprises overlapping circles of the 34 remaining commodity categories. The category of electronics (35) clearly stands apart from the others. According to the USCB, the electronics category includes items such as cell phones, batteries, electronic entertainment products, electric cooking appliances, computers, office equipment, recorded media, computer software, electronic components, and circuit boards [30]. This finding aligns with a statistic by the International Air Transport Association (IATA) that, every day, airlines around the world transport more than one million smartphones [4].

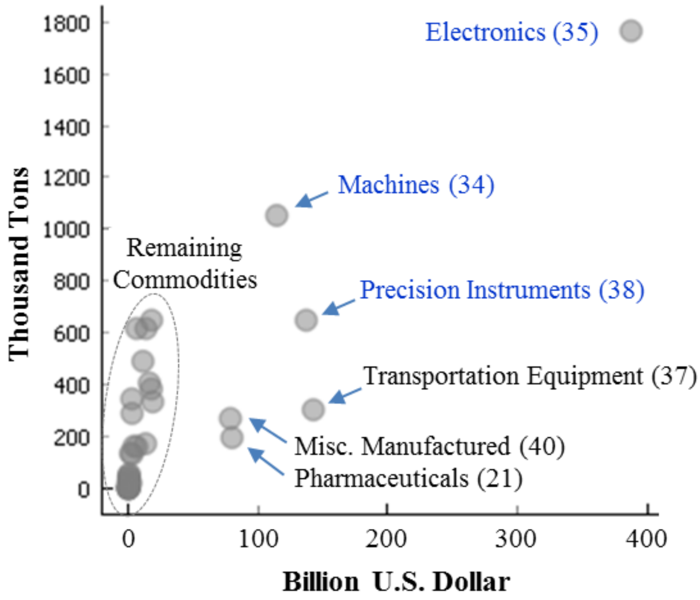


**Figure 4.** Commodity category outliers by weight and value moved by air.

Figure 5 shows the weight histogram of the outlier commodity categories across all MSAs. Each horizontal bar, separated with different colors, represents individual MSAs. The color bar separation helps to visualize the number of individual MSAs accounting for each bin of the weight distribution. That is, a single horizontal bar in a histogram bin represents a single MSA that handled that weight range. For example, Figure 5a indicates that LA (CA) is the only MSA that handled more than 260,000 tons of items in the electronics commodity category. Figure 5b–f show the weight distributions for the respective commodity categories as indicated.

Table 1 summarizes the top commodity categories moved by air and the MSAs that handled them. The last column shows the number of North American semitrailer trucks required to haul that weight through the MSA in 2017. The calculation is based on the maximum allowable *gross* weight for trucks on U.S. Interstates, which is 80,000 pounds or 40 tons [31]. The most common long-haul truck in North America (a combination 5-axle tractor-trailer, 18-wheeler, or big rig) typically pulls a dry van trailer that can carry approximately 45,000 pounds or 22.5 tons of freight without exceeding the gross weight limit [32]. This result suggests that, for example, air shuttling only the outlier commodity categories to and from airports or vertiports outside of the Chicago MSA would have removed 21,299 semitrailer trucks from the traffic stream in 2017.

The potential impact grows each year with the demand to ship those commodities. The six outlier commodity categories accounted for 29.7% of the total weight of all categories moved by air. Figure 6 shows that only 9.7% (top 8 of 82) of the MSAs handled 25% of the total weight of all commodities moved by air. Therefore, focusing EAA cargo service in less than 10% of the MSAs will yield the largest jump in truck traffic removed at those locations. For example, launching EAA cargo shuttle services in the Los Angeles (CA) and Chicago (IL) MSAs will yield a 10% decrease in truck traffic, with diminishing returns after deploying services in the additional MSAs.

**Table 1.** MSA Rank by Weight of Outlier Commodity Categories Moved by Air in 2017.

| MSA | Electronics | Machines | Precision Instruments | Transportation Equipment | Misc. Manufactured | Pharma. | Sum (Thousand Tons) | Semitrailer Equivalent |
|---|---|---|---|---|---|---|---|---|
| Chicago (IL) | 200.1 | 151.3 | 60.7 | 20.5 | 16.5 | 30.3 | 479.2 | 21,299 |
| Los Angeles (CA) | 262.6 | 81.0 | 62.6 | 24.0 | 39.2 | 8.7 | 478.2 | 21,251 |
| San Francisco (CA) | 218.4 | 59.3 | 38.5 | 7.0 | 24.2 | 5.3 | 352.7 | 15,674 |
| Memphis (TN) | 100.2 | 71.2 | 73.4 | 8.7 | 15.0 | 9.9 | 278.3 | 12,371 |
| Louisville (KY) | 124.0 | 77.8 | 39.6 | 7.9 | 16.9 | 6.9 | 273.2 | 12,141 |
| DFW (TX) | 78.9 | 40.6 | 18.6 | 46.2 | 19.9 | 2.7 | 206.9 | 9197 |
| Miami (FL) | 69.9 | 55.5 | 17.4 | 4.8 | 8.3 | 10.2 | 166.0 | 7378 |
| New York (NY) | 54.9 | 41.6 | 16.3 | 3.5 | 16.5 | 4.0 | 136.8 | 6082 |
| Atlanta (GA) | 39.8 | 38.1 | 24.5 | 14.7 | 4.8 | 13.4 | 135.4 | 6016 |
| Seattle (WA) | 31.9 | 18.4 | 10.1 | 57.7 | 6.7 | 3.6 | 128.3 | 5704 |
| Minneapolis (MN) | 22.3 | 15.7 | 82.1 | 1.0 | 3.3 | 2.2 | 126.5 | 5623 |
| Savannah (GA) | 0.8 | 0.7 | 0.5 | 34.6 | 0.1 | 0.1 | 36.8 | 1635 |
| Charleston (SC) | 2.8 | 2.2 | 1.2 | 13.5 | 0.7 | 0.5 | 20.8 | 926 |

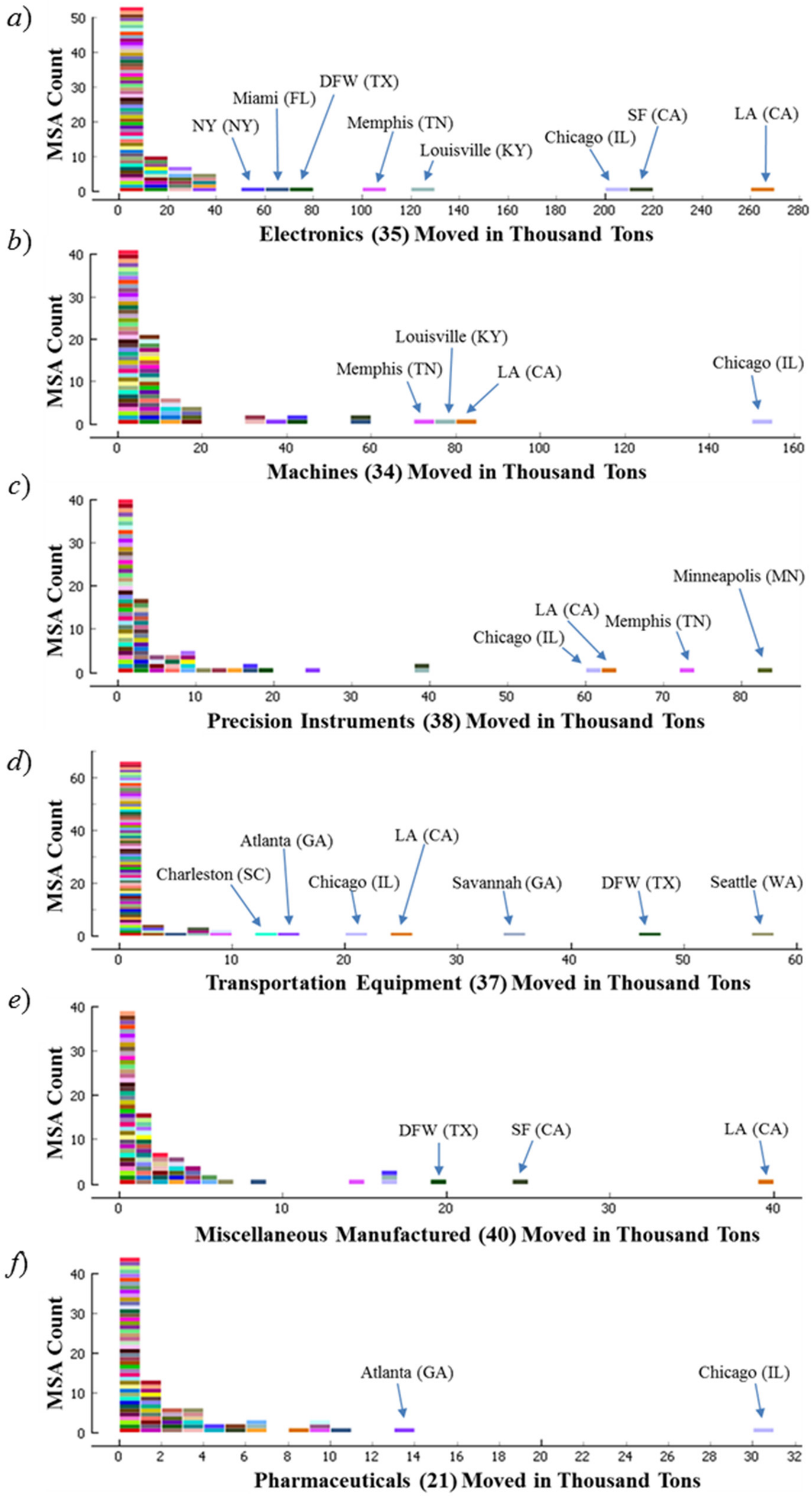


**Figure 5.** Weight histogram of MSAs for the outlier commodity categories moved by air.

With more passenger flights at those locations, the amount of belly cargo will increase, and the impact will become even more pronounced. Analysts found that in 2020 widebody jets at Chicago's O'Hare Airport carried 22% more cargo than the previous year, which was more than at any other major U.S. gateway airport [33]. Shippers will need fewer air cargo shuttles as manufacturers design EAA with much greater cargo capacity.

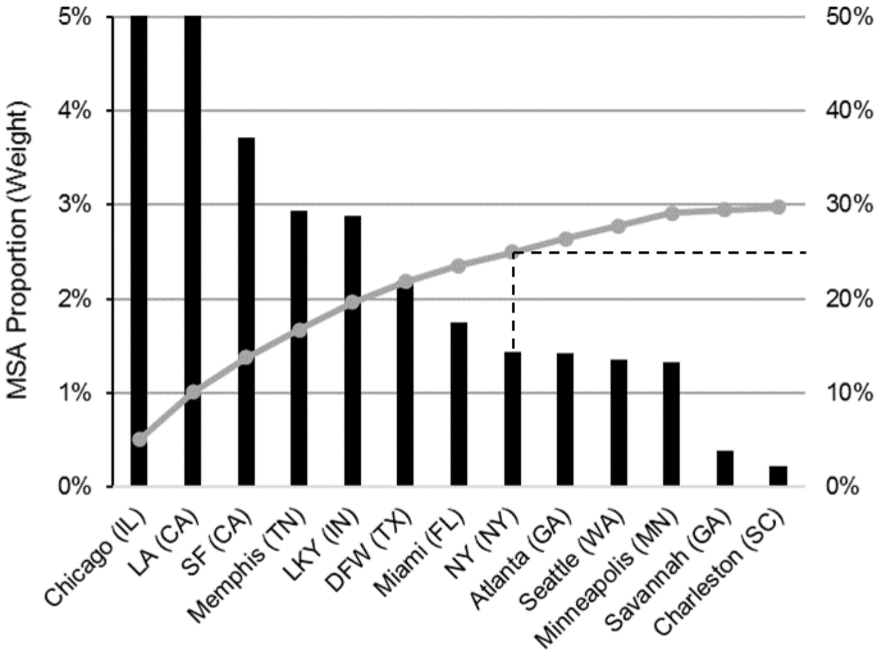


**Figure 6.** MSA impact ranking for EAA cargo service deployments.

The above results offer a compelling case for the integration of EAA into urban freight systems. The identification of outlier commodity categories and MSAs that disproportionately contribute to truck-induced congestion provides a targeted approach to alleviate such urban logistical bottlenecks. The implications of these results are multi-faceted and significant, extending to environmental, economic, and infrastructural domains. The standout position of electronics in air freight is due to their high value-to-weight ratio, making air transport economically viable. Given the rapid growth in technology and the surge in e-commerce, the demand for quick delivery of electronics is likely to continue to rise. EAA could thus play a crucial role in meeting these delivery expectations while reducing road congestion.

The results pinpoint MSAs like Los Angeles and Chicago as prime candidates for EAA deployment. These cities are critical nodes in the freight distribution network due to their substantial economic activities and strategic locations. Implementing EAA cargo shuttles in these areas could significantly reduce the number of trucks on the road, leading to decreased urban congestion and associated negative externalities. The establishment of EAA facilities like vertiports in less congested areas could redistribute freight traffic away from overburdened urban centers. This network of EAA facilities could leverage the unused capacity of regional airports, thus optimizing the existing aviation infrastructure.

There are numerous implications of these results. The use of EAA aligns with global sustainability goals by promising reduced pollutive emissions, including engine noise. By diverting urban freight from trucks to EAA, cities could see improvements in air quality and noise levels, contributing to a healthier urban environment. The adoption of EAA cargo shuttles could yield economic benefits by reducing the cost of freight transportation, stemming from decreased fuel consumption and lower reliance on trucking. Additionally, by alleviating congestion, EAA could also reduce the economic losses associated with delayed deliveries, idle trucks, and truck parking issues. This is an area that future work can address.

The focus on underutilized airports and new vertiport locations presents an opportunity to revitalize certain areas economically. Investments in these areas could spur job creation and infrastructural improvements, further supporting the urban economy. For urban planners and policymakers, these findings highlight the need for adaptive regulatory frameworks that support the safe and efficient integration of EAA into the existing air traffic management systems. Furthermore, policies encouraging investment in EAA infrastructure could accelerate the adoption of this technology. The successful deployment of EAA services would require close collaboration among various stakeholders, including city planners, logistics companies, tribal nations, technology providers, and regulatory bodies. Stakeholder engagement is crucial to addressing the technical, regulatory, and operational challenges associated with the introduction of EAA.

## 5. Conclusions

The findings of this study highlight an emerging transformation in urban freight logistics through the adoption of electrified and autonomous aircraft (EAA). Given the relentless growth in urban populations and the booming e-commerce sector, cities are facing the dual challenge of congestion-induced economic losses and the pressing need to expand air freight capacity. The deployment of EAA cargo shuttles offers a potential to mitigate these challenges by diverting a significant portion of freight from congested roadways to the vast airways. This analysis indicates that by targeting a strategic subset—less than 10%—of metropolitan statistical areas (MSAs) and focusing on six key commodity categories out of 40, this approach could potentially eliminate 25% of the weight that trucks currently transport to and from airports. This reduction not only promises a decrease in truck-induced congestion but also aligns with broader objectives of sustainable urban development by curtailing air and noise pollution.

The advancements in EAA technology, particularly in battery efficiency and cargo capacity, are set to broaden the horizons for air cargo logistics. These technological strides, coupled with the potential to scale EAA designs, pave the way for a more efficient and environmentally friendly logistics infrastructure. Integrating EAA shuttle services to connect critical trade gateways with underutilized airports and urban centers could revolutionize business operations, shifting logistics hubs to more optimal locations that promise lower operating costs and enhanced integration with warehousing and autonomous trucking services.

For this anticipated transformation to achieve global traction, adaptable regulatory frameworks that can evolve with EAA technology will become essential. Furthermore, the path forward should involve cross-sector collaboration and the continuous refinement of technological capabilities. As urban planners and logistics managers seek to harness the insights offered by this study, the robust data mining workflow presented in this study will help them to identify and prioritize MSA locations for future EAA deployments.

Future research will expand to include meticulous economic analyses that weigh the operational costs and efficiencies of EAA against traditional trucking. The objective is to identify specific underutilized airports and prospective vertiport sites within the targeted MSAs, aiming to maximize the logistical benefits anticipated. Moreover, the development of global standards for EAA operations will be essential, as will the exploration of how these new aerial logistics networks can seamlessly interlace with existing and evolving urban logistics infrastructures. This comprehensive approach promises not only to enhance the operational efficiency of air cargo logistics but also to serve as a cornerstone for sustainable urban development.

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