

# Unveiling Barriers in the Clouds: Environmental, Regulatory, and Technical Constraints on UAV Operations in Highland Urban Landscape



## Introduction

Unmanned Aerial Vehicles (UAVs) have garnered considerable attention in recent years due to their integration across diverse industries, including logistics and disaster management. Challenges such as limited accessibility to remote or hazardous locations, and the inability to perform real-time monitoring and situational analysis, have been effectively addressed through the deployment of UAV technologies [1]. Operating UAVs within urban environments presents several challenges and constraints. Regulatory requirements, the presence of numerous obstacles, air pollution, and energy consumption inefficiencies have prompted researchers to investigate methods for optimizing UAV flight routes [1] [2] [3]. Nevertheless, these optimizations may not be directly transferable to UAV operations in highland urban environments due to a variety of additional constraints. Highland urban landscapes were selected because their steep terrain and variable weather create uniquely complex operational conditions. UAVs are used for their flexibility, affordability, and ability to capture high-resolution data in hard-to-reach areas. Other platforms like satellites or manned aircraft lack the needed detail, maneuverability, or cost-effectiveness. This study seeks to systematically identify and analyse these constraints, which are classified into three principal domains: environmental, regulatory, and technical.

## Literature Review

Extensive research has been conducted on route optimization under various conditions and constraints. An optimization framework for UAVs was proposed in [1], wherein trajectory planning is formulated to satisfy energy efficiency and safety constraints. [3] proposes a UAV fleet planning methodology designed to optimize energy efficiency, minimize mission completion time, and facilitate just-in-time replenishment of supplies. [4] presents an approach for optimizing UAV routing within specified time windows, focusing on operations between mobile battery swapping stations (MBSs). [5] examines the use of UAVs for emergency blood distribution in Sri Lanka, comparing them to traditional transport methods, and applies the Capacitated UAV Routing Problem (CUAVRP) to optimize distribution among blood banks. Although prior studies have advanced UAV route optimization across energy, time, and capacity constraints, they largely focus on generalized or lowland environments with stable operating conditions. Little attention has been given to how highland urban landscapes with their complex terrain, microclimates, and regulatory hurdles fundamentally alter UAV performance and routing feasibility. This study addresses that gap by examining how environmental, regulatory, and technical constraints uniquely interact in highland cities, offering insights not captured in existing UAV optimization research.

## Research Methodology

This study adopted a mixed-methods research approach, combining quantitative and qualitative techniques to obtain a comprehensive understanding of the constraints affecting UAV operations in highland urban environments. An online survey was designed and administered to UAV operators, industry professionals, government officials and authorities, and researchers. A purposive sampling method was employed to intentionally target respondents with relevant expertise and experience, ensuring that the data collected would be contextually rich and technically informed. The survey gathered participant perspectives on multiple constraints across three domains: environmental, regulatory, and technical, allowing for broad yet domain-specific insights.

Survey responses were compiled into spreadsheets, with data categorized by domain to support focused quantitative analysis. Textual analysis was then applied to each domain-specific dataset, prioritizing constraints based on their frequency of occurrence. To visually represent the findings, bar charts and word clouds were generated, highlighting the predominant constraints limiting UAV operations in highland urban environments within each domain. Although context-specific, the findings can be extended to other countries with similar highland urban conditions.

## Results and Discussion

The survey link was distributed publicly among UAV operators, industry professionals, government officials and authorities and researchers. A total of 48 participants submitted responses. Figure 1 presents a word cloud visualization of the responses aggregated across all three domains, where the size of each word corresponds to its frequency of occurrence. The word cloud visually highlights the most prominent constraints affecting UAV operations in highland urban environments, with factors such as wind, rain, altitude, and battery limitations appearing most dominant. It also captures a range of secondary but important considerations like communication, air density, navigation, and security zones illustrating the multidimensional challenge of UAV deployment in complex terrains. Subsequently, a domain-specific analysis was performed to identify the primary constraints within each group. The top constraints identified in each domain were considered the key constraint factors. Bar graphs illustrating these findings for each domain are presented in Figures 2, 3, and 4, respectively.

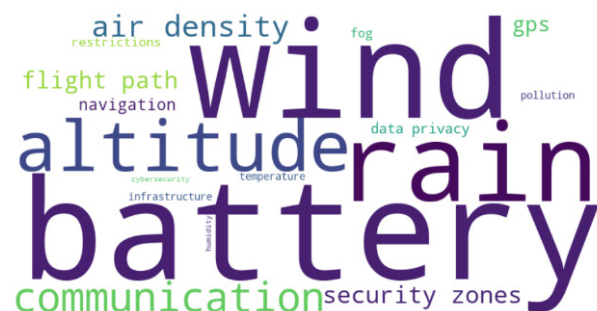


Fig. 1 Word cloud of the survey responses

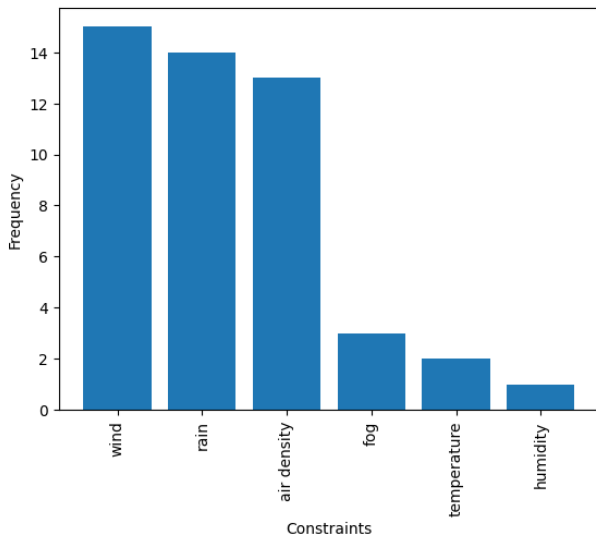


Fig. 2 Environment Constraints

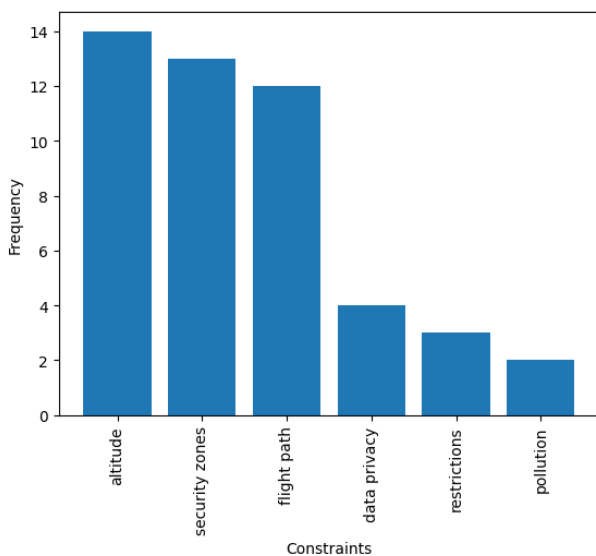


Fig. 3 Regulatory Constraints

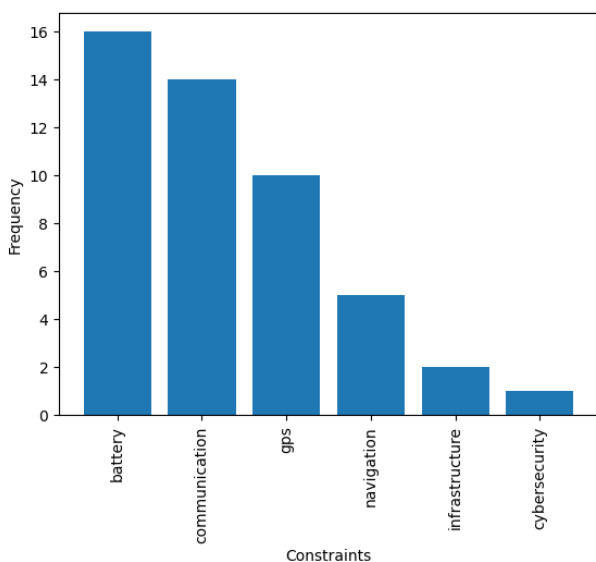


Fig. 4 Technical Constraints

For each domain, top 3 constraints are identified as the key factors.

Environmental:

- Wind – 30%
- Rain – 28%
- Air density – 26%

Regulatory:

- Altitude – 28%
- Security zones – 26%
- Flight path – 24%

Technical:

- Battery – 32%
- Communication – 28%
- GPS – 20%
- 

Environmental factors such as wind speed and direction, rainfall, and air density critically impact UAV operations in highland cities. Accurate environmental data must be integrated into UAV routing algorithms to optimize performance under these conditions. Regulatory constraints, including permissible altitudes, designated flight corridors, and restricted zones, necessitate dynamic route adjustments to ensure compliance, safe navigation, and avoidance of prohibited areas. Technical limitations, including UAV battery capacity, power consumption, communication link reliability, and GPS signal stability, require routing strategies that dynamically manage energy resources, maintain robust connectivity, and address potential navigation inaccuracies in highland environments.

### Conclusion

Extensive research has been undertaken to optimize Unmanned Aerial Vehicle (UAV) route configurations under a range of operational constraints. However, there remains a paucity of studies that specifically address the distinctive challenges posed by highland urban environments. The key constraints identified through existing investigations provide a foundational basis for informing route optimization strategies. This study contributes to theory by clarifying how environmental, regulatory, and technical factors uniquely interact in highland urban landscapes, an area largely overlooked in existing UAV optimization research. Practically, it offers actionable guidance for planners and aviation authorities to design data-driven UAV corridors, altitude protocols, and support in-

frastructure tailored to high-elevation cities. Nevertheless, further comprehensive research is necessary to elucidate the underlying scientific factors inherent to such environments and to develop rigorous methodologies for their effective integration into UAV route planning frameworks. City planners and aviation authorities like DGCA/CAA can collaborate to map UAV micro-corridors and implement dynamic altitude bands tailored to highland cities' unique topography and airspace constraints. Additionally, they can pilot Mobile Battery Swap (MBS) zones at strategic elevations to extend drone range and ensure efficient, compliant UAV operations.

**References:**

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