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Views & Comments

Urban Air Mobility: Confronting the Fundamental Constraints of Urban Space

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1. Fundamental logic of urban spatial scarcity

Urban congestion is an inevitable consequence of finite urban space [1]. Although vehicle capacity can be increased, it often comes at the cost of scarce space. Consequently, urban transport planning hinges on two interrelated tasks: providing accessibility within a limited space and ensuring effective use of the scarce capacity. Three general strategies are typically employed to address this issue: space-efficient modes such as walking, cycling, and transit [2]; compact spatial planning [3]; and utilizing pricing instruments such as congestion charges, parking fees, and peak fares [4–6]. Urban agglomeration generates productivity benefits through proximity [7], and therefore, the same concentration that creates economic value intensifies the competition for limited space. Against this backdrop, the emergence of urban air mobility (UAM) warrants careful examination through the same analytical lens that historically guided successful urban transport policies.

UAM encompasses on-demand aerial transport utilizing electric vertical take-off and landing (eVTOL) aircraft, which is envisioned as a premium point-to-point service carrying two to six passengers between dedicated vertiports. This framework is salient in rapidly urbanizing regions such as China, where high densities and long commuting distances generate strong latent demand. Our analysis focuses on this network-level scenario instead of individual vehicle performance. We adopt the following position: At the network scale, the binding constraint on UAM is neither vehicle performance nor airspace. Instead, it is constrained by the geometry of the central-city land, and consequently, trillion-dollar growth projections [8] abstracted from this geometry are not optimistic but internally inconsistent. The remainder of this study focuses on this condition, examines its falsifiability, and outlines its implications for pricing, equity, and governance.

2. Node capacity and bid-rent structure of UAM demand

UAM expands transport capacity by exploiting a largely unused dimension, that is, urban airspace [9,10]. Airspace corridors pass at different altitudes, and therefore, they are unlikely to become bottlenecks. The theoretical airspace throughput significantly exceeds any plausible short-term demand. However, every UAM journey must begin and end at ground level, which is limited by spatial scarcity. Vehicles require surface space, land, and parking infrastructure. Although rooftop deployment expands the pool of usable sites, it does not mitigate the competition for urban space simply because rooftops are finite, structurally constrained, and subject to competing demands.

This inverts the conventional paradigm of transport constraints. Unlike ground networks that are limited by link capacity, that is, the throughput of roads or rail corridors, UAM systems face negligible link constraints. Instead, node capacity defined as the ability to process arrivals and departures at vertiports is a binding constraint (Fig. 1). The vertiport infrastructure must accommodate landing pads, passenger processing gates, charging stations, and off-peak storage within a limited footprint. Consequently, achieving adequate network coverage requires dozens, potentially hundreds, of vertiport locations [11,12], each competing with housing, commerce, amenities, and legacy infrastructure.

Physical space is not the sole dimension governing node capacity; spectrum allocation, communication latency, and edge computing impose parallel constraints. Although these digital-layer challenges are amenable to technical investments, spatial scarcity is dictated by urban land economics. Engineering improvements in vehicle dimensions, vertiport stacking, or operational tempo can ease these constraints; however, the underlying competition for scarce central city spaces is unlikely to be resolved through technology alone. Therefore, we challenge the common framing in industry roadmaps and emerging policy briefs that treats UAM scaling as a problem to be unlocked by certification, automation, and battery density. The harder ceiling is geographic, and certification milestones cannot lift it.

2.1. Simple numerical illustration

Consider a hypothetical city of five million inhabitants with a central business district (CBD) comparable to inner Paris, generating 50 000 UAM trips per day in a 50 km^2 core. Each trip consumes vertiport capacity at both endpoints, that is, one departure operation at the origin and one arrival at the destination, producing about 100 000 movements per day to be absorbed within the core.

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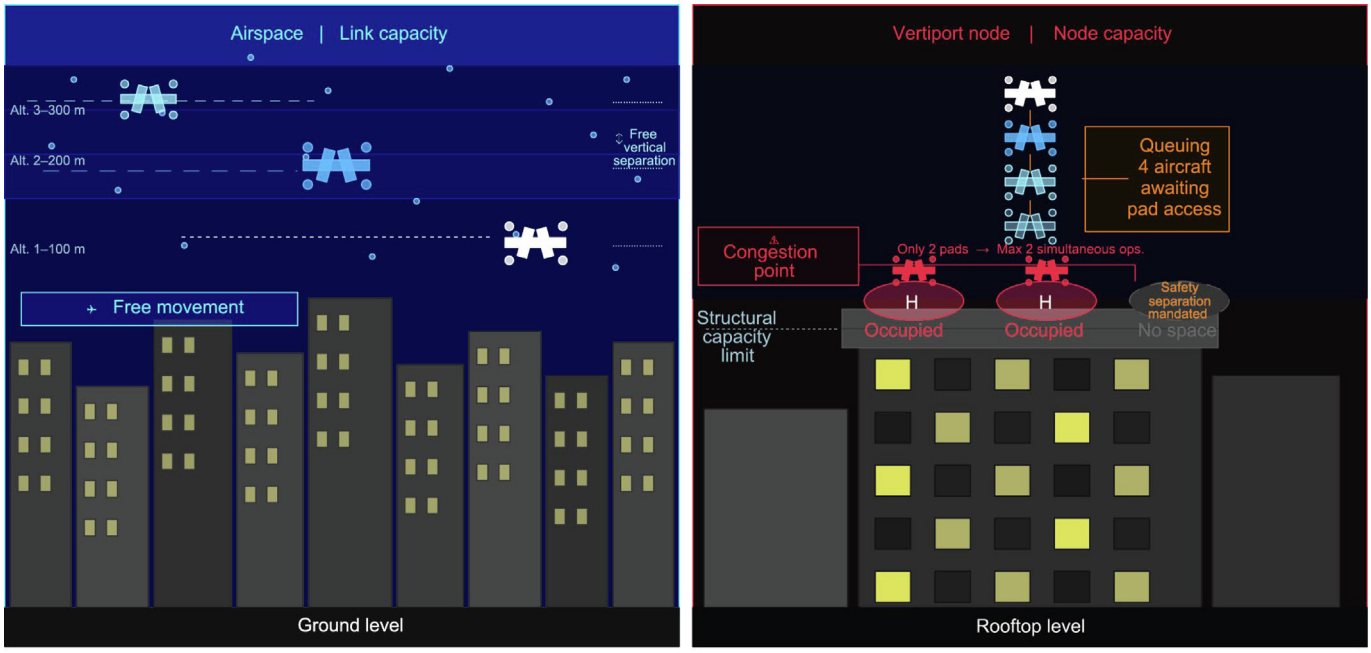


Fig. 1. Schematic of the capacity inversion in UAM systems. (a) Aerial link (airspace), where vertical separation permits simultaneous use of the same horizontal coordinates, enabling throughput to far exceed plausible demand. Alt.: altitude. (b) Vertiport node, where the number of touchdown and lift-off pads, mandatory safety buffers, and structural constraints on candidate buildings impose severely limit simultaneous operations (Ops.). Every UAM journey begins and ends at such a node, and therefore, node capacity and not airspace, binds system performance.

Vertiport throughput is determined by the balance between the touchdown and lift-off (TLOF) pads, which serially handle landings and take-offs, and gates, where aircraft turns around in parallel. For a small-footprint vertiport with one TLOF pad and a throughput-balancing complement of five gates, the modeled maximum is on the order of 24 movements per hour under realistic operational parameters: a 5 min turnaround, 60 s arrival and departure times, and dependent airborne and airside operations [13]. An independent analysis of the vertiport passenger throughput capacity across prominent eVTOL designs reported figures of the same order of magnitude for urban-constrained sites [14]. Sustained over a 16 h operating day, this yields about 380 movements or 190 trip-endings per facility. Meeting the core-area demand under these assumptions would therefore require about 260 vertiports within the 50 km^2 zone, even before accounting for off-peak parking needs, safety buffers, or redundancy.

Even under highly optimistic conditions such as fully independent paired-pad operations, 30 s arrivals and departures, 2 min turnaround times, and 24 h operation, the per-vertiport capacity rises by approximately an order of magnitude. However, the implied facility count remains in the dozens within a single CBD. By contrast, network design studies for analogous metropolitan areas confirm that candidate sites that meet the joint conditions of adequate floor area, structural capacity, and airspace clearance numbers in the tens to hundreds [11,12]. The gap between plausible supply and projected demand is not narrow. In our view, this gap is sufficient to invalidate the mass-transit framing of UAM, confining the mode for the foreseeable future to a premium-priced capacity-rationed service. Although automation can shorten the turnarounds and tighten UAM separation, raising the per-pad ceiling cannot expand the number of pads available at a constrained urban site.

2.2. Bid-rent logic and demand-side feedback

The constraint on raising the number of vertiports is captured by the standard bid-rent theory [15]: Accessibility premiums and land scarcity are jointly determined, which means that locations where UAM can deliver the greatest travel time savings are precisely those where deploying vertiport infrastructure is the most difficult. Consequently, the transport-relevant question is not whether central land is scarce; instead, it is how a capacity-constrained, premium-priced aerial mode can reshape the equilibrium distribution of trips. Three feedbacks deserve quantitative follow-on research: ① mode substitution because UAM draws from premium rails and taxi services before generating net new trips, wherein the magnitude is governed by access and egress times [16]; ② destination-choice adjustment because high vertiport charges may redirect discretionary trips to secondary centers, which is a decentralizing effect contrary to the usual CBD access narrative [17,18]; and ③ long-run capitalization because slot scarcity is absorbed into vertiport-adjacent land values instead of expanding effective CBD capacity. These effects are tractable within existing equilibrium models, and we flag them as priority research agendas.

3. Parallels with automobility and considerations of equity

UAM shares strengths and weaknesses with private automobiles: Both are fast, and in the long run, cost-competitive with premium ground transport [19]. Furthermore, both generate demands on scarce urban space and produce noise externalities [20,21]. However, the mechanisms of the spatial competition differ. Although cars can park almost anywhere, UAM vehicles are confined to dedicated vertiports, making spatial concentration inevitable. Automobile spatial externalities materialize diffusely across public road networks, rendering socialized costs largely invisible. The spatial footprint of the UAM is concentrated at nodes, which potentially makes costs more visible and politically contested. The reviews of shared autonomous vehicles similarly note the clustering of idle vehicles in high-demand zones and role of access point siting (e.g., charging stations) in shaping spatial coverage [22].

However, the node-versus-link framing for capacity should not be carried over to externalities. Although the binding throughput constraint is the vertiport node, the acoustic, visual, and safety-buffer effects of eVTOL operations are dispersed along the approach and departure funnels and across the overflow surface [23,24]. Therefore, the governance must address two distinct externality geometries: point-based charges at vertiports (land opportunity cost and local noise) and corridor-based charges tied to overflow population exposure. The latter is closer to airport noise-contour regulation than to parking pricing. More broadly, urban traffic is being increasingly recognized as an open complex giant system whose emergent behaviors arise from the coupling of capacity, demand, and externality channels instead of from any single subsystem in isolation [25]. UAM precisely intensifies these couplings. Governance designs that treat node capacity, corridor noise, and equity provisions as separate problems systematically underperform compared to integrated frameworks.

Environmental justice deserves explicit attention. Vertiport siting is likely to follow the paths of least political resistance, where developers may exploit the weaker planning-objection capacity of lower-income communities, thereby concentrating externalities on already burdened populations while benefits accrue to affluent users. Public-perception studies of related automated mobility technologies indicate that acceptance is stratified by socioeconomic context [26], reinforcing the case for explicit equity provisions in UAM deployment. Space–time accessibility frameworks confirm that without deliberate equity provisions, UAM will likely reinforce existing inequalities in multimodal urban systems [27]. We argue that a UAM system allowed to mature on a "fly first, regulate later" trajectory will, by the time mass certification arrives, have hard-coded a spatial inequality structure into the urban fabric that cannot be undone by retrofitted pricing. Therefore, pricing frameworks must pre-emptively incorporate distributional objectives such as channeling vertiport levies toward transit improvements in affected communities.

4. Toward rational governance

These observations argue not against UAM development, but rather for governance frameworks that ensure the efficient allocation of scarce resources [28]. When the landing capacity is scarce, efficient allocation requires that scarcity to be reflected in the prices faced by operators and users [4]. Implementing mechanisms analogous to parking pricing [29] and congestion charging [30,31] will prove essential, lest UAM replicates the failures of automobile-centric planning

However, this pricing problem is structurally distinct from traditional road congestion. Although road congestion pricing is a macro demand-management tool in which individual vehicles self-manage microlevel avoidance, vertiport slot pricing is inseparable from air-traffic-control separation standards. A delayed eVTOL cannot be simply pulled over from the flow. Therefore, the problem is closer in structure to airport slot allocation under separation minima than to cordon-based charging [32,33]. Two temporal layers must be distinguished: A strategic slot allocation layer (hours-to-days horizon), where administered prices or auctions shape operator bidding, and a tactical separation layer (seconds-to-minutes), governed by deterministic safety rules that cannot be priced. Prices in the first layer shift the demand distribution that the second layer must absorb; they do not substitute for it.

A further consideration is that the concentration of physical operations at high-density vertiports also concentrates cyber-physical risk. Communication and scheduling failures can transform a spatial scarcity challenge into an acute safety failure. In aviation safety literature, these failure modes are analyzed as system-of-systems problems, where interdependent subsystems propagate rather than absorb faults [34]. This risk is an argument for staged deployment, beginning with lower-density peripheral nodes supported by operational platforms developed for safe unmanned aircraft system operations in critical urban areas [35].

Vehicle design is directly implicated in this spatial dynamic: Compact aircraft reduce vertiport footprints, enabling higher throughput from constrained sites, where larger vehicles demand correspondingly larger pads and buffers. Regulatory frameworks that price spatial externalities would tilt manufacturer incentives toward compact, quieter platforms. Although aircraft design is ultimately constrained by physics and international certification and local pricing cannot override aerodynamics, it can influence design optimization within the feasible envelope. Once certified, aircraft platforms possess fixed footprints. Governance frameworks must therefore be established early in the development trajectory before major manufacturers finalize their specifications. Cities that wait for federal certification to settle before pricing local externalities will find themselves forced to accept prices for a global airframe whose dimensions were optimized for the lowest-friction jurisdiction.

Finally, deployment sequencing holds strategic significance. Establishing vertiports first at peripheral locations, which connects suburbs to airports, transport hubs, or edge employment centers, is more tractable than serving central locations where constraints are most severe. Peripheral deployment offers lower land costs, weaker political opposition, and integration with existing transit networks [36]. Over time, the demonstrated safety and community experience may enable gradual expansion toward the urban center.

5. Conclusions

Although UAM represents genuine technological innovation, it cannot transcend the fundamental reality that urban space is finite and contested. The air above cities may be vast; however, the surfaces on which aerial journeys begin and end remain exceptionally scarce. Consequently, the primary challenge for the next decade is not to force UAM into a mass-transit technology, but to candidly govern it as a niche premium mode; extracting the maximum public benefit through pricing, equity earmarking, and disciplined siting. Therefore, researchers, planners, and policymakers must develop analytical frameworks that integrate UAM into the broader logic of urban spatial efficiency [37], assessing when and where aerial mobility genuinely adds value, and incorporating pricing and regulatory mechanisms that can allocate scarce vertiport capacity efficiently and equitably. Cities that approach UAM through this disciplined perspective can capture its genuine benefits while avoiding the spatial externalities that compromised many previous transport innovations. While the sky beckons with apparent freedom, the ground remains immutably finite.

CRediT authorship contribution statement

Yiping Yan: Writing – original draft, Investigation, Conceptualization. **Bangyang Wei:** Writing – review & editing, Project administration, Methodology. **Yang Liu:** Writing – review & editing, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Jonas Eliasson:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare no known competing financial interests or personal relationships that could have influenced this work.

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