Planning and Implementation of Emerging Advanced Ariel Mobility

Yu Zhang
Smart Urban Mobility Laboratory
University of South Florida

TRB Executive Committee Policy Session
August 18, 2020
Road Map

• Network design of Urban Air Mobility considering mode competition
• Policy questions and discussion of landside infrastructure and market entrance of AAM
• Trajectory planning of high-density operations for automated traffic management of AAM
• Policy question and discussion of airspace design and traffic management of AAM
Problem Statement
Given a metropolitan area, how many vertiports are needed and where they should be located to attract the most of potential users considering the competition from other modes? (City Planners, UAM Service Providers)
Solution Method

- Generate 3-D map from LIDAR data to obtain the candidate locations of vertiports: Rooftop, parking lot, open space ......

- Mathematical modeling of network design and travel mode choice as a single location hub-and-spoke problem

<table>
<thead>
<tr>
<th>Network Design</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertiport Placement</strong></td>
</tr>
<tr>
<td><strong>Budget limit and spatial requirement</strong> for eVTOL aircraft operation restrict available locations and number of vertiports.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Travel Mode Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price &amp; Time Tradeoffs</strong></td>
</tr>
<tr>
<td>Compared with pure ground transportation, commuting through eVTOL aircrafts can greatly reduce travel time with higher travel cost.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>User Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAM service involves multimodal trips: ground trip access to or egress from vertiports and air trip between vertiports. Each user will always select route with minimum travel time.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value of Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>As long as the ratio of reduced travel time to increased travel cost is smaller than users’ value of time, they will use UAM service.</td>
</tr>
</tbody>
</table>
Single Allocation Hub-and-Spoke Network

- Origin/Destination node
- Candidate vertiports
- Access to/Egress from vertiports
- Selected vertiports
- Ground transportation
- Cruise between vertiports
Case Study – Tampa Bay Region

Identified optimal vertiport locations and user allocation

Minimize total generalized cost (travel cost + monetarized travel time)

\[
\min \sum_{p \in P} \left\{ \left( t_p^p \ast y_p^p + c_p^p \right) \ast z_p^p + \sum_k \sum_{d \neq k} \left( c_{kd} + (t_{kd} + t_{tw} + t_{tl}) \ast x_{kd}^p \right) \right\} + \sum_{e} \sum_{d} h_{ed}^p \left( t_{ed}^p \ast \right)
\]

s.t.
\[
\begin{align*}
\sum_{k} y_k &= u, \forall k \in M \\
z_p^{p} + \sum_{k} \sum_{d \neq k} x_{kd}^p &= 1, \forall p \in P \\
\sum_{d \in M} x_{kd}^p + \sum_{d \in M} x_{dk}^p &\leq y_k, \forall k \in M, \forall p \in P \\
\sum_{k} \sum_{d \neq k} x_{kd}^p = \sum_{d} g_{ak}^p ; \sum_{k} \sum_{d \neq k} x_{kd}^p = \sum_{e} h_{ed}^p, \forall p \in P \\
2x_{kd}^p \leq \sum_{a} g_{ak}^p + \sum_{e} h_{ed}^p, \forall k, d \neq k \in M, \forall p \in P \\
t_p^p - \sum_{k} \sum_{d \neq k} \left( (t_{kd} + t_{tw} + t_{tl}) \ast x_{kd}^p \right) - \sum_{a} g_{ak}^p t_{ak}^p - \sum_{e} h_{ed}^p c_{ed}^p \geq \sum_{k} \sum_{d} c_{kd}^p \ast x_{kd}^p + \sum_{a} \sum_{k} g_{ak}^p c_{ak}^p + \sum_{e} \sum_{d} h_{ed}^p c_{ed}^p - c_p^p, \forall p \in P \\
z_p^p \in \{0,1\}, y_k \in \{0,1\}, x_{kd}^p \in \{0,1\}, g_{ak}^p \in \{0,1\}, h_{ed}^p \in \{0,1\} k, d \in M, p \in P, a, e \in F
\end{align*}
\]

Hub-and-spoke modeling structure: limit the number of vertiports, travelers will select between UAM service and pure ground trip and restrict each UAM trip transferred through selected vertiports.

Restrict relations between UAM selection and vertiport access/egress mode choice.

Users will only adopt UAM service if value of saved travel time is larger than the additional cost.

Legend
- Selected Vertiports
- Candidate Vertiports
- Air Trip
- Vertiport Access and Egress

Identified optimal vertiport locations and user allocation
Policy Questions on Landside Infrastructure of AAM

Airport landside
- Airport authority
- Local transportation agency

Advanced Aerial Mobility
1. Urban and regional air mobility
2. Cargo logistics
3. Others

Micromobility
- City
- Transit authority

Photo Source: https://www.nasa.gov/sites/default/files/thumbnails/image/uam-3-4x3-v2-sm.jpg
Policy Questions on Landside Infrastructure of AAM

Advanced Aerial Mobility
1. Urban and regional air mobility
   • City
   • County
   • County transit authority
   • Regional transit authority
   • State

2. Cargo delivery
   • Besides, local community

3. Emergency medical services, first responders, disaster relief

• Public owned or private owned?
• Exclusive, Preferential, or Shared?
• Integrate with local transit, park n ride?

Photo Source: https://www.nasa.gov/sites/default/files/thumbnails/image/uam-3-4x3-v2-sm.jpg
Policy Questions on Market Entrance of AAM

Local regulation and license structure on advanced aerial mobility? What should be considered?
This instrument flight rules chart shows low altitude airways in the Oakland Area Control Center (near San Francisco, California).

Unmanned Aircraft System (UAS) Traffic Management (UTM)
Enabling Civilian Low-altitude Airspace and Unmanned Aircraft System Operations
Source: https://utm.arc.nasa.gov/index.shtml
Concept of Automated Traffic Management of AAM

Safety
• Obstacles avoidance
• Trajectory deconfliction

Efficiency
• Energy consumption

Equity
• Nash social welfare

- Centralized service center
- Airspace design
- Management schemes
- Trajectories planning
  - Conflict detection and resolution
  - System efficiency
Airspace Design and Trajectory Planning for AAM

- **Low-altitude airspace system (LUAS)**: generate flyable airspace and flight routes.
- **Trajectory planning**: conflict-free, energy-efficient, and equitable operations.

**Flight operations (origin, destination, departure time)**

- Vertiport locations
- 3D map of region of interest and flyable airspace
- Shortest trajectories at each level
- Intersecting trajectory database

**Detection of potential conflicts**

- Optimization: Summation model
- Optimization: Multiplication model

**Conflict-free trajectories**

**Exist intersections in flight operations**

- Yes
- No
Case Study - Trajectory Planning for Tampa Bay Area AAM Operations
Policy Questions on Airspace Design of AAM

National roadway system with hierarchy and different imposed speeds

Advanced Aerial Mobility
- Size
- Speed
- Cargo or passenger
- Emergency exemption
- Others
Policy Questions on Airspace Structure of AAM

Air Route Traffic Control Center

Advanced Aerial Mobility Region? End-to-end coverage?
THANK YOU

yuzhang@usf.edu