Drones for Commercial Last-Mile Deliveries: A Discussion of Logistical, Environmental, and Economic Trade-Offs

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Drones for commercial last-mile deliveries: a discussion of logistical, environmental, and economic trade-offs

Miguel Figliozzi, Professor
Director Transportation Technology and People (TTP) Lab
Civil Engineering – Portland State University

Seminar – University of Toronto
September 15, 2017
Drones for commercial last-mile deliveries: a discussion of logistical, environmental, and economic trade-offs

3 papers in one presentation

No formulae in this presentation
Urban Delivery Industry Landscape

• Congestion
• Pollution – air, water, and noise
• Scarcity of parking in urban areas
• Pressure to meet environmental mandates
• Rapid increase in package deliveries and service calls
• Urban population growth
• Growing problems – growing market (online, real-time)
“reinventing” the last-mile

Conventional supply chain with truck last-mile deliveries

“New” supply chain with drone last-mile deliveries
Survey of UAV capabilities

- Methodology: extensive internet search
- Information on websites along and downloadable material
- In some cases, customer service was contacted to request additional information.
- Smaller drones: not designed to carry packages (weight of cameras, etc. is a proxy for payload)
- **21 UAVs** currently available in the market.
Survey of UAV capabilities

- Inclusion of multicopter UAVs that cover the range of existing capabilities, sizes and prices.
- Search limited to multicopter drones that can potentially deliver in both urban and rural areas.
- No helicopters (1 propeller) due to safety reasons
- No fixed wing drones due to lack of VTOL
- Electric due to noise and environmental reasons (more later)
Photo sources: microdrones and DHL
Speed, Flying Times, Ranges and Payloads

- **Speeds:** Most speeds are in the range of 16 to 20 meters per second (35 to 45 miles per hour)

- **Flying times:** 20 to 30 minutes.

- **Ranges:** heavily dependent on a multitude of factors (payload size, weather, flown within LOS etc.). Typical range 15 - 35 kms (~ 10 - 22 miles).

- **Payloads:** affect range, depending on configuration, typical 6.4 kg to 1.8 kg. (14 to 4 lbs).
Size and Weight

• Typical payload/takeoff-weight ratio ranges from 0.33 to 0.20; battery/takeoff-weight ratio typically ranges from 0.30 to 0.25.

• Average size across the diagonal is 1,045 mm, typical range 1485 to 350 mm (w.o. propellers)

• The typical takeoff weight is approximately 4 kg longer-range drones have a takeoff weight of 10 kg or more.
Costs

• Wide range of costs:
  – Small multicopters cost a few hundred dollars.
  – The most expensive multicopters cost over $20,000 each.

• The wide range is explained by the different capabilities and the cost of the batteries.
Typical UAV and delivery van specification:

<table>
<thead>
<tr>
<th>Specification</th>
<th>UAV (MD4-3000)</th>
<th>Diesel cargo van (RAM ProMaster 2500)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take off / Gross weight</td>
<td>15.1 kg</td>
<td>4060 kg</td>
</tr>
<tr>
<td>Tare / Curb Weight</td>
<td>10.1 kg</td>
<td>2170 kg</td>
</tr>
<tr>
<td>Max. Payload</td>
<td>5.0 kg</td>
<td>1890 kg</td>
</tr>
<tr>
<td>Max. Range</td>
<td>36 km</td>
<td>695 km</td>
</tr>
</tbody>
</table>
Drones for commercial last-mile deliveries: a discussion of economic, logistical, and environmental trade-offs
One-to-one last-mile routes

One vehicle serves 1 (one) customer per round trip
One-to-one last-mile routes

**One vehicle serves 1 (one) customer per round trip**
Typical UAV and delivery van

<table>
<thead>
<tr>
<th>Specification</th>
<th>UAV</th>
<th>Diesel cargo van</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MD4-3000</td>
<td>RAM ProMaster 2500</td>
</tr>
<tr>
<td>Range</td>
<td>25 km (practical)</td>
<td>695 km</td>
</tr>
<tr>
<td>Battery/Fuel Capacity</td>
<td>0.777 kWh</td>
<td>8.63 kWh</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>21.6 wh/km</td>
<td>1016 wh/km</td>
</tr>
</tbody>
</table>

Per-unit distance the UAV is almost 50 times more energy efficient than the van assuming a 5kg payload.
Why? Physics!
Per-unit distance the UAV is 50 times more energy efficient than the van (assuming a 5kg payload), but...

The van can deliver almost 400 times more cargo than the UAV; assuming maximum payloads the van is almost 8 times more energy efficient
Well-to-tank (WTT) and Tank-to-wheel (TTW) Fuel CO$_2$e emissions

Typical UAV and delivery van

Per-unit distance the UAV is 1050 times cleaner than the van (assuming a 5kg payload)

<table>
<thead>
<tr>
<th>Specification</th>
<th>UAV</th>
<th>Diesel cargo van</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DJI S1000</strong></td>
<td><strong>RAM ProMaster 2500</strong></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>25 km</td>
<td>695 km</td>
</tr>
<tr>
<td>Battery/Fuel Capacity</td>
<td>0.777 kWh</td>
<td>8.63 kWh</td>
</tr>
<tr>
<td>WTT emissions</td>
<td>1.235 lbs CO2e / kWh</td>
<td>5.108 lbs CO2e / gallon</td>
</tr>
<tr>
<td>TTW emissions</td>
<td>-</td>
<td>22.72 lbs CO2e / gallon</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>10.8 wh/km</td>
<td>1016 wh/km</td>
</tr>
</tbody>
</table>

WTT = well to tank     TTW = tank to wheel

**Portland State University**  **Maseeh College of Engineering and Computer Science**  **TIP Lab**
Typical UAV and delivery van

Per-unit distance the UAV is 1050 times cleaner than the van (assuming a 5kg payload), but…

The van can deliver almost 400 times more cargo than the UAV; assuming maximum payloads the van is 8 times more efficient in terms of energy consumption but the van is almost 2.8 times less efficient regarding CO₂ emissions.
One-to-many last-mile routes

One vehicle serves $n$ (many) customers

More efficient as $n$ grows (distance traveled by customer)

UAV carry just one package at the time
# Energy efficiency breakeven points

*Reference point:* how many packages are delivered by a typical UPS vehicle? (urban areas)

## TABLE 3. UAV and Diesel Van Breakeven Energy Scenarios - One-to-one Routes

<table>
<thead>
<tr>
<th>Avg. Dist. depot to Customers (km)</th>
<th>Service Area (km²)</th>
<th>$\rho_{1}^{en} \approx 94$ wh/km</th>
<th>$\rho_{1}^{en} \approx 47$ wh/km</th>
<th>$\rho_{1}^{en} \approx 31$ wh/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>60</td>
<td>1,340</td>
<td>362</td>
<td>173</td>
</tr>
<tr>
<td>9</td>
<td>40</td>
<td>785</td>
<td>224</td>
<td>113</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>413</td>
<td>131</td>
<td>72</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>219</td>
<td>83</td>
<td>50</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>127</td>
<td>58</td>
<td>37</td>
</tr>
</tbody>
</table>
Energy/emissions efficiency breakeven points

Reference point: how many packages are delivered by an electric van/truck?

<table>
<thead>
<tr>
<th>Avg. Dist. depot to Customers (km)</th>
<th>Service Area (km²)</th>
<th>$n^*$</th>
<th>$n^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\rho_1^{en}\approx 35$ vs. E-truck</td>
<td>$\rho_1^{en}\approx 9.5$ vs. E-van</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>214</td>
<td>26</td>
</tr>
<tr>
<td>9</td>
<td>40</td>
<td>137</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>85</td>
<td>15</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>58</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>42</td>
<td>10</td>
</tr>
</tbody>
</table>
Energy/emissions efficiency breakeven points

Reference point: how many packages are delivered by a typical tricycle?

<table>
<thead>
<tr>
<th>Avg. Dist. depot to Customers (km)</th>
<th>Service Area (km²)</th>
<th>$n^*$ vs. E-tricycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>60</td>
<td>2.1</td>
</tr>
<tr>
<td>9</td>
<td>40</td>
<td>1.9</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>1.7</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>1.6</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>1.5</td>
</tr>
</tbody>
</table>
**Lifecycle**: add production, maintenance and disposal

(also includes maintenance and spare parts)

**Fuel / Electricity - Utilization Cycle**
- Petroleum Refining
- Fuel / Electricity Production
- Petroleum Transport
- Fuel / Electricity Distribution
- Petroleum pumping & extracting

**Vehicle Cycle**
- Vehicle & Battery Assembly
- Fuel / Electricity and Vehicle use
- Vehicle Distribution
- Vehicle & Battery Assembly

Source: adapted from M. Shahraeeni et al.
## Lifecycle assessment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UAV</th>
<th>Tricycle</th>
<th>Diesel Van</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of daily deliveries</td>
<td>4</td>
<td>25</td>
<td>150</td>
</tr>
<tr>
<td>Delivery days per year (days)</td>
<td>260</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>Vehicle life (years)</td>
<td>3</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Emissions per delivery (kg CO2e per delivery)</td>
<td>0.16</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>Equivalent travel distance (in km)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kg CO2e per delivery)</td>
<td>13.0</td>
<td>1.2</td>
<td>0.002</td>
</tr>
<tr>
<td>Range (km)</td>
<td>25</td>
<td>48</td>
<td>625</td>
</tr>
<tr>
<td>Equivalent travel distance as % of range</td>
<td>52</td>
<td>2.5</td>
<td>0.0</td>
</tr>
</tbody>
</table>

(*) Included in the vehicle chassis  
(**) To improve readability numbers have been rounded
Economics

- Vehicle costs
- Battery costs
- Labor costs
- Energy costs
- Other costs (overhead, fixed costs)
Many potential scenarios

- Impact of regulation, BLOS operation?

- Utilization? Useful life?

- Weight of energy costs

- Key cost elements
Key logistical tradeoffs

- Speed and reliable (uncongested airways?)
- Low payloads and limited range
- For high payloads (more than 7 kgs) or long distances, ground vehicles are still dominant
- Drop-off technology/solutions? Multiple?
Key environmental tradeoffs

• Relatively low per-mile emissions
• Relatively high vehicle phase emissions
• UAVs very CO$_2$e efficient (per-unit distance)
• EVs and Tricycles more CO$_2$e efficient with multiple dropoffs
Key economical tradeoffs

• High cost per delivery when compared to traditional parcel deliveries

• Dynamic and uncertain cost variables

• New markets and opportunities?
Other key issues

• Air traffic control
• Safety, liability and litigations
• Energy (clean electric vs. carbon based)
• Regulation and land use restrictions
  — Noise
  — Privacy
• Technology: batteries, electronics, ...
Related Publications

• Figliozzi M., Lifecycle Modeling and Assessment of Unmanned Aerial Vehicles (Drones) CO2e Emissions, forthcoming 2017 Transportation Research Part D

• Figliozzi and Tucker, What can multicopter drones deliver? A survey and analysis of the capabilities and limitations of state of the art drones, Submitted to TRB 2018

• Figliozzi M., Economic and Market Analysis of multicopter drones deliveries, Working paper.
Acknowledgements

• Freight Mobility Research Institute (FMRI) funding
THANK YOU

Questions? Comments...

Visit the TTP Lab webpage:

http://www.pdx.edu/transportation-lab/

Email us at: ttplab@pdx.edu or figliozzi@pdx.edu