How Sustainable Are Drone (UAV) Deliveries?

Miguel Figliozzi  
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How Sustainable Are Drone (UAV) Deliveries?

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

Friday Seminar – Portland State University
April 13, 2017
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)
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

<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>
One-to-one last-mile routes

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

One ground 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
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 2.7 times less efficient regarding CO$_2$ emissions.
One-to-many last-mile routes

One ground 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

Drone = Van

**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>$\rho_1^{en} \sim 94$ wh/km</th>
<th>$\rho_1^{en} \sim 47$ wh/km</th>
<th>$\rho_1^{en} \sim 31$ 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>

**Reference point:** how many packages are delivered by a typical UPS vehicle? (urban areas)
# Energy/emissions efficiency breakeven points

**Drone = Electric Van**

<table>
<thead>
<tr>
<th>Avg. Dist. depot to Customers (km)</th>
<th>Service Area (km²)</th>
<th>$n^*$ vs. E-truck</th>
<th>$n^*$ vs. E-van</th>
</tr>
</thead>
<tbody>
<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>

**Reference point:** how many packages are delivered by an electric van/truck?
## Energy/emissions efficiency breakeven points

Drone = Electric Tricycle

<table>
<thead>
<tr>
<th>Avg. Dist. depot to Customers (km)</th>
<th>Service Area (km²)</th>
<th>$\rho_1^{en}$ ~ 1.4 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>

**Reference point:** how many packages are delivered by a typical tricycle?
**Lifecycle**: add production, maintenance and disposal

(Also includes maintenance and spare parts)

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

**Vehicle Cycle**
- Vehicle & Battery Assembly
- Material Transport
- Material Production
- Vehicle Disposal

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

**TABLE 7. Per Delivery Vehicle Phase CO$_2$e Emissions (**)**

<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>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>UAV</th>
<th>Tricycle</th>
<th>Diesel Van</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions per delivery (kg CO2e per delivery)</td>
<td>0.16</td>
<td>0.02</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>UAV</th>
<th>Tricycle</th>
<th>Diesel Van</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent travel distance (in km) (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
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 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?
Economics

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

(can be downloaded from my website)

No formulae in this presentation, details and formulas in the paper

Under Review

Figliozzi, M., (2018) Modeling unmanned aerial vehicles (Drones) delivery costs
Related EV and Tricycle Publications


Acknowledgements

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Polina Polikakhina
Acknowledgements

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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