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How Sustainable Are Drone (UAV) Deliveries?

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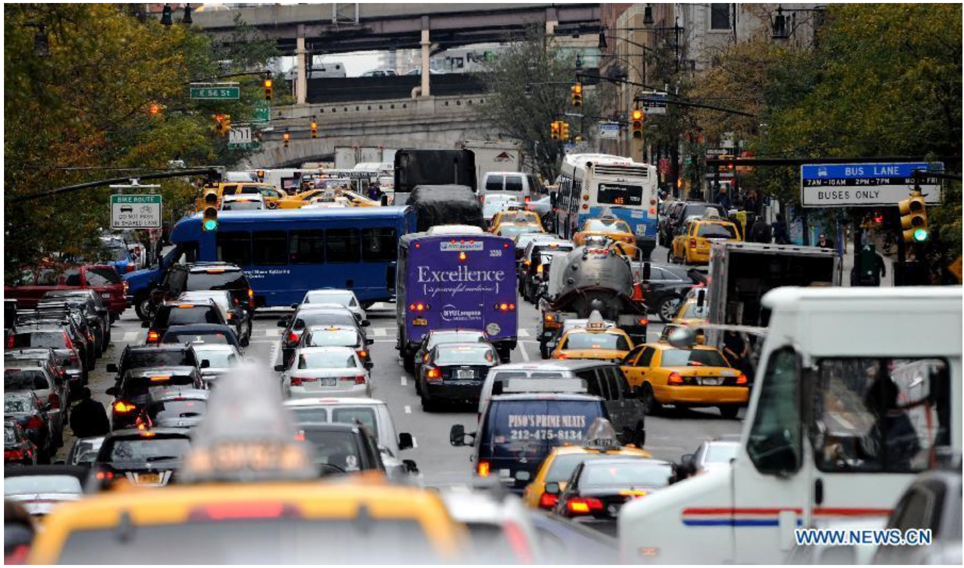
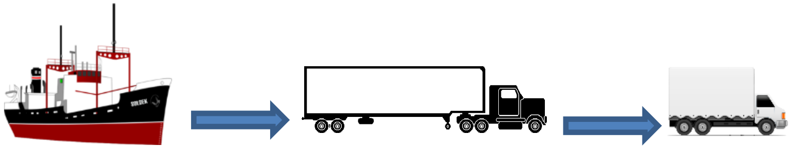
Urban Delivery Industry Landscape

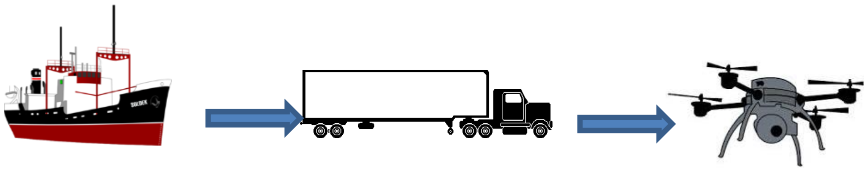
- Congestion
- Pollution – air, water, and noise
- Scarcity of parking in urban areas
- Pressure to meet environmental mandates
- Rapid increase in package deliveries and service calls
- Urban population growth
- Growing problems – growing market (online, real-time)



“reinventing” the last-mile



Conventional supply chain with truck last-mile deliveries



“New” supply chain with drone last-mile deliveries

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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.

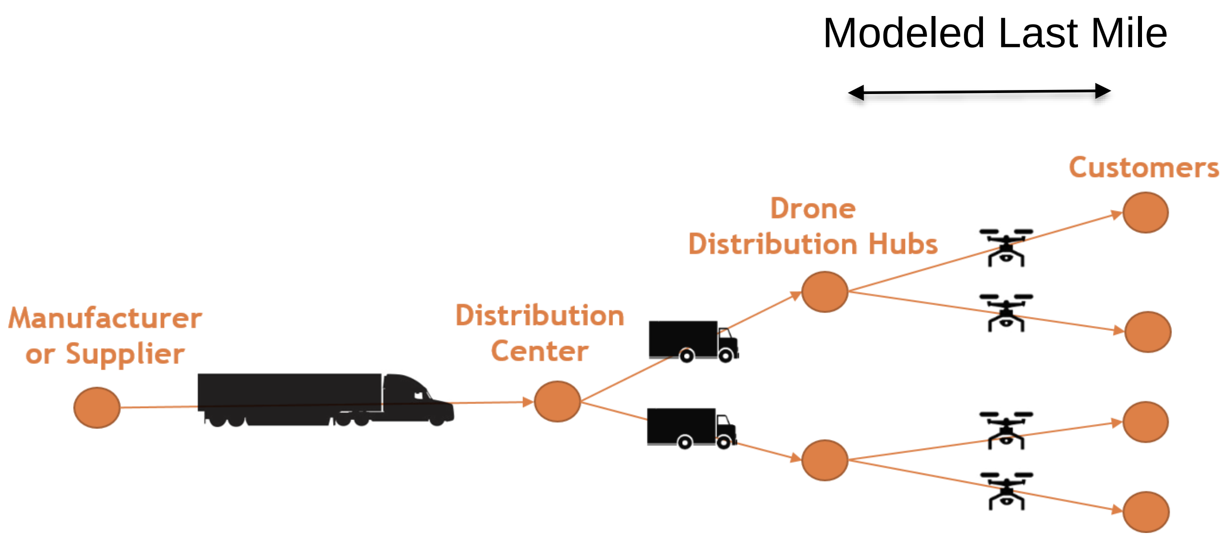
Costs

- 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

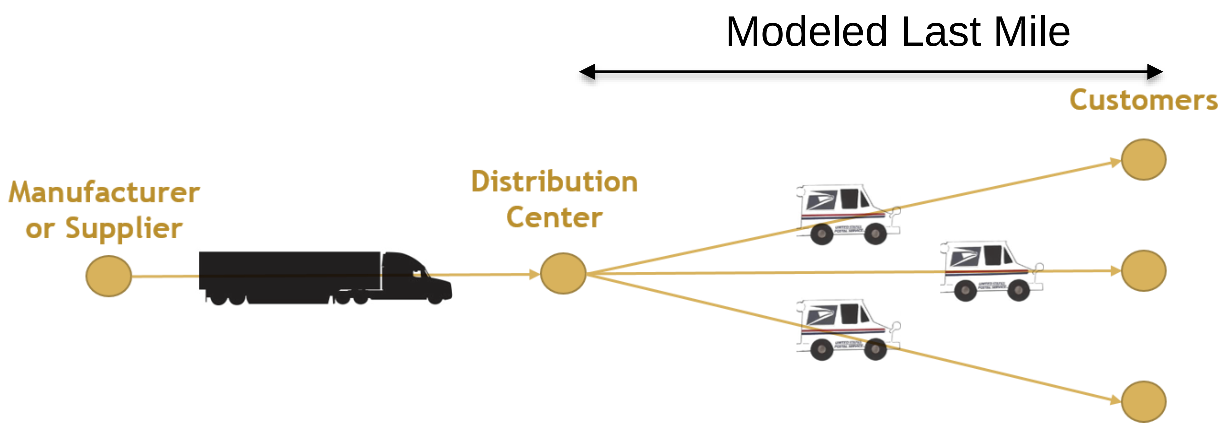
	UAV	Diesel cargo van
Specification	**MD4-3000**	**RAM ProMaster 2500**
Take off / Gross weight	15.1 kg	4060 kg
Tare / Curb Weight	10.1 kg	2170 kg
Max. Payload	5.0 kg	1890 kg
Max. Range	36 km	695 km

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

	UAV	Diesel cargo van
Specification	**MD4-3000**	**RAM ProMaster 2500**
Range	25 km (practical)	695 km
Battery/Fuel Capacity	0.777 kWh	8.63 kWh
Energy consumption	21.6 wh/km	1016 wh/km

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

Typical UAV and delivery van

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_2e emissions

Source: White Paper on Fueling EU Transport, EUROPIA, 2011

Typical UAV and delivery van

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

	UAV	Diesel cargo van
Specification	**DJI S1000**	**RAM ProMaster 2500**
Range	25 km	695 km
Battery/Fuel Capacity	0.777 kWh	8.63 kWh
WTT emissions	1.235 lbs CO2e / kWh	5.108 lbs CO2e / gallon
TTW emissions	-	22.72 lbs CO2e / gallon
Energy consumption	10.8 wh/km	1016 wh/km

WTT = well to tank TTW = tank to wheel

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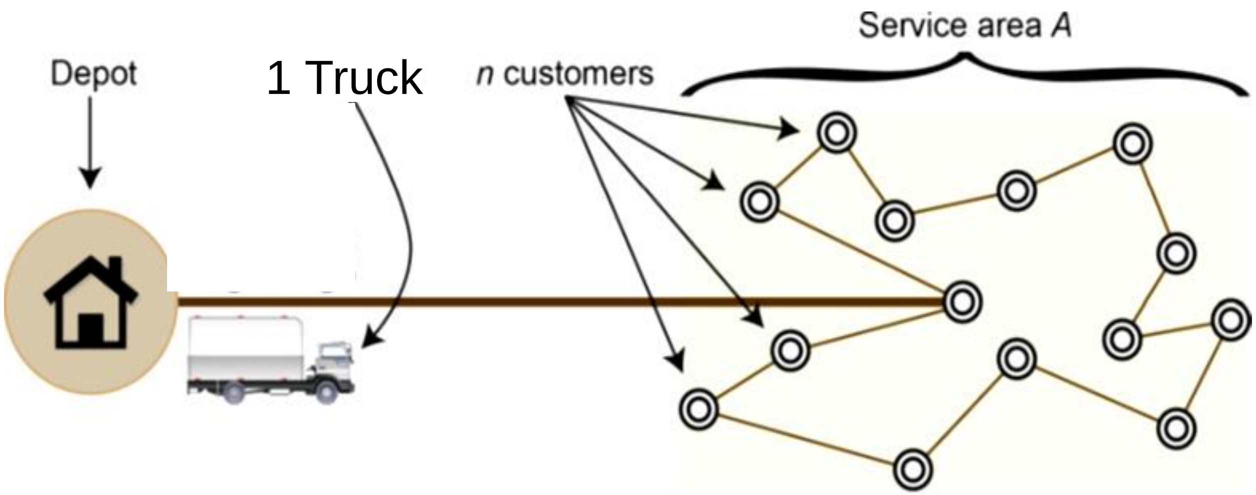
Typical UAV and delivery van

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

Avg. Dist. depot to Customers (km)	**Service Area** (km^2)	n^* $\rho_1^{en}\sim 94$ 10.8 wh/km	$\rho_1^{en}\sim 47$ 21.6 wh/km	$\rho_1^{en}\sim 31$ 32.4 wh/km
8	60	1,340	362	173
9	40	785	224	113
10	20	413	131	72
11	7	219	83	50
12	1	127	58	37

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

Energy/emissions efficiency breakeven points

Drone = Electric Van

Avg. Dist. depot to Customers (km)	**Service Area** (km^2)	n^* $\rho_1^{en}\sim 35$ vs. E-truck	n^* $\rho_1^{en}\sim 9.5$ vs. E-van
8	60	214	26
9	40	137	20
10	20	85	15
11	7	58	12
12	1	42	10

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

Energy/emissions efficiency breakeven points

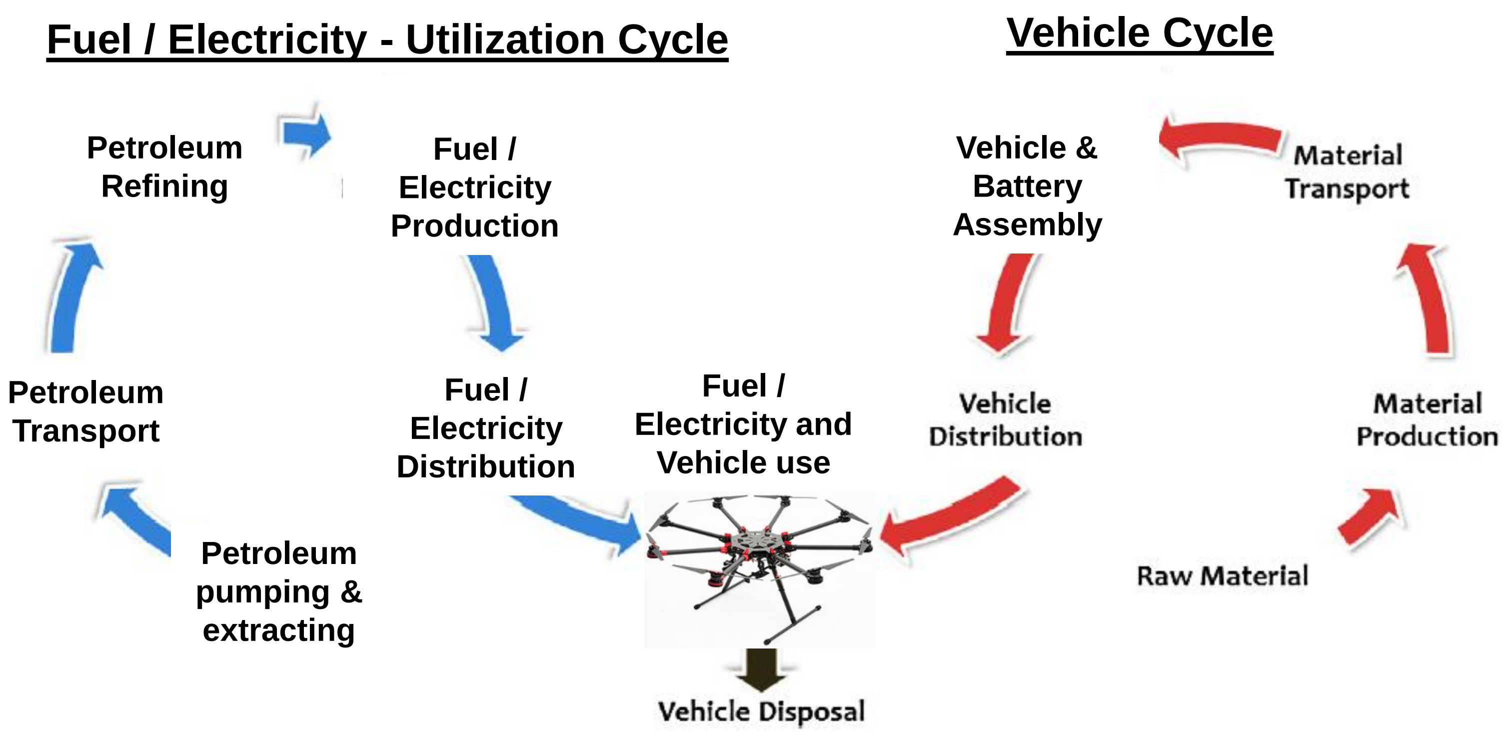
Drone = Electric Tricycle

Avg. Dist. depot to Customers (km)	**Service Area** (km^2)	$\boldsymbol{n^*}$ $\boldsymbol{\rho_1^{en} \sim 1.4}$ vs. E-tricycle
8	60	2.1
9	40	1.9
10	20	1.7
11	7	1.6
12	1	1.5

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

Lifecycle: add production, maintenance and disposal

(also includes maintenance and spare parts)



Source: adapted from M. Shahraeeni et al.

Lifecycle assessment

TABLE 7. Per Delivery Vehicle Phase CO_2e Emissions (**)

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

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

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Key environmental tradeoffs

- Relatively low per-mile emissions
- Relatively high vehicle phase emissions

- UAVs very CO_2e efficient (per-unit distance)
- EVs and Tricycles more CO_2e 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

Figliozzi, M. A. (2017) Lifecycle modeling and assessment of unmanned aerial vehicles (Drones) CO_2e emissions, Transportation Research Part D: Transport and Environment, 2017, 57, 251-261

(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

- Feng, W., Figliozzi, M., Economic and Technological Analysis of the Key Factors Affecting the Competitiveness of Electric Commercial Vehicles, Transportation Research Part C (new technologies), Volume 26, p. 135-145, 2012.
- Davis, B., Figliozzi, M., A Methodology to Evaluate the Logistical Competitiveness of Electric Trucks in the LTL Delivery Industry, Transportation Research Part E (logistics and transportation), Volume 49, Issue 1, p. 8-23, 2012.
- J. Saenz, M. Figliozzi, J. Faulin, An Assessment of the Carbon Footprint Reductions of Tricycle Logistics Services, Transportation Research Record: Journal of the Transportation Research Board, Vol. 2570, pp. 48-56, 2016.
- Tipagornwong, C., Figliozzi, M., An Analysis of the Competitiveness of Freight Tricycle Delivery Services in Urban Areas, Transportation Research Record, Dec 2014, Vol. 2410, pp. 76-84.

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THANK YOU

Questions? Comments…

Visit the TTP Lab webpage:

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