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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

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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

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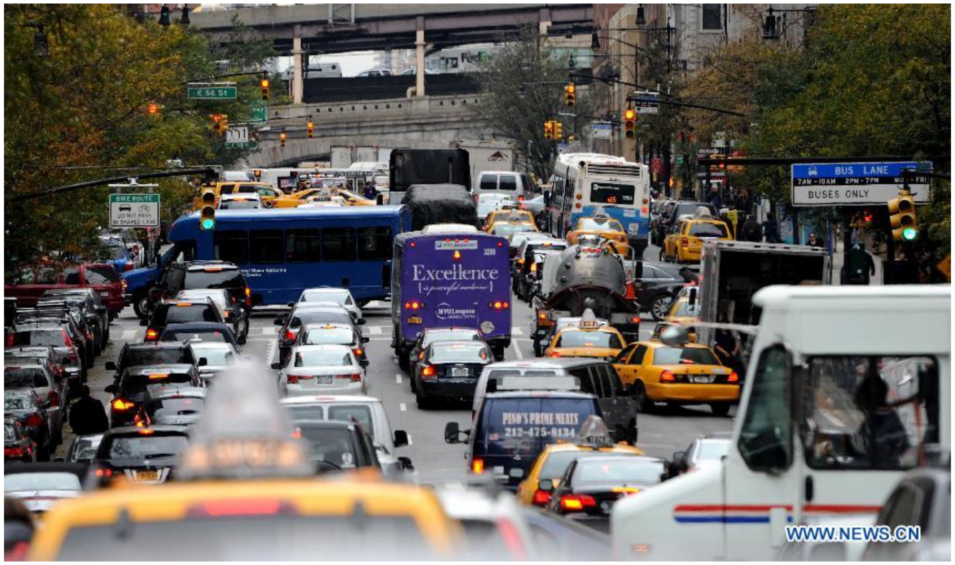
Urban Delivery Industry Landscape

- 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)



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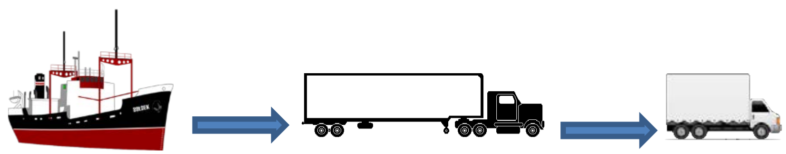
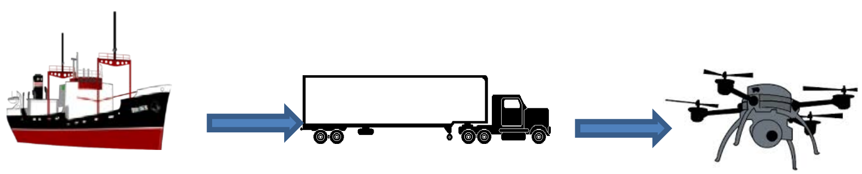
“reinventing” the last-mile



Conventional supply chain with truck last-mile deliveries



“New” supply chain with drone last-mile deliveries

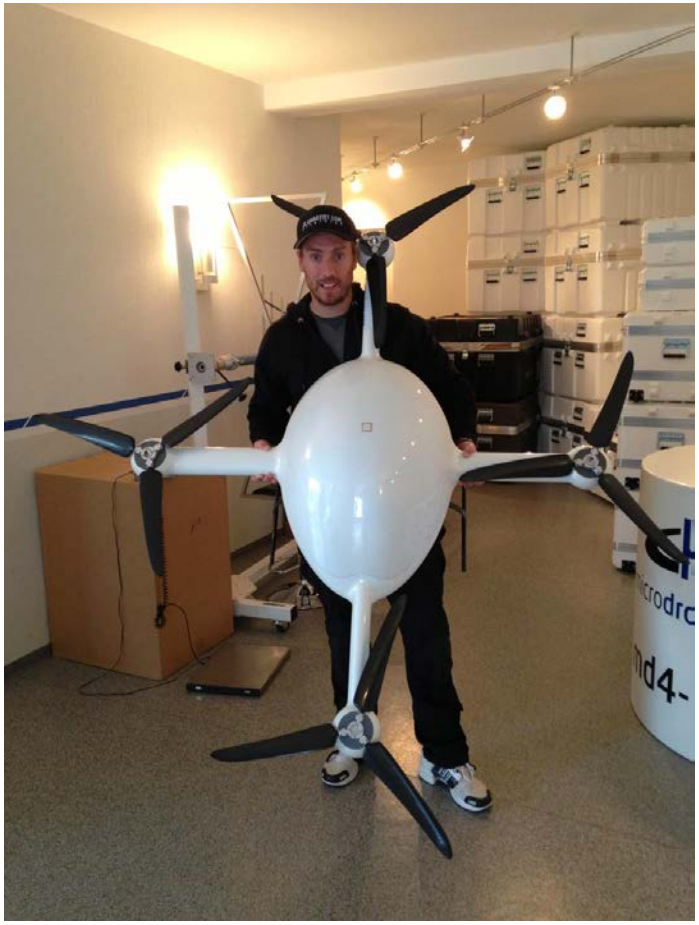
Survey of UAV capabilities

- 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



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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

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

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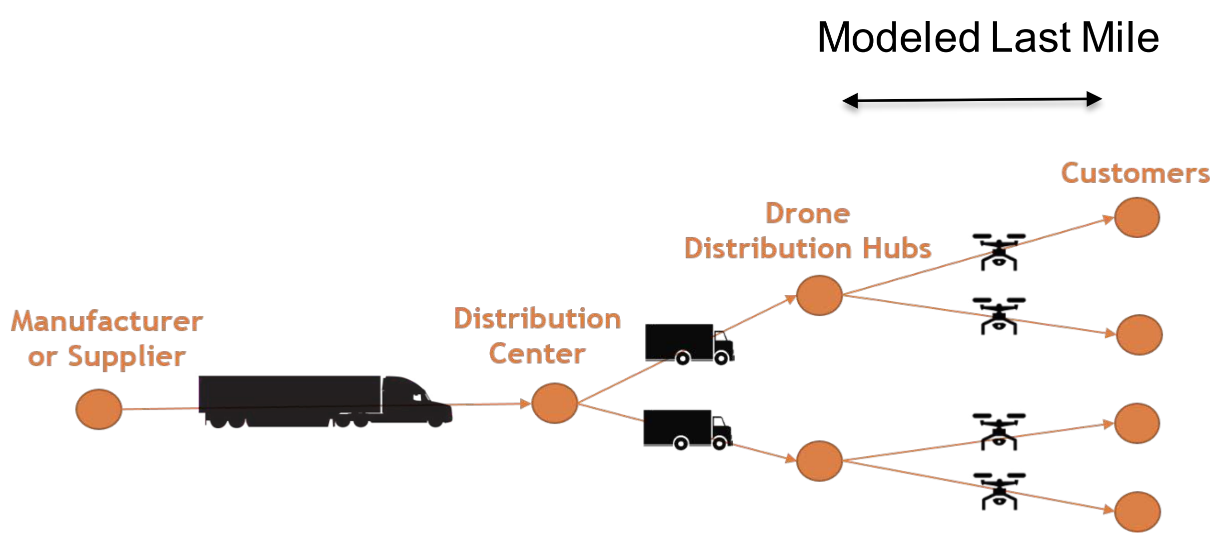
One-to-one last-mile routes



One vehicle serves *1* (one) customer per round trip

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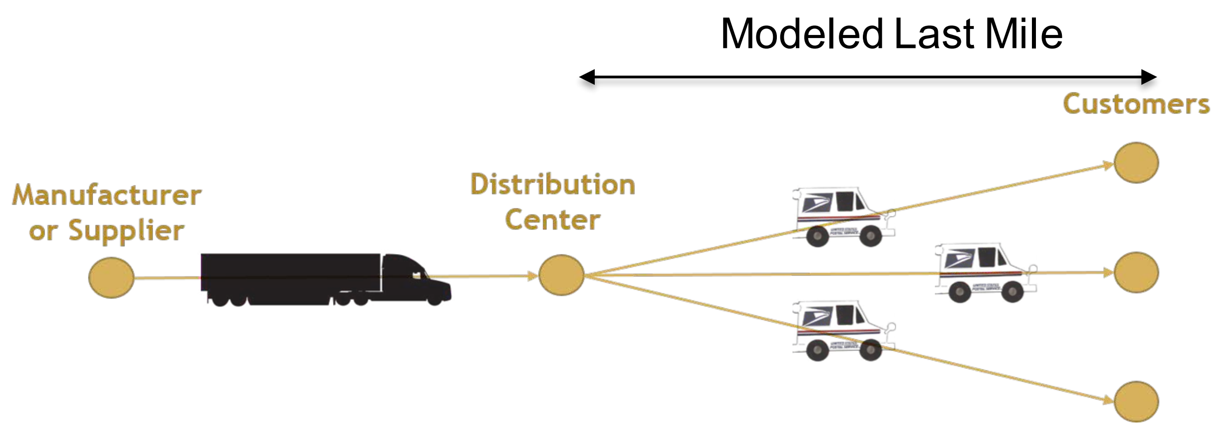
One-to-one last-mile routes



One vehicle serves *1* (one) customer per round trip

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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 !

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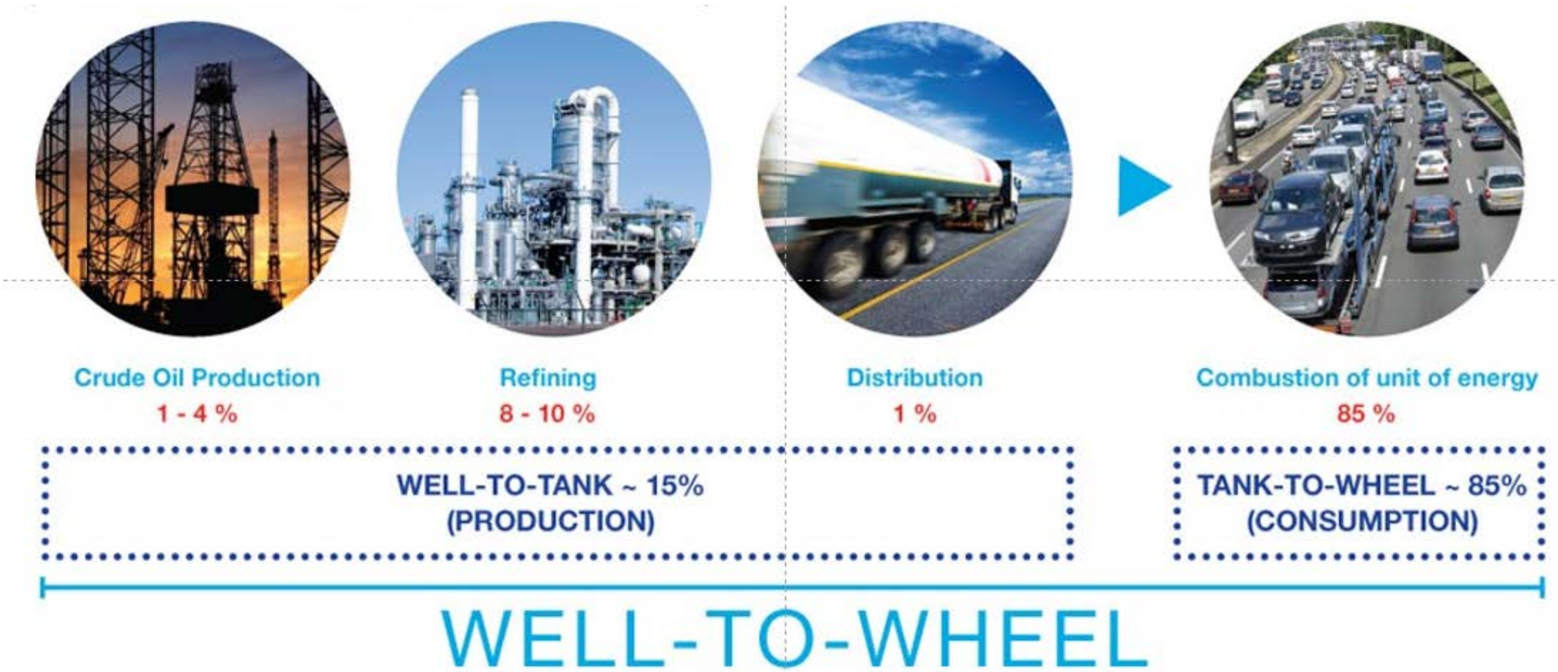
Typical UAV and delivery van

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 2.8 times less efficient regarding CO_2 emissions.

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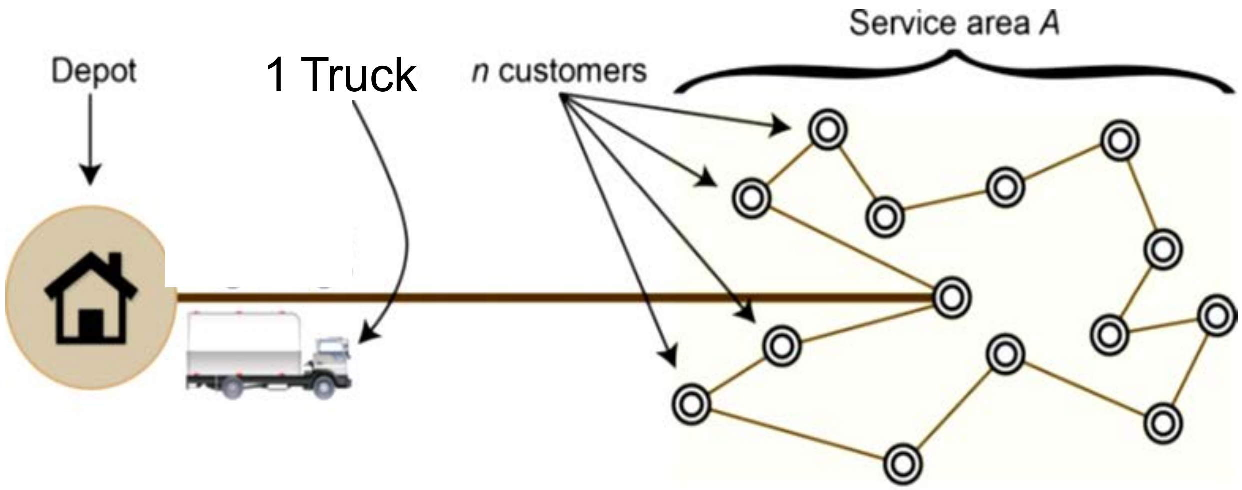
One-to-many last-mile routes



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

=

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

Avg. Dist. depot to Customers (km)	**Service Area** (km^2)	n^*		
		ρ_1^{en}~94 10.8 wh/km	ρ_1^{en}~47 21.6 wh/km	ρ_1^{en}~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

=

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

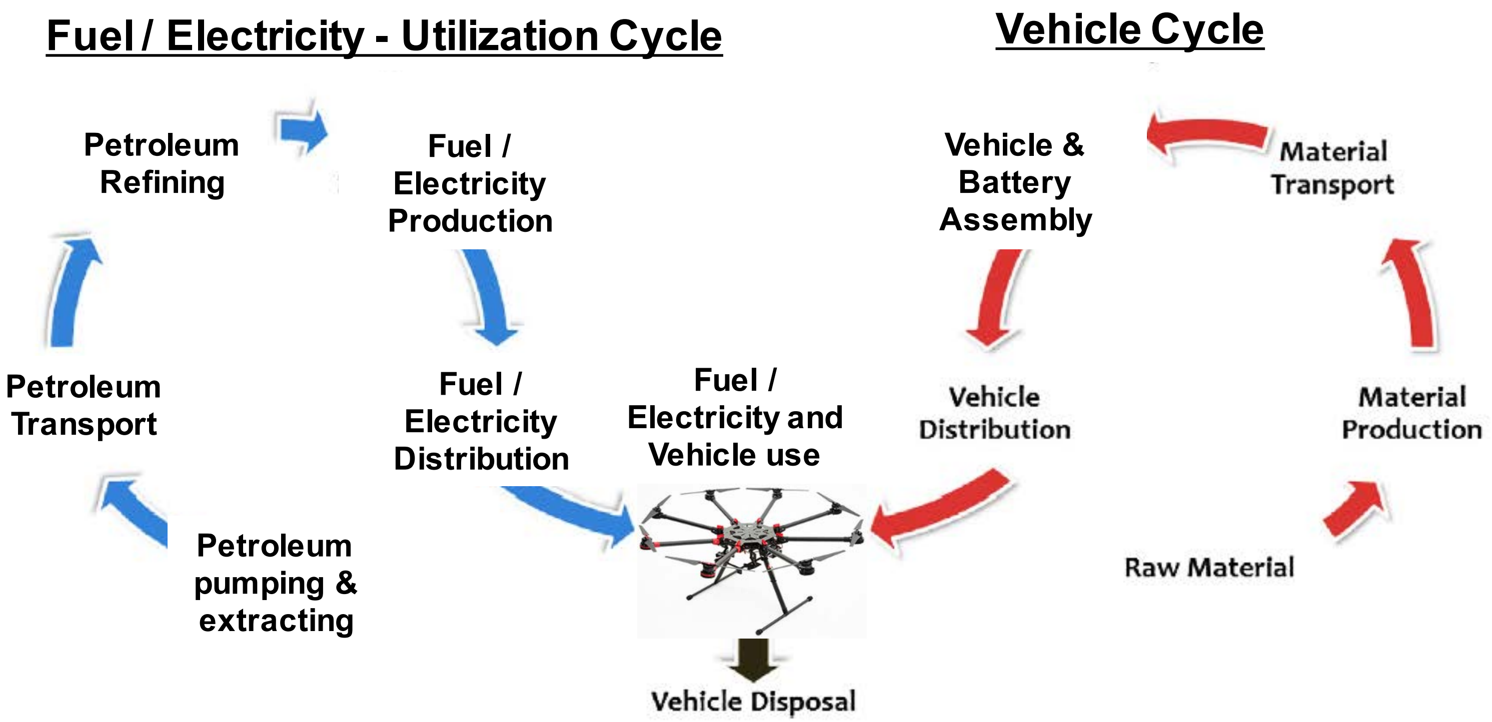
=

Avg. Dist. depot to Customers (km)	**Service Area** (km^2)	n^* ρ_1^{en}~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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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_2e efficient (per-unit distance)
- EVs and Tricycles more CO_2e 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.

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Acknowledgements

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THANK YOU

Questions? Comments…

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