Drone Delivery

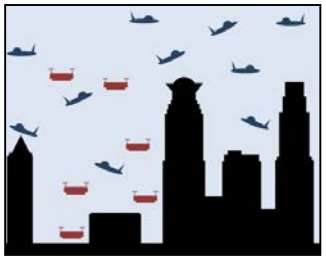
Urban airspace traffic density estimation

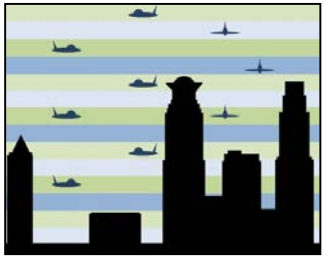
Prof.dr.ir. Jacco M. Hoekstra
Faculty of Aerospace Engineering
Control and Simulation/Air Traffic Management

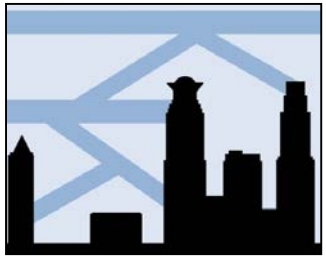
Ir. Malik Doole, Dr. ir. Joost Ellerbroek , Prof. dr. ir. Jacco Hoekstra

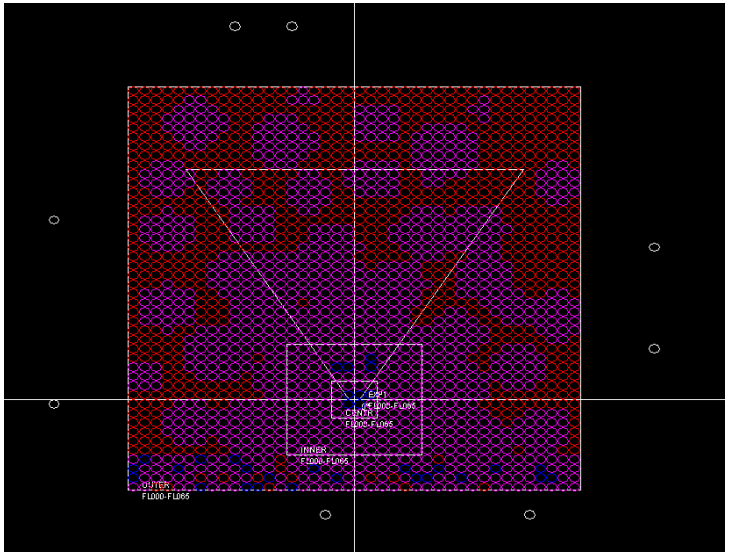
Predictions are hard…

Metropolis project: First “U-space”





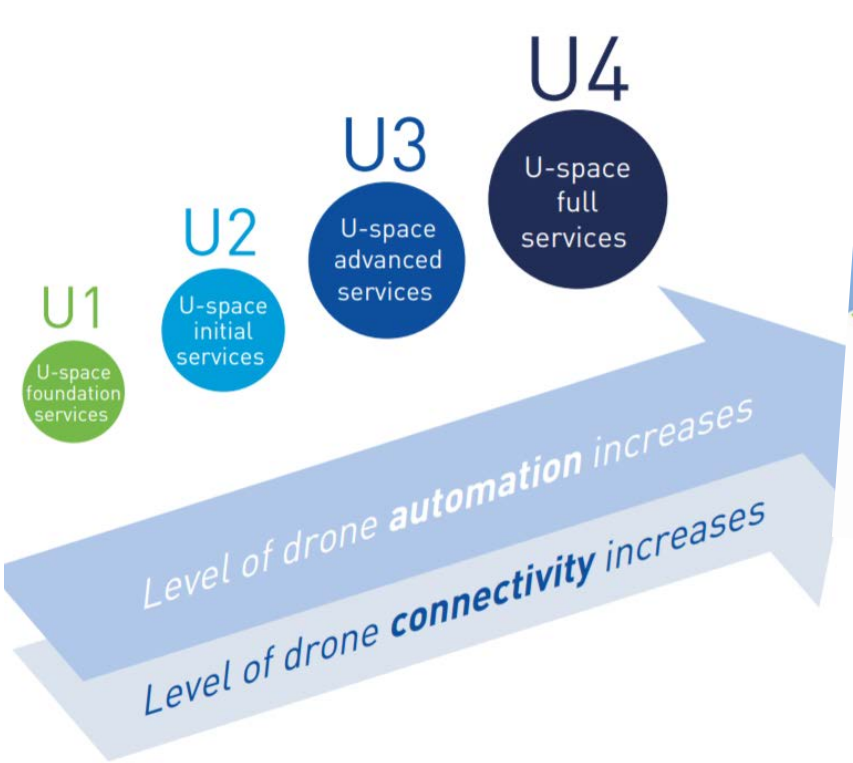




Batch simulation: 9.5 million flights: TMX & BlueSky Open Air Traffic Sim

Download zip-file: http://github.com/ProfHoekstra/bluesky/

SESARs U-Space



How many parcel delivery drones should we expect in our urban airspace?

Source: curioustechnologist.com

Contents

- Context
- Method
- Case-study Density
- Case-study Feasibility
- Conclusions

TU Delft

Context: Why delivery drones?

- Current road traffic congestion:
  - Increase in CO_2 emissions
  - Loss in productivity

Source: economist.com

Source: earth.com

Traffic congestion hurts economy

- 2-5% of a country's GDP lost annually [1]
- Traffic congestion in the US, UK and Germany was $461 Billion in 2017 [2]
- Population of urban cities are growing at 1.5 million people per week [3]
- Traffic congestion increases…

Could package delivery drones help?

[1] Asian Development Bank, "Urban Transport", *Transport Key Priorities,* 2018.
[2] Economist, "Hidden cost of congestion", 2018
[3] PWC, "A New Agenda: Accommodating 2 billion new urban citizens", 2018.

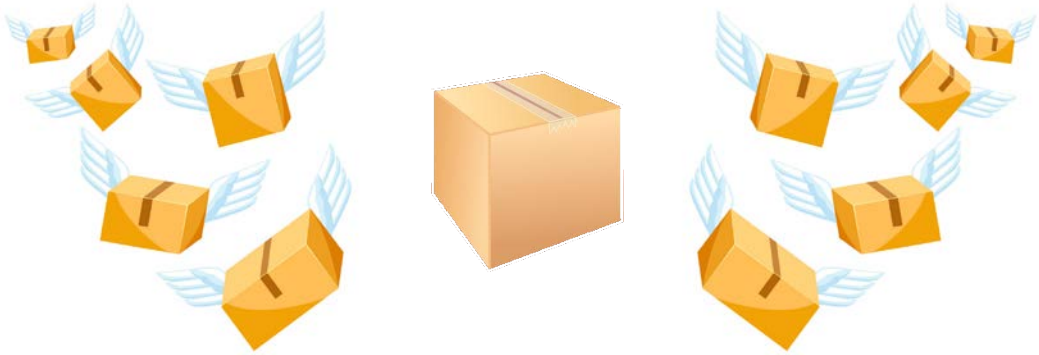
Drone delivery

- Ok, let’s assume drones will be used **mainly for package delivery**.
- What is **the density** based on this application alone?
- **How** can we even begin to estimate this traffic density?

Method: Step 1 # Parcels

- Using existing statistics for **all parcels** nationally

- With a set of assumptions/fractions we can to convert this to an estimate of # **flying parcels**



Governing assumptions

1. 85 % parcel demand delivered nationally
2.
3.
4.
5.

Among others:
- *UPS, “UPS fact sheet”, 2017. [Online]. Available: http://pressroom.ups.com/assets/pdf/pressroom/fact%20sheet/UPS*

Governing assumptions

1. 85 % parcel demand delivered nationally
2. Drones only deliver in urban area
3.
4.
5.

Based on mentioned benefits
Based on urbanisation trends by a.o. UN

Governing assumptions

1. 85 % parcel demand delivered nationally
2. Drones only deliver in urban area
3. Only last mile segment drone delivery:
   Range constraints:
   70 % of the fraction of domestic parcels by drones
4.
5.

McKinsey & Company, “Parcel delivery: The future of last-mile”, *Special report,* 2016.

Governing assumptions

1. 85 % parcel demand delivered nationally
2. Drones only deliver in urban area
3. Only last mile segment drone delivery:
   Range constraints:
   70 % of the fraction of domestic parcels by drones
4. Only parcels weighing ≤ 2.2kg
   = 86 % of Amazon's orders
5.

R. D'Andrea, "Guest editorial can drones deliver?", *Automation Science and Engineering,* IEEE transcations, vol. 11, pp.647-648, 2014.

Governing assumptions

1. 85 % parcel demand delivered nationally
2. Drones only deliver in urban area
3. Only last mile segment drone delivery:
   Range constraints:
   70 % of the fraction of domestic parcels by drones
4. Only parcels weighing ≤ 2.2kg
   = 86 % of Amazon's orders
5.

McKinsey & Company, "Parcel delivery: The future of last-mile", *Special report,* 2016.

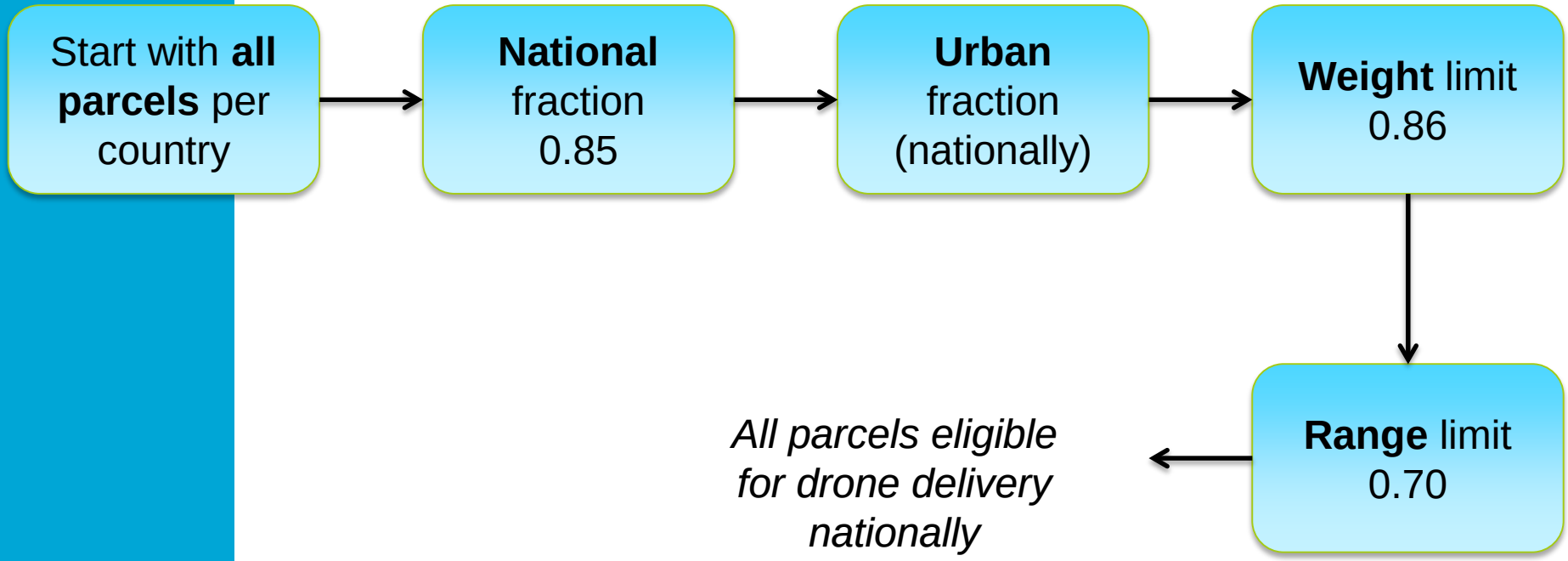
TU Delft

Governing assumptions

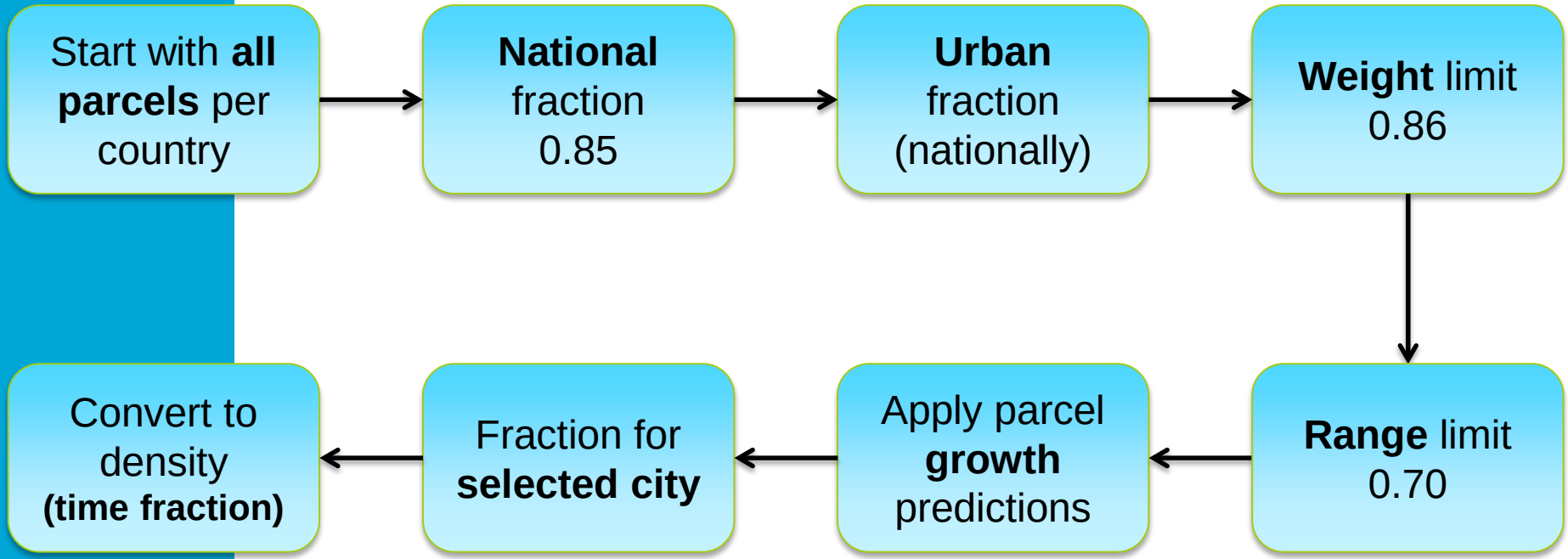
1. 85 % parcel demand delivered nationally
2. Drones only deliver in urban area
3. Only last mile segment drone delivery:
   Range constraints:
   70 % of the fraction of domestic parcels by drones
4. Only parcels weighing ≤ 2.2kg
   = 86 % of Amazon's orders
5. One delivery mission takes 30 mins (one parcel)

R. D'Andrea, "Guest editorial can drones deliver?", *Automation Science and Engineering,* IEEE transcations, vol. 11, pp.647-648, 2014 and several others

Future density estimation



Future density estimation



TU Delft

Case-study: Paris example(1/4)

- In 2018, **1.5 billion parcels** were delivered **nationally** in France
- France has an **urban population of 81 %** hence, **1.2 billion** “urban” parcels
- **Weight factor**: **86 %** => **1.0 billion**
- “Drone enabled” parcels (**range-payload**) factor: **70 %**

This gives us **700 million parcels/year** for all urban areas in France

Case-study: Paris example (2/4)

Apply compound annual **growth predictions** for 2035 - 2050 (OCED):

- Low: 3%
- Medium: 6%
- High: 9%

Year	France Urban Parcels (Billions)		
	Lo	Med	Hi
2035	1.2	1.9	3.0
2040	1.4	2.5	4.7
2045	1.6	3.4	7.2
2050	1.9	4.5	11.0

Case-study: Paris example (3/4)

- The urban **city of Paris** accounts for 23 % of France's total urban population (in millions)

Year	Low	Med	Hi
2035	276	437	690
2040	322	575	1,081
2045	368	782	1,656
2050	437	1,035	2,530

Urban Drone Delivery Forecast for Paris (million)

Case-study: Paris example (4/4)

Temporal effect for the drone delivery density:

- 6 days per week and 8 hour per day
- One delivery trip takes 30 mins

Year	Low	Med	Hi
2035	55,112	87,260	137,780
2040	64,297	114,817	215,855
2045	73,482	156,150	330,671
2050	87,260	206,670	505,192

Compare today: Globally ≈ 10,000 aircraft in the sky

Uniform 24/7: factor 0.30

TU Delft

What does it mean?

- Larger urban area Paris:
  55,000-500,000 in the sky in 2035-2050
  (85,000 realistically in 2035)

- Core area: 2.1 million people on 100 km^2:
  100 – 900 drones per 1 km^2 (160 in 2035)

- 1 – 9 per area of 100 x 100 m (2 in 2035)

And what about food delivery?

Source: Uber.com

Case-study: Cost comparison

vs

Case-study: Cost comparison

vs

Case-study: Cost comparison

vs

Source: Zdnet.com

Source: ebike4delivery.com

Case-study:

Cost comparison drone vs e-bike food delivery

Assumptions for this example (Paris again):

1. 1 % of the population of Paris request for fast-food deliveries on a daily basis
   a) 123,000 daily delivery requests
2. Deliveries take place between 6pm – 12am
   a) 20,500 hourly delivery request per day
3. A drone is able to deliver 2 orders to 2 independent customers per hour
   a) 10,250 delivery drones needed
4. An e-bike is able to deliver 5 orders to 5 independent customers per hour
   a) 4,100 e-bikes needed

TU Delft

Costs included in comparison

- Number of vehicles
- Cost of vehicle
- Cost of modification per vehicle
- Cost of extra battery
- Annual maintenance cost per vehicle
- Annual liability insurance cost per vehicle
- Total investment cost
- Depreciation time (years)
- Annual investment cost
- Number of operational days
- Daily investment cost (fixed cost)
- Airspace cost per vehicle per hour
- Labor cost per hour
- Number of operators
- Number of operational hours per day

Cost analysis: Food delivery via drones

	Drone		
	Pessimistic	Realistic	Optimistic
Number of vehicles	10,250	10,250	10,250
Cost of vehicle	€ 5,699.00	€4,267.50	€2,849.50
Cost of modification per vehicle	€ 150.00	€50.0	€0
Cost of extra battery	€ 899.00	€449.50	€224.75
Annual maintenance cost per vehicle	€ 1,709.70	€427.50	€142.47
Annual liability insurance cost per vehicle	€ 1,000.00	€500.00	€100.00
Total investment cost	€ 95,941,425.00	€58,868,312.5	€34,503,550.0
Depreciation time (years)	7	7	7
Annual investment cost	€ 13,848,775.00	€8,409,758.93	€4,929,078.57
Number of operational days	365	365	365
Daily investment cost (fixed cost)	€ 37,941.85	€23,040.44	€13,504.32
Airspace cost per vehicle per hour	€ 2.00	€0.50	€0.25
Labor cost per hour	€ 30.00	€30.00	0
Number of operators	25	5	0
Number of operational hours per day	6	6	6
Daily operational cost (variable cost)	€ 127,500.00	€31,650.00	€15,375.00
Total daily cost	€ 165,441.85	€54,690.44	€28,879.32
Delivery cost per order	**€ 1.35**	**€ 0.44**	**€ 0.23**

Cost analysis: Food delivery via e-bikes

	E-bike		
	Pessimistic	Realistic	Optimistic
Number of vehicles	4,100	4,100	4,100
Cost of vehicle	€2,500.00	€ 1,875.00	€1,500.00
Cost of modification per vehicle	€150.00	€ 100.00	€50.00
Cost of extra battery	€100.00	€50.00	€25.00
Annual maintenance cost per vehicle	€180.00	€ 142.50	€105.00
Annual insurance cost per vehicle	€84.00	€ 58.50	€33.00
Total investment cost	€12,357,400.00	€ 9,124,550.00	€7,023,300.00
Depreciation time (years)	7	7	7
Annual investment cost	€1,765,342.86	€ 1,303,507.14	€1,003,328.57
Number of operational days	365	365	365
Daily investment cost (fixed cost)	€4,836.56	€ 3,571.25	€2,748.85
Labor cost per hour	€10.00	€ 10.00	€10.00
Number of couriers	4,100	4,100	4,100
Number of operational hours per day	6	6	6
Daily operational cost (variable cost)	€ 246,000.00	€ 246,000.00	€ 246,000.00
Total daily cost	€ 250,836.56	€ 249,571.25	€ 248,748.85
Delivery cost per order	**€2.04**	**€ 2.03**	**€ 2.02**

Cost analysis: Food delivery comparison

	Drone		
	Pessimistic	Realistic	Optimistic
Number of vehicles	10,250	10,250	10,250
Cost of vehicle	€ 5,699.00	€4,267.50	€2,849.50
Cost of modification per vehicle	€ 150.00		
Cost of extra battery	€ 899.00		
Annual maintenance cost per vehicle	€ 1,709.70		
Annual liability insurance cost per vehicle	€ 1,000.00	€500.00	€100.00
Total investment cost	€ 95,941,425.00	€58,868,312.5	€34,503,550

	E-bike		
	Pessimistic	Realistic	Optimistic
Number of vehicles	4,100	4,100	4,100
	€2,500.00	€ 1,875.00	€1,500.00
	€150.00	€ 100.00	€50.00
	€100.00	€50.00	€25.00
Annual maintenance cost per vehicle	€180.00	€ 142.50	€105.00
Annual insurance cost per vehicle	€84.00	€ 58.50	€33.00

Amazon estimate:
€ 0.71 per parcel

	Drone		
	Pessimistic	Realistic	Optimistic
Delivery cost per order	€ 1.35	€ 0.44	€ 0.23

	E-bike		
	Pessimistic	Realistic	Optimistic
Delivery cost per order	€2.04	€ 2.03	€ 2.02

Cost analysis

- Food delivery: E-bikes cost is 2x drone cost
- Labour cost is the main driving factor
-

Cost analysis

- Food delivery: E-bikes cost is 2x drone cost
- Labour cost is the main driving factor
- Food delivery via drones is a viable option!

Conclusion

- The application of **delivery drones** presents the greatest demands compared to other drone applications

- Potential benefits:
  - reduce **congestion**
  - **economic** benefit for operator
  - reduce **environmental** impact

- Assumptions + growth predictions from realistic scenario:
  85,000 delivery drones by 2035 in Paris

- Based on demand & economics:
  realisation depends on capacity of U-Space

TU Delft


Questions?
Salzburg: 500 – 5000 drones