MODEL FOR A SUSTAINABLE DEVELOPMENT OF THE LAST MILE DELIVERY LOGISTICS BY DRONES

Bruno Lamiscarre

NMS Lab, Neometsys, France

Presented by: Bruno Lamiscarre

bruno.lamiscarre@neometsys.fr

Bruno Lamiscarre
Scientific Director and Asia-Pacific Director

Bruno.lamiscarre@neometsys.fr

Bruno Lamiscarre was graduated with the Master of science in engineering in photonics in 1980; he worked first at Onera in several locations Chatillon, Meudon and Toulouse in France. He has acquired over 16 years in the Physics Scientific Branch a large experience in the domain of Optical Sensors and Signal processing. Since 1997, he has been involved in the field of Airport related research within the frame of the project called « Airport of the future » as the head of this project. He was involved in EU projects in the field of Air Transport System (ATS) covering, Drones, Airports, Automation, Fast time simulation, Security. Since 2007, he was the program manager of IESTA platform development: IESTA is a fast time simulation of the ATS with particular focus on environmental issues and future ATS concepts.

He joined ENAC (Ecole Nationale d'Aviation Civile), the French civil aviation university, in 2010 and until mid 2014, he was the Director for Research, in charge of the development of ENAC research on academics grounds but also towards applications like Unmanned Aircraft System (UAS), Air Traffic Management (ATM) and Airports, Human Machine Interface (HMI) in Aviation, Sustainable Air Transport, Safety.

Since then and until march 2017, he was back at ONERA to take the responsibility of the Systems Control and Flight Dynamics department. The department is focused on control and piloting, monitoring and decision, robotics systems, HMI and Human factors, and System design for aerospace vehicles and systems.

In the framework of new ONERA organisation in 2017, he took the position of Program Director of the Air Transport System Directorate. More specifically, he was coordinating the whole ONERA research activities in the domains of ATM (including UAS Traffic Management - UTM), Airport and Avionics Systems.

Since he left ONERA in December 2018, he joined NeoMetSys as the Scientific Director and the Asia Pacific Director.

https://www.linkedin.com/in/bruno-lamiscarre-34102aa?lipi=urn%3Ali%3Apage%3Ad_flagship3_profile_view_base_contact_details%3Bksc9mRTgTeW

NeoMetSys knowledge and skills in Aviation

- Collaborative Decision Making (CDM) and Airport CDM (A-CDM)
- Traffic Flow Management (ATFCM – Air Traffic Flow and Capacity Management), Dynamic Airspace Configuration (DAC)
- Dynamic Capacity Balancing (DCB)
- Trajectories Optimization (Airstreams)
- Commercial Aircraft and Drones Traffic Simulation
- Urban Air Mobility (UAM): Airspace Design, Trajectories optimization, Traffic complexity, Detect & Avoid, Societal Acceptance, Drone Regulation

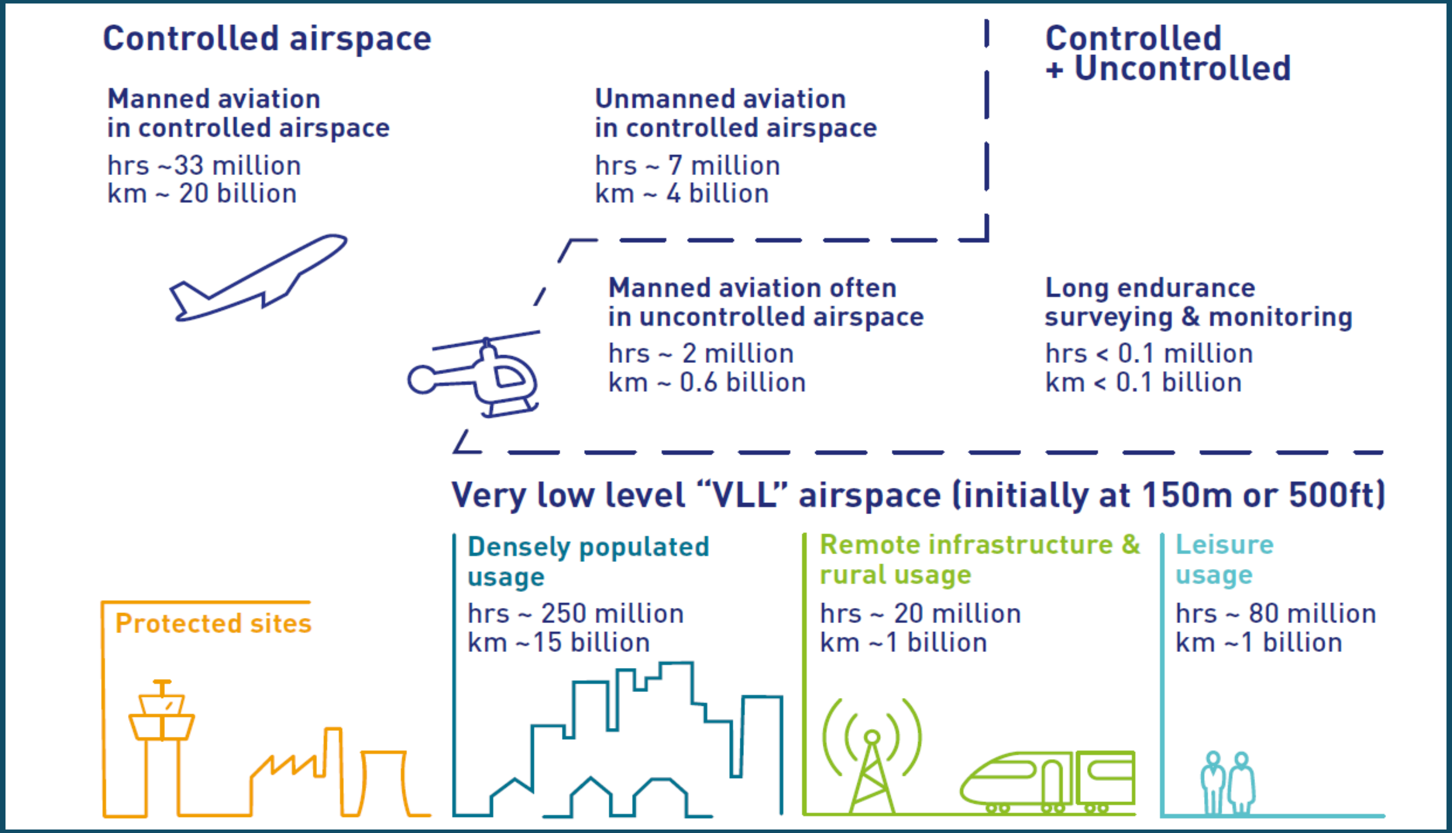
Content

1- Definitions

- UAV: Unmanned Aerial Vehicles (**UAVs**), sometimes referred to as **drones**, are aircrafts without an onboard pilot; UAVs operate with varying degrees of autonomy, such as remotely controlled by a human operator or autonomously by onboard computers
- UAS: Unmanned Aerial Systems
- UAM: Urban Air Mobility, incudes goods delivery, drone taxi
- LMD: Last Mile Delivery in Logistics
- TSP: Travelling Salesman Problem
- VRP: Vehicule Routing Problem

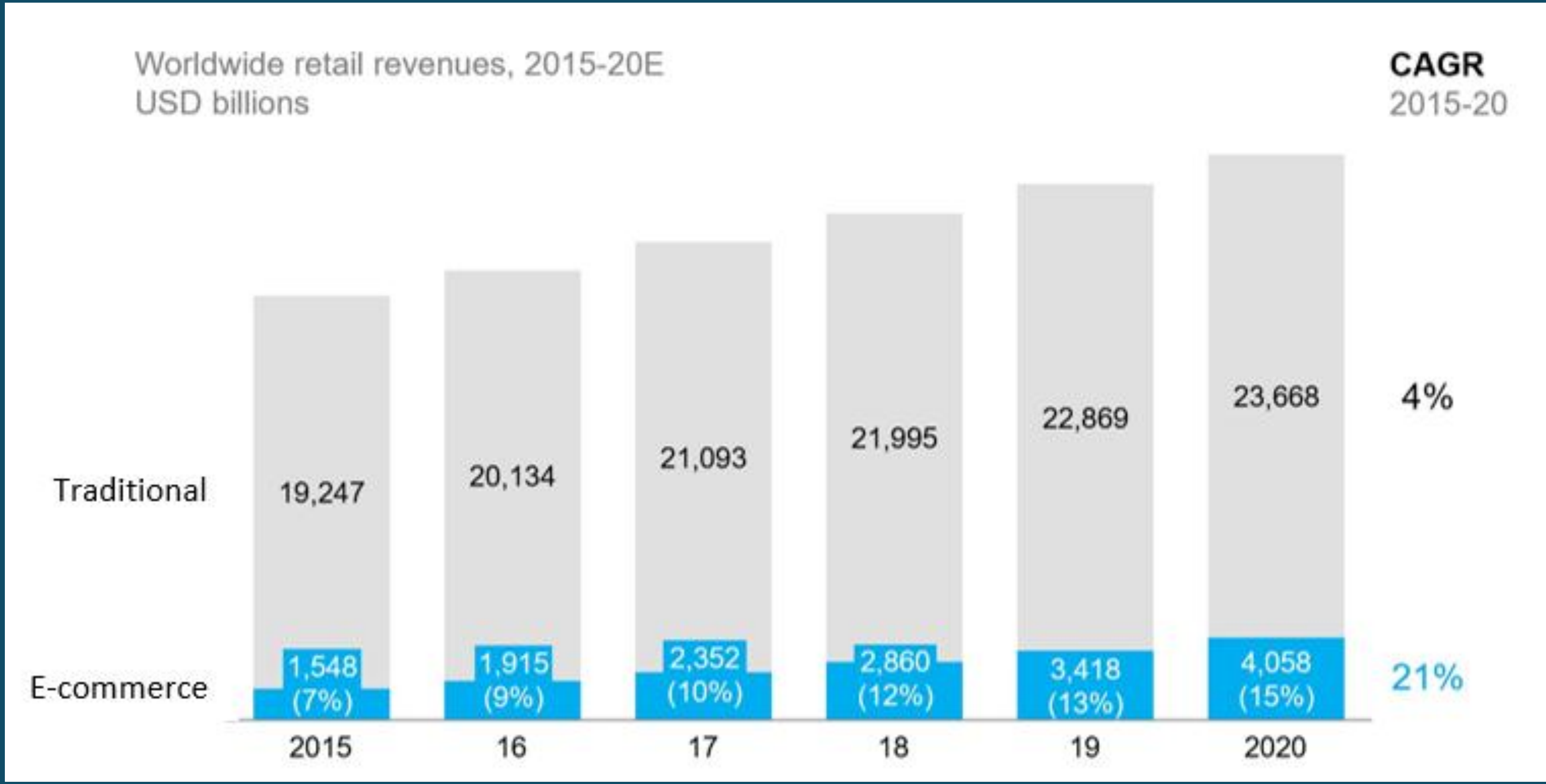
2- Introduction: SESAR view point

High potential of development of Urban Air Mobility (UAM), specially for Aerial Logistics:



2- Introduction: Market view

- E-commerce continues to outgrow offline retail revenues and is expected to reach 15% of global retail share in 2020



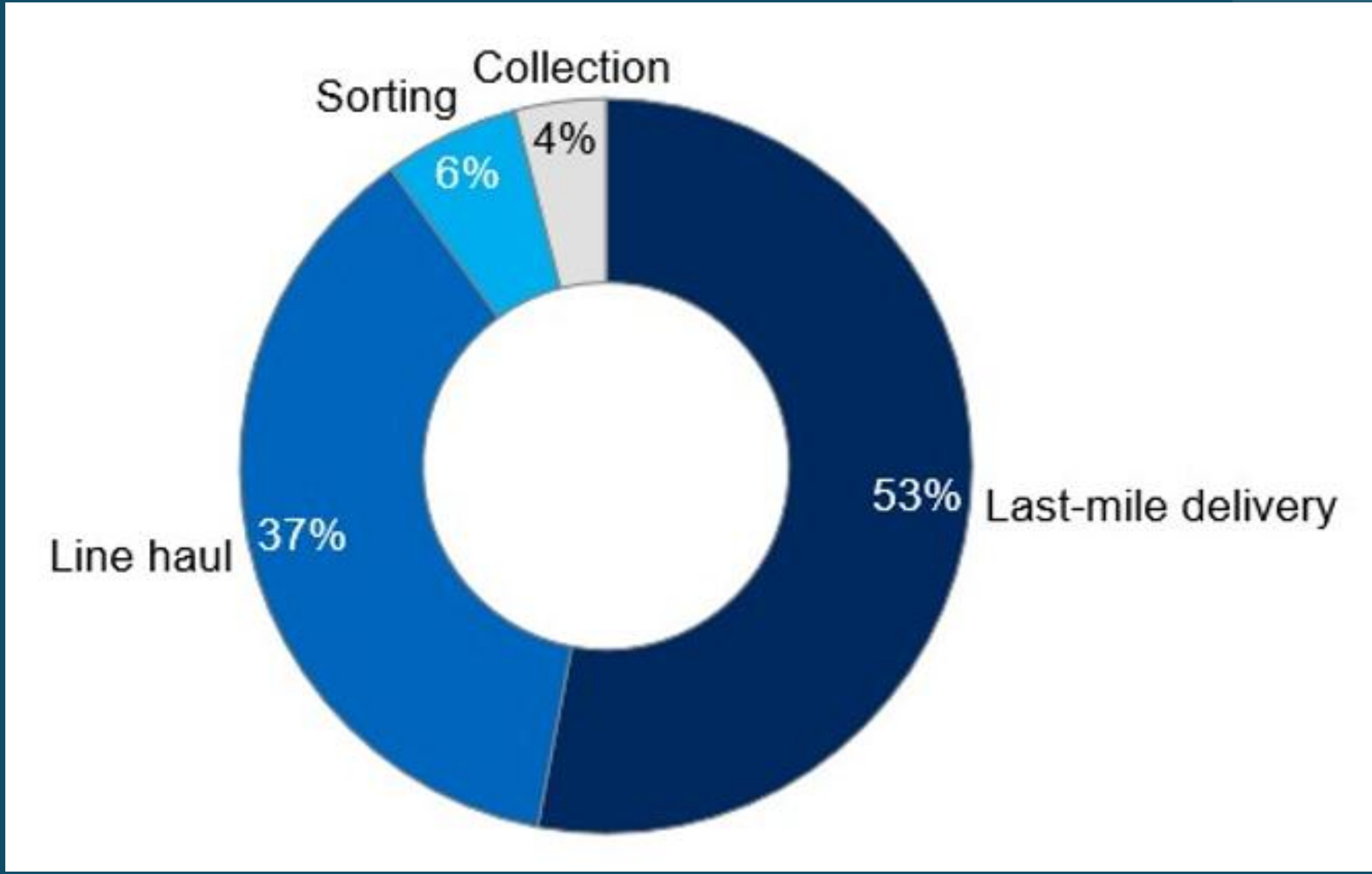
2- Introduction: LMD ineffiencency

Last-mile delivery is one of the most complex and inefficient steps in supply chain due to:

- Fragmentation of deliveries by different players with different business models. Examples include integrated logistics players, such as DHL and UPS; same-day logistics providers, such as Deliv; retailers, such as Amazon; and pure tech players, such as UBERRush.
- Inefficient delivery routes caused by urban congestion: 65% of all humans will live in cities by 2050. This rising urbanization coupled with unprecedented growth in e-commerce is increasing the volume of urban freight deliveries and consequently putting strain on cities grappling with congestion problems.

2- Introduction: LMD ineffiencency

LMD inefficiencies make last-mile delivery as the costliest step in supply chain, accounting for up to 53% of the total shipment costs



2- Introduction: Significance of drones in urban delivery

- Reduce cost: Based on research by Deutsche Bank, for typical small-box delivery, drones' delivery cost is USD 0.05 per mile - compared to USD 2 for USPS last-mile delivery or USD 6-6.5 for premium ground like FedEx or UPS
- Enhance reach area: In areas with poor infrastructure access, drones can increase reach to remote areas which cannot be served by ground transportation.
- Reduce delivery time: Drones significantly reduce delivery transit times compared to those of terrestrial delivery systems, such as trucking. This is because drones are capable of flying in straight lines to their destinations and bypass traffic congestion.

2- Introduction: Value Created by freight UAVs

Improving efficiency and reducing costs:

- Reduce operating and maintenance costs for freight and delivery by using automated or remotely controlled aerial vehicles.
- Increase freight service offering with solutions that can be operated out of usual working hours and potential to increase efficiency due to the predictability and exact timetabling of automated transportation.
- Reduction in damage to and maintenance required for road infrastructure as many heavy vehicles could be taken off the road in favour of UAVs.

Enhancing economic, social and environmental value:

- Increase efficiency enabling cheaper delivery services and shorter waiting times for deliveries through automated real-time optimisation of delivery routes, and less pressure and congestion on the road network.
- Reduce emissions and pollution, as road vehicles are replaced by UAVs powered by electricity.
- Improve road safety by reducing the number of freight vehicles on the road and replacing them with aerial vehicles in a dedicated aerial space.

2- Introduction: scope

- The LMD is an organizational challenge (cost, sustainability, environmental impact)
- The evolution of the technologies making LMD afforfable with (UAV), allowing high Safety Levels
- UAVs have been successfully used for military applications for decades and are now increasingly being adopted by the freight and logistics industry
- The societal acceptance of LMD via UAV is a question together with regulatory issues
- Several models for LMD logistics are already developped
- Heuristic & metaheuristic methods approach are developed

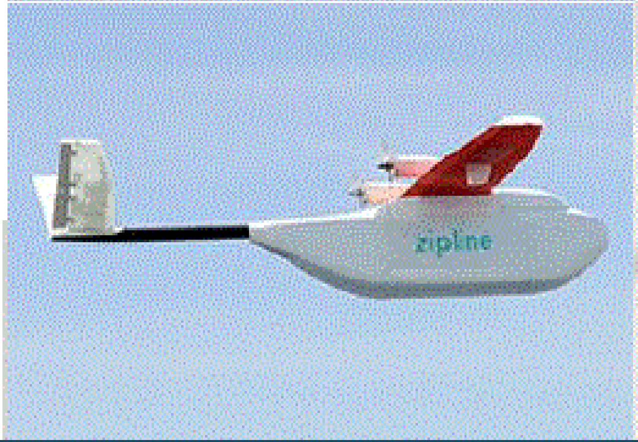
3- Enabling technologies: UAVs

- Freight UAVs are currently being developed by an array of companies including start-ups like Natilus and Sabrewing, and major players like Amazon, FedEx, DHL, and UPS
- Each prototype varies in shape and size, with Boeing's cargo air vehicle weighing 338kg (747 lb) and carrying a 227kg (500 lb) payload, versus Wing's 5kg (11 lb) drone that can carry 1.4kg (3 lb) payload
- Fast technological development (electrical engines, navigation & guidance systems and communication devices)

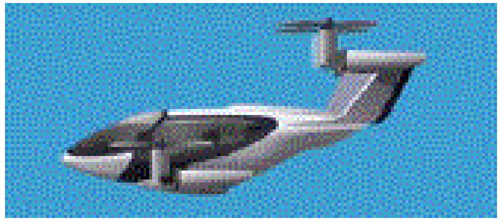
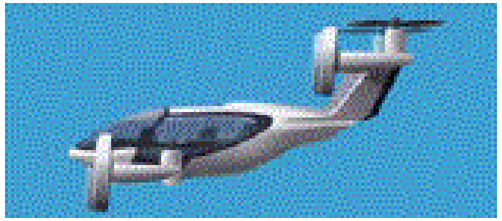
=> **Increased availability of commercial UAVs** at low cost and a wide range of payload (1.5 Kg to 350 Kg) and mission endurance (30 minutes to several hours)

3- Enabling technologies: Light UAVs Types (Light Cargo, Medical)

Fixed Wing Drone	Multi-Rotor Drone	Hybrid Drone
e.g. Zipline, Wings for Aid	e.g. Matternet, Flirtey	e.g. Drones for Development, Vayu
Aeroplane-like	Quad-copter, helicopter or octo-copter	Combines advantages of Fixed Wing and Multi-Rotor
Faster (up to 100 km/h)	Shorter flight time	Faster (up to 100 km/h)
Longer distances (up to 150 km)	Shorter distance (up to 20 km)	Longer distances (up to 80 km)
Payload (1.5-4.5 kg)	Payload (up to 4.5 kg)	Payload (up to 5 kg)
Require landing strip and catapult	Vertical take-off and landing	Vertical take-off and landing
Can only go one way; cannot return supplies	Battery replacement on the way optional; could return supplies	Battery replacement on the way optional; could return supplies
Parachute option to drop supplies	Generally cheaper	Generally more expensive



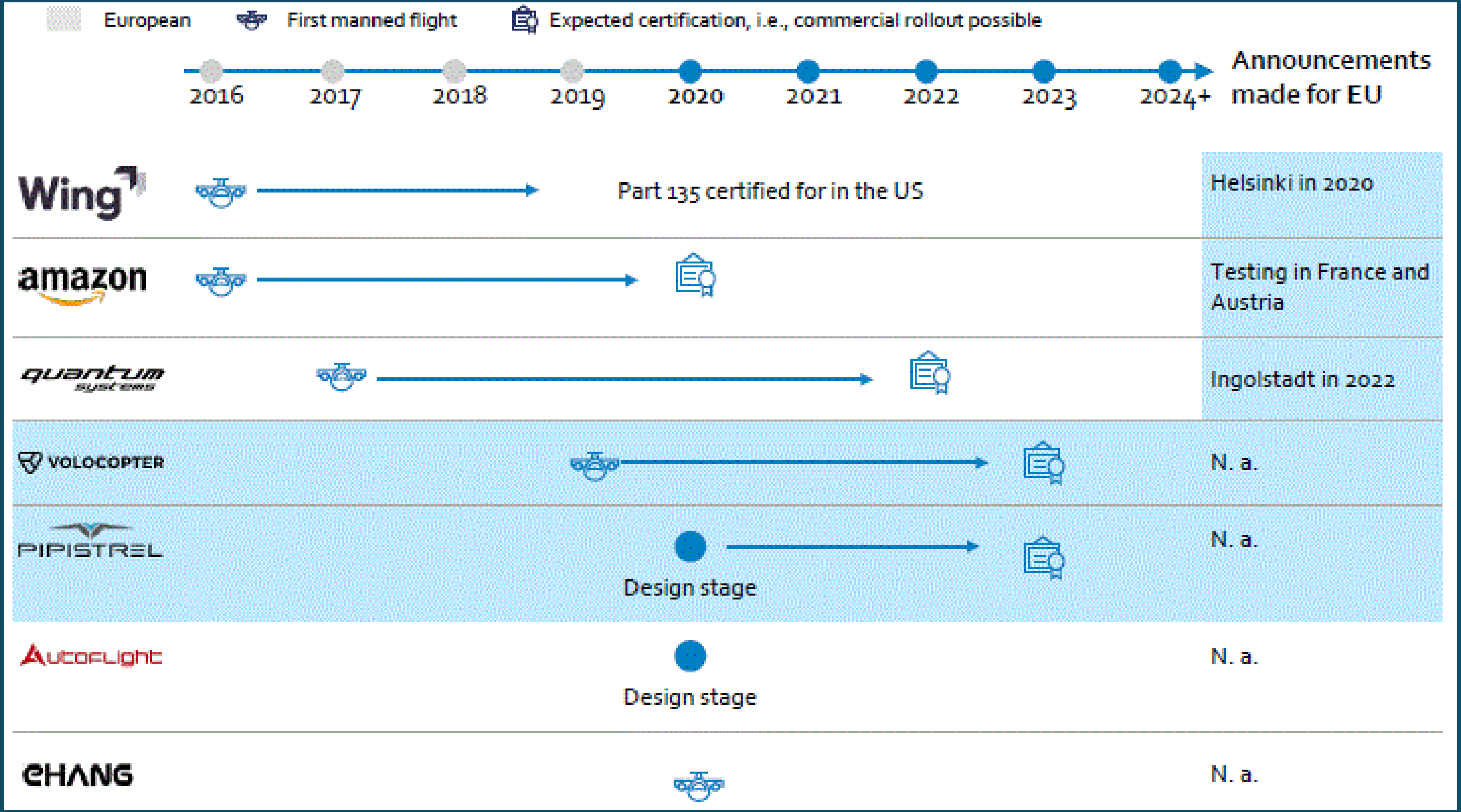

3- Enabling technologies: heavy UAVs Types (Taxi, heavy Cargo)

	Vectored Thrust	Lift + Cruise	Wingless (Multicopter)
	Thrusters used for lift and cruise	Independent thrusters used for cruise as for lift	Thrusters only for lift, cruise via rotor pitch
			
Example	Hyundai SA1 eVTOL	Wisk (Kitty Hawk) Cora	Volocopter 2X
Benefits	Optimized for both hover and cruise Lift provided by wings for cruise for highest efficiency Highest cruising speeds	Redundancy benefits of multicopter without collective or cyclic actuation Wing configuration allows for more speed in cruise	High redundancy and simple controls Significantly quieter than helicopters Lower maintenance and lightweight

3- Enabling technologies: Light UAVs Costs

	Zipline	Matternet	Vayu	Drones for Development Dr.One
Immediate cost	Model on a per flight basis with a minimun number of flights agreed upon. Drones are not for sale	USD 5,000-USD 7,500 per drone	USD 30,000 per drone	USD 5,000 per drone. Cost are expected to decrease with scale-up
Further cost	No long-term capital or maintenance costs	Cost for infrastructure e.g. landing stations or maintanance costs if needed for battery, motor or propeller	Replacement cost of battery after 1000 cycles	The life time of a drone is expected to be 5 years, the battery life 12 month

3- Enabling technologies: UAVs Cargo projects



4- Societal Acceptance & Sustainability:
UAM high level societal benefits in EU and Europe

IARIA

~4.2 bn €

market size in Europe in 2030[1]

~90 000

jobs created in the Europe in 2030[3]

15-40 min

saved in average on travel time by UAM for a city to airport transfer[5]

~31%

of global UAM market to be located in Europe in 2030[1]

100%

reduction of local emissions for electric propulsion[4]

~73%

faster delivery of organs between city hospitals possible[5]

1 500 times

less likely to be involved in a fatal accident compared to road transport on a passenger kilometre basis[2]

1. Based on McKinsey VTOL market model
2. Assuming same safety level as commercial air transport in the EU
3. Based on direct, indirect and induced jobs created by CAPEX and OPEX spend of UAM industry in Europe in 2030
4. Compared to a helicopter with conventional kerosene propulsion
5. Compared to a car drive on a Thursday at 5pm

Source: VTOL team, Eurostat, Google Maps

4- Societal Acceptance & Sustainability:
UAM high level societal risks in EU and Europe

Noise
"..there are certain threats that could impede the sustainable and thus successful introduction of UAM to our cities, with **noise** being a prominent limitation."

Safety
"The key areas of discussion to move forward will be to meet, or exceed, the current **safety** parameters with these new vehicles."

Privacy
"Civil liberties groups have **privacy** concerns with widespread UAM adoption..."

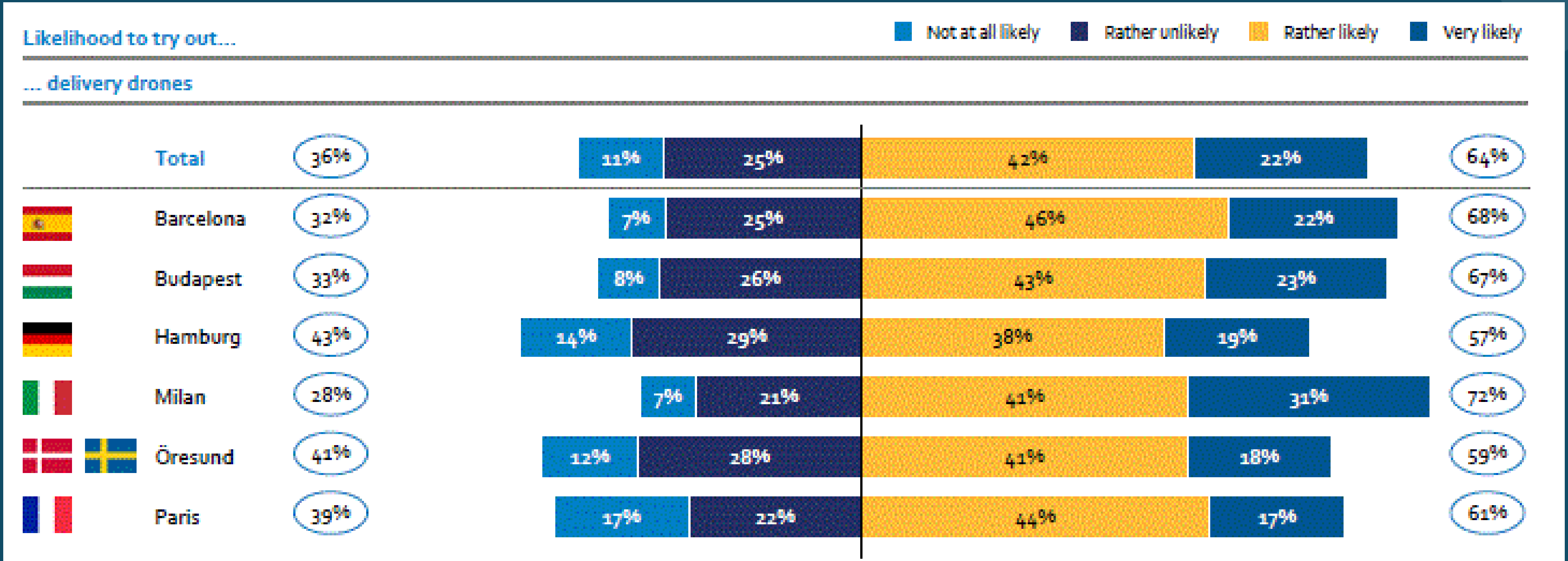
Visual pollution
"The sensitive topic of **visual** and noise **pollution** must also be addressed."

Affordability
"Public acceptance of these new systems and services is imperative, driven by ... ...and **affordability**."

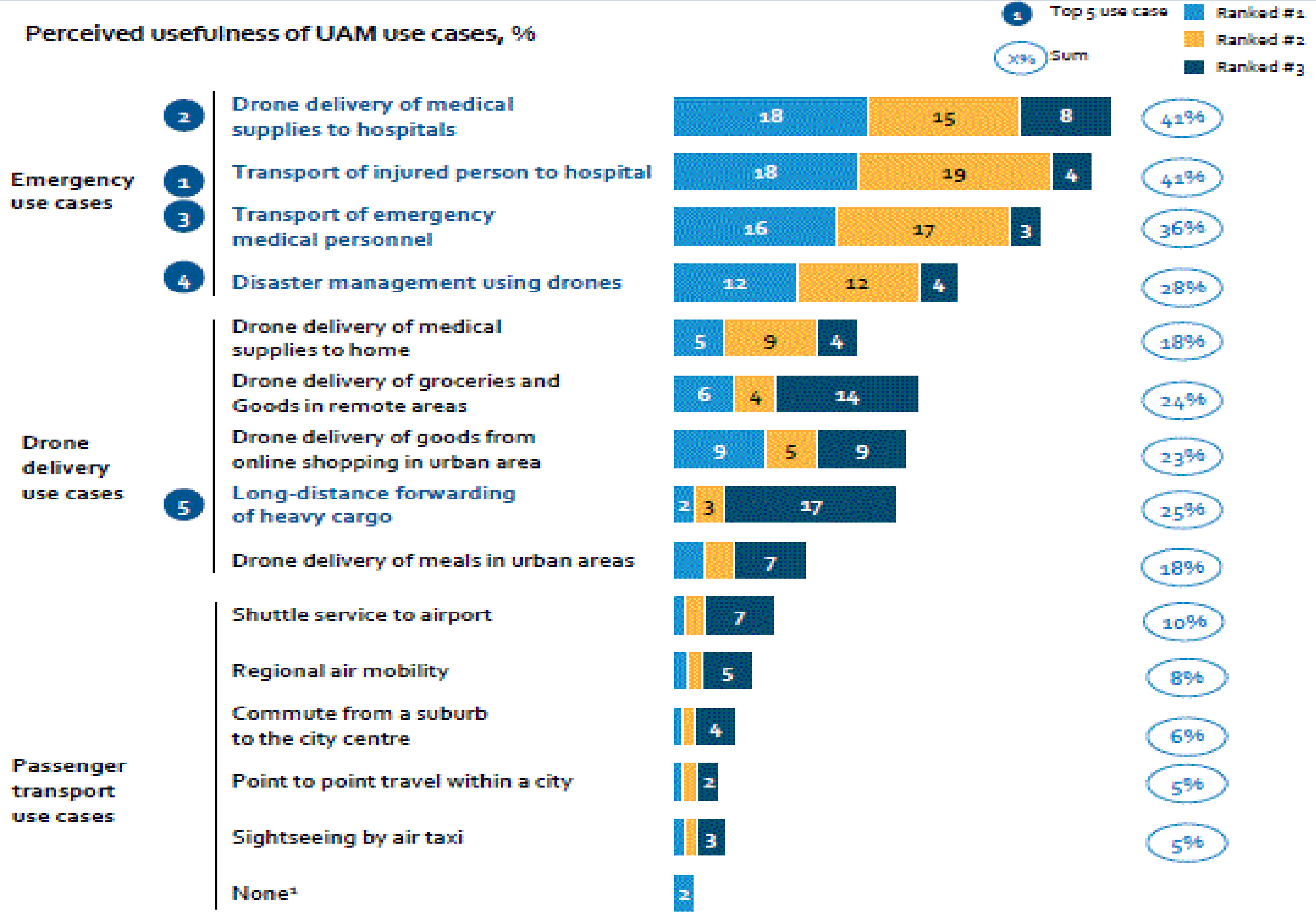
Obsolete jobs
"There is concern that autonomous technology will render **jobs** obsolete across multiple industries"

Environmental impact
"**Air pollution** caused by pollutants such as particulate matter, nitrogen oxides and ozone, as well as odour nuisance should be avoided."

4- Societal Acceptance & Sustainability: EU
Survey for implementation of delivery drones



4- Societal Acceptance & Sustainability: EU
Survey, perceived usefulness of UAVs services



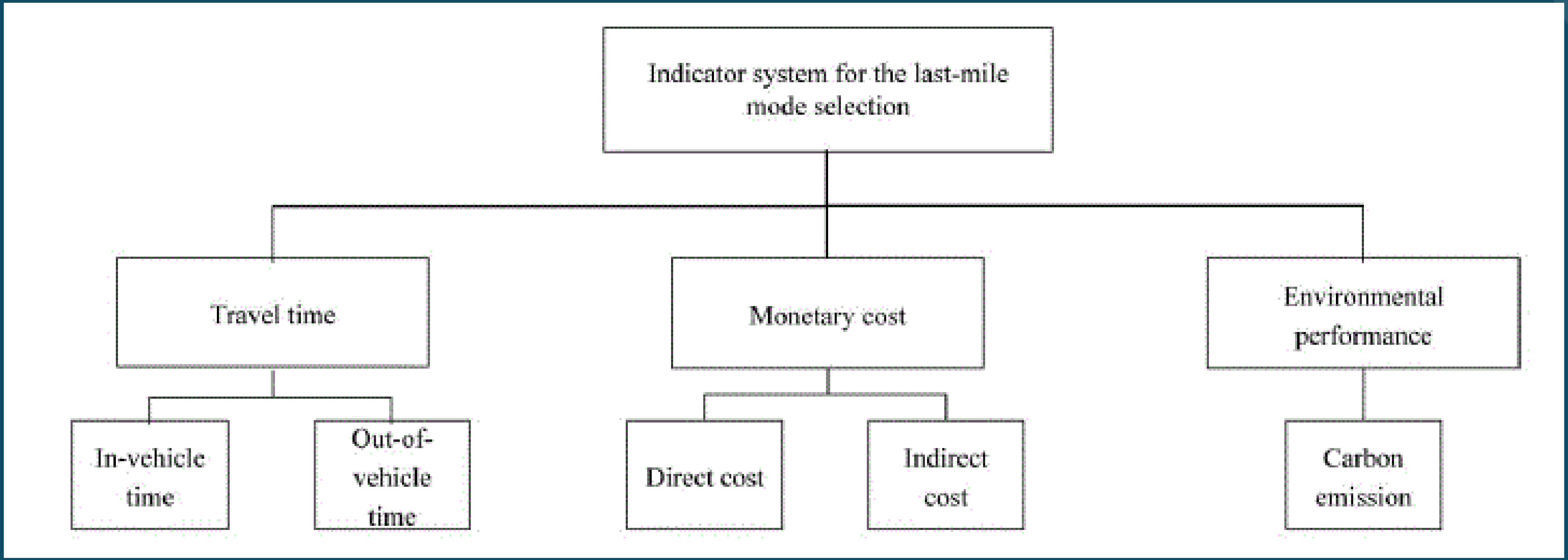
5- LMD modes & Decision Making: LMD modes

- Reception Box (RB): Shared RB, Own RB, Delivery Box own by LMD provider
- Collection-and-delivery points (CDPs): Locker point or unattended point is a shared reception box that installed at public area
- Post office (PO): traditional local service mode
- Attended home delivery (AHD): widely used and still be a popular mode
- Unattended home delivery (UAHD): could offer a choice of solutions to the ‘not at home’ and ‘time windows’ problems

5- LMD modes & Decision Making: LMD modes comparison wrt operational topic & stakeholders

Topic	In perspectives of	Modes							
		RB			*CDPs*		*Post office*	*AHD*	*UAHD*
		Shared reception box	*Own reception box*	*Delivery box*	*Service point*	*Locker point*			
Opening hours	Customers	+	+	+	–	+	–	–	–
Convenience	Customer	–	+	+	0	–	0	+	0
Security	All stakeholders	–	0	0	+	–	+	+	–
Failed first-time delivery	Service providers	+	+	+	+	+	0	–	+
Delivery cost	Service providers	+	+	–	+	+	–	–	+
Sustainability	All stakeholders	+	+	0	+	+	0	–	+

5- LMD modes & Decision Making: Indicator System for the Last-Mile Travel-Mode Selection



6- Mathematical Models: Optimisation theories for last-mile delivery networks

- **The Travelling Salesman Problem:** The TSP is a non-deterministic problem within combinatorial optimisation, used in operation research to find the shortest path that connects a set of nodes, for which the order of visit is not important. It takes its name from the analogy of a salesman who, given a set of destinations, must visit each one of them starting from a certain node and ending at his starting location. The goal of the problem is to minimise the total length of the tour
- **The Vehicle Routing Problem:** The Vehicle Routing Problem (VRP) is a combinatorial optimisation and integer programming problem, which generalises the TSP. The goal of the VRP is to define the optimal tour given a set of nodes and a fleet of vehicles, such that each node is visited at least once and only once, and the costs of operations are minimised

6- Mathematical Models: the TSP

- The objective function is to minimise the cost of visiting each node. The decision variable x_{ij} refers to the binary integer value that returns 1 if the path goes from node i to node j and zero otherwise. The combinatorial model involves n cities and it only allows path solutions that visit each node once and only once and that define a tour.
- Some adaptation of the TSP with combined drones and van fleets

OF $\quad min \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} * x_{ij}$

ST $\quad min \sum_{i=1}^{n} x_{ij} = 1 \qquad 1 \leq j \leq n \qquad (1)$

$min \sum_{j=1}^{n} x_{ij} = 1 \qquad 1 \leq i \leq n \qquad (2)$

$x_{ij} \geq 0 \qquad 1 \leq i \leq n, 1 \leq j \leq n \qquad (3)$

6- Mathematical Models: the VRP

The objective function is to minimise the cost of the tour, by providing the cheapest possible sequence of nodes to be visited. The decision variable x_{ijk} can assume the value of 1 if customer j is visited immediately after customer i by vehicle k, and 0 otherwise. The variable y_{ik} defines whether customer i is visited with vehicle k. The capacity of the vehicles is limited by constraint 3, in which q_i indicates the demand at each node visited by vehicle k and Q_k the capacity of vehicle k. Constraint 6 guarantees that not sub tours are generated

OF	$min \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} * x_{ij}$		
ST	$\sum_{k=1}^{m} y_{ik} = 1$	$1 \leq i \leq n$	(1)
	$\sum_{k=1}^{m} y_{ik} = m$	$i = 0$	(2)
	$\sum_{i=1}^{n} q_i * y_{ik} \leq Q_k$	$1 \leq k \leq m$	(3)
	$\sum_{j=0}^{n} x_{ijk} = y_{ik}$	$0 \leq i \leq n, 1 \leq k \leq m$	(4)
	$\sum_{i=0}^{n} x_{ijk} = y_{jk}$	$0 \leq j \leq n, 1 \leq k \leq m$	(5)
	$\sum_{i \epsilon S} \sum_{j \epsilon S} x_{ijk} \leq \lvert S \rvert - 1$	$S \subseteq 1, \ldots, n,\ 1 \leq k \leq m$	(6)

6- Mathematical Models: Adaptations of the VRP

- VRP with pick-up and delivery (VRPPD): goods are first moved from the retail shop to pick-up points and then to the delivery locations;
- VRP with last in first out (VRPLIFO): the VRPPD is extended with another restriction that the first item to be delivered must be the last one that was picked up. This is usually used when the loading and unloading time at the delivery location is limited;
- VRP with multiple trips (VRPMT): vehicles are allowed to do more than one route in their tour;
- Open VRP (OVRP): vehicles do not have to return to the initial node (depot or retail store);
- VRP with time windows (VRPTW): used when deliveries have pre-arranged times for the delivery visit;
- Dynamic VRPTW (DVRPTW): extension of the VRPTW in which two types of customers are defined, the known customers and the new customers. Known customers refers to the ones that are already planned in the delivery schedule, while new customers refer to the one that call in and must be inserted in the existing route;
- Capacitated VRP (CVRP): used in the case that the vehicles have a limited capacity.

7- Models Implementation: example of the VRP

- The VRP belongs to the category of **NP-complete** problems, a class of computational problems for which no efficient solution algorithm has been found. For this reason, exact algorithms can be used to obtain true optimal routes only up to 30 nodes. In case of more than 30 nodes, **heuristic algorithms** must be used
- An example of exact algorithm for the VRP is the Branch-and-Bound algorithm, the BnB algorithm is used to solve discrete and combinatorial optimization problems, using a systematic enumeration of candidate solutions by means of state space search. The iterations are seen as forming a tree, which branches represent subsets of the solution set. At each iteration, feasible sets are broken up into successively smaller subsets, for which the upper and lower bounds of the objective function are calculated and used for discard certain subsets from further consideration, in case they cannot produce a better solution than the best one already found

7- Models Implementation: Heuristic algorithms for VRP implementation

Two types of heuristic algorithms to solve the Vehicle Routing Problem:

- **Constructive heuristics**: Constructive heuristics gradually build a feasible solution, while minimizing the solution cost. The construction method is based either on the nearest, the farthest or the cheapest neighbour, depending on the criteria used for the selection method. In all cases, constructive heuristics can fail to provide the best optimal solution, given the greedy nature of their algorithms.
- **Improvement heuristics**: Improvement heuristics aim to obtain a feasible solution upgrading the previous one obtained, by changing the sequence of edges within or between vehicle routes. Improvements come from a neighbourhood search process, for which each route is associated with a neighbourhood, and better solutions are sought within that specific neighbourhood.

7- Models Implementation: Metaheuristic algorithms for VRP implementation

- Metaheuristic algorithms are a category of modern heuristics that are used for generate or select the best heuristic method to solve an optimisation problem, providing a sufficiently good solution in case of imperfect information or limited computation capabilities
- Global optimal solution is not guaranteed, given the fact that this type of solution approach relies on assumptions about the optimisation problem to be solved
- To find a sufficiently good solution in case of imperfect information, metaheuristics implement a stochastic optimisation, generating a random set of variables and solving the problem for that specific set; in this way, the solution is highly dependent on the chosen variables, which contributes to the reasons why global optimal solution is not guaranteed

7- Models Implementation: Metaheuristic algorithms for VRP implementation

Six types of metaheuristics can be used to solve the VRP: Simulated Annealing (SA), Deterministic Annealing (DA), Tabu Search (TS), Genetic Algorithm (GA), Ant System (AS) and Neural Networks (NN)

- SA, DA and TS, start from the initial solution x_1, each iteration t is characterised by a starting solution x_t and provides a new solution x_{t+1}, which belongs to the neighbour $N(x_t)$ of the starting solution x_t. Cost improvements are not guaranteed
- GA takes its name from the geneticevolution of species; it considers at each iteration a population of solutions derived from previous iterations by combining their best elements and getting rid of the worst
- AS is a probabilistic constructive approach that finds the optimal path to be followed through graph theory, inspired by the behaviour of real ants. In each iteration, several new solutions are created as a result of information gathered at previous iterations
- NN are a learning mechanism that base their solution on previous results, gradually adjusting the outcome values or implementation mechanism until an acceptable solution is reached

8- Conclusion

Last Mile Delivery by Drone is a fast growing domain with several issues / opportunities to be adressed:

- UAS Regulation and UAS Traffic Management (UTM)
- LMD Drone Public Acceptance evaluation via Surveys
- LMD modes selection wrt cost, environmental performance & efficiency (travel time)
- LMD combined vehicules routing optimisation (Drone, Van, Tricycle, Bicycle…) through TSP and VRP, and evolutions
- LMD Traffic evaluation and optimisation in Urban Areas

NeoMetSys

Thank you

Questions?

Bruno Lamiscarre
Bruno.lamiscarre@neometsys.fr
LinkedIn: Bruno Lamiscarre