The business case for autonomous deliveries: does it exist?

An economic analysis of the use of autonomous vehicle technology for last mile deliveries

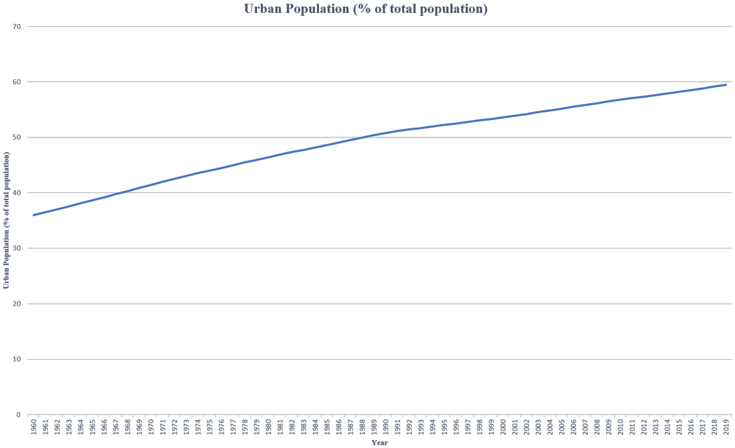
Kartik Varma[12] supervised by François Combes[1]
Pierre Eykerman[2]

[1]SPLOTT Laboratory, Universite Gustav Eiffel

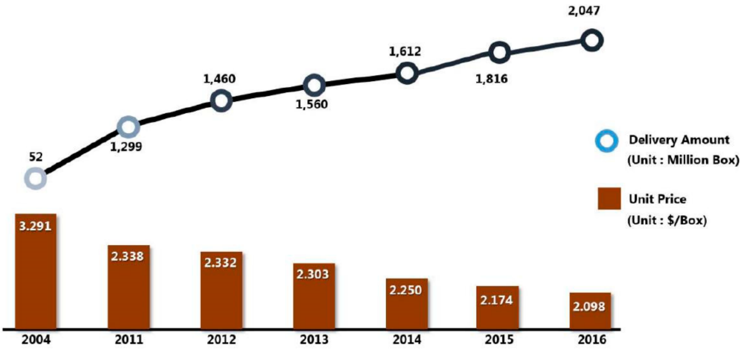
[2]Innovation and Research Department, Groupe Renault

26 May 2022

Urban Population as a Percentage of Total Population



The rise of e-commerce



Renault, LCVs and AVs

- Groupe Renault manufacturers Light Commercial Vehicles. These
  - are used extensively for Last Mile Deliveries (LMDs).
  - contribute significantly to the revenue of the firm.
- A new technology arises; Autonomous Vehicles (AVs).
  - These vehicles may be used for LMDs.
  - This may impact LCV sales.
- *Do these vehicles have a business case for LMDs?*
  - Removal of driver creates value.
  - Private perspective.

Autonomous *Single* Delivery Vehicle

ASDVs make a single delivery at a time. Here is Amazon Scout. It goes slow, can use sidewalks.

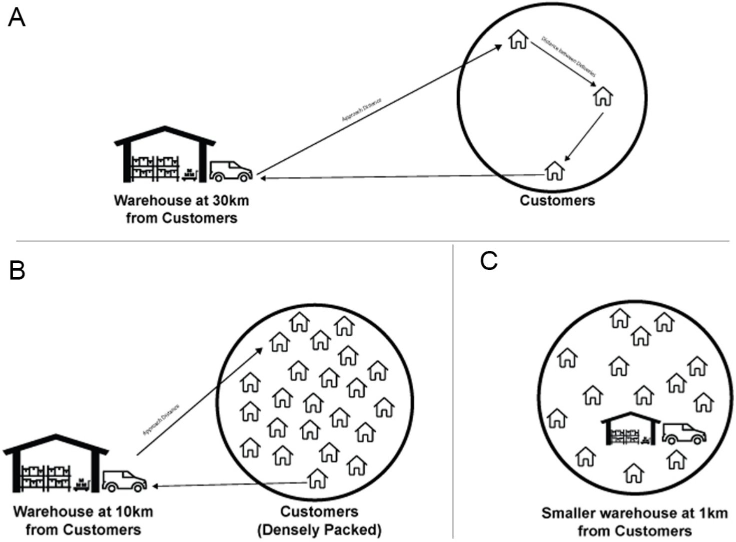
Autonomous *Multiple* Delivery Vehicle

AMDVs make multiple deliveries in 1 round. Here is Nuro; it makes 4. It goes fast, uses roads.

Methodology

- Prospective analysis
  - A cost structure of last mile deliveries is modelled, and then extended.
- Data was gathered from three sources
  - Academic Literature and Professional Reports
  - Interviews
  - Field Visits
- Operational context/constraints identified, understood and modelled.

Modelling: Overview



Modelling: Summary

Distance from Warehouse	**Size of Warehouse**	**Average distance b/w customers**	**Vehicle Used**[1]	**Market Segment**	**Output**
1 km	7500 m2	0.5 km	Diesel Van	Parcels	
10 km	15000 m2	0.6 km	Electric Van		
30 km	25000 m2	0.7 km	Cargo Bike	Groceries	**Cost/Delivery**
	40000 m2	...	ASDV[2]		
		5 km	AMDV[3]	B2B[4]	

[1] Assumption: Fleet is unimodal
[2] Autonomous Single Delivery Vehicle
[3] Autonomous Multiple Delivery Vehicle
[4] Business to Business

Literature Overview

- Previous Literature
  - Total Cost of Ownership (TCO) approach for vehicle choice - (Lebeau et al.,2019), (Figenbaum,2018), (Camilleri,2017)
  - Warehouse Location - (Combes, 2019)
  - Autonomous Vehicles - (Figliozzi, 2019, 2020)
- Contribution
  - Creation of integrated model (warehouse location AND vehicle choice)
  - Include real world operational constraints
    - Account for heterogeneity of LMDs - different Market Segments
    - Level of service penalty
    - Driver/Deliverer experience

Level of Service Penalty

Table: Level of Service Penalty

	Task	**Handled by in Conventional Delivery**	**Handled by in Autonomous Delivery**
1.	Navigating	Driver	Vehicle
2.	Calling and notifying customer of arrival	Driver	Vehicle
3.	Locating merchandise in storage	Driver	*Customer*
4.	Unloading merchandise	Driver	*Customer*
5.	Delivering merchandise to end customer	Driver	*Customer* (collects it himself)
6.	Getting proof of successful delivery from customer	Driver	Vehicle (registers opening/closing of door)

Market Segments

Table: Market Segments considered for Analysis.

Variables	**Unit**	**Parcels**	**Groceries**	**B2B**[5]
Deliveries per Round	-	100+	20	20
Avg. Weight/Delivery	Kg	0.3	25	50
Time per Delivery	Minutes	3	12	12
Vehicle Refrigerated	-	No	Yes	No
Level of Service Penalty[6]	€/Delivery	*1.5*	*3*	*5*

Values above for Diesel Van.

[5] Business to Business
[6] iff AVs used

Modelling: Math

$$\text{Cost/Delivery} = \left(\frac{Costs/Week_{warehouse} + Costs/Week_{fleet}}{Deliveries/Week} \right) \tag{1}$$

$$Costs/Week_{warehouse} = f(size, distancefromcitycenter) \tag{2}$$

$$\text{Costs/Week}_{fleet} = (tco_{vehicle} + wage_{driver}) * numberofvehicles_{fleet} \tag{3}$$

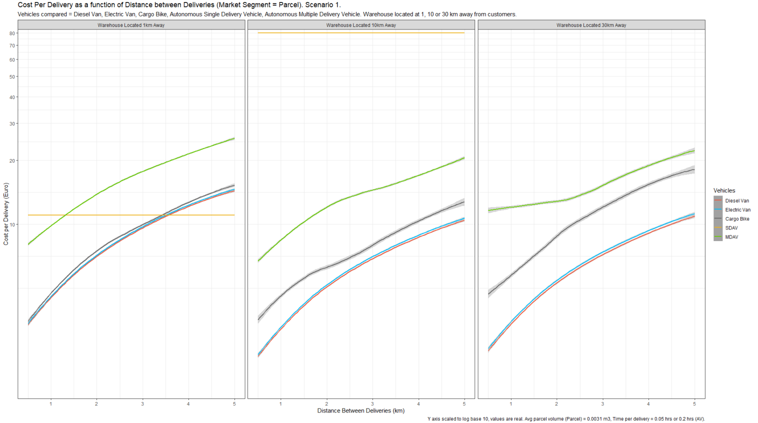
$$\begin{aligned} Deliveries/Week = f(&Vehicle, MarketSegment, \\ &CustomerDensity, SpeedBetweenDeliveries, \\ &LocationofWarehouse, ApproachSpeed) \end{aligned} \tag{4}$$

Results: Scenarios

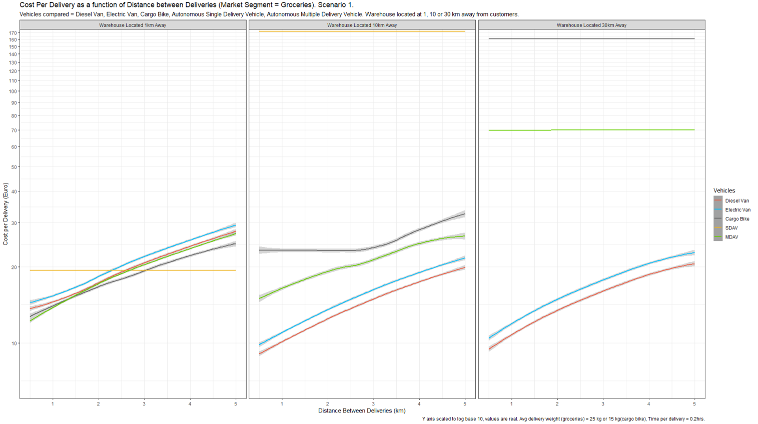
Scenarios	**Purchase Costs(Euros)**		**Losses Linked to Driver Experience**	**Costs Linked to Remote Operators**	**Level of Service Penalty**	**Driver Wage per Hour**
Scenario 1	SDAV = 250,000	MDAV = 300,000	None	None	None	11.17 €
Scenario 2	SDAV = 250,000	MDAV = 300,000	20% loss of deliveries per day	1 remote operator for 20 vehicles	1.5,3 and 5 Euros acc. to Market Segment	11.17 €
Scenario 3	SDAV = Price of Cargo Bike (7,890)	MDAV = Price of Electric Van (64,643)	20% loss of deliveries per day	1 remote operator for 20 vehicles	1.5,3 and 5 Euros acc. to Market Segment	11.17 €
Scenario 4	SDAV = Price of Cargo Bike (7,890)	MDAV = Price of Electric Van (64,643)	20% loss of deliveries per day	1 remote operator for 20 vehicles	None	11.17 €
Scenario 5	SDAV = Price of Cargo Bike (7,890)	MDAV = Price of Electric Van (64,643)	20% loss of deliveries per day	1 remote operator for 20 vehicles	None	80 cents
Scenario 6 (Green Vehicles Only)	SDAV = Price of Cargo Bike (7,890)	MDAV = Price of Electric Van (64,643)	20% loss of deliveries per day	1 remote operator for 20 vehicles	None	80 cents

Table: Scenarios

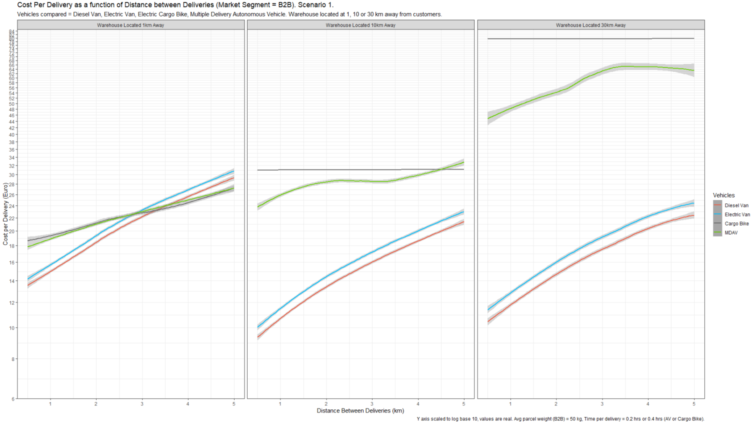
Cost per delivery: S1, Parcels



Cost per delivery: S1, Groceries



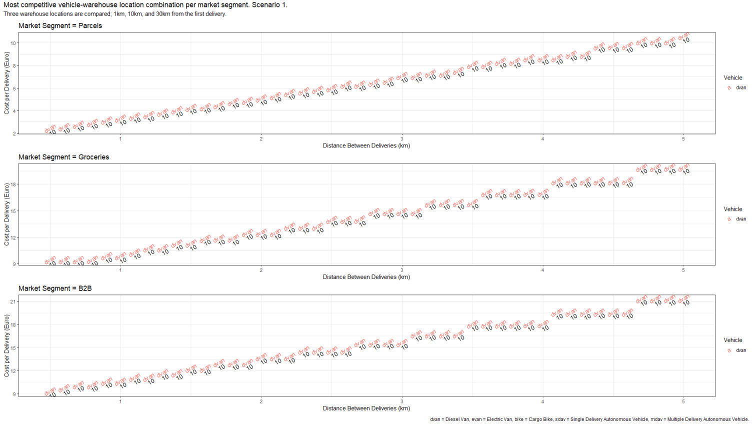
Cost per delivery: S1, B2B



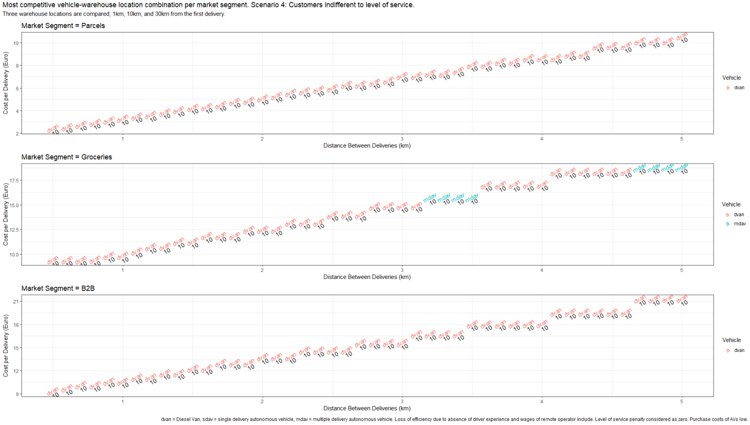
Optimal Warehouse Location/Vehicle Combination

- Warehouse location and vehicle choice are not independent:
  - Some vehicles - ex. Cargo Bikes - are severely limited by their autonomy
  - Comparing TCO over different vehicles is not appropriate if some vehicles have different operational constraints
- A logistics firm will choose a combination of warehouse location/vehicle type that offers the least cost per delivery.

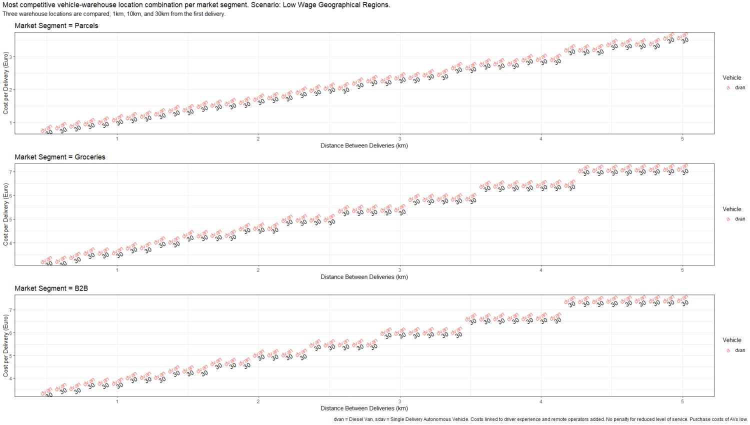
Optimal Warehouse Location/Vehicle type: S1



Optimal Warehouse Location/Vehicle type: S4



Optimal Warehouse Location/Vehicle type: Low Wage regions



Conclusion

- Model which compares cost per delivery over different vehicles, warehouse locations, size, customer densities and market segments is developed.
- Competitiveness domains for different vehicles are determined.
  - Conventional vehicles extremely efficient under current operating scenario.
  - If AVs become cheaper, and service penalty is borne by customers, AVs are competitive for certain market segments, under certain conditions.
- Future work: Model to be extended to mixed fleets, question of lead time to be addressed.

Contact

Thanks for your time and insights!

e-mail: kartik.varma@univ-eiffel.fr

Model: Overview

- In this theses, a microeconomic model of *cost per delivery* is developed. Its components are
  - Warehouse
  - Vehicles
  - Elements specific to the use of AECS vehicles

Appendix 1: Warehouse Costs

A warehouse consists of

- A physical structure at a location
- Employees
- Equipment, Electricity, Maintenance etc.

$$warehouse_{costs} = warehouse_{rent} + warehouse_{employeecost} + warehouse_{othercosts} \quad (5)$$

The following assumptions are made;

- A logistic firm requires a warehouse for its cross-docking operations.
- This warehouse is rented.
- Firm operates only 1 warehouse with unimodal fleet.
- Equipment, Electricity, Maintenance and other costs are assumed to be dependant on Market segment to which warehouse caters.

Warehouse Rent: Size, Location

The rent of a warehouse depends on two criteria;

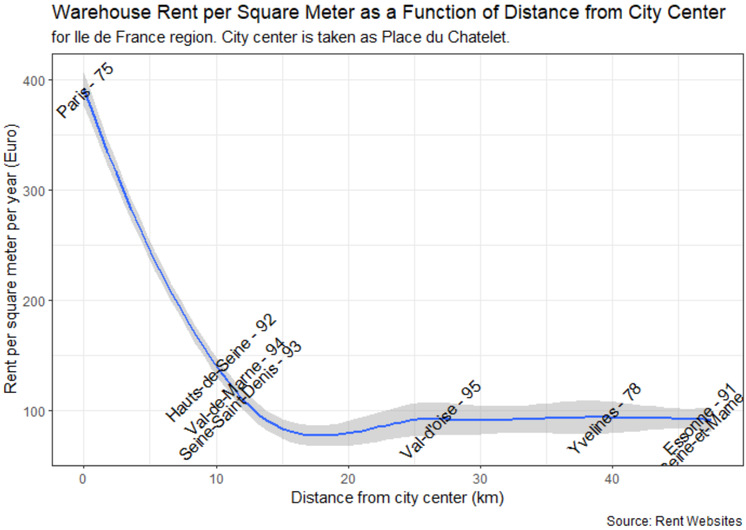
- its size and,
- its distance from the city center.

Based on data from property rental sites, this can be expressed as;

$$\text{warehouse}_{rent} = (0.0003 * (wh_d^4) - 0.04 * (wh_d^3) + 2.15 * (\text{wh}_d^2) - 43.1 * (wh_d) + 392.3 \quad (6)$$

Where $warehouse_{rent}$ is the rent per square meter and wh_d is the distance of the warehouse from city center.

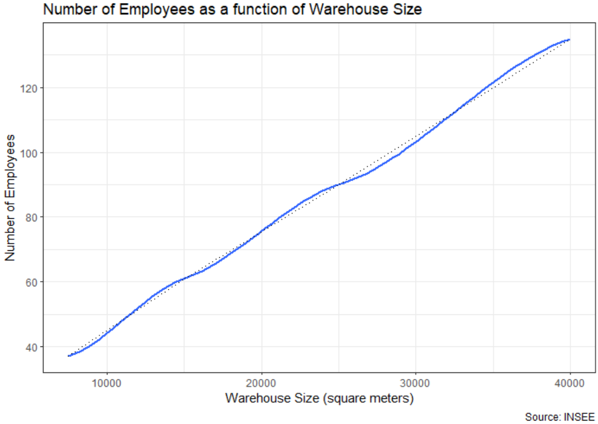
Warehouse Rent: Size, Location (contd.)



Warehouse Size and Number of Employees

Based on available (limited) data, the number of employees as a function of the size of the warehouse follows a linear relation.

$$\text{warehouse}_{employeecost} = warehouse_{size} * employees_{m2} * cost_{employee} \quad (7)$$



Warehouse: other costs

Apart from rental costs, and wage costs to employees, there are other costs in running a warehouse. These include, but are not limited to;

- Equipment costs
- Electricity costs
- Maintenance costs

Equipment costs include the costs of sorting machines, or Automated Storage and Retrieval Machine, which are extremely expensive.

Warehouse: other costs (contd.)

All other costs, not indicated by rent or employment costs are represented by the greek letter δ.

$$warehouse_{othercosts} = \delta \tag{8}$$

In this model it is assumed that for a given market segment, for a given warehouse size, these other costs are the same. These costs are not known. This creates a problem that can be tackled in at least two ways;

1. calibrate model such that cost/delivery reflect real world values.[7]
2. subtract the min. cost/delivery from all other costs/delivery for each configuration such that δ is removed.

[7] These values are known through field visits.

Warehouse: other costs (contd.)

Method 2 can be represented as:

$$warehouse_{costs}^{configuration1} = warehouse_{rent}^{configuration1} + warehouse_{employeecost}^{configuration1} + warehouse_{othercosts}^{configuration1} \quad (9)$$

$$warehouse_{costs}^{configuration2} = warehouse_{rent}^{configuration2} + warehouse_{employeecost}^{configuration2} + warehouse_{othercosts}^{configuration2} \quad (10)$$

Warehouse: other costs (contd.)

As for a given configuration (warehouse location, warehouse size, customer density, vehicle, market segment),

$$warehouse^{configuration1}_{othercosts} = warehouse^{configuration2}_{othercosts} = \delta \qquad (11)$$

From 9, 10 and 11 we have;

$$\begin{aligned} warehouse^{configuration1}_{costs} - warehouse^{configuration2}_{costs} = \\ warehouse^{configuration1}_{rent} - warehouse^{configuration2}_{rent} + \\ warehouse^{configuration1}_{employeecost} - warehouse^{configuration2}_{employeecost} \end{aligned} \qquad (12)$$

Warehouse Size and Throughput

Throughput of a warehouse is assumed proportional to its size.

$$warehouse_{throughput} \propto warehouse_{size} \tag{13}$$

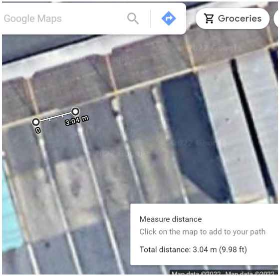
$$warehouse_{throughput} \propto fleet_{size} \tag{14}$$

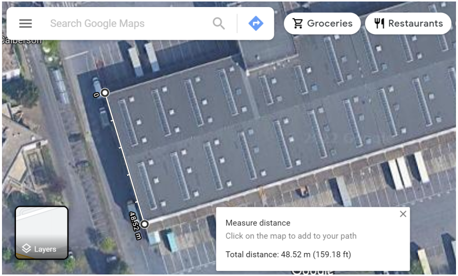
$$warehouse_{size} \propto fleet_{size} \tag{15}$$

$$warehouse_{size} = k * fleet_{size} \tag{16}$$

- Width and number of bays are determined using Google Maps.
- Area of warehouse is determined using Google Maps.
- Number of vehicles per square meter is thus calculated.

Warehouse Size and Throughput (contd.)





From above images;

- Area of building = 48m*248m = 11904m2
- Length required by 1 vehicle = 3m
- Length of warehouse = 248*2 = 496m
- No. of vehicles = 496/3 = 165.33
- No. of vehicles/m2 = 165.33/11904 = 0.014 vans/m2
- No. of vehicles/m2 (only 1 side) = 0.007

Warehouse Size and Throughput (contd.)

- No.vehicles/m2 depends on the type of vehicle.
- *an ASDV is not as wide as a Cargo Bike is not as wide as an AMDV is not as wide as a Van.*
- Area reqd(ASDV) = 0.5*Area reqd(Van)
- Area reqd(Cargo Bike) = 0.7*Area reqd(Van)
- Area reqd(AMDV) = 0.8*Area reqd(Van)

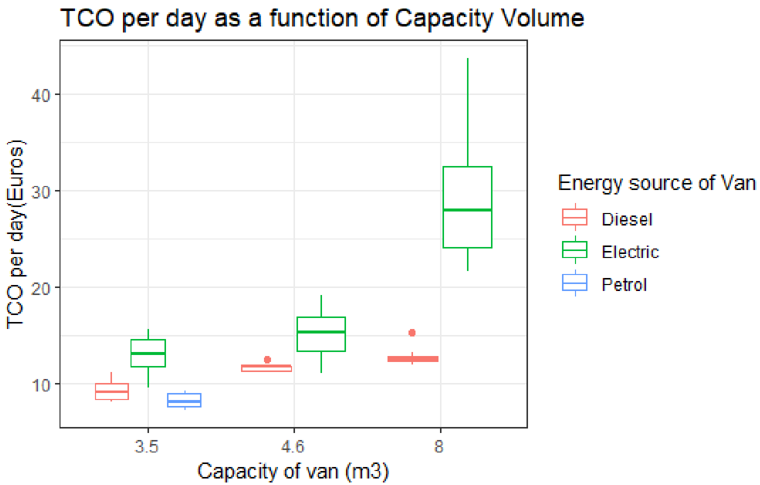
Total Cost of Ownership (TCO) of a Vehicle

- The TCO is a widely used approach to compare different cost structures over differing vehicle technologies.
- It involves comparing actualised costs for each period over the life of a vehicle. These costs include;
  - Costs independent of distance travelled
    - Purchase, resale, insurance, subsidies
  - Costs dependent on distance travelled
    - Fuel, maintenance

Vehicles Compared for TCO Analysis

- Maximum number of deliveries a vehicle can accomplish in a day is determined.
- This is used to determine - using TCO, Warehouse Costs and Driver Wages - the Cost per Delivery
- The following vehicles are compared;
  - Diesel Vans (often the base case)
  - Electric Vans
  - Electric Cargo Bikes
  - Single Delivery Autonomous Vehicles (SDAV)
  - Multiple Delivery Autonomous Vehicles (MDAV)

Vehicles Compared: TCO Data I



Vehicles Compared: TCO Data II

- Analysis based on data of 50 Vans of differing energy source, capacity, manufacturer, etc.
- Vans of different volume capacities used in different market segments. Parcels use van with capacity of 3.5 m3, Groceries and B2B of 8m3.
- Purchase and Energy costs for Grocery Market Segments are 1.2 times that of B2B segment due to refrigeration.
- ASDVs cost 2x, and AMDVs cost 3x diesel vans.[8]

[8] arbitrary choice, will soon change it to 2x,3x of Electric Vans.

Methodology: determining Number of Deliveries per day

Table: Variables used

Variable	**Description**	Unit
n	number of deliveries in a day	-
t_{lod}	length of day	hours
$t_{loading}$	time to load vehicle	hours
$t_{delivery}$	time per delivery	hours
d_{wfd}	distance of warehouse to first delivery	kilometers
d_{bd}	average distance between deliveries	kilometers
s_{wfd}	average speed between warehouse and delivery area	kilometers per hour
s_{bd}	average speed between deliveries	kilometers per hour
dps	deliveries per stop	-
dps_{coeff}	time coefficient if more than 1 deliveries per stop	-
$v_{autonomy}$	vehicle autonomy	kilometers
$v_{volumecapacity}$	vehicle volume capacity	cubic meters
$v_{weightcapacity}$	vehicle weight capacity	kilograms
p_{vol}	average parcel volume	cubic meters
p_{wt}	average parcel weight	kilograms

Methodology: Equations - Number of Deliveries per day I

To find number of deliveries per day, the following steps are implemented;

1. Solve for n subject to
   1. Time constraint

$$\mathsf{n}_1 = \left(\frac{\left(t_{lod} - \frac{2*d_{wfd}}{s_{wfd}} + \frac{d_{bd}}{s_{bd}} - t_{loading}\right) * dps}{\frac{d_{bd}}{s_{bd}} + ((1 + (dps - 1) * dps_{coeff}) * tpd)} \right) \quad (17)$$

   2. Autonomy Constraint

$$n_2 = \left(v_{autonomy} - \frac{2 * d_{wfd}}{s_{wfd}} \right) * \frac{d_{bd}}{s_{bd}} + 1 \quad (18)$$

   3. Volume Constraint

$$n_3 = \frac{v_{volumecapacity}}{p_{vol}} \quad (19)$$

Methodology: Equations - Number of Deliveries per day II

4. Weight Constraint

$$n_4 = \frac{v_{weightcapacity}}{p_{wt}} \tag{20}$$

5. Choose min from 17,18,19,20

$$n_{round1} = min(n_1, n_2, n_3, n_4) \tag{21}$$

2. Determine time of round with n_{round1}

$$t_{round1} = 2 * \frac{d_{wfd}}{s_{wfd}} + \left(\frac{n_{round1}}{dps} - 1\right) * \frac{d_{bd}}{s_{bd}} + \left(\frac{n_{round1}}{dps}\right) * (1 + (dps - 1) * dps_{coeff}) * t_{delivery} + t_{loading} \tag{22}$$

3. Determine no. of 'complete' rounds per day

$$r_n = \left\lfloor \frac{t_{lod}}{t_{round1}} \right\rfloor \tag{23}$$

Methodology: Equations - Number of Deliveries per day III

4. Determine time left

$$t_{left} = t_{lod} - r_n * t_{round1} \tag{24}$$

5. Determine number of other deliveries
   1. Time constraint

$$n_5 = \left(\frac{\left(t_{left} - \frac{2 * d_{wfd}}{s_{wfd}} + \frac{d_{bd}}{s_{bd}} - t_{loading} \right) * dps}{\frac{d_{bd}}{s_{bd}} + ((1 + (dps - 1) * dps_{coeff}) * tpd)} \right) \tag{25}$$

   2. Autonomy Constraint will be same as 18
   3. Volume Constraint will be same as 19
   4. Weight Constraint will be same as 20
   5. Choose min from 25,18,19,20

$$n_{other} = min(n_5, n_2, n_3, n_4) \tag{26}$$

Methodology: Equations - Number of Deliveries per day IV

6 Thus, from 23, 21,26, total deliveries in a day are given as;

$$d_{total} = r_n * n_{round1} + n_{other} \tag{27}$$

- From d_{total},d_{total}^{week} is determined.
- This is applied across whole fleet to determine $dfleet_{total}^{week}$.
- This is used to determine cost/delivery.

The Driver/Deliverer

- In conventional deliveries, the driver/deliverer accomplishes the last meters of the last mile and obtains a confirmation of delivery from the end customer.
- He is paid an hourly wage of 11 euros/hour. He works 40 hours/week.
- In deliveries using autonomous vehicles, the driver wage is zero.

.

Latent Knowledge I

Table: Latent Knowledge in Drivers

S.No	Skill/Knowledge	Application
1.	Personal relationships with various inhabitants	- Alternate delivery possibilities (ex. If customer is not available, driver delivers to neighbour, based on previous agreements)
		- Accommodating non prepared return on other rounds (Especially true for business deliveries, If a return form a customer is not prepared, s/he can call the driver and inform them, making the round more efficient)

Latent Knowledge II

		-Concierge
2.	Knowledge of Parking spaces	- Reduction of time spent to look for a parking space
		- Knowledge of parking time restrictions
		- Alternate parking spots
3.	Knowledge of traffic conditions and trends	Ex. Higher traffic in a specific repeated delivery address at a particular time (commercial center)
		-Reordering delivery order to achieve faster overall delivery

Latent Knowledge III

4.	Knowledge of geographical quirks	Ex. Access codes, GPS Map Failures : Dead Ends
		- Driver saves a lot of time by already knowing the access code, or the requirement of it.
		-Driver aware of GPS failures in certain specific scenarios, ex. Dead ends, and avoids them.

Latent Knowledge IV

An experienced driver can be 40% more effective during his/her rounds. *"the difference between two of our drivers (D22 and D24) with similar round sizes and parcel volumes shows a considerable variation in effective- ness, with D22 driving 44% less distance, spending 35% less time per parcel, 29% less driving time per parcel, and 39% less parking time per parcel. The variation in effectiveness of our drivers relates to better route planning, exploitation of accumulated knowledge of the round, personal relation- ships with other stakeholders, the amount of time spent at the curbside and the influence of walking. These statistics show that more effective drivers achieve higher rate of delivery of parcels per minute while spending less time driving and parking in the van".(Bates et al., 2018)*