CO_2 emissions of truck and drone deliveries

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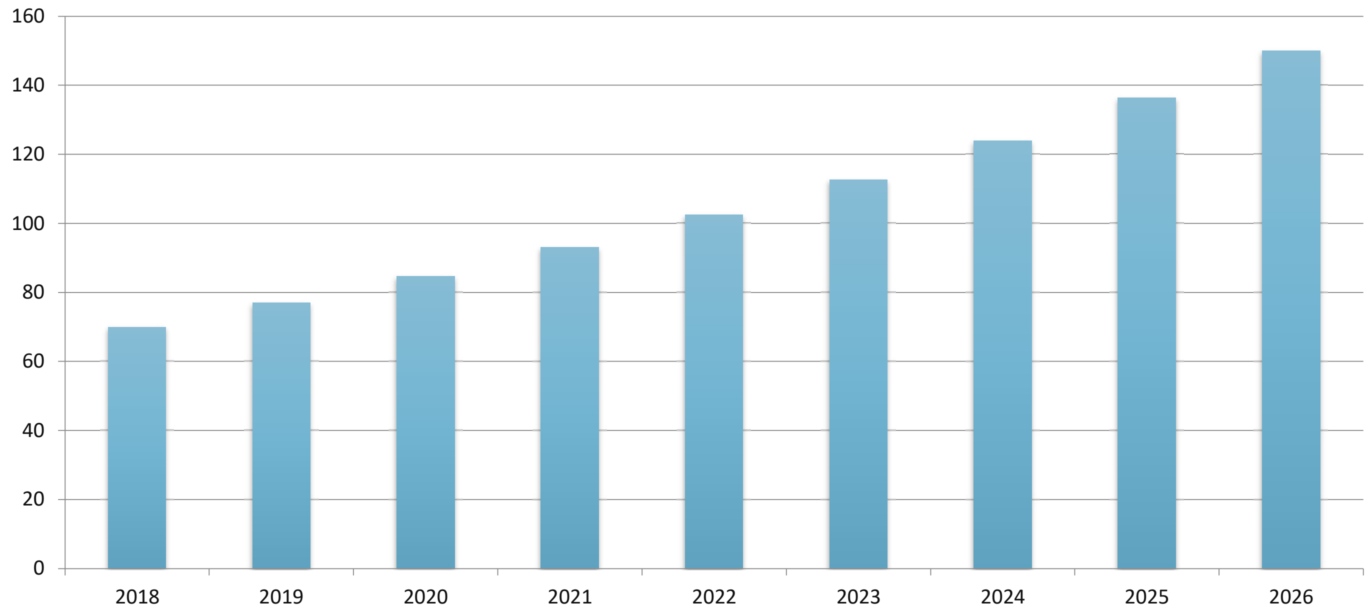
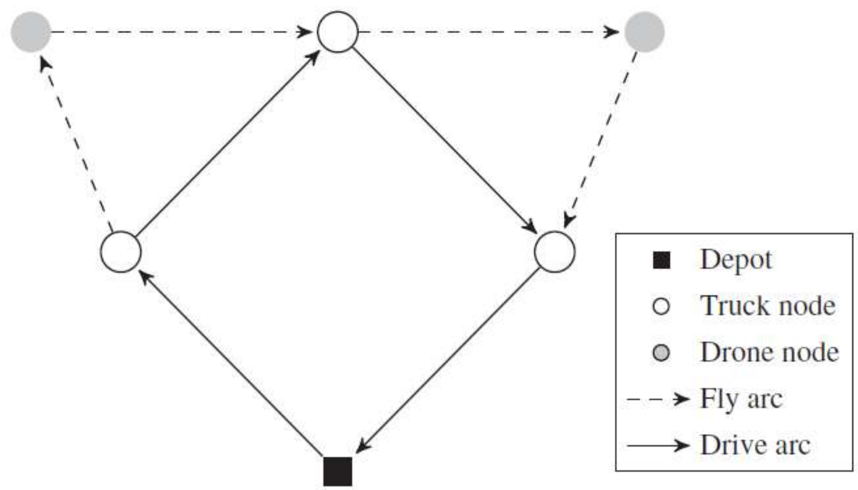
Motivation

Market of last-mile delivery exceeds 80 billion USD with growth rates ranging between 7 and 10 percent in mature markets and almost 300 percent in developing markets.



What is truck and drone delivery?

- Truck serves one set of customers, while a drone at the same time serves the rest of the customers.
- Also referred to as Travelling Salesman Problem with Drone (TSP-D)



Research questions

Most existing research has focused on efficiency & optimization. Meanwhile, very little is known about CO_2 emissions of innovative last-mile delivery systems.

- Which **systems** (e.g. truck alone vs. truck plus drone) are more likely to reduce pollution in comparison to traditional truck deliveries?

- What is the influence of different **design features** (e.g. range, speed)?

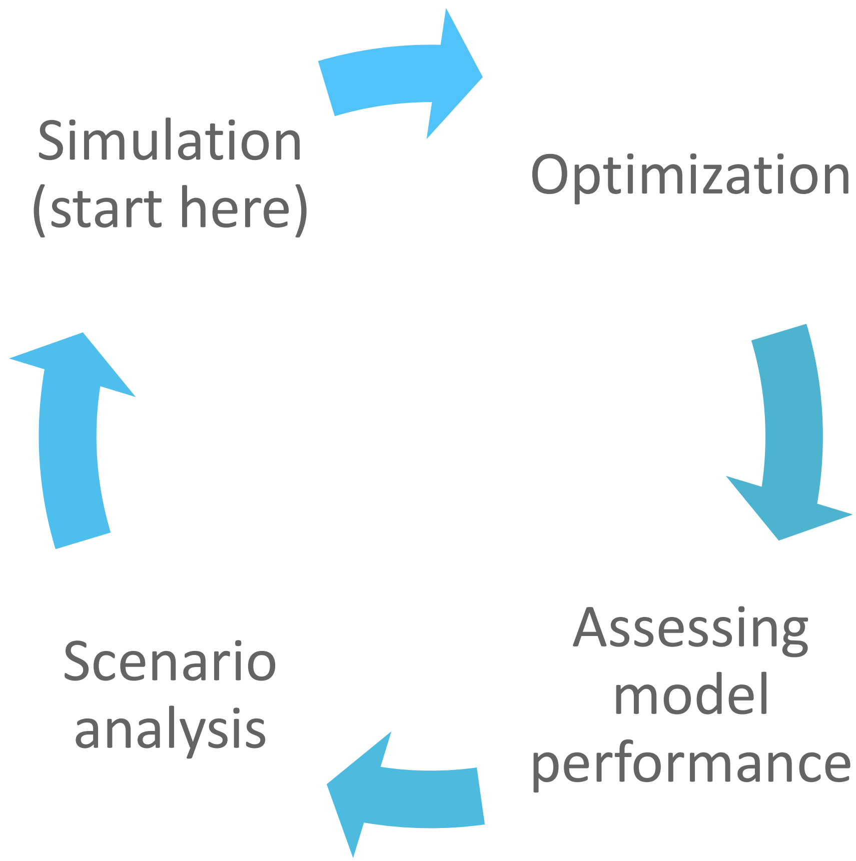
Literature review

Several papers describing MILP formulation of TSP-D and various heuristic approaches have been published:

- Murray and Chu (2015)
- Agatz et al. (2018)

But none of them considers time-dependent nature of the problem when truck speed is affected by **traffic congestion** that changes with time!

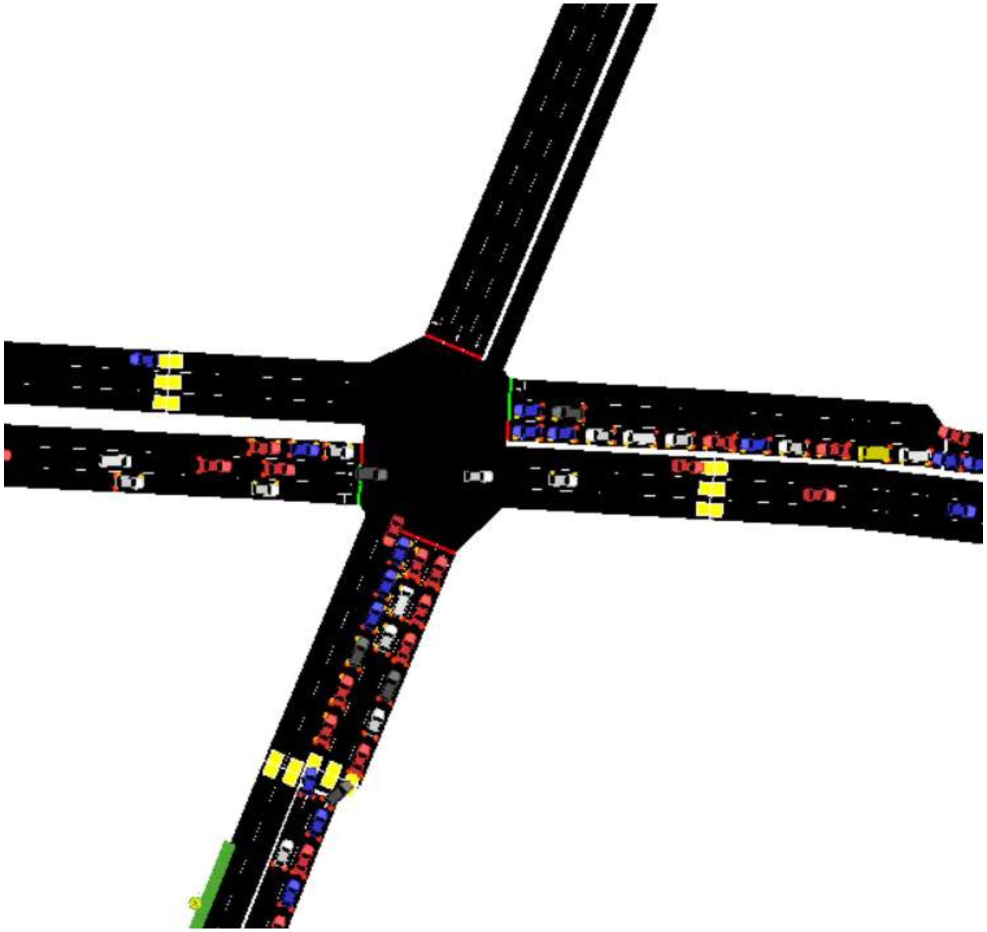
Methodology



Simulation

- Simulation of Urban Mobility (SUMO) software was used to derive vehicles' average speed dependent on traffic level.

- SUMO allows realistic simulation of urban traffic with great level of detail.



Baseline scenario

- The Bologna scenario represents the Andrea Costa area in the city of Bologna, Italy with an area of about 2*2 km.

- Morning traffic for the peak hour from 8:00 a.m. to 9:00 a.m. (8621 independent vehicles with various origins and destinations).

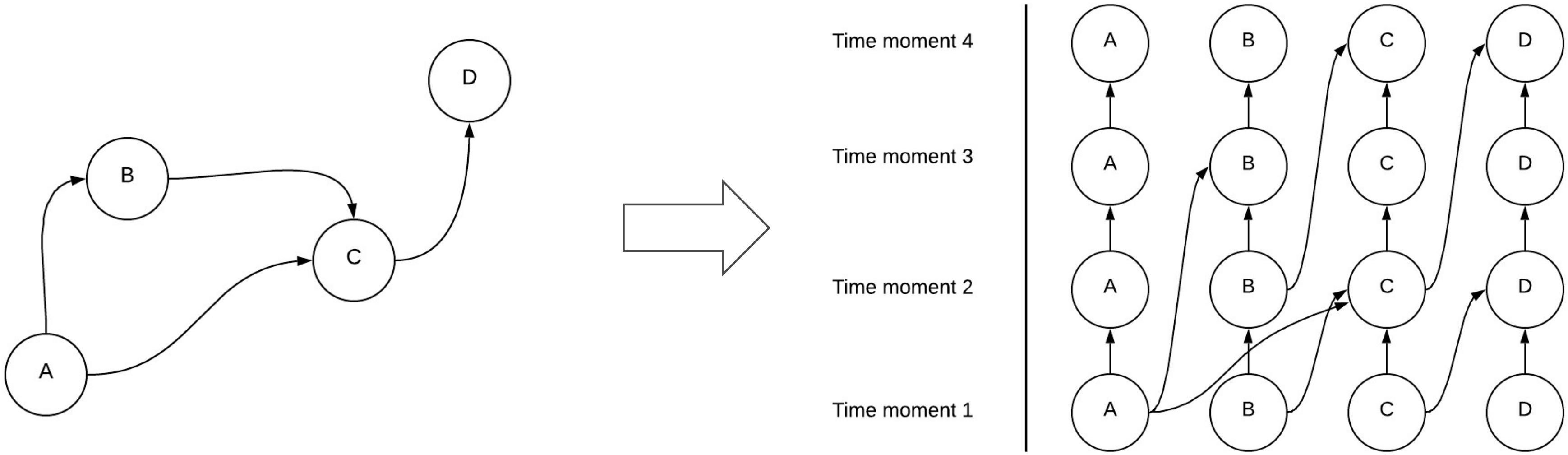
- 16 traffic lights, 27 bus stops, and hundreds of other infrastructure constraints.

Optimization 1

Output of simulation is used to build time-dependent graph.

Initial time-independent graph

Time-dependent graph

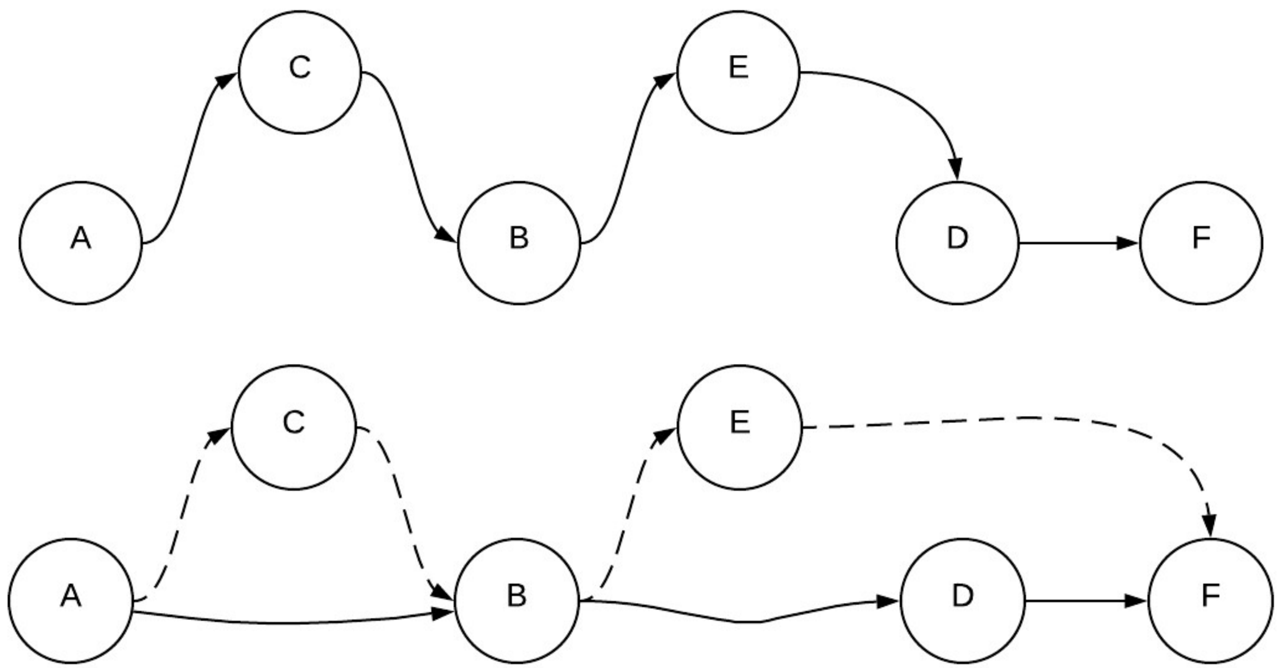


Optimization 2

Split Algorithm is implemented that optimally splits any truck tour into TSP-D tour.

Truck only Tour:

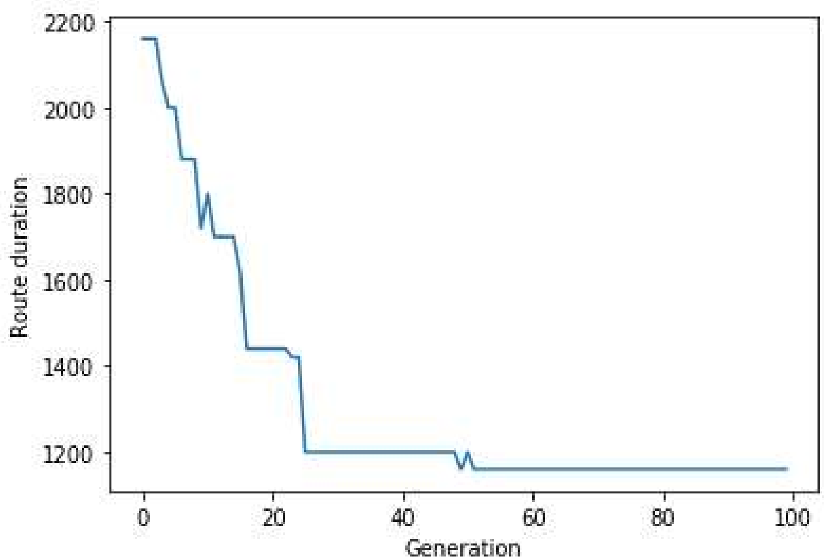
Truck & Drone Tour:



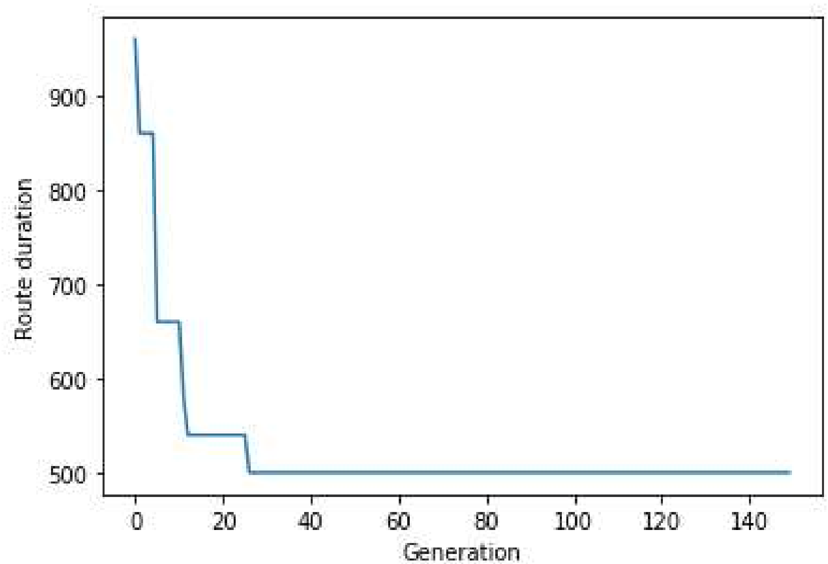
Optimization 3

Genetic algorithm for TSP is adopted to solve TSP-D: fitness of the chromosome is assessed via split procedure.

TSP convergence



TSP-D convergence



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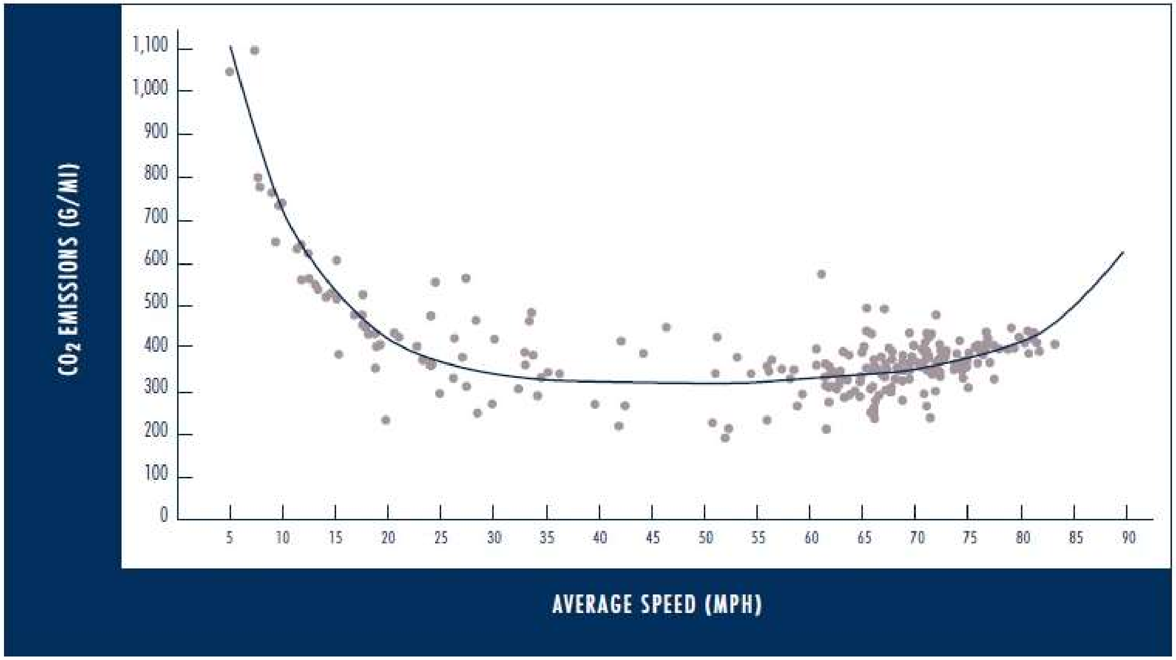
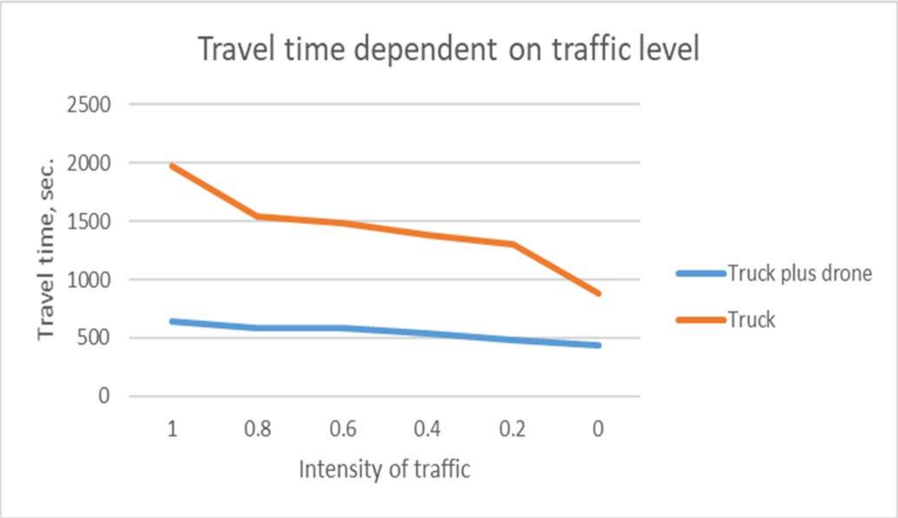
Assessing model performance

Output of genetic algorithm is suboptimal **time-dependent** TSP-D tour used to calculate CO_2 emissions.



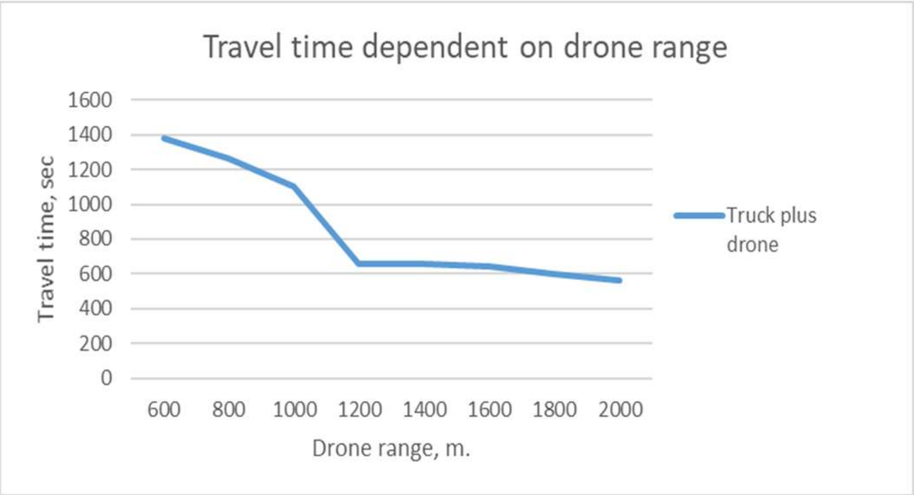
Computational results

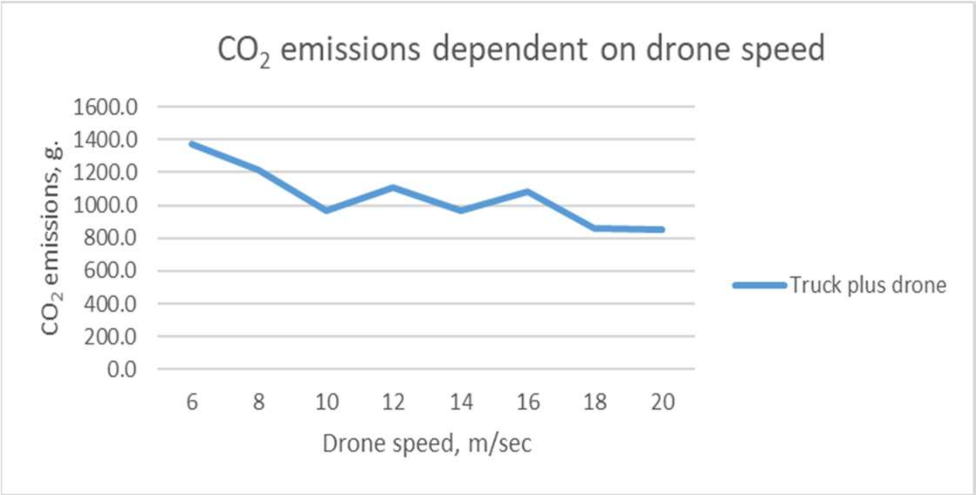
- Integrated delivery mode (truck plus drone) is much more efficient in terms of travel time. On average, it is more than twice as fast as truck delivery.
- Traffic level almost does not affect the amount of emissions produced by the truck and drone in tandem.



Computational results

- First, drone range significantly affects travel time and CO_2 emissions - up to a certain threshold.
- CO_2 emissions also tend to decrease as drone speed increases, but don`t directly correlate to drone speed.





Further model improvement

- Optimize the algorithm to deliver better performance.
- Expand the algorithm for the multiple trucks/multiple drones case.
- Consider more real-life constraints related to truck and drone synchronization. For instance, in this study it was assumed that the drone can land before being picked up by the truck, but in real life this is not likely.

Thank you! Questions?