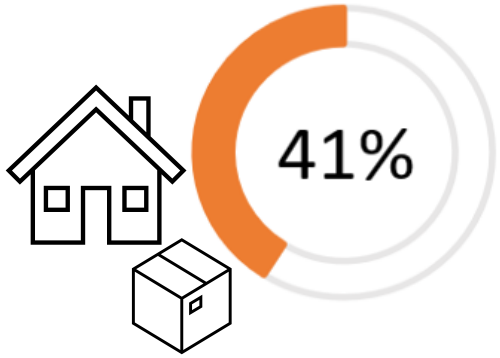
Sustainable Last Mile Logistics Employing Drones and E-bikes

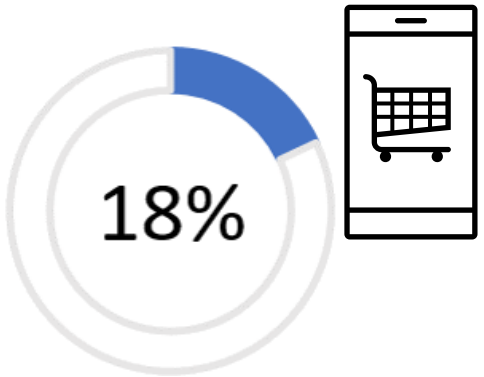
Stephanie Santiago-Montano; Daniel F. Silva, PhD; Alice E. Smith, PhD

Department of Industrial and Systems Engineering, Auburn University

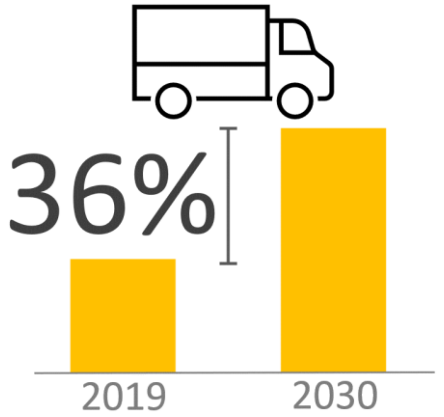
Background



last-mile delivery costs accounted for 41% of the total supply chain costs in 2018 [1]



e-commerce demands accounted for 18% of all retail sales in 2020 [2]



number of delivery vehicles from 2019 is expected to increase by 36% in 2030, resulting in additional **6 million tons of CO_2** and a **21% increase in average commute time** [3]

Objective

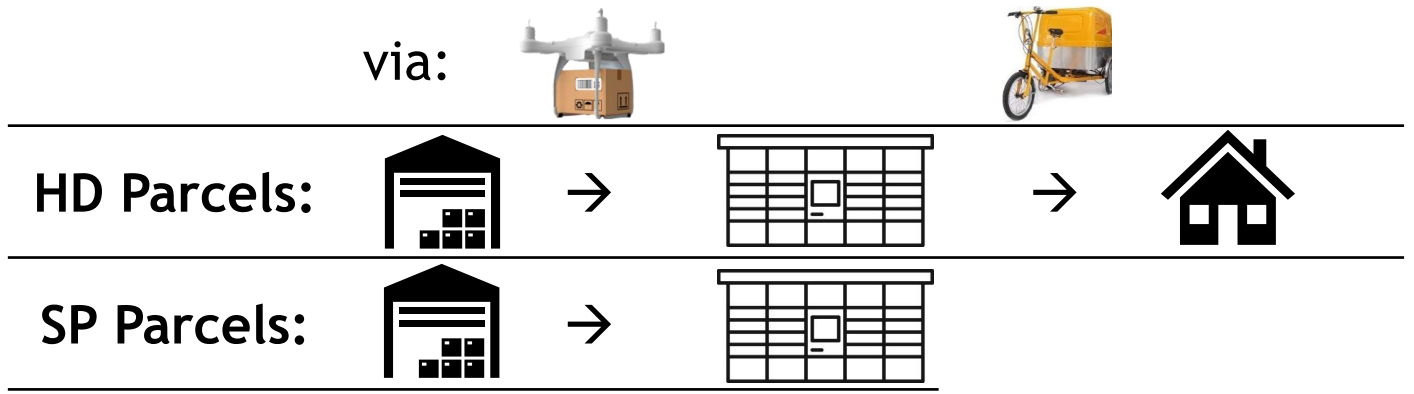
- Improve traditional truck-based network by proposing an efficient and sustainable drone-bike network with parcel lockers

[1] Capgemini Research Institute, 2019. *The Last-Mile Delivery Challenge*. Retrieved from https://www.capgemini.com/us-en/news/the-last-mile-delivery-challenge/.
[2] Statista, 2021. *E-Commerce Share of Retail Sales Worldwide*. Retrieved from https://www.statista.com/statistics/534123/e-commerce-share-of-retail-sales-worldwide/.
[3] World Economic Forum, 2020. *The Future of the Last-mile Ecosystem*. Retrieved from https://www.weforum.org/reports/the-future-of-the-last-mile-ecosystem.

AUBURN UNIVERSITY

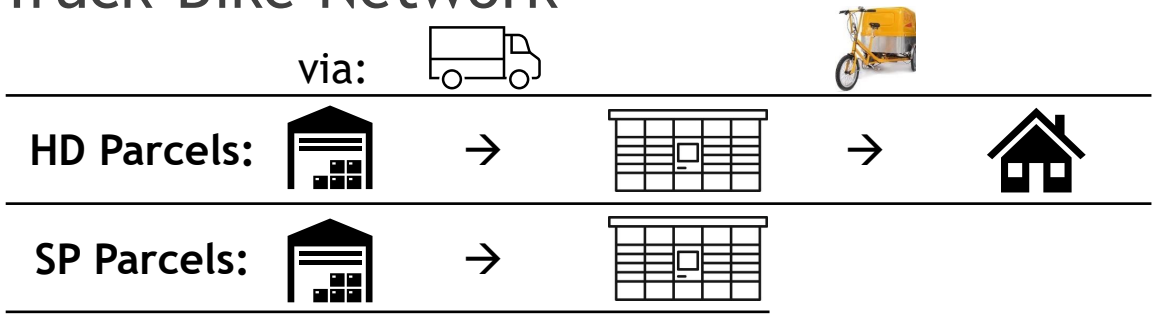
Proposed Approach (Drone-Bike Network)

- **Home-Delivery (HD)** parcels are transported from the depot to a parcel locker (via drone), and then to the customer location (via bike). **Self-Pickup (SP)** parcels are transported from the depot to the parcel locker (via drone) on or before the earliest pickup time.

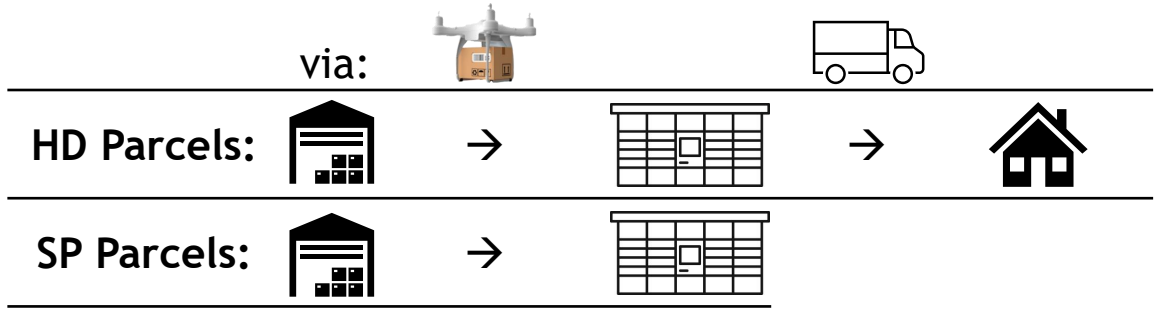


Other Networks Considered

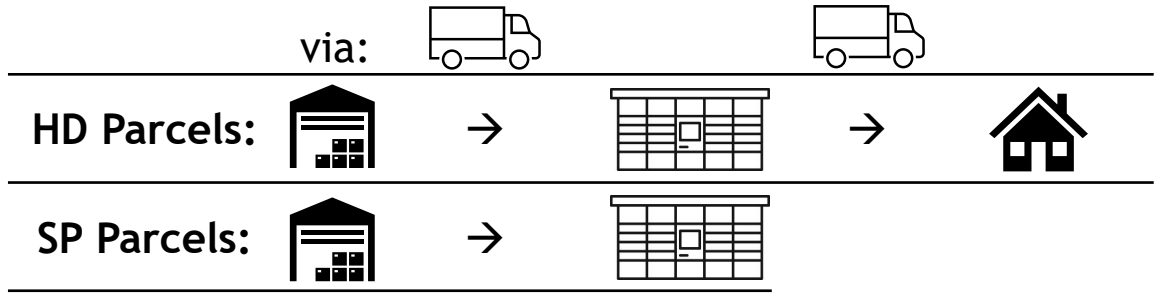
- Truck-Bike Network



- Drone-Truck Network



- Truck-Truck Network



Mathematical Formulation

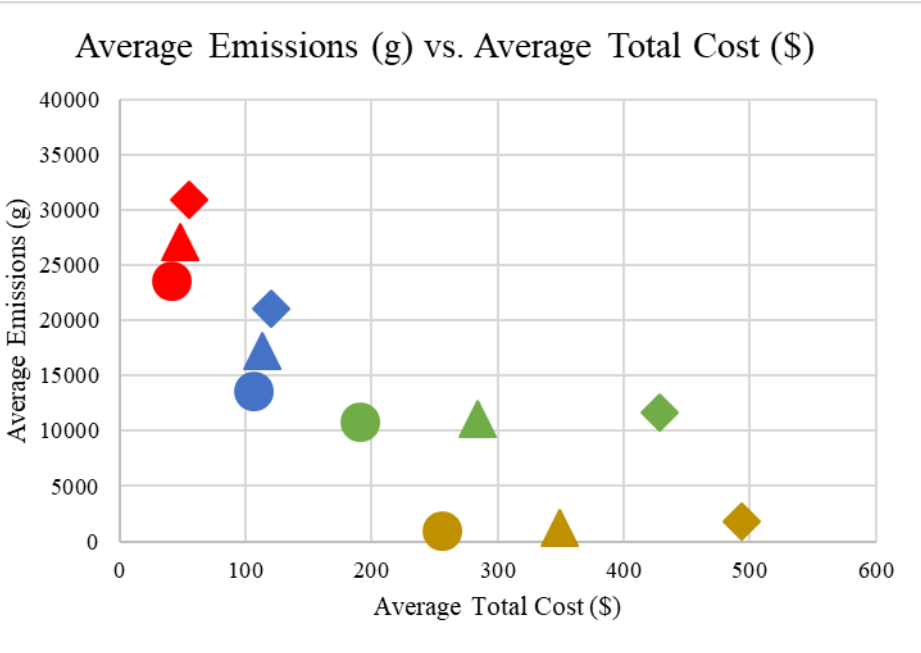
- Objective Function
  - $\min(total\ cost)$

     : drone/bike operational cost  : drone/bike operator wage
- Key Constraints
  - routing
  - capacity
  - flow conservation
  - scheduling
  - others
- Programming Software: python GUROBI OPTIMIZATION

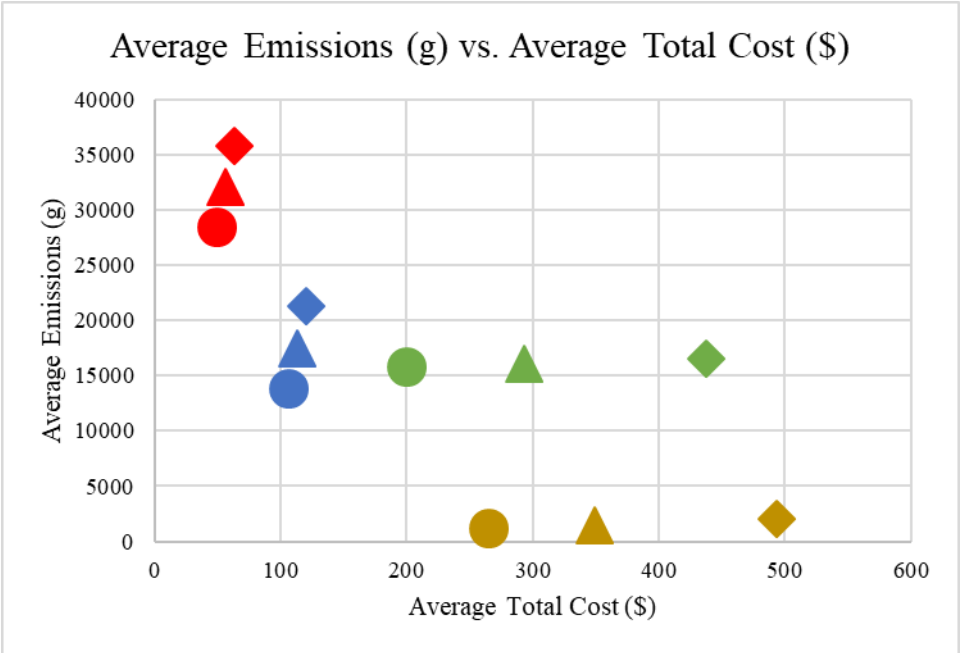
AUBURN UNIVERSITY

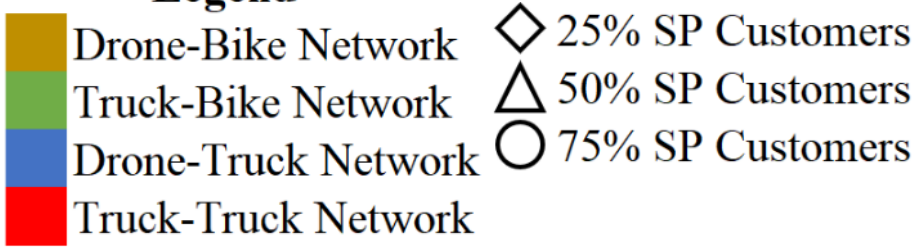
Experimental Results

Uniformly Distributed Instances with Center Depot



Uniformly Distributed Instances with Corner Depot

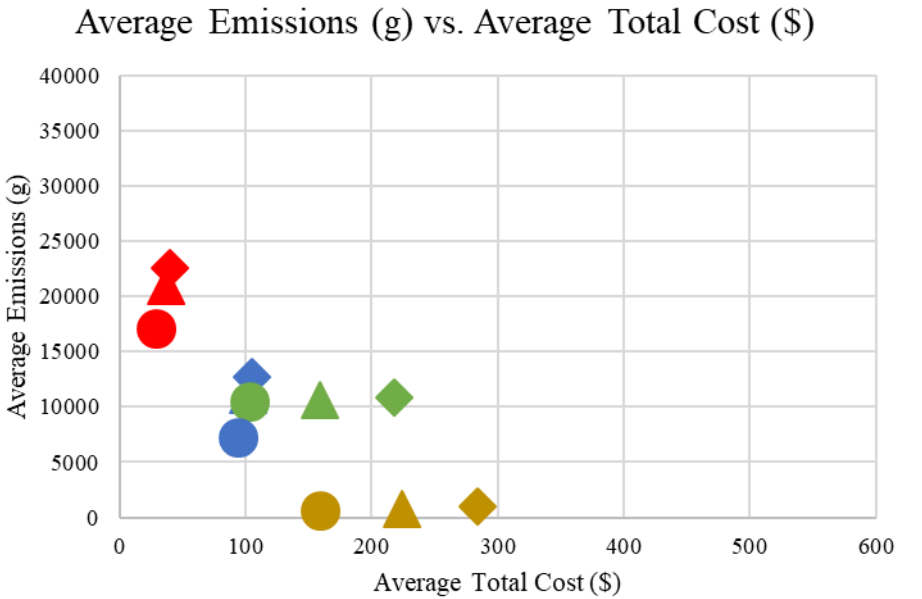




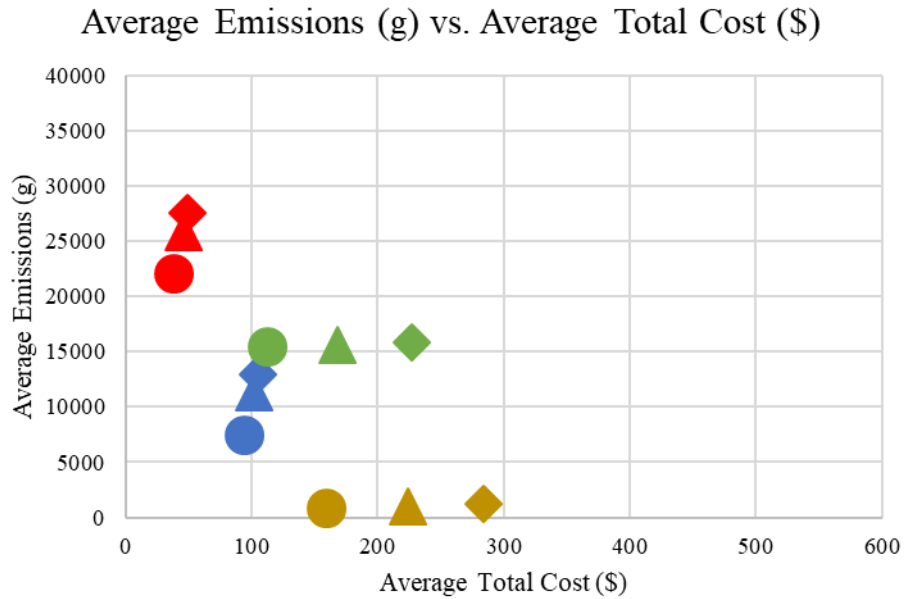
AUBURN UNIVERSITY

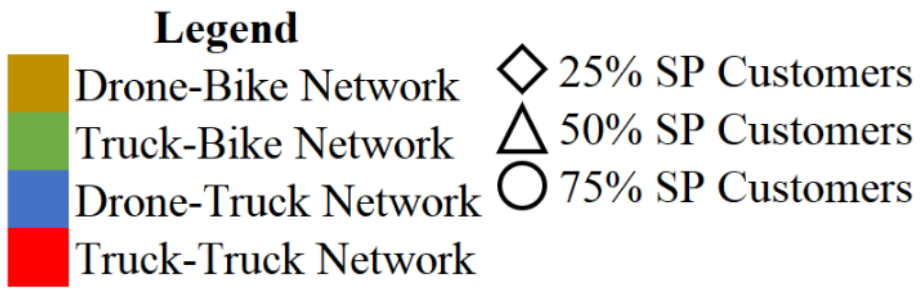
Experimental Results (cont.)

Normally Distributed Instances with Center Depot



Normally Distributed Instances with Corner Depot





AUBURN UNIVERSITY

Conclusions

- This study aims to improve the traditional truck-based last-mile network by proposing a drone-bike network
- Results from an analysis of variance (ANOVA) suggest that the type of **network**, **percent SP customers**, and their 2-factor **interaction** significantly affect total cost
- Experimental results suggest with a **small increase in total cost of as little as 12.9%** can achieve a **reduction in emissions of 88.3%** on average in the proposed network, resulting in considerable environmental benefit going forward