Modeling Optimal Drone Courier Fleet Size and Sustainability Tradeoffs

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Motivation

- The rise of courier type services that range from medicines and health services to food delivery.

- The last mile delivery is particularly challenging for stochastic deliveries with narrow time windows.

Contributions

- An optimization approach, extending the newsvendor model, for drone fleet sizing with stochastic demand (number and payload).

- Analysis of energy consumption and sustainability, tradeoffs when electric trucks and drones are utilized.

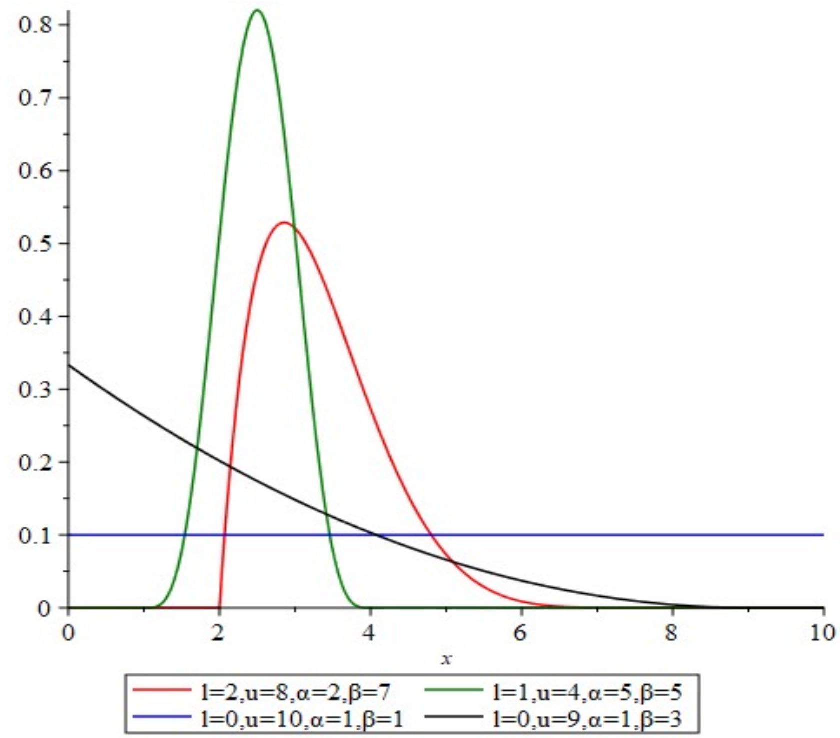
Demand and payload distributions

Beta, a very versatile distribution.

$$f(x) = \frac{(x-l)^{\alpha-1} \cdot (u-x)^{\beta-1}}{(u-l)^{\alpha+\beta-1} \cdot \frac{\Gamma(\alpha) \cdot \Gamma(\beta)}{\Gamma(\alpha+\beta)}}$$

$$E(x) = l + \frac{\alpha}{\alpha+\beta}(u-l)$$

$$Var(x) = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)}(u-l)^2$$



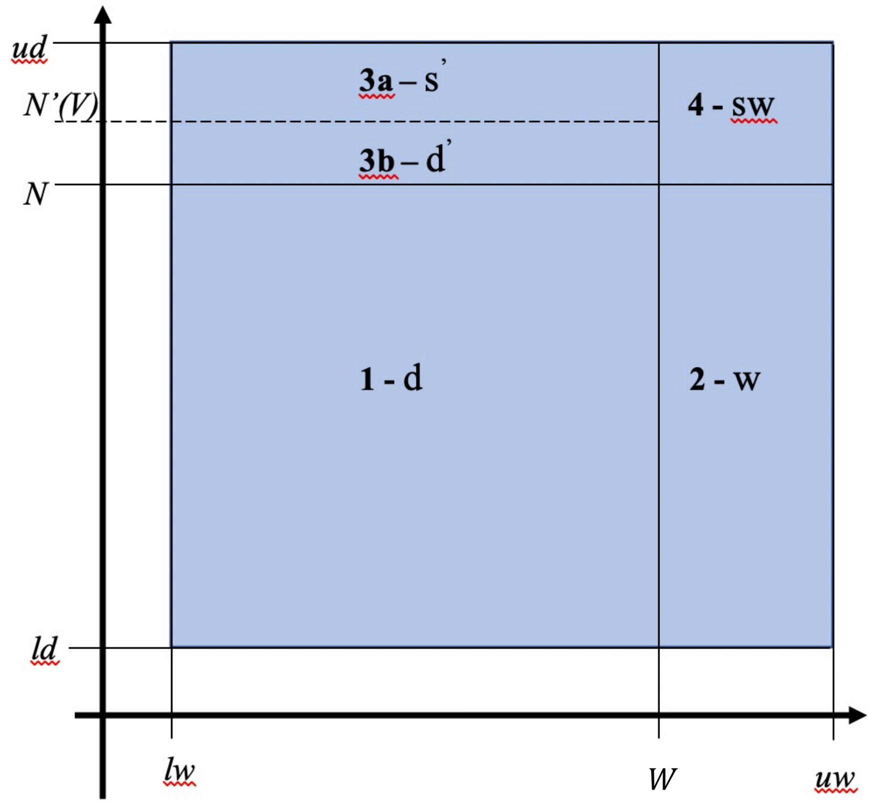
Assumptions

- Short-delivery times (1/2 hour).
- Actual demand to be served in each period is only known at the start of the period.
- One trip for one customer per drone per ½-hour period.
- Drone purchase cost is a function of payload capability.
- Drone operational cost is a function of drone type and distance.
- Drone service area and range constant and independent of drone size.

Feasible space

The model considers two decision variables, the fleet size (N) and drone's capacity or payload (W).

Demand upper and lower limits (ud , ld) and payload upper and lower limits (uw , lw) respectively.



Formulation

Maximize profits = revenue – operational & ownership costs – lost sales

Integrals to define each revenue/cost element, for example to estimate the expected number of deliveries in region 1-d of the previous slide (one formula for each region)

$$
\begin{aligned}
Ed(N,V) &= \int_{ld}^{ud} Min(x,N)\, fd(x)\, dx \cdot Fw(V) \\
&= \left(\int_{ld}^{N} x \cdot fd(x)\, dx + \int_{N}^{ud} N \cdot fd(x)\, dx \right) \cdot Fw(V)
\end{aligned}
$$

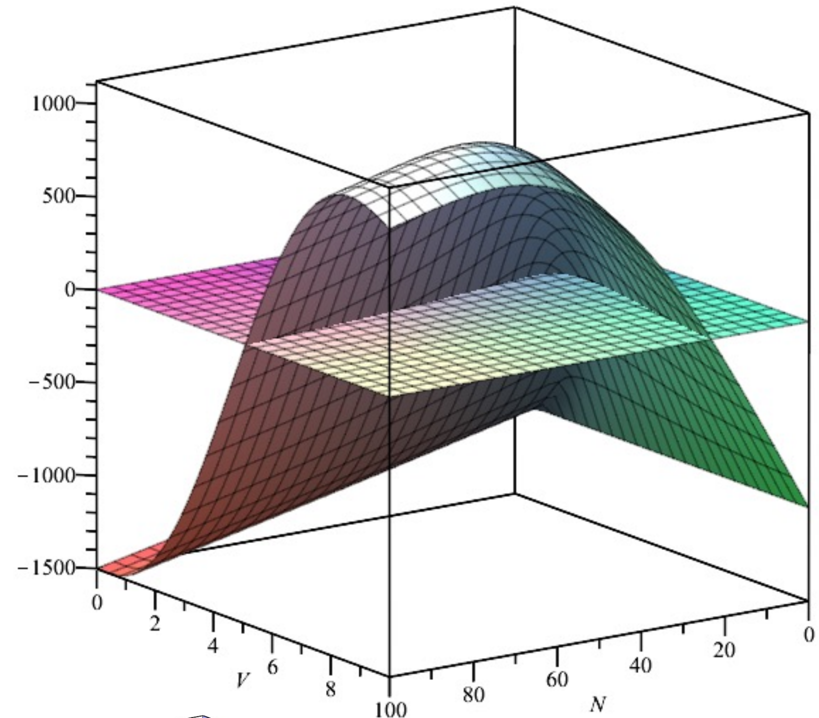
Solution approach Global search

- Leverage algorithms that use convex relaxation of non-linear twice continuously differentiable functions can obtain the global optima.
- Step A: model relaxation and unconstrained solution.
- Step B: Lagrange multipliers for constrained solution.

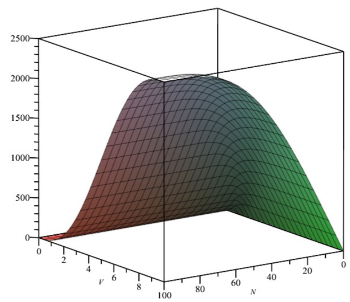
Results using these parameters

- r = \$50 / delivery
- c_l = \$20 / unmet delivery
- c_f = \$5 / trip
- c_e = \$2 / trip-kg payload
- c_v = \$0.1 / trip-kg payload

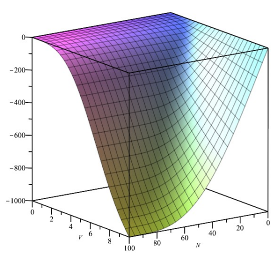
Solution N = 72, V = 8.4kg



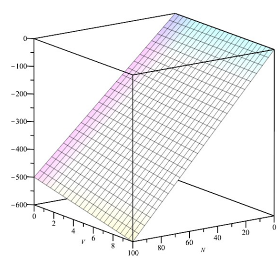
Revenue



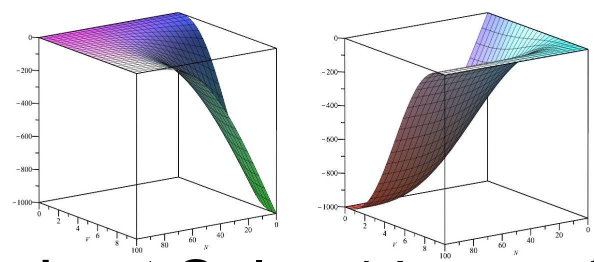
Costs



Ownership



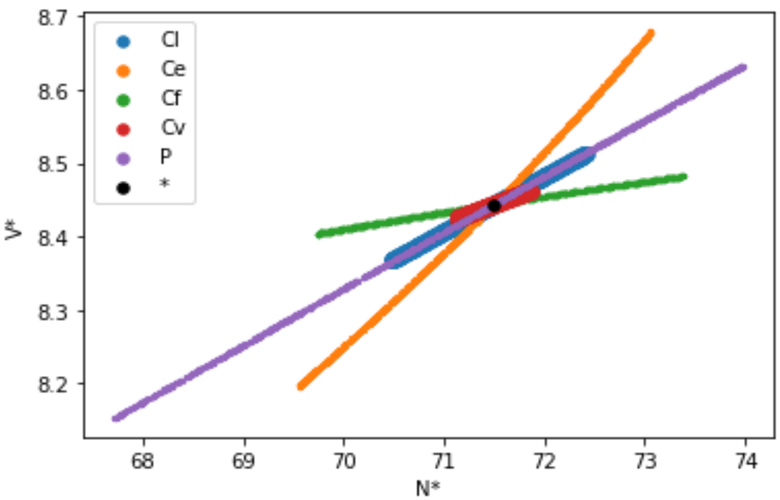
Operation



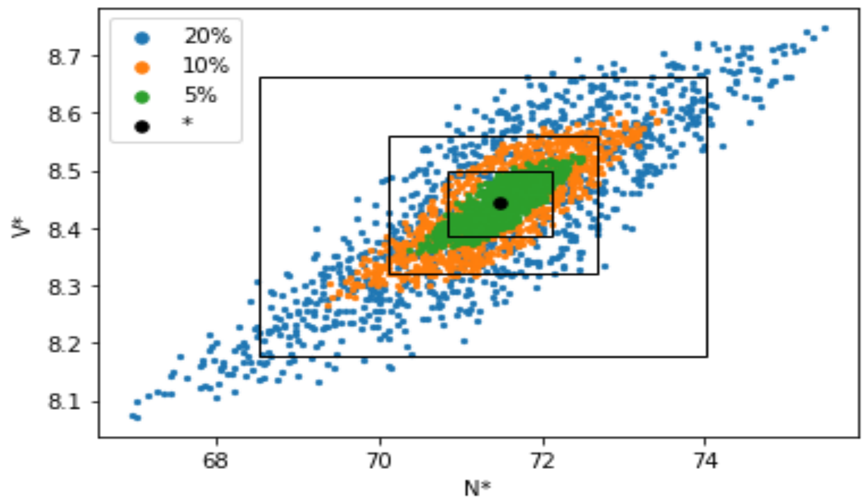
Lost Sales (demand and payload)

Sensitivity analysis

One parameter, +/- 20%



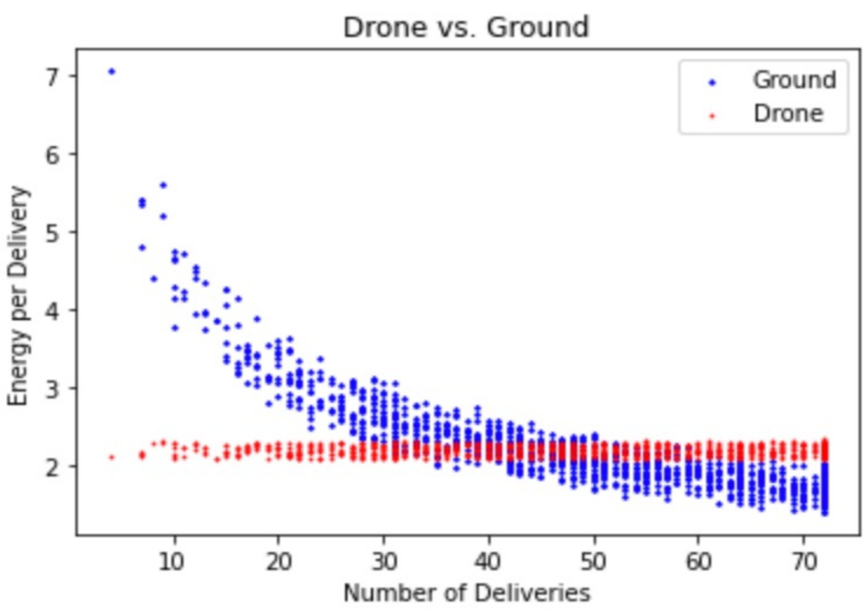
Noise (all)



Utilizing drones or EVs

Simulation utilizing a circular service area of radius 10 kms and uniform demand. A delivery time window of ½ hour.

It is possible to design operational policies to minimize energy/emissions using <u>both</u> vehicles.



Sensitivity analysis

Baseline : symmetrical distributions

Positive and negative skewed distributions and tails have a sizable effect on the fleet size and drone size.

Conclusions

- Robust solutions for a novel problem related to stochastic last mile deliveries with mixed fleets
- Profit maximization and energy minimization goals are not necessarily aligned, though there is potential to reduce energy and/or emissions.

Acknowledgments

Yuval Hadas

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QUESTIONS?