Modeling Optimal Drone Courier Fleet Size and Sustainability Tradeoffs

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Yuval Hadas, Bar-Ilan University
Miguel Figliozzi, Portland State University
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.

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

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

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

\[ Ed(N, V) = \int_{ld}^{ud} \text{Min}(x, N) f_d(x) dx \cdot F_w(V) \]

\[ = \left( \int_{ld}^{N} x \cdot f_d(x) dx + \int_{N}^{ud} N \cdot f_d(x) dx \right) \cdot F_w(V) \]
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 \( N = 72, \, V = 8.4\text{kg} \)

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 $\frac{1}{2}$ hour.

It is possible to design operational policies to minimize energy/emissions using both 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.
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Yuval Hadas

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QUESTIONS?