Robust Multi-Period Maximum Coverage Facility Location Problem Considering Coverage Reliability
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ABSTRACT
- Public service agencies like hospitals, fire, rescue, and police departments are required to maintain high levels of service. These service standards often come as reliability constraints. For example, fire-related incidents require a 90% response rate in 4 minutes.
- Drones or Unmanned Aerial Vehicles (UAVs) are already being site-tested for delivery of automatic external defibrillators (AEDs), medical prescriptions, and medical emergency response as part of federal programs. We consider a case study of tackling out-of-hospital cardiac events using AED-enabled drones in Portland Metro Area, OR-Wa.
- Travel time uncertainty in drone deliveries arise from weather conditions, mainly from uncertainty about wind speed and direction [Glick et al. 2021]. The effect of stochasticity in environmental factors is hard to quantify exactly, apart from being data intensive.
- A robust optimization (RO) approach allows for incorporating uncertainty with limited information by using uncertainty sets. Further, splitting of a planning period into multiple smaller periods would disaggregate uncertainties and possibly aid RO in tackling them.
- We develop a compact mixed-integer linear programming formulation of the problem using polyhedral uncertainty sets [Bertsimas and Sim 2004].
- Increasing the number of opened facilities (q) improves coverage reliability by 57% compared to SP-2.

RESULTS AND CONCLUSIONS
- Description of multiple periods: We consider a planning period of one whole year. As wind direction distributions are significantly different in summer (April–September) and winter (October–March) months, these are considered as different periods. For a single-period formulation, average of the whole year is utilized.
- Analysis is conducted on four types of models: multi-period robust (MP-R) which considers uncertainty in period, multi-period deterministic (MP-D) which does not consider uncertainty in period, single-period deterministic (SP-D).
- Computational effort: Out of 108 models solved for different parameter combinations, 104 converged in 2 hours, and all of them converged in 8 hours. Generally, adding more time periods is more computationally intensive than adding robustness.
- Value of adding multiple periods and robustness: Utilizing a multi-period formulation is particularly beneficial when response time thresholds are short, or uncertainty is not accounted for. Adding robustness to deterministic formulations is more beneficial for single-period formulations or when response time thresholds are longer. Combining these different strengths, MP-R improves coverage by 57% compared to SP-D.
- Geographical impact: Adding robustness consolidates the facilities towards the densely-populated urban core, thereby improving reliability outcomes.
- Additional considerations: Some of the gap between model coverage (coverage provided by the model) and simulated coverage (coverage experienced during Monte-Carlo simulations) can be reduced by either increasing robustness (also reduces model coverage) or increasing the number of opened facilities (has additional associated costs).

MODEL PERFORMANCE FOR CASE STUDY
- SS1: providing 90% coverage reliability in 4 min; SS2: providing 95% coverage reliability in 10 min.
- Improvements in coverage reliability (q=15; SS2) Compared to SP-2 with 90% coverage reliability guarantees.
- Extent of facility relocation
- Reducing the gap between model coverage and simulated coverage
- Increasing decision consideration (MP-R; q=35; SS1)

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