

Portland State University

PDXScholar

TREC Friday Seminar Series

Transportation Research and Education Center
(TREC)

1-21-2022

PSU Student Research from the TRB 2022 Annual Meeting: Drone Facility Location Considering Coverage Reliability: Application to Emergency Medical Scenarios

Darshan Chauhan

Portland State University, drc9@pdx.edu

Follow this and additional works at: https://pdxscholar.library.pdx.edu/trec_seminar



Part of the [Transportation Commons](#)

Let us know how access to this document benefits you.

Recommended Citation

Chauhan, Darshan, "PSU Student Research from the TRB 2022 Annual Meeting: Drone Facility Location Considering Coverage Reliability: Application to Emergency Medical Scenarios" (2022). *TREC Friday Seminar Series*. 218.

https://pdxscholar.library.pdx.edu/trec_seminar/218

This Book is brought to you for free and open access. It has been accepted for inclusion in TREC Friday Seminar Series by an authorized administrator of PDXScholar. Please contact us if we can make this document more accessible: pdxscholar@pdx.edu.

DRONE FACILITY LOCATION CONSIDERING COVERAGE RELIABILITY: APPLICATION TO EMERGENCY MEDICAL SCENARIOS

Darshan Rajesh Chauhan

PSU Friday Transportation
Seminar

21 January 2022

ACKNOWLEDGMENTS

- Collaborators Avinash Unnikrishnan, Miguel A. Figliozzi, and Stephen D. Boyles
- National Science Foundation
 - CMMI 1826320/1826337: Collaborative Research: Real-Time Stochastic Matching Models for Freight Electronic Marketplace
 - CMMI-1636154: Optimal Control of a Swarm of Unmanned Aerial Vehicles for Traffic Flow Monitoring in Post-disaster Conditions
 - CMMI 1562109/1562291: Collaborative Research: Non-Additive Network Routing and Assignment Models
- University Transportation Centers
 - Freight Mobility Research Institute (FMRI)
 - Center for Advanced Multimodal Mobility Solutions and Education (CMMSE)

OUTLINE

- Emergency services
- Modeling coverage reliability
- The drone facility location problem
- Other considerations
- Results
- Conclusions

EMERGENCY SERVICES

Need to maintain high level of service:

- US Fire: 90% response rate in 4 minutes response time^a
- US EMS Act 1997: 95% response rate in 10 minutes^b
- UK NHS: 75% and 95% response rates in 8 and 14 minutes^c
- Medical drone applications active in the US: Nevada, North Carolina, North Dakota^d



These photos by Unknown Author is licensed under [CC BY](#)

^a National Fire Protection Agency, 2020. NFPA 1710.

^b Lutter, P., Degel, D., Büsing, C., Koster, A.M. and Werners, B., 2017. Improved handling of uncertainty and robustness in set covering problems. *European Journal of Operational Research*, 263(1), pp.35-49.

^c Budge, S., Ingolfsson, A. and Zerom, D., 2010. Empirical analysis of ambulance travel times: The case of Calgary emergency medical services. *Management Science*, 56(4), pp.716-723.

^d FAA, 2021. UAS BEYOND. https://www.faa.gov/uas/programs_partnerships/beyond/

MODELING SERVICE RELIABILITY

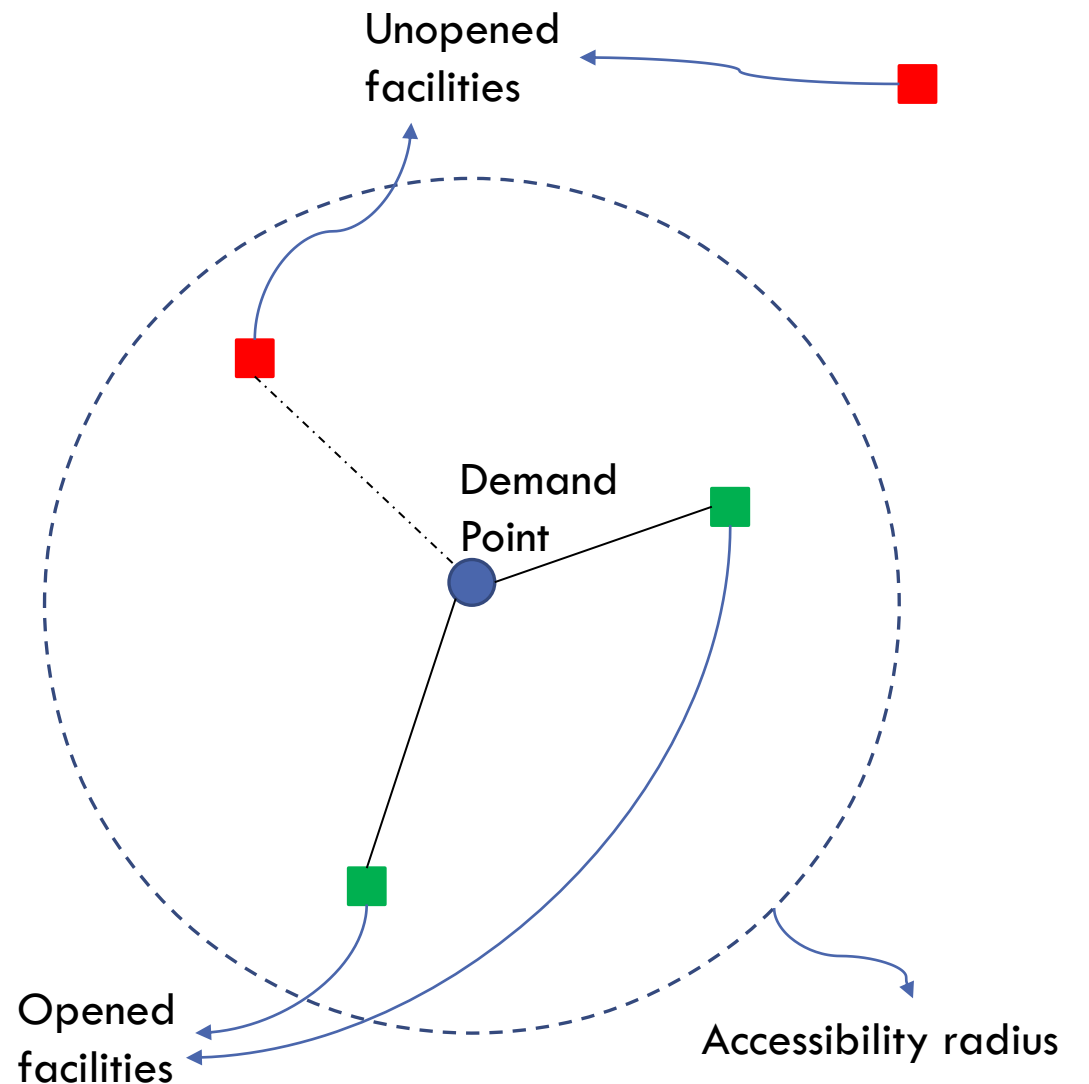
- S_i : Set of open facilities that can access demand point i
- p_{ij} : probability of failing to reach demand point i from location j
- a_{ij} : 1, with probability $(1 - p_{ij})$, and 0 with probability p_{ij}
- α : reliability standard (e.g., 90%)

For demand point i to be covered:

$$\text{Prob} \left(\sum_{j \in S_i} a_{ij} \geq 1 \right) \geq \alpha$$

Assuming independence:

$$\text{Prob} \left(\sum_{j \in S_i} a_{ij} \geq 1 \right) = 1 - \prod_{j \in S_i} p_{ij} \geq \alpha$$



A BASIC FACILITY LOCATION MODEL (SP-D)

Objective: Maximize Coverage

$$\text{Max}_{x,y} \sum_{i \in I} c_i x_i$$

Coverage Reliability Constraints for each demand point $i \in I$

$$\prod_{j \in S_i} (p_{ij})^{y_j} \leq (1 - \alpha)^{x_i}$$

Facility Opening Constraint

$$\sum_{j \in J} y_j \leq q$$

Variable definitions

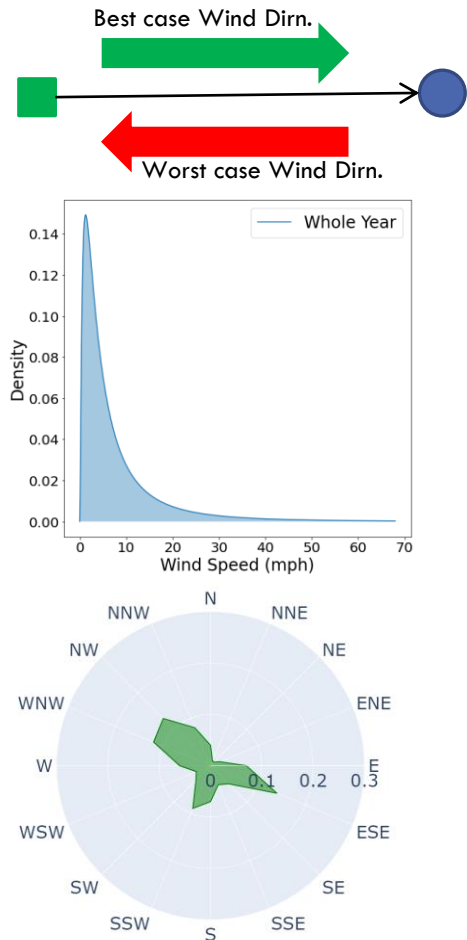
$$x_i, y_j \in \{0,1\}$$

c_i defines importance of covering a demand point $i \in I$. Therefore, it is a composite metric and can include factors like:

- Population and demographics
- Emergency calls history
- Equity considerations
- others...

HOW ARE LOCATION DECISIONS AFFECTED?

Initial Information



Monte-Carlo Sampling

Estimating Failure Probabilities

\bar{p}_{ij} is weighted average of p_{ij}^{best} and p_{ij}^{worst} .

Weights are decided by the proportion of time wind direction is aligned with delivery direction.

SP-D assumes $p_{ij} = \bar{p}_{ij}$

Facility Location Model

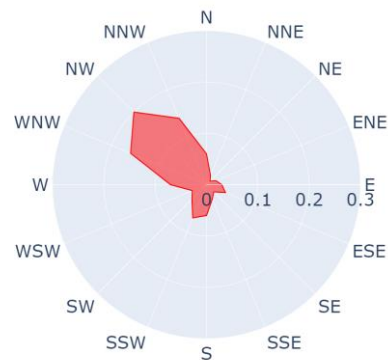
Final Output

Selected locations for drone operations

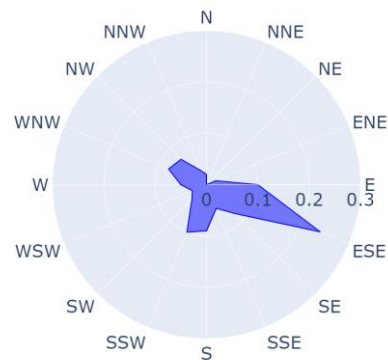
Demand Locations that would be "reliably" covered

OTHER CONSIDERATIONS

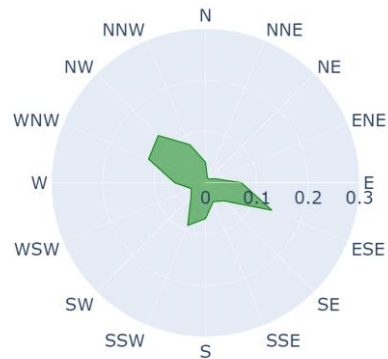
Seasonality in Wind Directions



Summer Months
(Apr – Sept)



Winter Months
(Oct – Mar)



Whole Year

Captured using multiple periods.

Allows opportunity to model changes in facility locations between periods

Failure Probability Estimation Uncertainty

Assuming $p_{ij} \in [p_{ij}^{best}, p_{ij}^{worst}]$, instead of $p_{ij} = \bar{p}_{ij}$

Use Robust Optimization framework

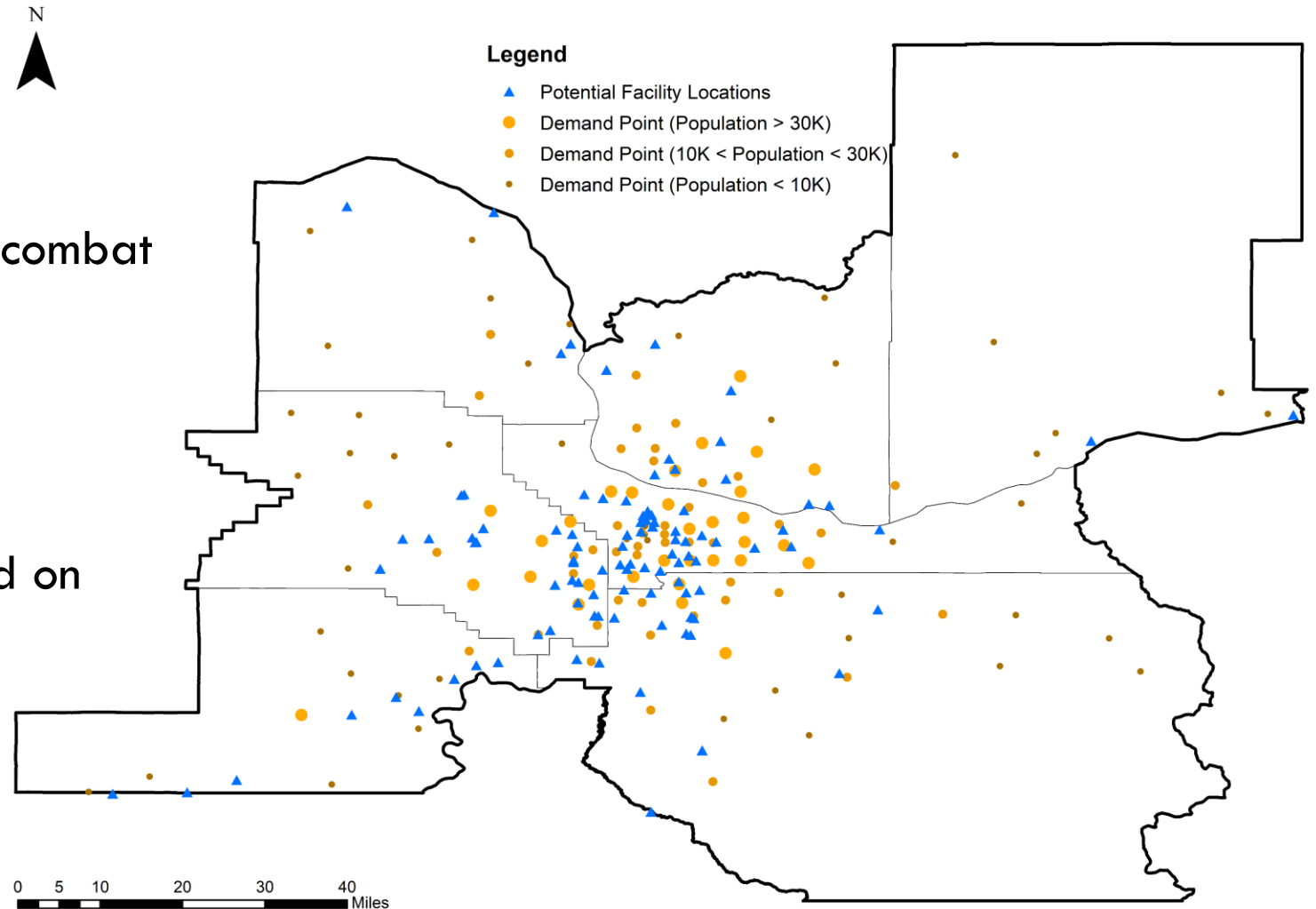
Conservatism induced by capturing uncertainty is controlled using parameter Γ

New facility location models developed that capture:

- Seasonality only: MP-D
- Uncertainty only: SP-R
- Both seasonality and uncertainty: MP-R

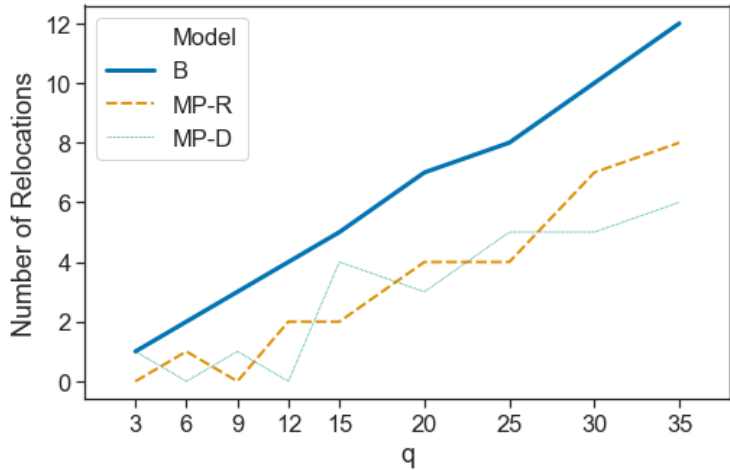
CASE STUDY

- Deploy AED-enabled drones to combat out-of-hospital cardiac arrests
- 122 demand locations
- 104 potential facility locations
- Coverage importance (C_i) based on normalized population
- Two Service Standards:
 - SS1: providing 90% coverage reliability in 4 minutes
 - SS2: providing 95% coverage reliability in 10 minutes

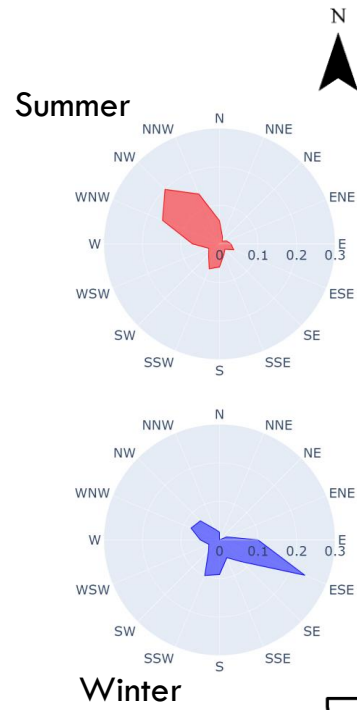
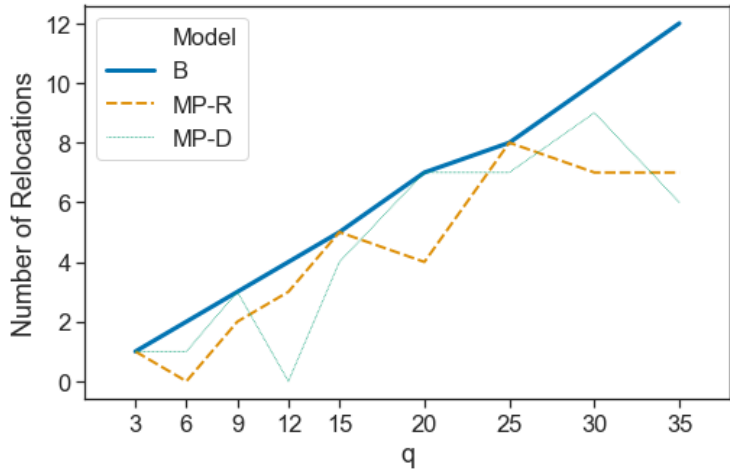


EXTENT OF FACILITY RELOCATION

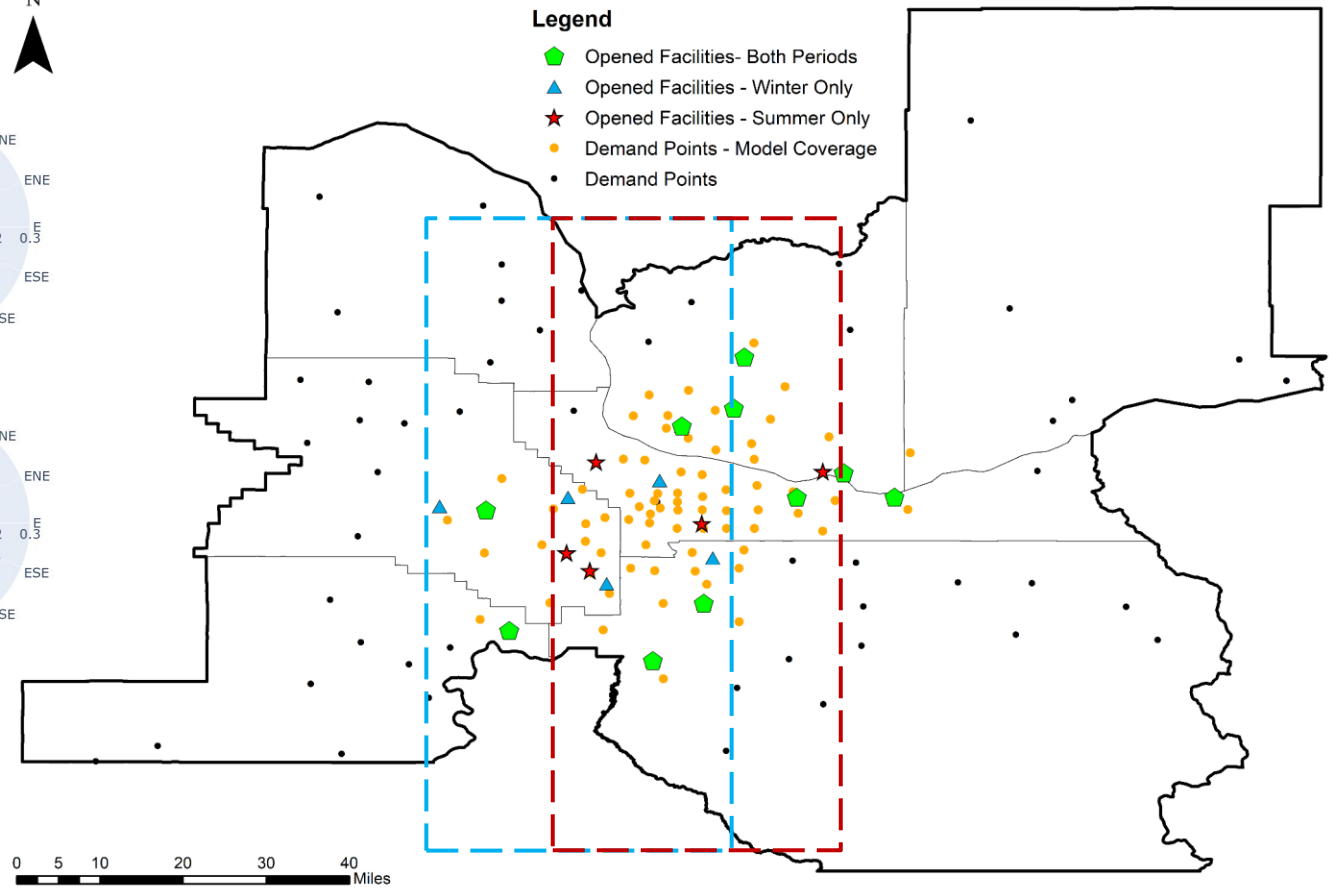
SS1



SS2

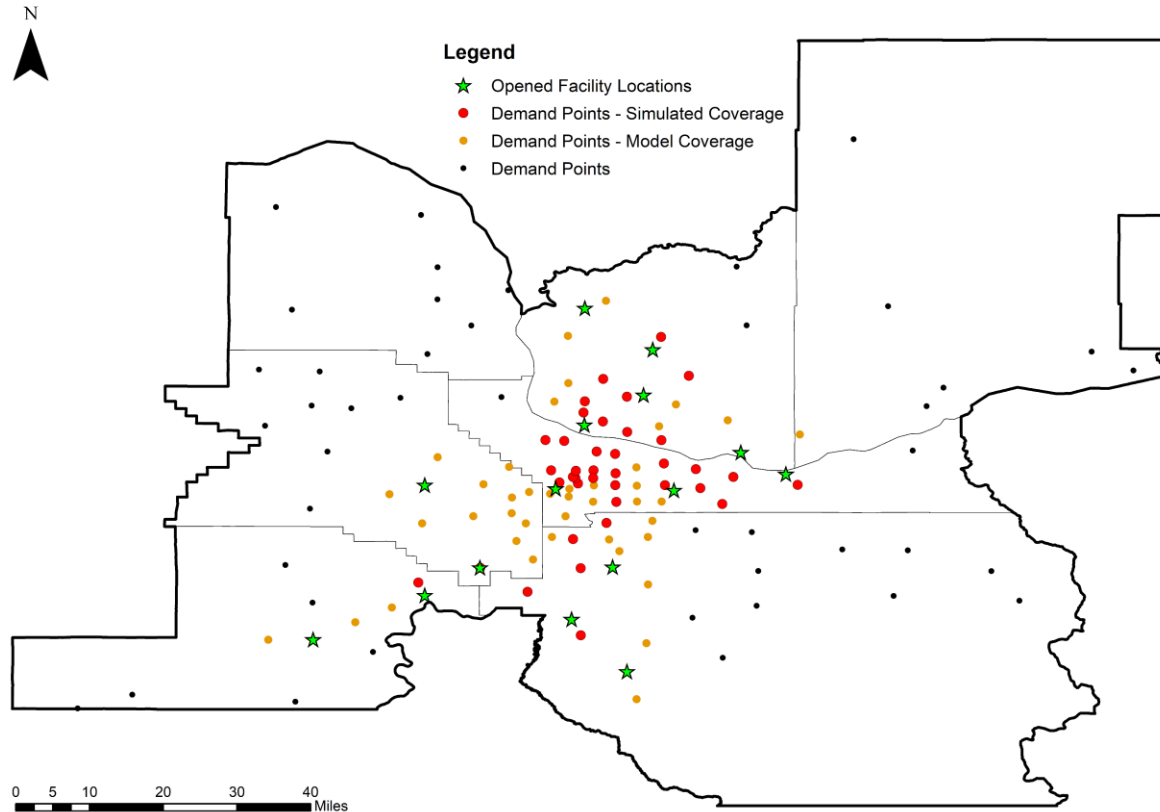


MP-R with $\Gamma=1$; SS2; $q=15$; at most 5 facilities can change locations between Summer and Winter

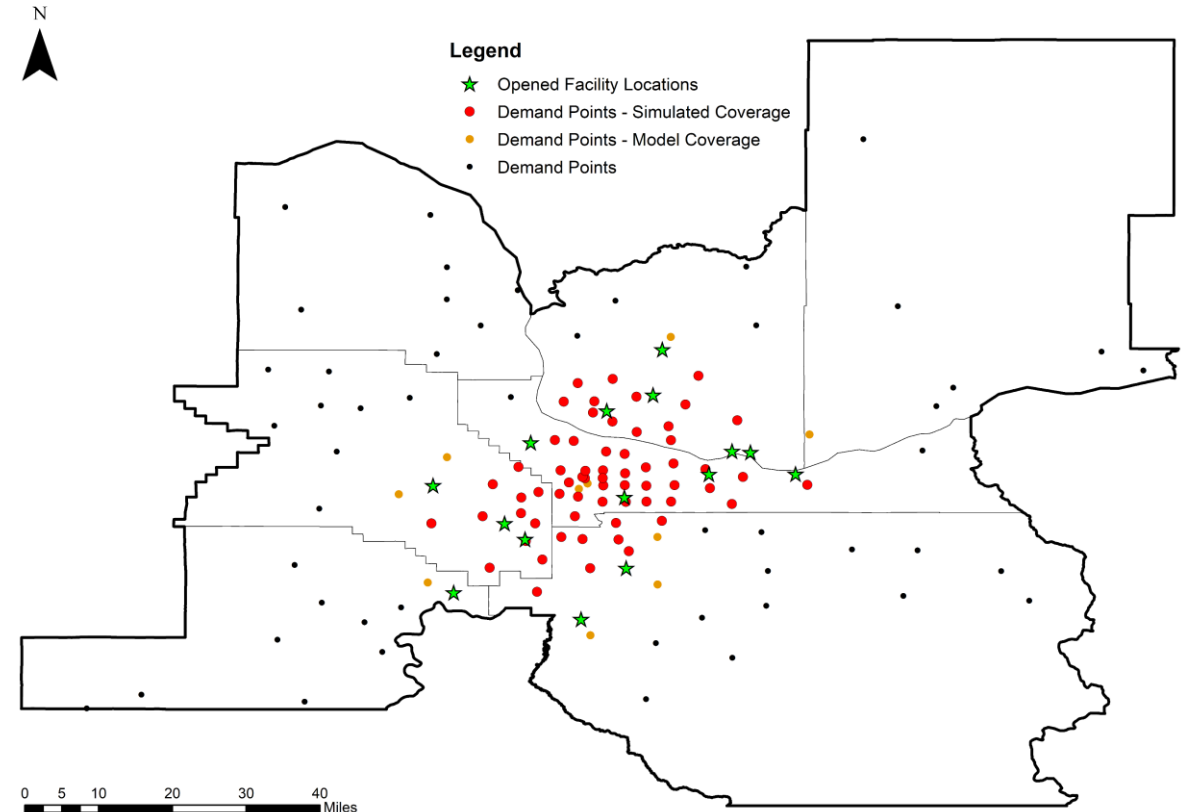


IMPROVEMENTS IN COVERAGE RELIABILITY

SP-D



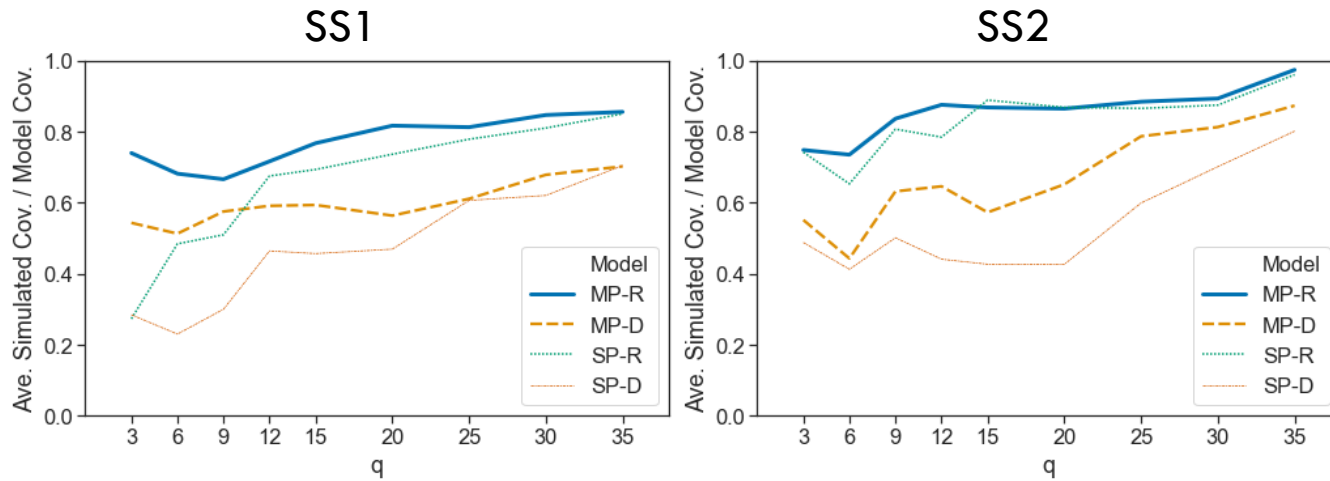
MP-R with $\Gamma=1$



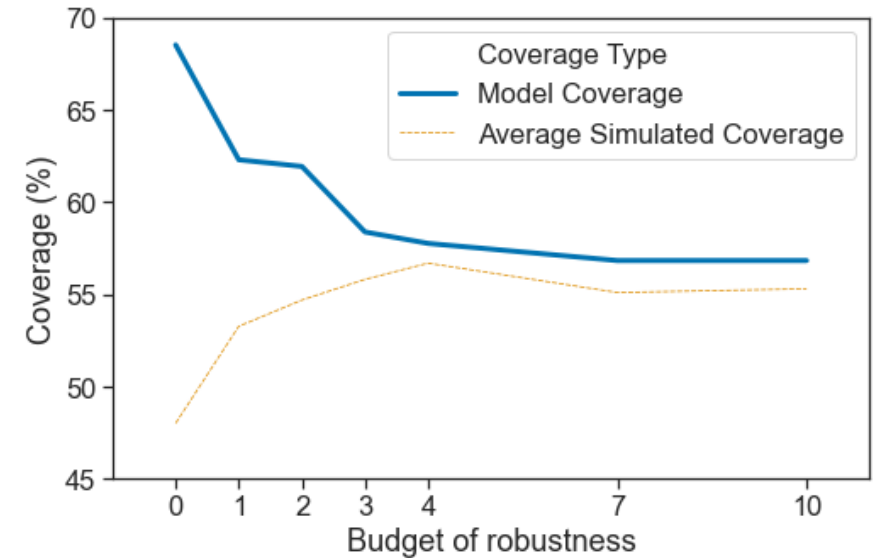
SS2 (95% reliability in 10 minutes); $q=15$

REDUCING THE GAP BETWEEN MODEL AND SIMULATED COVERAGE VALUES

Increasing the number of opened facilities (q)
(robust models use $\Gamma_i^t=1$)



Increasing decision conservatism
(MP-R; SS1; $q=35$; $B=12$)



CONCLUSIONS

- Facility location problem considering coverage reliability is modeled. The model uses multiple periods to capture seasonality and robust optimization to capture uncertainty in estimation of failure probabilities.
- Capturing both seasonality and uncertainty improves simulated coverage values by 57% (or, 0.57 times), on average.
- Capturing both seasonality and uncertainty are required for best decisions when travel time threshold is small (SS1), while just capturing uncertainty would suffice when travel time thresholds are long (SS2).
- Capturing uncertainty consolidates facilities in the urban core to improve reliability.
- The performance gap between model coverage and simulated coverage can be reduced by either increasing conservatism in decisions, or by opening more facilities.

THANK YOU!

Contact:

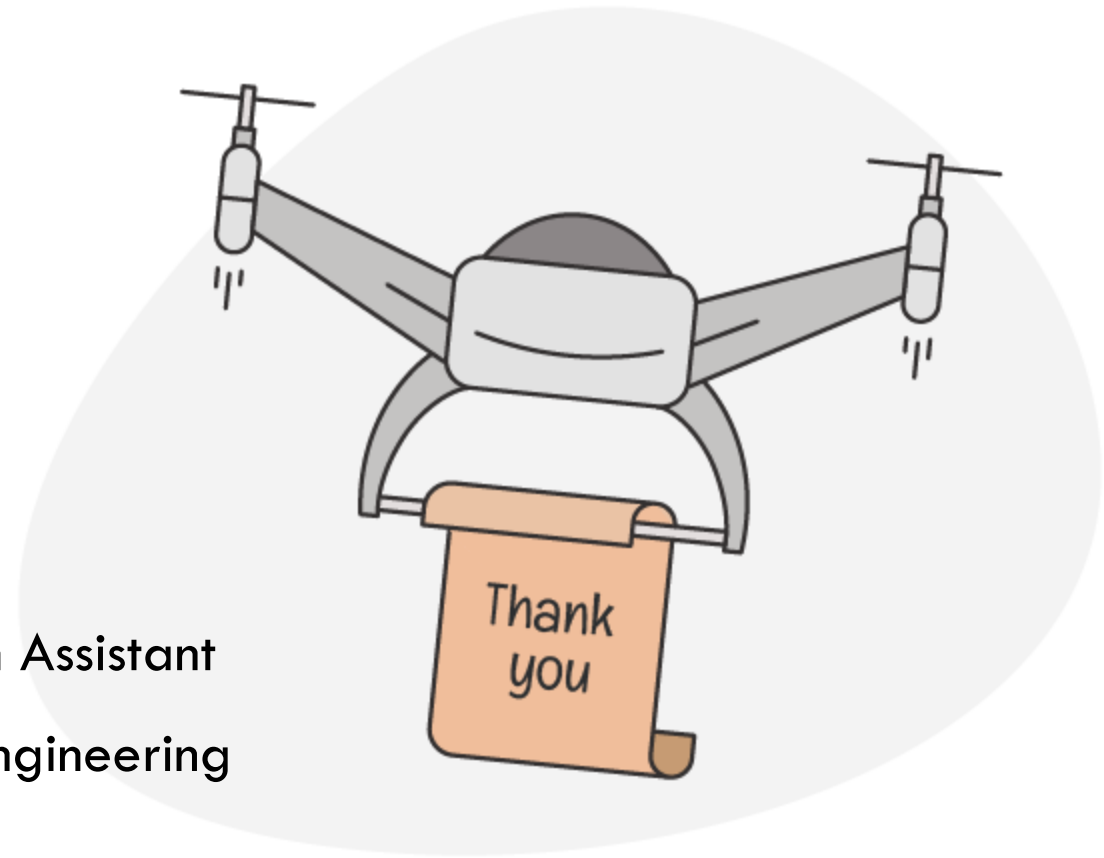
Darshan R. Chauhan

Ph.D. Candidate and Graduate Research Assistant

Department of Civil and Environmental Engineering

Portland State University

drc9@pdx.edu | <https://www.linkedin.com/in/drc9/>



SUPPLEMENTARY MATERIAL |

MULTI-PERIOD ROBUST (MP-R) FORMULATION

Objective:

$$\text{Max}_{x,y,z} \sum_{i \in I} c_i x_i$$

Coverage Reliability Constraints for each demand point $i \in I$ and time period $t \in T$

$$\text{Max}_{\{U \subseteq S_i, |U| \leq \Gamma\}} \left[\prod_{j \in U} (p_{\text{-worst}_{ij}}^t)^{y_j^t} \cdot \prod_{j \in S_i \setminus U} (\bar{p}_{ij}^t)^{y_j^t} \right] \leq (1 - \alpha)^{x_i}$$

Facility Opening Constraint for each time period $t \in T$

$$\sum_{j \in J} y_j^t \leq q$$

MULTI-PERIOD ROBUST (MP-R) FORMULATION

Facility Relocation Budget Constraint

$$\sum_{t \in T \setminus \{1\}} \sum_{j \in J} \sum_{k \in J} f_{jk}^t z_{jk}^t \leq B$$

Facility Relocation Logical Constraints

$$\sum_{k \in J} z_{jk}^t = y_j^{t-1} \quad \forall j \in J, t \in T \setminus \{1\}$$

$$\sum_{j \in J} z_{jk}^t = y_k^t \quad \forall k \in J, t \in T \setminus \{1\}$$

Variable Definitions

$$x_i, y_j^t, z_{jk}^t \in \{0, 1\}$$

MODEL PERFORMANCE RESULTS

- SS1: service standard of providing 90% reliability in 4 minutes

Computational time increment by:

- Adding multiple periods: 37 times
- Adding robustness ($\Gamma=1$): 5.2 times

- SS2: service standard of providing 95% reliability in 10 minutes

Computational time increment by:

- Adding multiple periods: 49.5 times
- Adding robustness ($\Gamma=1$): 24.5 times

MODEL PERFORMANCE RESULTS

- SS1: service standard of providing 90% reliability in 4 minutes

Improvement in average simulated coverage for SS1:

- Adding multiple periods:
 - Deterministic model: 0.41 times
 - Robust model ($\Gamma=1$): 0.29 times
- Adding robustness ($\Gamma=1$)
 - Single period: 0.28 times
 - Multiple period: 0.14 times
- SP-D to MP-R: 0.60 times

- SS2: service standard of providing 95% reliability in 10 minutes

Improvement in average simulated coverage for SS2:

- Adding multiple periods:
 - Deterministic model: 0.24 times
 - Robust model ($\Gamma=1$): 0.02 times
- Adding robustness ($\Gamma=1$)
 - Single period: 0.51 times
 - Multiple period: 0.23 times
- SP-D to MP-R: 0.54 times

WIND SPEED AND DISTRIBUTION DATA

Available openly at <https://github.com/drc1807/RMP-MCFLP-CR>