Pi in the Sky: Drone-delivered defibrillators for out-of-hospital cardiac arrest

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"I could calculate your chances of survival – but you won't like it"

-- Marvin from 'The Hitchhiker's Guide to the Galaxy'

Out-of-hospital cardiac arrest (OHCA)

- Kills 400,000 people in North America annually
- Only 5-10% of patients survive to hospital discharge
- Survival is very time-sensitive
  - Survival odds fall up to 10% per minute
- Prompt CPR and defibrillation can improve survival substantially
  - Thus, focus on getting treatment to OHCA victims quickly

Automated external defibrillator (AED)

- A defibrillator can deliver an electric shock to “reset” the heart

- Easy to use – just follow audio/visual instructions

Defibrillator drone

Drone delivery of medical supplies

The ambulance drone that could save your life: Flying defibrillator can reach speeds of 60mph

- $19,000 drone tracks emergency mobile calls and uses
- Operators can watch, talk and instruct those helping th
board camera

Drones will begin delivering blood and medicine in the US

After launching in Rwanda, Zipline brings its fleet of medical drones to three US states

First FAA-approved drone delivery brings medical supplies to rural Virginia

Jayne O'Donnell and Laura Ungar, USA TODAY Published 12:35 p.m. ET July 17, 2015 | Updat

UPS Tests Drone Delivery of Medical Supplies

Swiss hospitals will start using drones to exchange lab samples

It's the first time drones will be used commercially for this purpose in an urban area

by James Vincent | @jjvincent | Mar 31, 2017, 6:00am EDT

Peel and drone company launch research into airborne delivery of emergency medical aid

Defibrillators carried to patients by drones envisioned

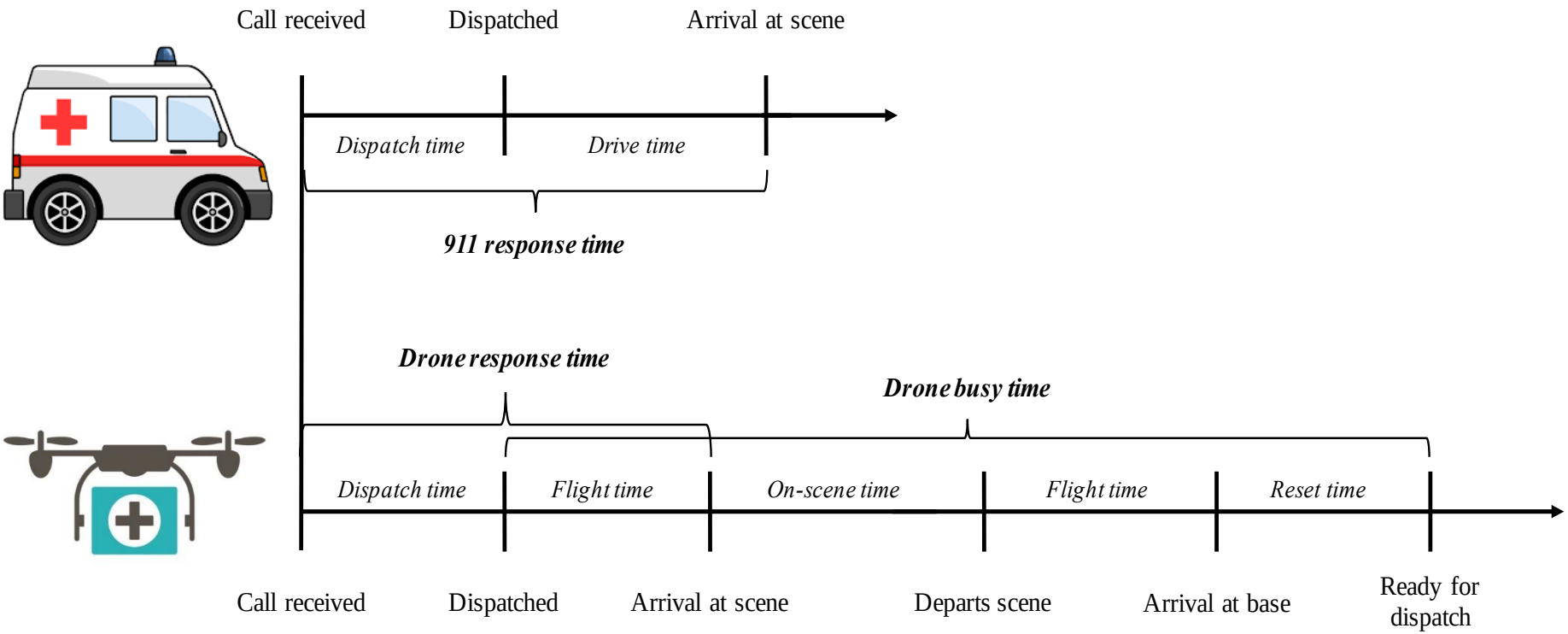
NEWS Jun 29, 2017 by Roger Belgrave Brampton Guardian

Today's talk

Project 1: Network design

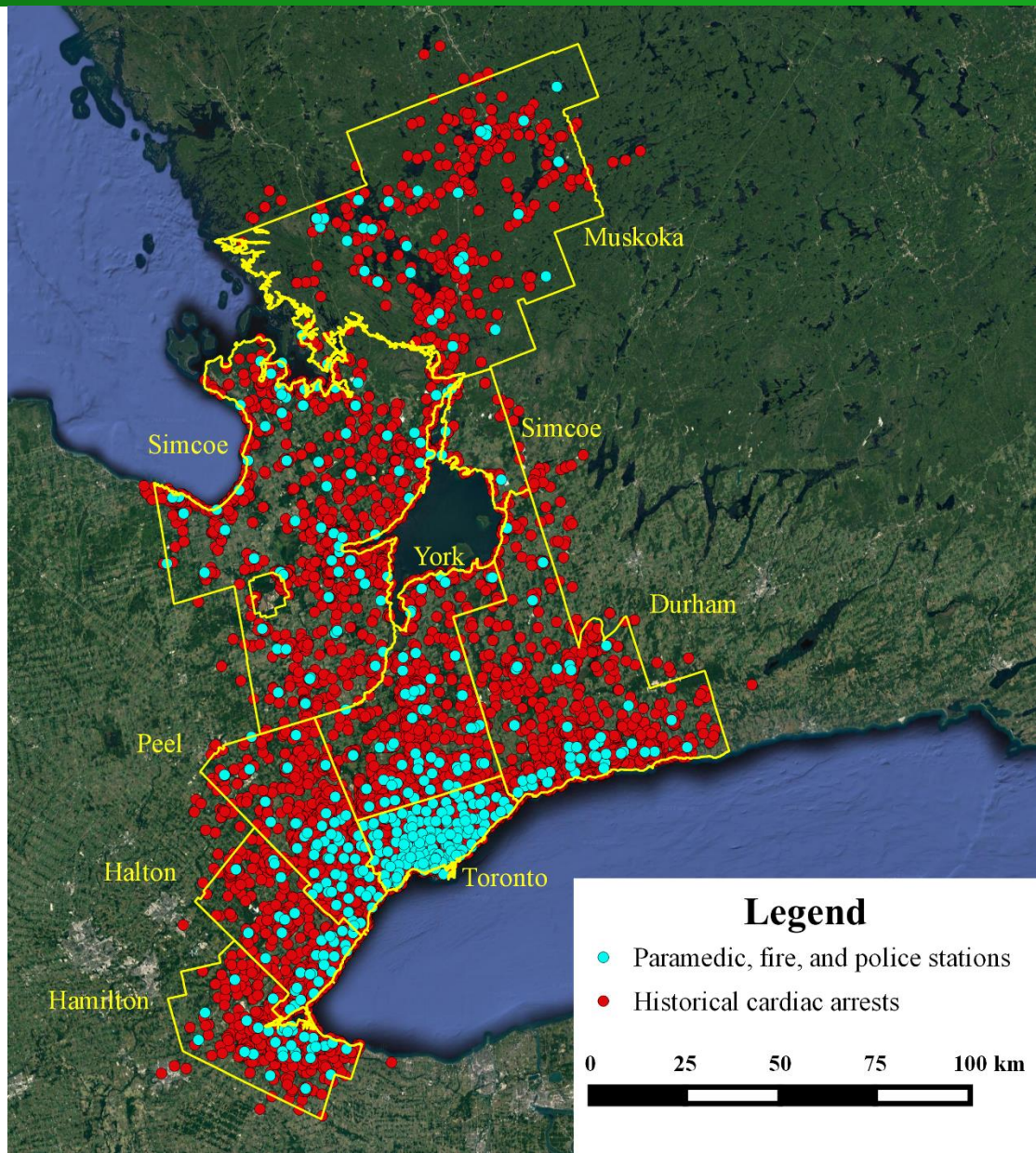
- Modeling framework to design drone network to meet any AED arrival time goal
- Optimization model to determine number and location of drone bases
- Queuing model to determine number of drones to locate at each base to meet certain service level
- Ongoing work that aims to integrate these two models

Comparing response timelines



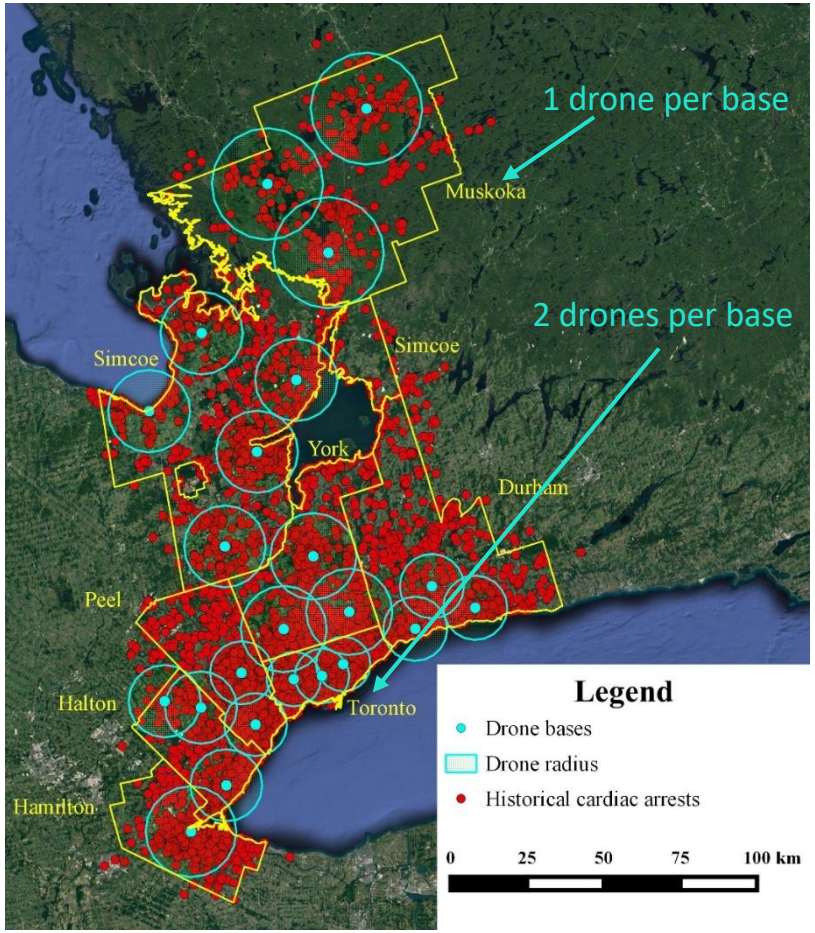
Data

- 8 regions
  - 7.5 million people
  - 10,000 sq. miles
- 53,702 OHCAs from 2006 to 2014
  - 86% private location
  - 7.8% survival
- 538 paramedic, fire, and police stations

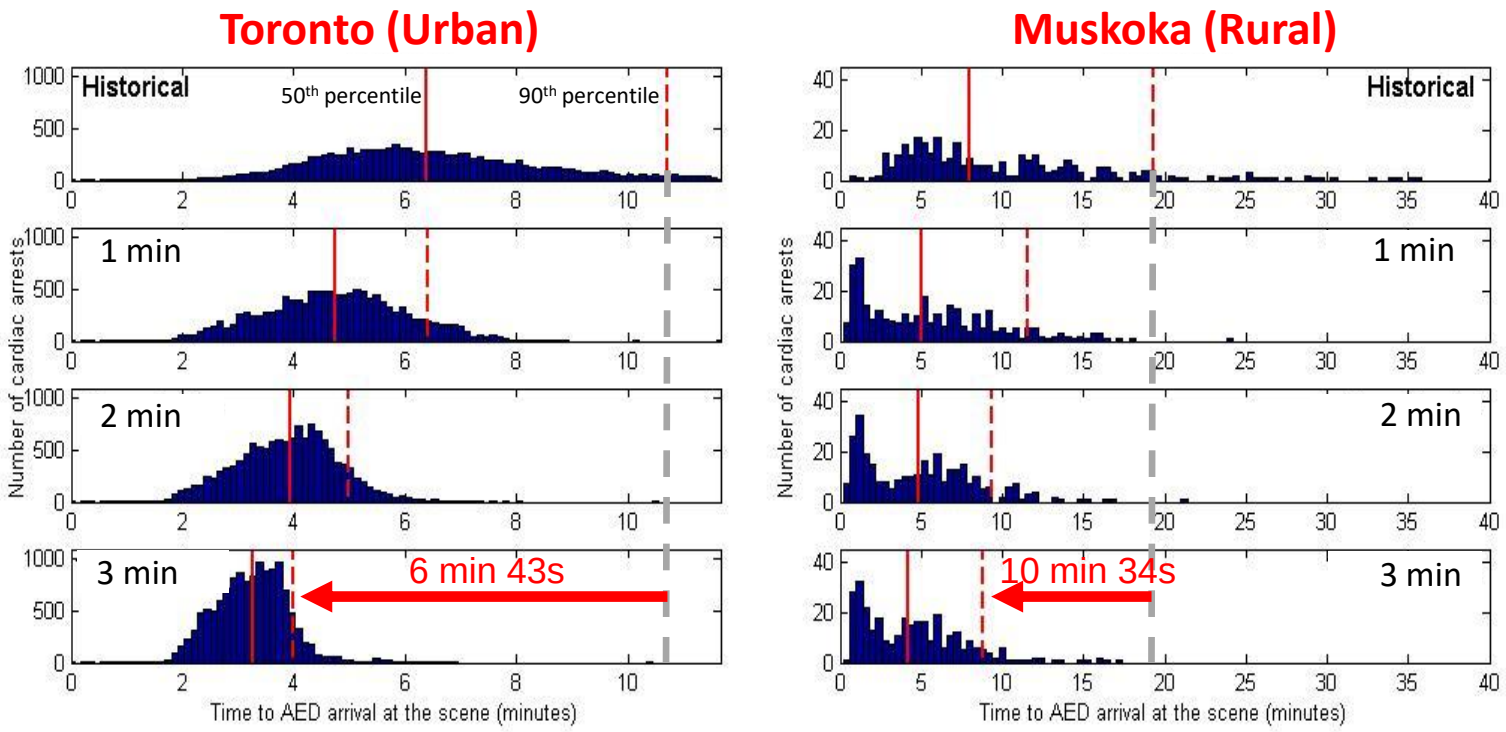


Results: an example drone network

- 23 bases, 37 drones:
  - Reduce median response time by 1 minute
  - Reduce 90th percentile response time by over 6 min in some regions
  - 2/3 of the time drone arrives ahead of EMS



Impact on response time distribution



Project 2: Dispatch

- Should we send a drone to each OHCA?
  - Only useful if it arrives before EMS
- Over-dispatching has drawbacks
  - Cost
  - Risk of adverse events
  - Unavailability for subsequent missions
- Goal: Develop dispatch rules based on predicted EMS response times

Problem setting

- Peel Region, Ontario
  - 3 municipalities, 1.4 million people
- Suspected OHCAs from Jan. 2015 – Dec. 2019
  - After applying inclusion/exclusion criteria, n = 3,573
- Base locations determined using optimization model

Methodology

- Predicted ambulance response time using:
  - Linear Regression
  - Neural network
  - Inputs: day/time variables, locations of ambulance and OHCA, road distance

- Dispatch drone if:

Drone response time < ambulance response time + δ

(δ = buffer)

Evaluation metrics

- Evaluate dispatch rules by mean, median, and 90th percentile of:

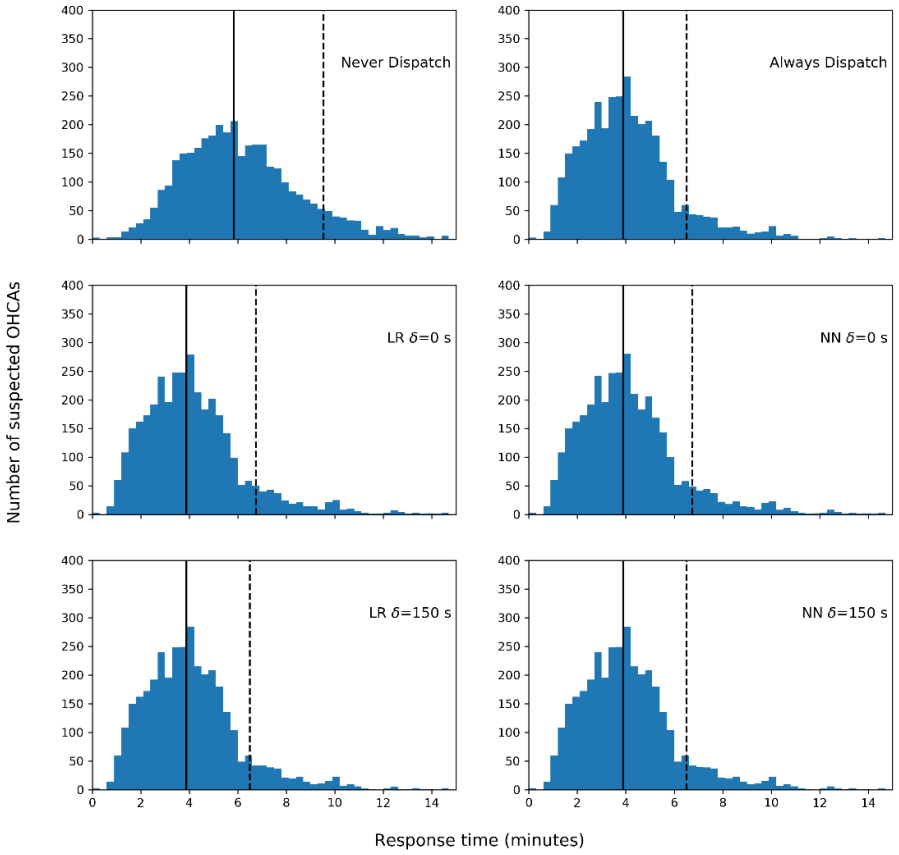
  first response time = min(drone, ambulance)

- Correctness of dispatch decision:

Dispatch Decision	Outcome: Drone would have arrived before EMS	Outcome: Drone would have arrived after EMS
Send Drone	True Positive	False Positive
Don't Send Drone	False Negative	True Negative

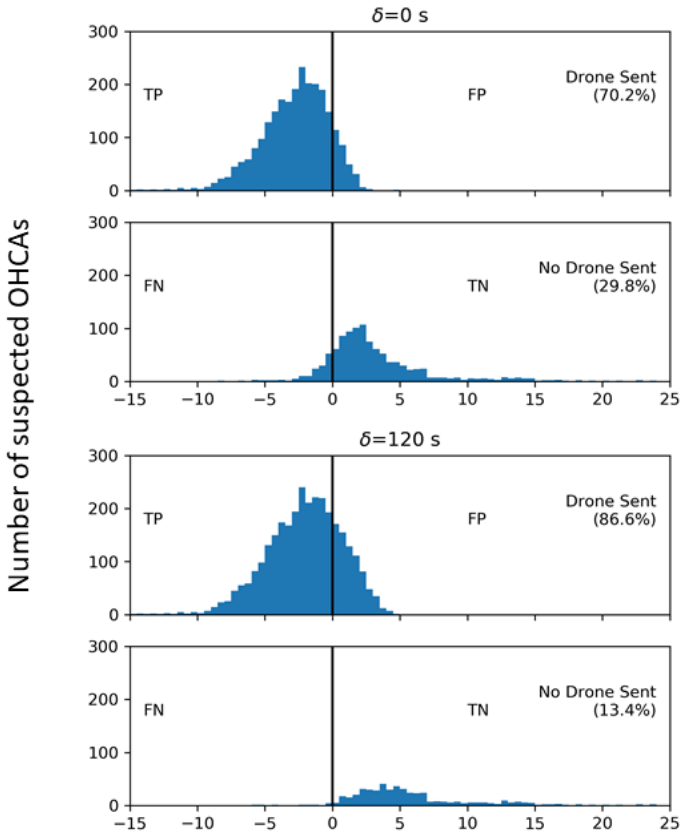
Results: Response times

- All dispatch rules significantly reduce response time compared to historical EMS
  - Mean: 6.2 → 4.1-4.2 min
  - Median: 5.8 → 3.9 min
  - 90th pct: 9.5 → 6.5-6.7 min
- Comparable response time distribution to "universal dispatch"



Results: Sensitivity vs. Specificity

- Suspected OHCAs with improved first response time plateaus at ~65%
  - Reaches a maximum number of “beneficial” drone trips
- ML-based dispatch rules reduce the number of trips by 10-30% compared to “universal dispatch”



Project 3: Feasibility study

Peel Region ponders adding drone-mounted, talking defibrillators to its EMS fleet

Research shows drones can cut down response times 6 minutes in urban centres and 10 minutes in rural centres

Michael Smee · CBC News · Posted: Mar 28, 2019 5:00 AM ET | Last Updated: March 28

Peel pilot project tests drone delivery of defibrillators to help cardiac arrest victims

By **Marta Marychuk** Mississauga News
Tues., April 2, 2019 | 2 min. read

Test flights (summer 2020)

Progress and next steps

- Completed large number of flights
- Successful AED drops, faster response to mock OHCAs, night flights, temperature
- Phone attached to AED provides real-time training and feedback to bystander
- Next steps:
  - Flights without “spotter” at destination
  - Simultaneous dispatch with EMS
  - Go live with municipal and Transport Canada approval
  - Extensions to broader medical response (e.g., EpiPen, naloxone, glucose, trauma sling, etc.)

Summary

- Exciting interdisciplinary collaboration that has moved a “theoretical” idea to reality in a short time

- OR and analytics have an important role to play in designing a drone response system and integrating it within the broader EMS landscape

Collaborators

- Justin Boutilier
- Steven Brooks
- Alyf Janmohamed
- Adam Byers
- Jason Buick
- Cathy Zhan
- Angela Schoellig
- Sheldon Cheskes
- Laurie Morrison
- Shelley McLeod
- Michael Nolan
- Paul Snobelen
- Christian Vaillancourt
- Katie Dainty
- Ian Drennan
- Jamal Chu
- Benjamin Leung
- Gordon Nevils

References

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- J. Chu et al., "Machine learning-based dispatch of drone-delivered defibrillators for out-of-hospital cardiac arrest," *Resuscitation*, Vol. 162, pp. 120-127 2021.
- S. Cheskes et al., "Improving access to automated external defibrillators in rural and remote settings: A drone delivery feasibility study," *Journal of the American Heart Association*, Vol. 9 (Article No. e016687), 2020.

Thanks for listening!

Questions?

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