A simulation study of the performance of a person-following delivery robot in crowded pedestrian environments

UNIVERSITY OF TORONTO

Ruowei Li, Farah Ghizzawi, Tho V. Le & Matthew J. Roorda

Outline

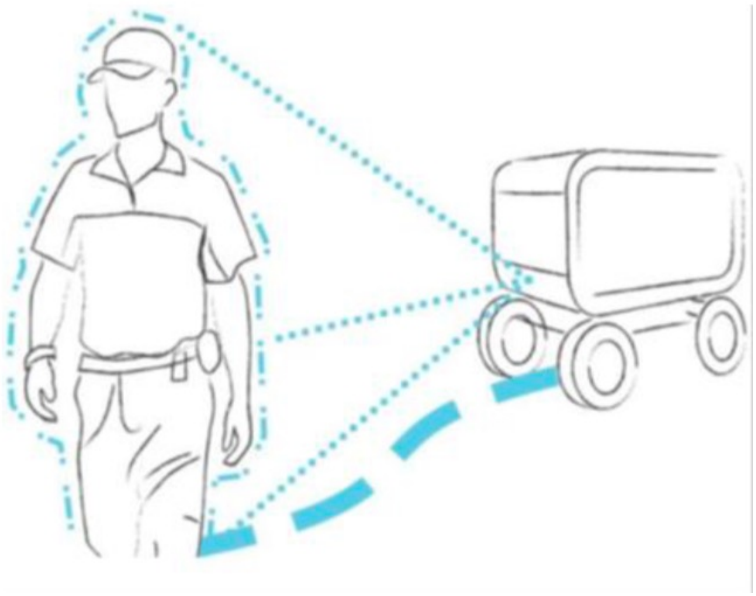
Background

Objectives

Project Phases

- Experimentation
- Model development and calibration
- Performance evaluation

Collaborative Delivery Robots



EffiBOT

Objectives

- Develop tools to evaluate the performance of EffiBOT in a crowded pedestrian environment
  - Observe the following and obstacle avoidance behavior of EffiBOT through lab experiments
  - Build and calibrate a micro-simulation model
  - Assess the performance of EffiBOT in an indoor pedestrian environment via simulation

Project Phases

Phase 1. Develop laboratory experiments to understand EffiBOT's person-following and obstacle avoidance behavior

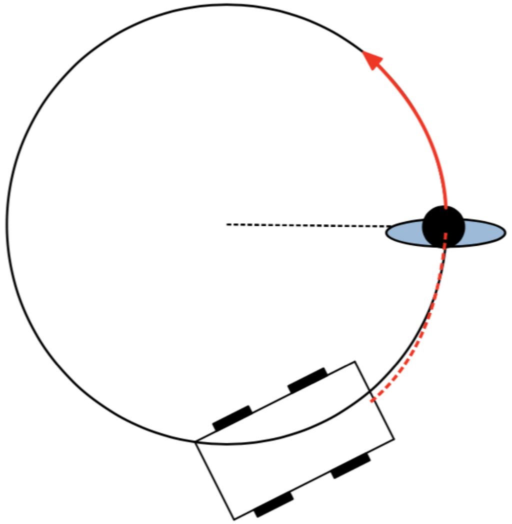
Phase 2. Develop and calibrate EffiBOT model in simulation software

Phase 3. Develop a simulation that incorporates EffiBOT in a pedstrian environment and evaluate its performance

Category A: Bot + Operator

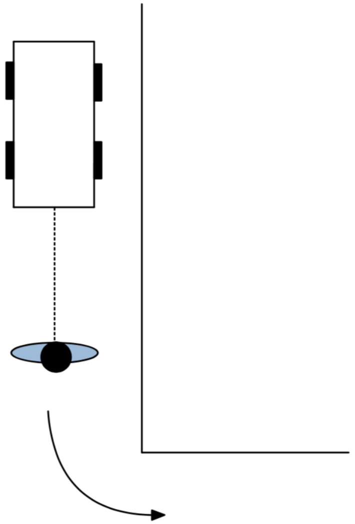
Straight Line
Following Test

Circular Line
Following Test

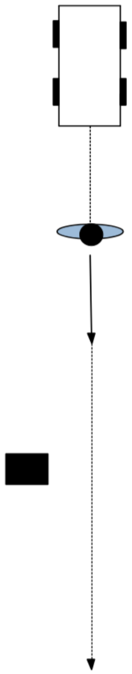


Category B: Bot + Operator + Static Obstacles

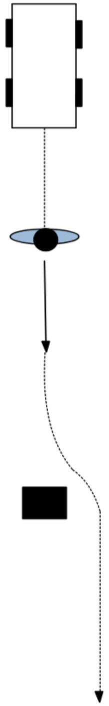
Occlusion Test



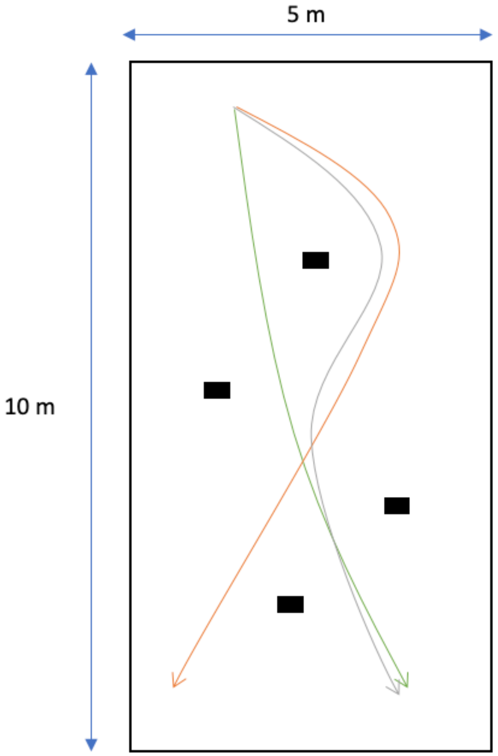
Passing Static Obstacle Test



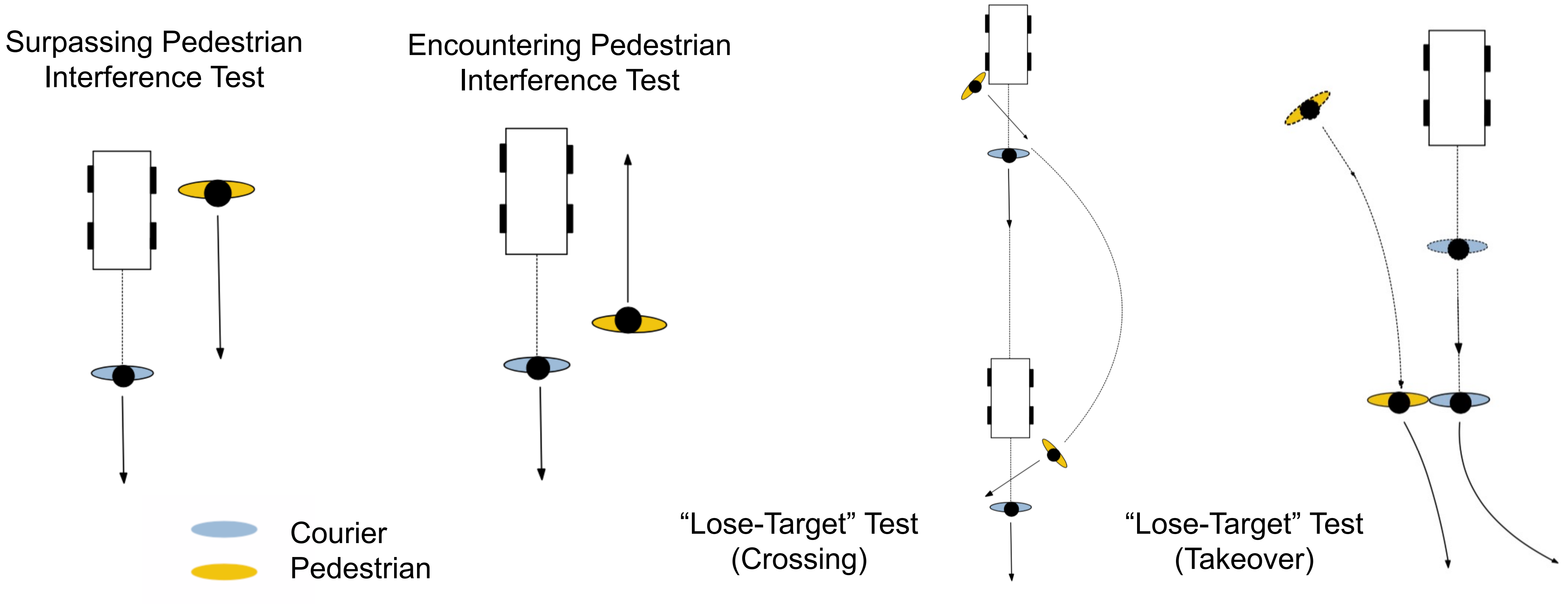
Avoiding Static Obstacle Test



Obstacle Map

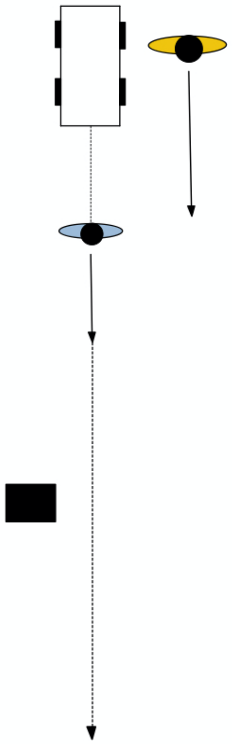


Category C: Bot + Operator + Pedestrian

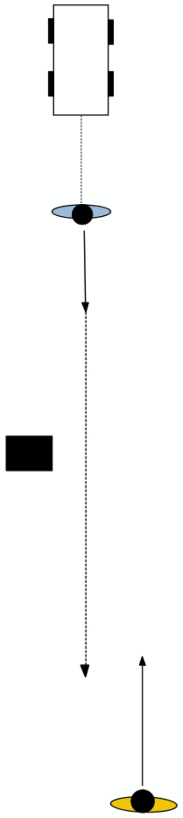


Category D: Bot + Operator + Static Obstacles + Pedestrian

Static & Dynamic
Obstacles Test (Surpass)



Static & Dynamic
Obstacles Test (Encounter)



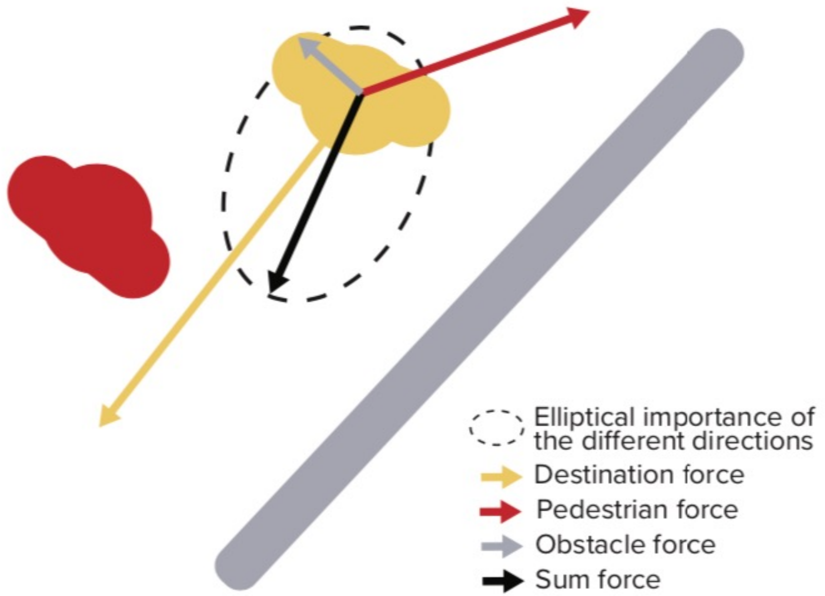
Courier
Pedestrian

Key Findings from Experimentation

- Maximum speed reached by the robot was 5.76 km/hr.
- Minimum turning radius of 1.2 m could be achieved at relatively low speeds (~ 2km/hr).
- Some challenges experienced during 90-degree turns, at 40-cm distance from the wall, and at an operator speed of ~ 6 km/hr.
- Robot often stopped upon encountering obstacles from both sides; e.g., 25 cm from box and 0.6 m from the pedestrian.
- Robot followed the operator even when a pedestrian walked between them.
- Operator speed of about 4 km/hr allows for more accurate robot following.

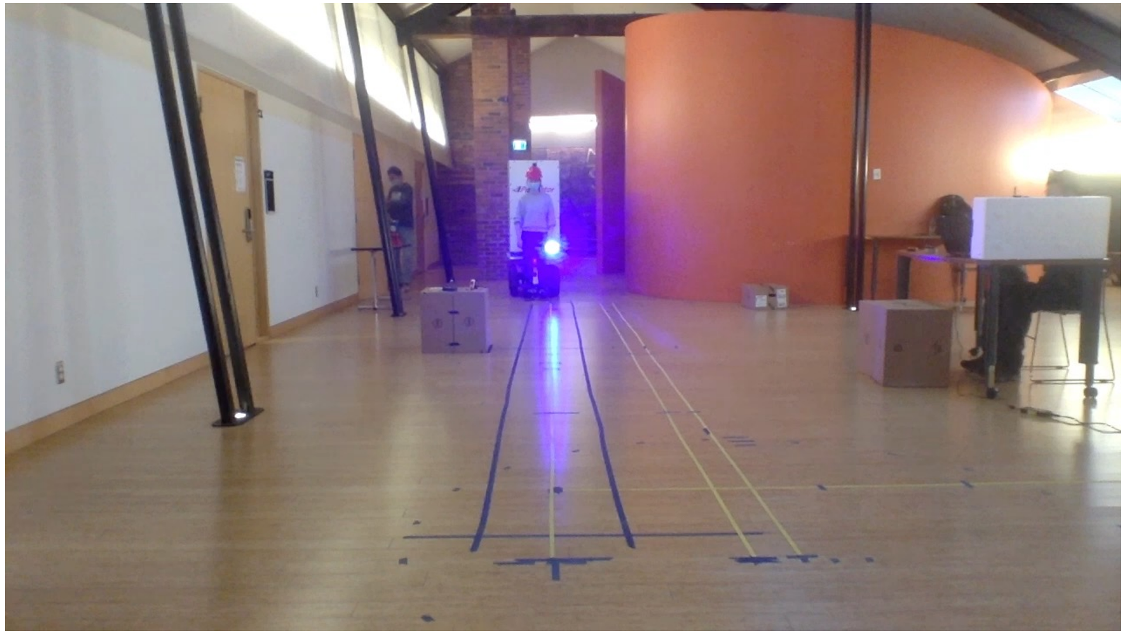
Development of Simulation Model

- Robot simulation: Modified social force model
- Pedestrian simulation: Social force model (Helbing & Johansson, 2009)
- Software: MassMotion
- Programming Interface: MassMotion Software Development Kit (SDK)

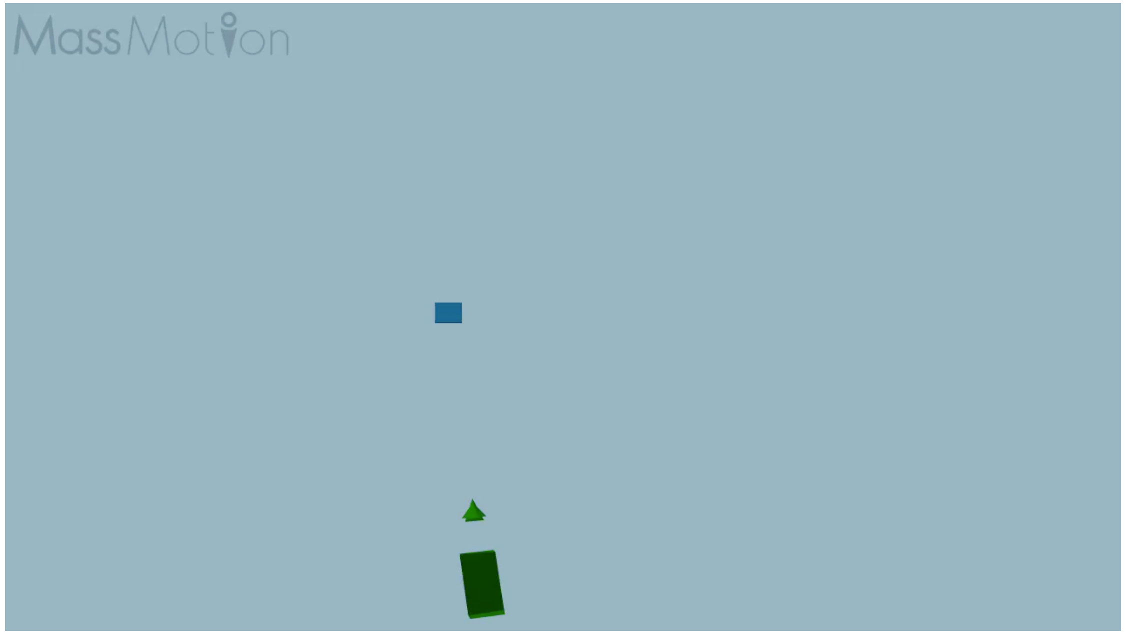


Experiment Versus Simulation Model

Recording of Experiment 4



Simulation of Experiment 4



Calibration of Simulation Model

- To ensure that the simulated robot's behaviour replicates that of the actual robot, the developed operator-following algorithm is calibrated based on experiments' data.
- Key calibration parameters include:
  - Neighbour force strength and range, A_β and B_β
  - Obstacle force strength and range, A_i and B_i
  - Relaxation parameter, τ

Robot Performance Evaluation

Evaluate robot's performance under various crowding scenarios.

Average Travel Speed

Journey Length & Time

Performance Metrics ⟷ **Crowding Scenarios**

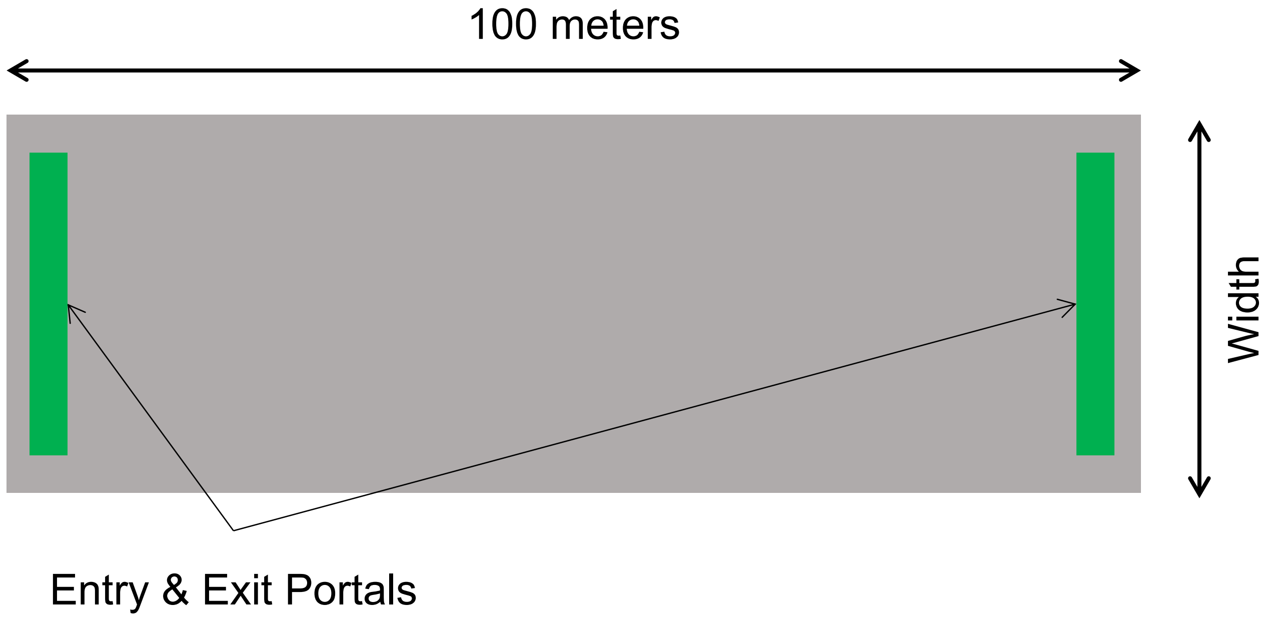
Average Pedestrian Density

Pedestrian Flow Direction

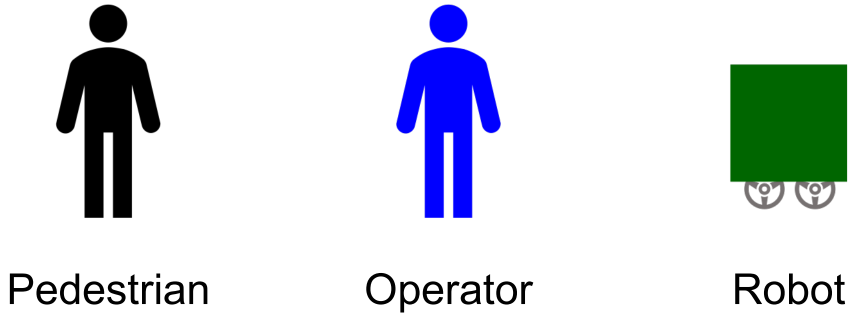
Corridor Width

Simulation Environment Setup

Indoor Pedestrian Walkway

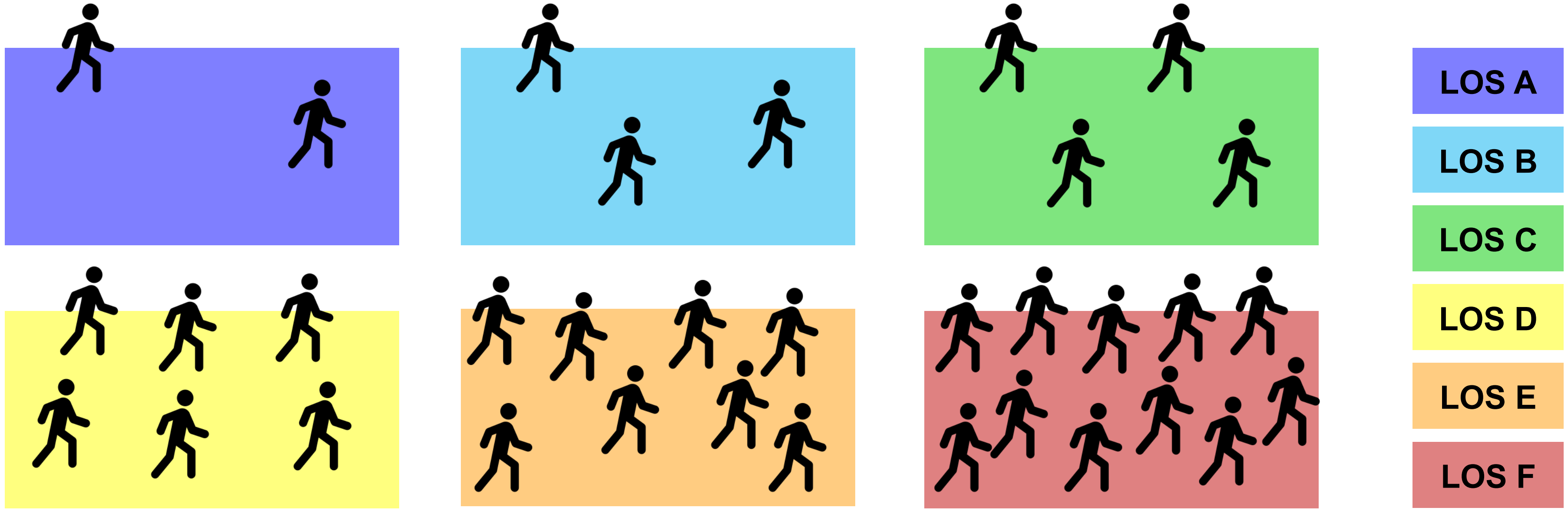


Agents



Varying Pedestrian Density

The pedestrian density is the number of pedestrians occupying a unit area of space at a certain instant.

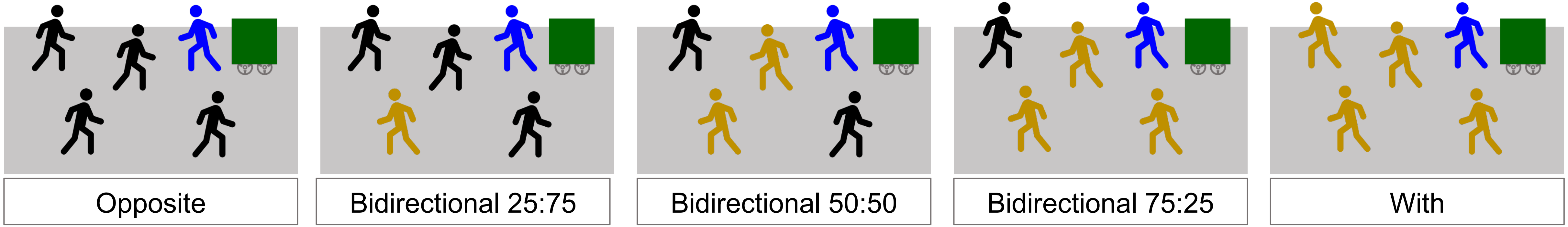


The more crowded a space becomes, the higher the average pedestrian density.

The level of service (LOS) of a walkway is labelled A to F, from least to most crowded, respectively.

Varying Pedestrian Flow Direction

The pedestrians flow directions are set with respect to the operator and robot.

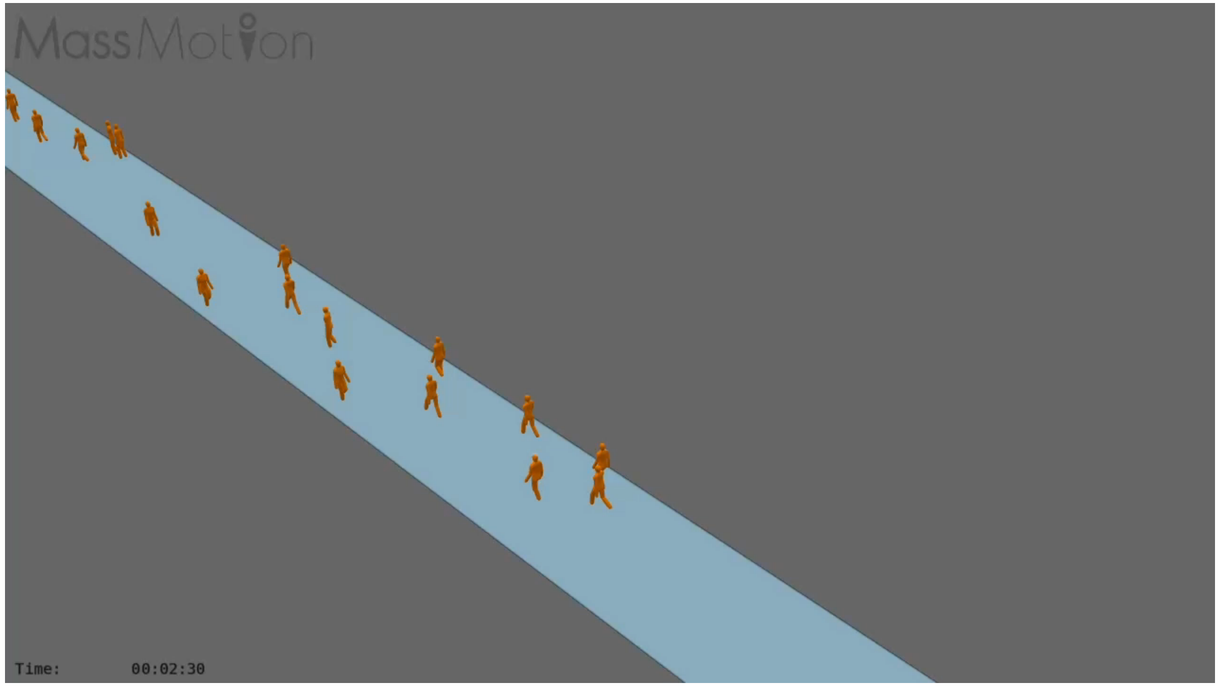


Pedestrian walking opposite to operator and robot

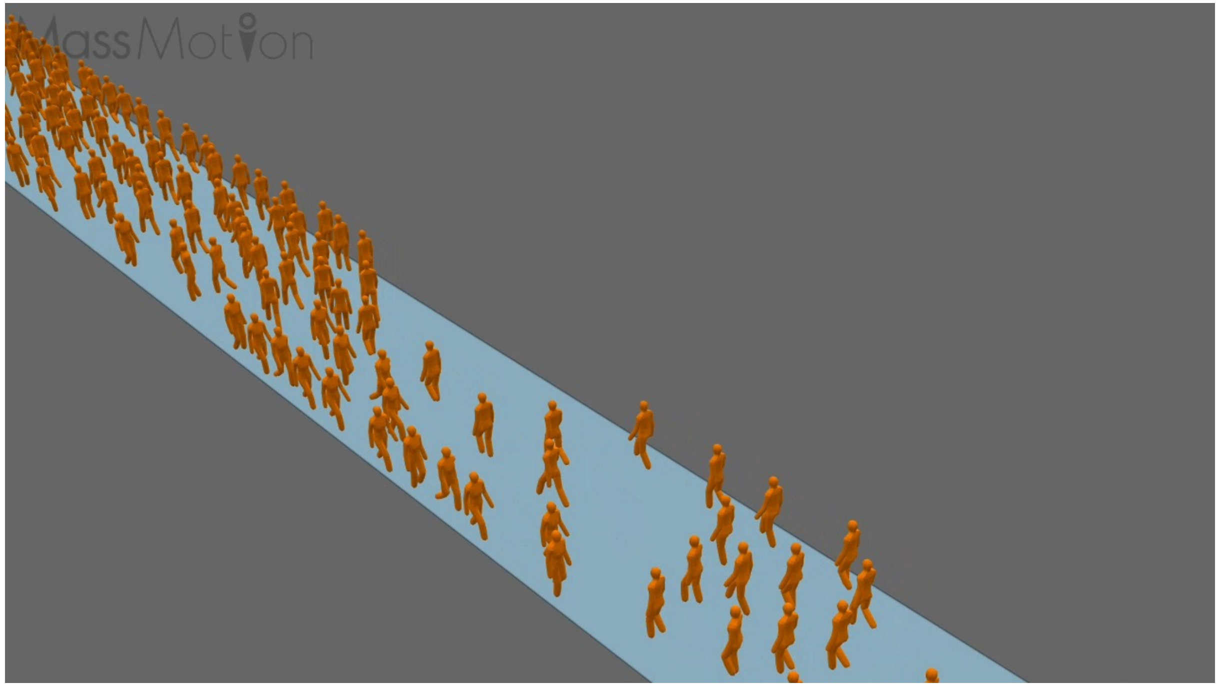
Pedestrian walking with operator and robot

Simulation of Crowding Scenarios

Low-Density Bidirectional Pedestrian Flow

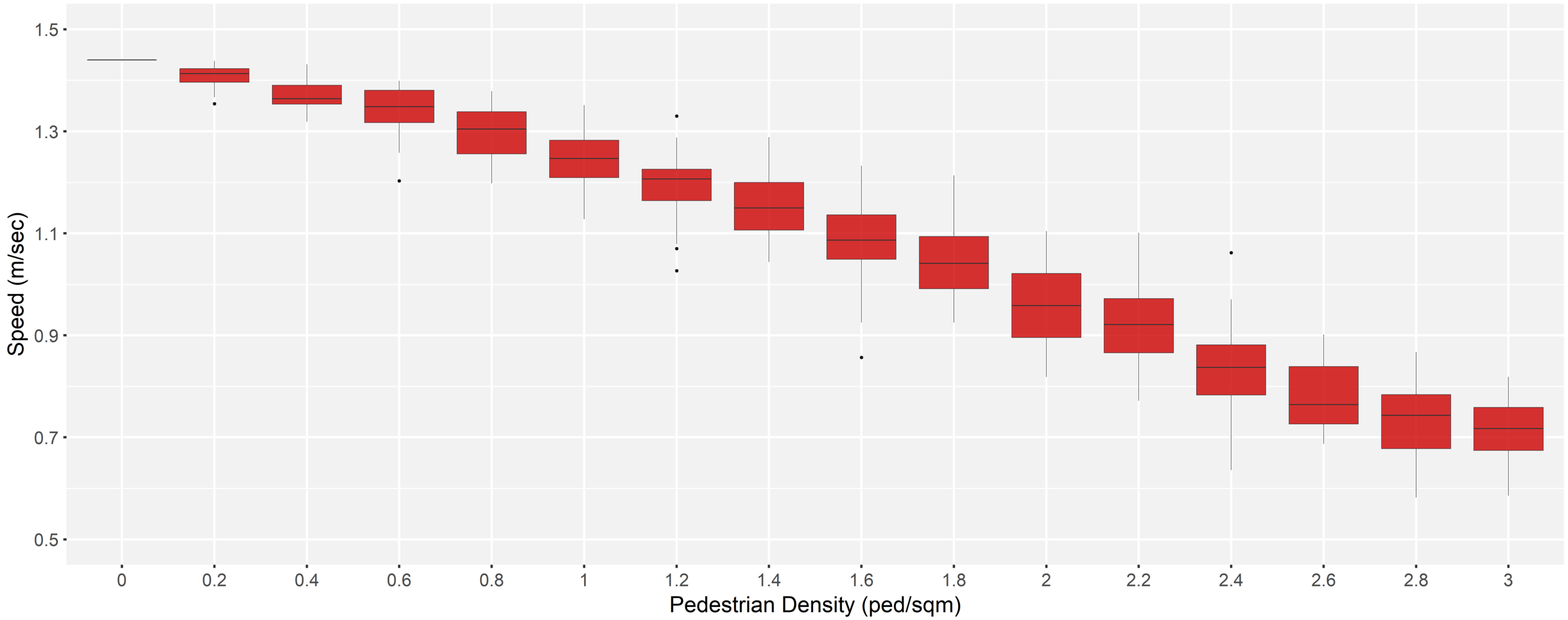


High-Density Bidirectional Pedestrian Flow



Impacts of Varying Pedestrian Density

Effect of varying average pedestrian density on distribution of robot's mean speed



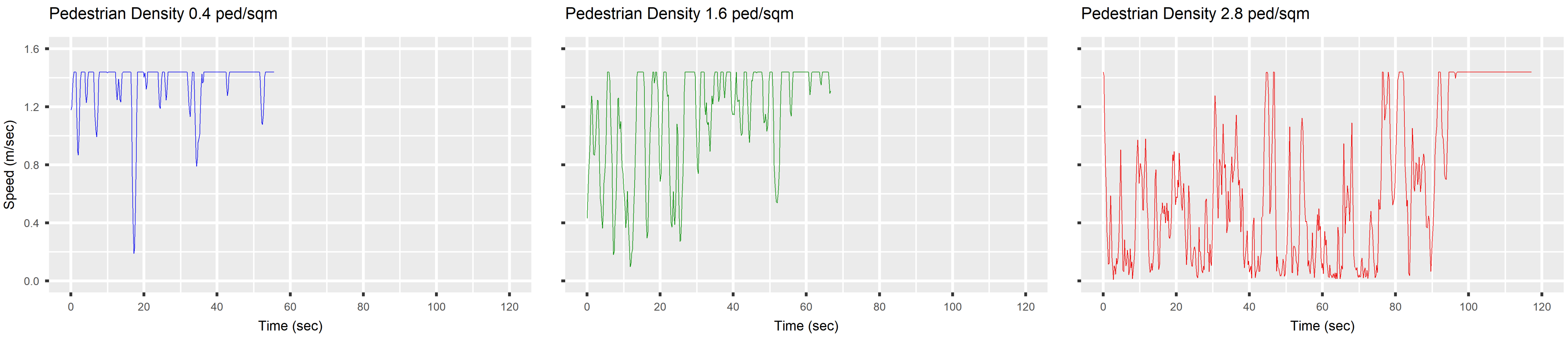
Impacts of Varying Pedestrian Density

A closer look at intra-scenario variations of the robot’s travel speed

- Speed Profile
- Distribution of Speed

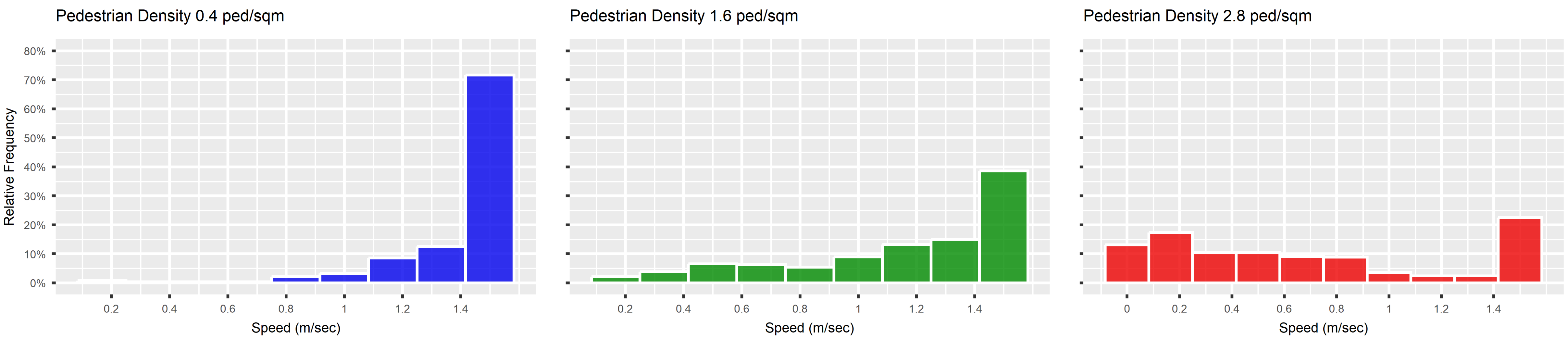
Impacts of Varying Pedestrian Density

Speed profile of the robot for randomly-selected run for each scenario



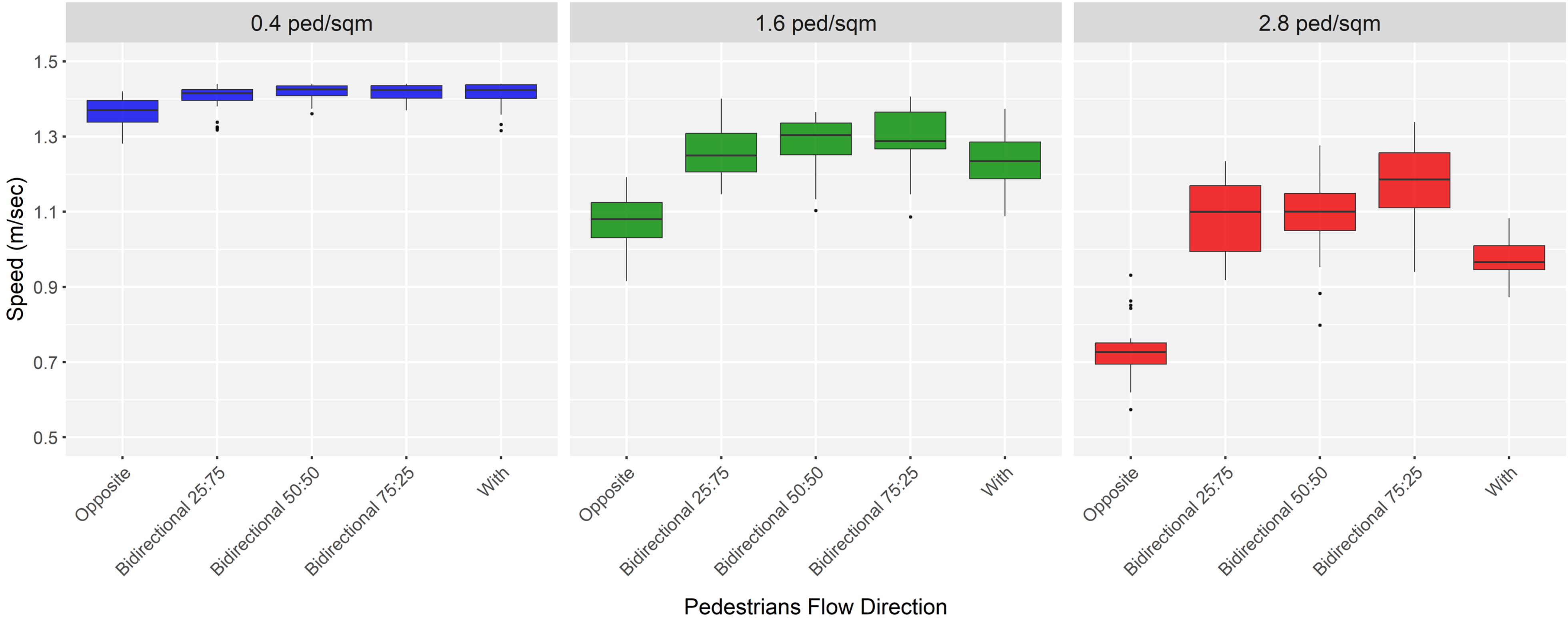
Impacts of Varying Pedestrian Density

Distribution of robot's speed for randomly-selected run for each scenario



Impacts of Varying Pedestrian Flow Directions

Effect of varying directions of pedestrian flow on distribution of mean robot speed



Summary of Key Findings

- Optimal pedestrian environments for person-following robots comprises low-to-medium density regimes
- For indoor walkways, the robot's speed drops as the pedestrian density increases.
- The more crowded a walkway becomes, the robot conducts more lateral deviation to avoid conflicts with pedestrians.
- When more pedestrians move with the robot, its speed improves, yet it may be delayed by slow pedestrians.
- Beyond eliminating boundary effects, varying the corridor width has little impact on the performance of the bot.

Future Research Endeavors

- Assess the performance of a person-following robot in more complex pedestrian environments.
- Compare the simulated behaviour of a person-following robot to the observed behaviour of a similar robot operating in Toronto Eaton Centre.
- Explore the potential of fully autonomous delivery robots in similar pedestrian environments.

Thank You!

Questions