Simulation And Analysis of Performance of Delivery Bots in Dense Indoor Urban Areas

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Presentation Outline

- Project Overview
- Literature Review
- Simulation Model Development
- Simulation Results
- Project Limitation & Future Research

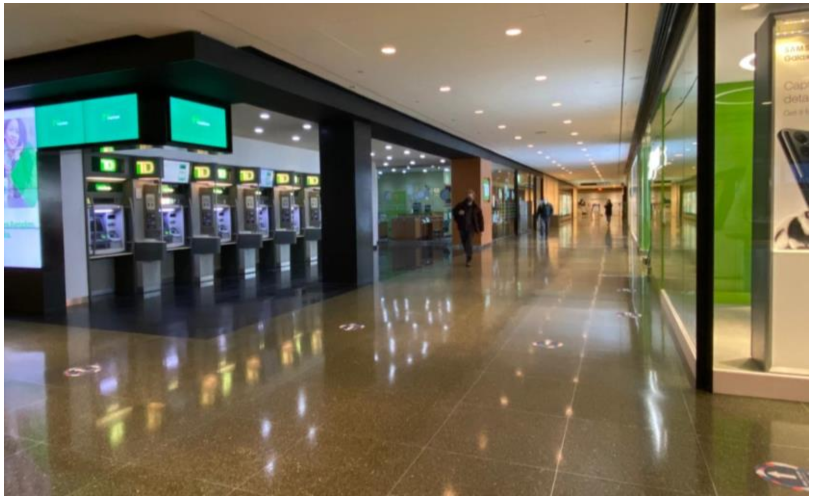
Project Overview

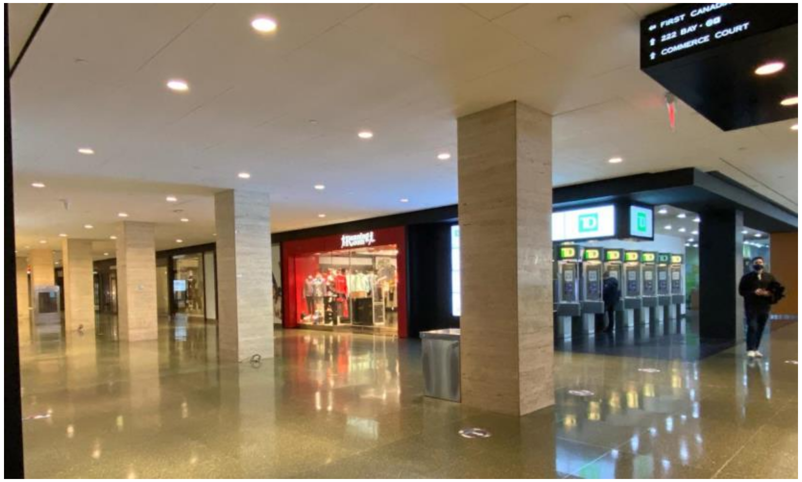
Project Overview

Simulation-based sensitivity analysis of the performance of autonomous delivery robots (bots) in a dense indoor pedestrian area:

- Objective: Evaluate the sensitivity of the bot's average speed with respect to varying design speed, size and personal space
- Simulation Setting: Intersection of 2 underground pedestrian walkways in PATH

Project Overview





Literature Review Summary

Literature Review Summary

TECHNOLOGY

Navigation

Communication & Control

OPERATIONS

Last mile delivery

Scheduling & Routing

REGULATIONS

Safety & Liability

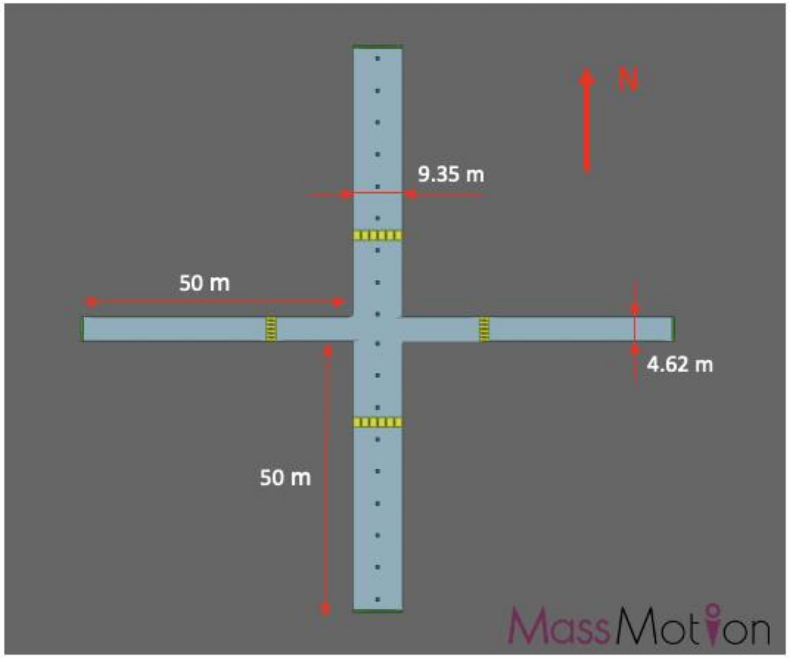
Data Protection

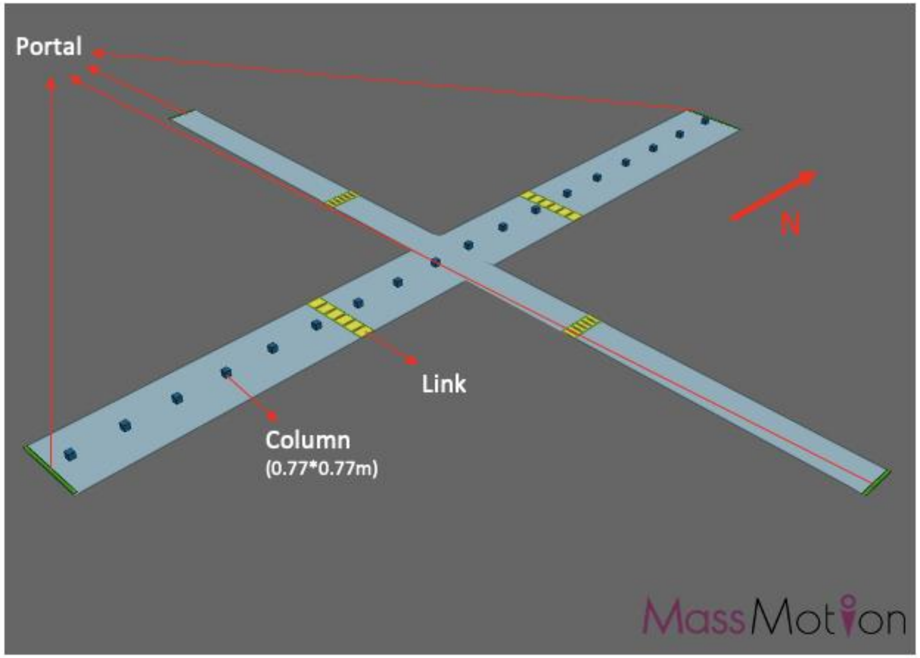
Performance of bots in a dense pedestrian environment

Simulation Model Development

Simulation Model Development

- Intersection of Pedestrian Walkways in MassMotion





Simulation Model Development


Postmates[1]

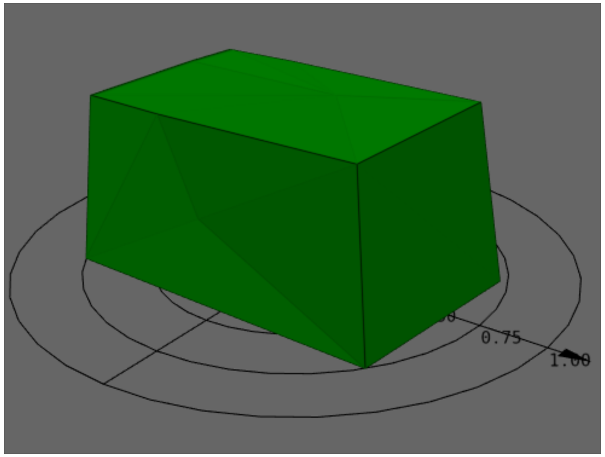
Marble[2]

FedEx Roxo[3]


Starship[4]

Simulation Model Development

- Input: Bot Parameters



Bot Avatar
in MassMotion

Parameters		
Design Speed [m/s]	Bot Size [m]	Personal Space [m]
1.4	0.3	0.2
1.6	0.5	0.3
1.8	0.7	0.4
2.0	0.9	0.5
2.2	1.1	0.6
1.8	**0.7**	**0.4**

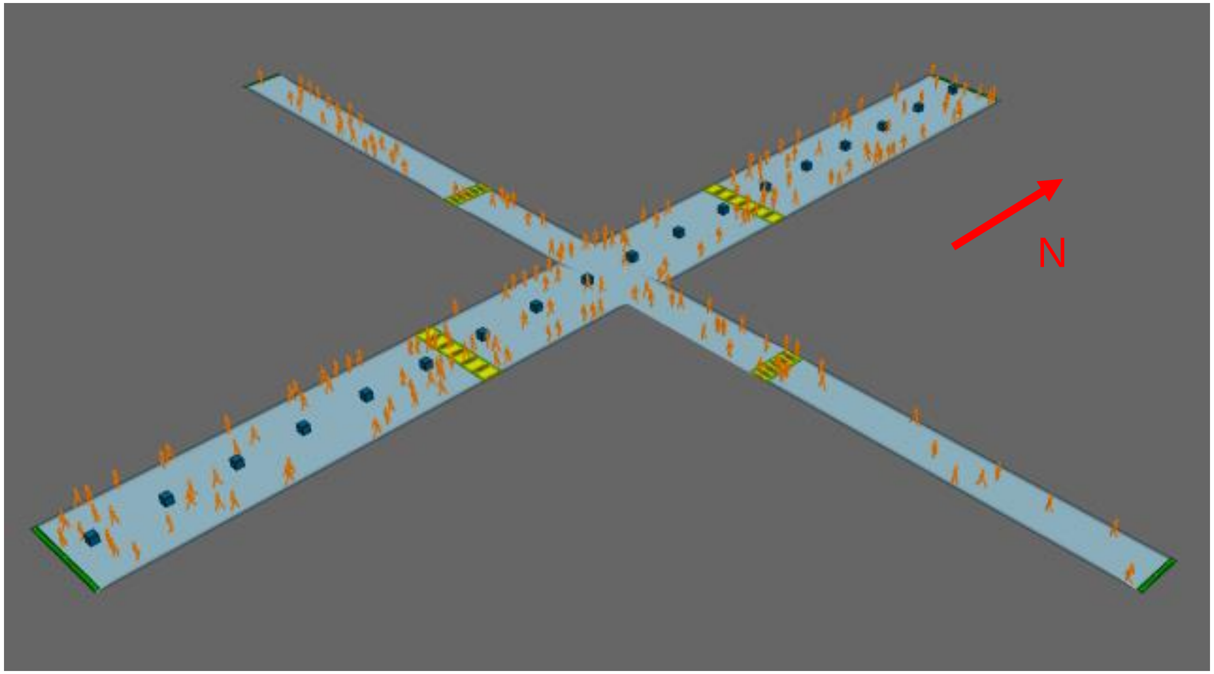
Average Values

Simulation Model Development

- Input: Pedestrian Flows

PEDESTRIAN FLOW LEVELS

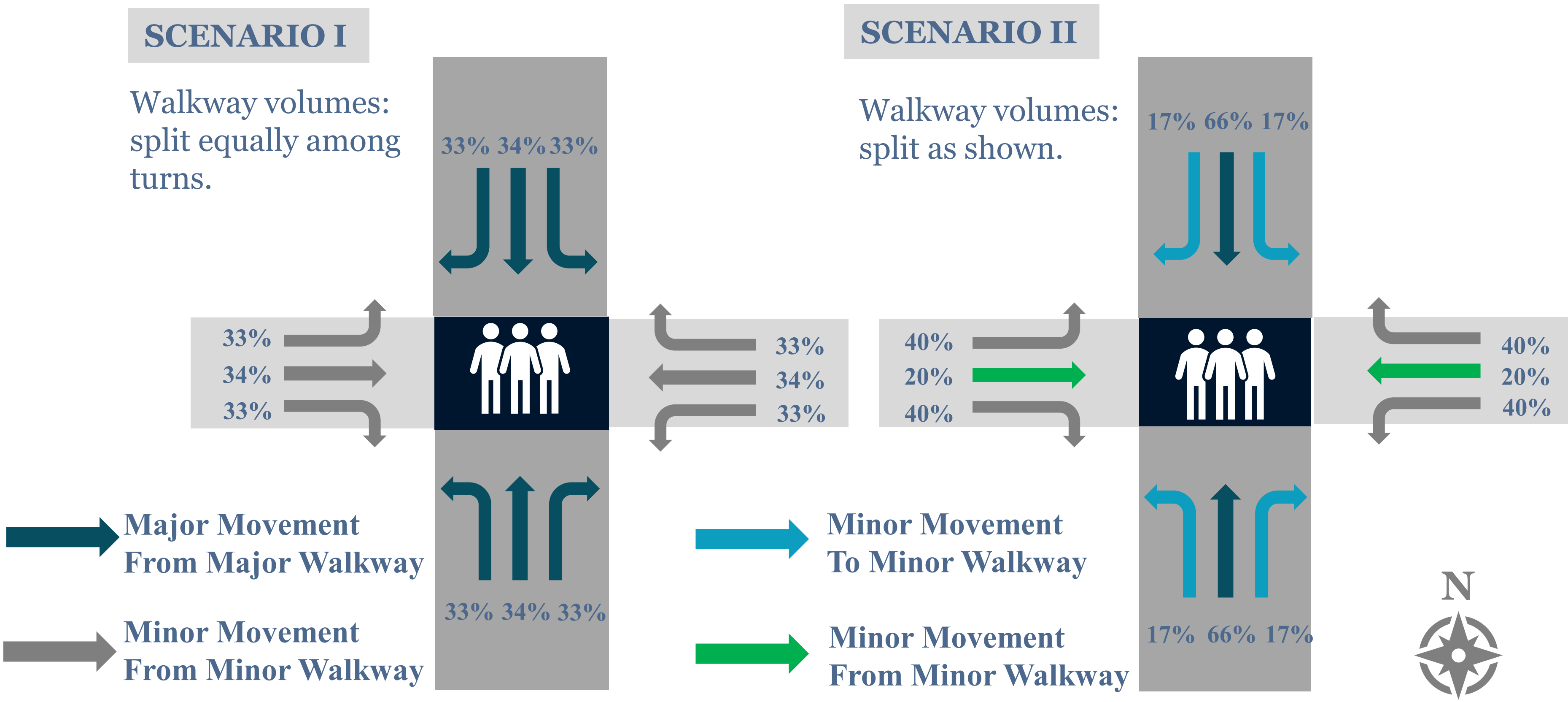
0	1200
300	1500
600	1800
900	2100



- Intersection volume is split at a 2:1 ratio between walkways.
- Turning movements are further split based on 2 pedestrian flow scenarios.

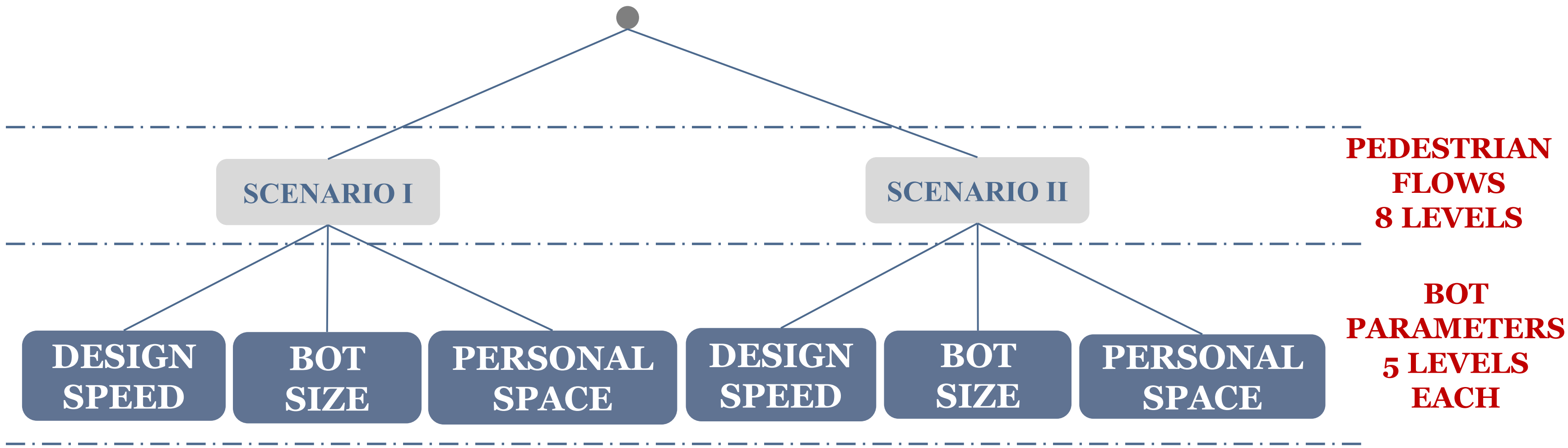
Simulation Model Development

- Input: Pedestrian Flows



Simulation Model Development

- Scenarios



- The sensitivity analysis is conducted per parameter at a one-at-a-time approach, with the other two parameters fixed at their average values.
- The total number of scenarios is 240 (2 x 8 x 5 x 3).

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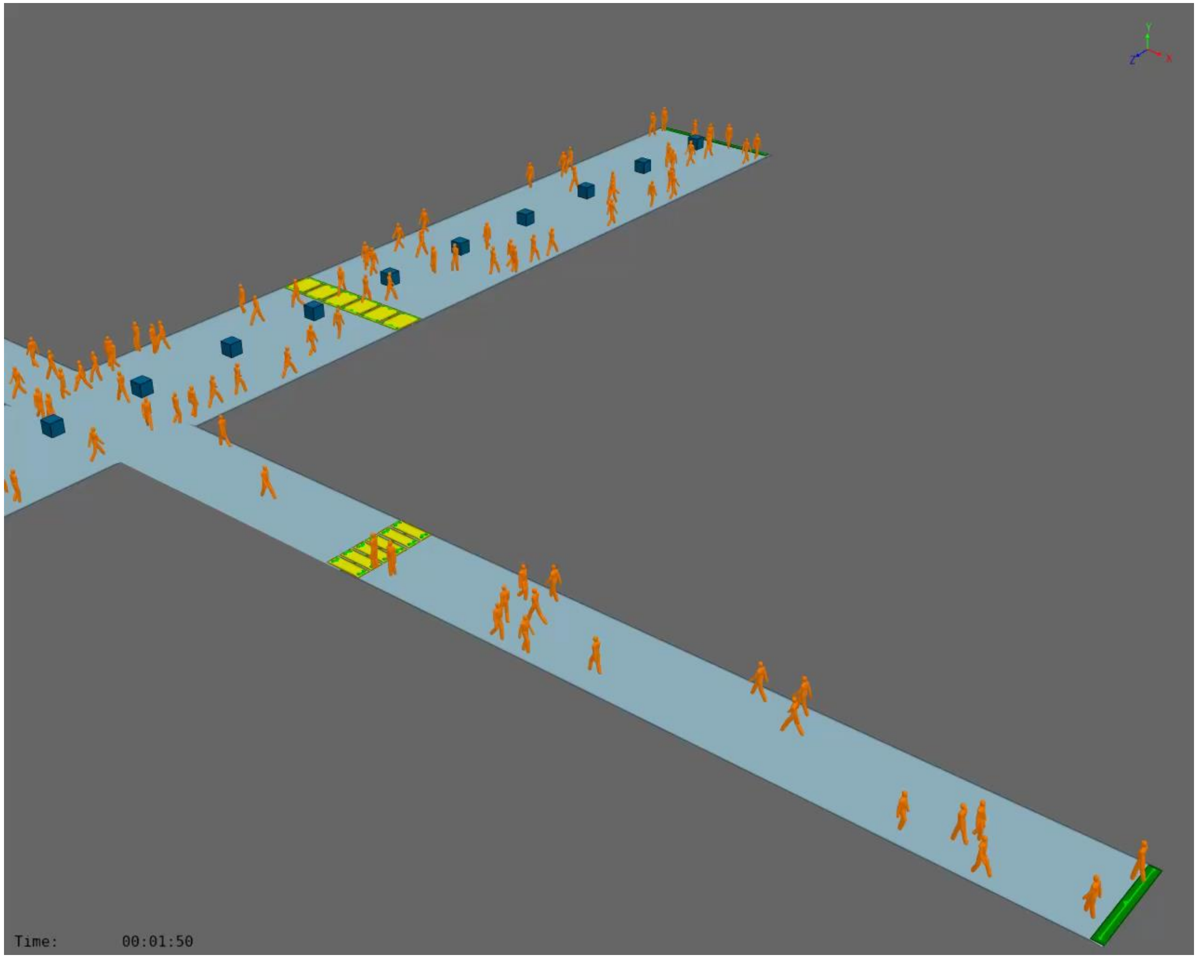
Simulation Model Development

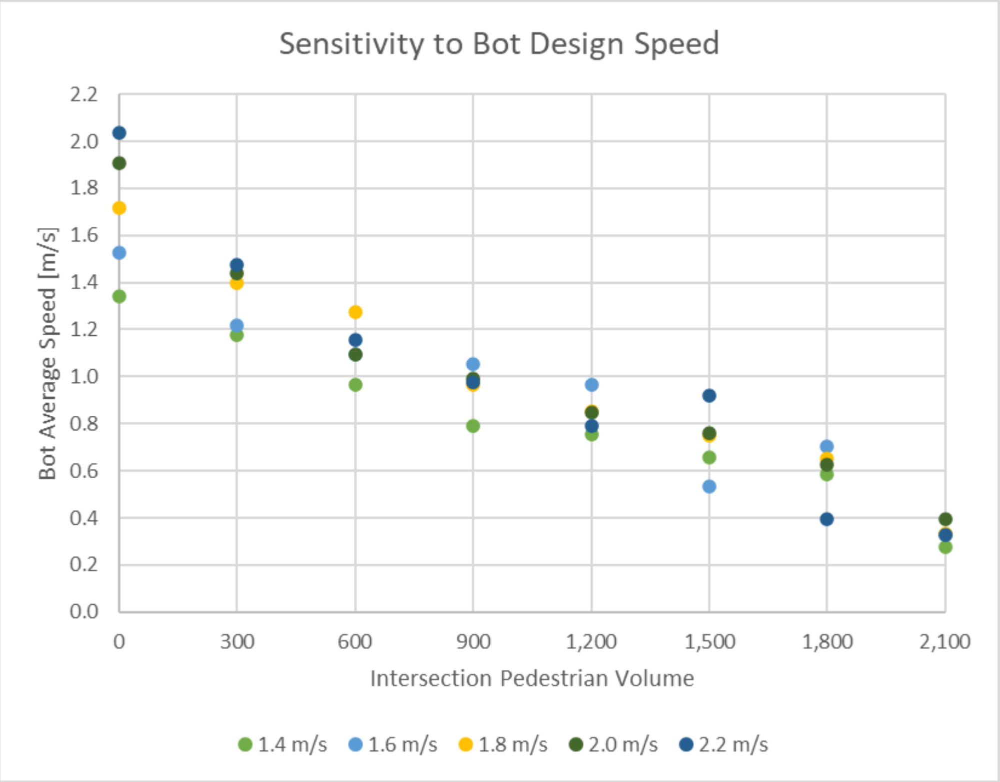


Simulation Results

Simulation Results

Scenario I: Design Speed

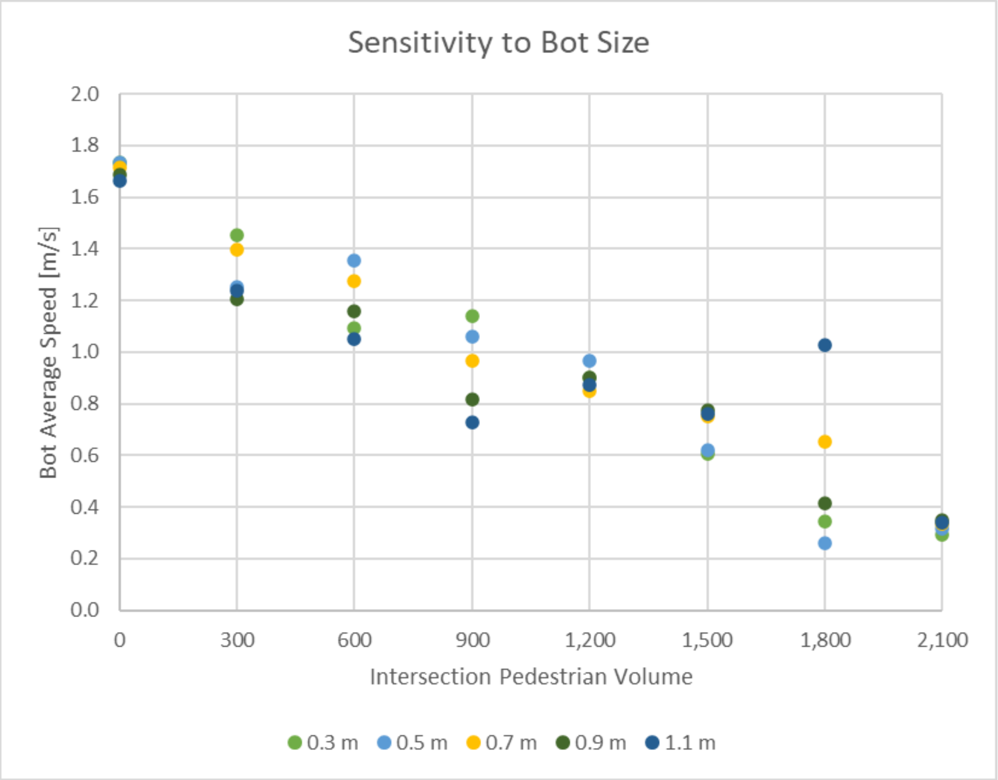
- Generally, the greater the design speed, the more difficult it becomes to attain it.
- Given a certain design speed, the bot's average speed drops as the intersection volume increases.
- The bot's average speed increases as its design speed increases at intersection volumes not more than 900.
- The bot's average speed does not follow a particular trend for higher intersection volumes (> 1,200).
- The bot's size and space are fixed at 0.7m and 0.4m, respectively.



Simulation Results

Scenario I: Bot Size

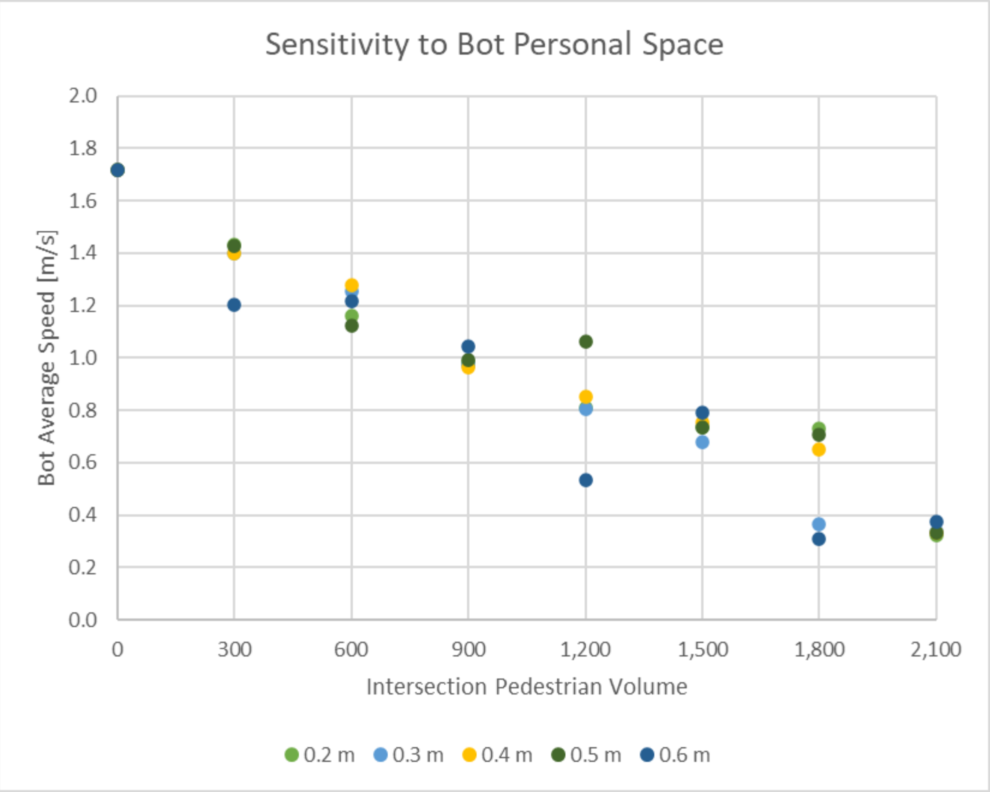
- The bot's average speed decreases significantly as congestion increases regardless of its size.
- Larger bots are generally slower where intersection volume does not exceed 900 pedestrians.
- For intersection volumes of 1,200 or greater, the bot's speed does not seem to follow a specific trend. Except for 1,800, the average speed varies only slightly regardless of size.
- The bot's design speed and space are fixed at 1.8m/s and 0.4m, respectively.



Simulation Results

Scenario I: Personal Space

- Greater intersection volumes hinder the mobility of the bot regardless of its space requirement.
- Except for a few outliers, the space requirement does not have a clear impact on the bot's average speed.
- From observing the simulation runs, it seems that even the smallest space requirement at lower intersection volumes is not easy to maintain.
- The bot's design speed and size are fixed at 1.8m/s and 0.7m, respectively.



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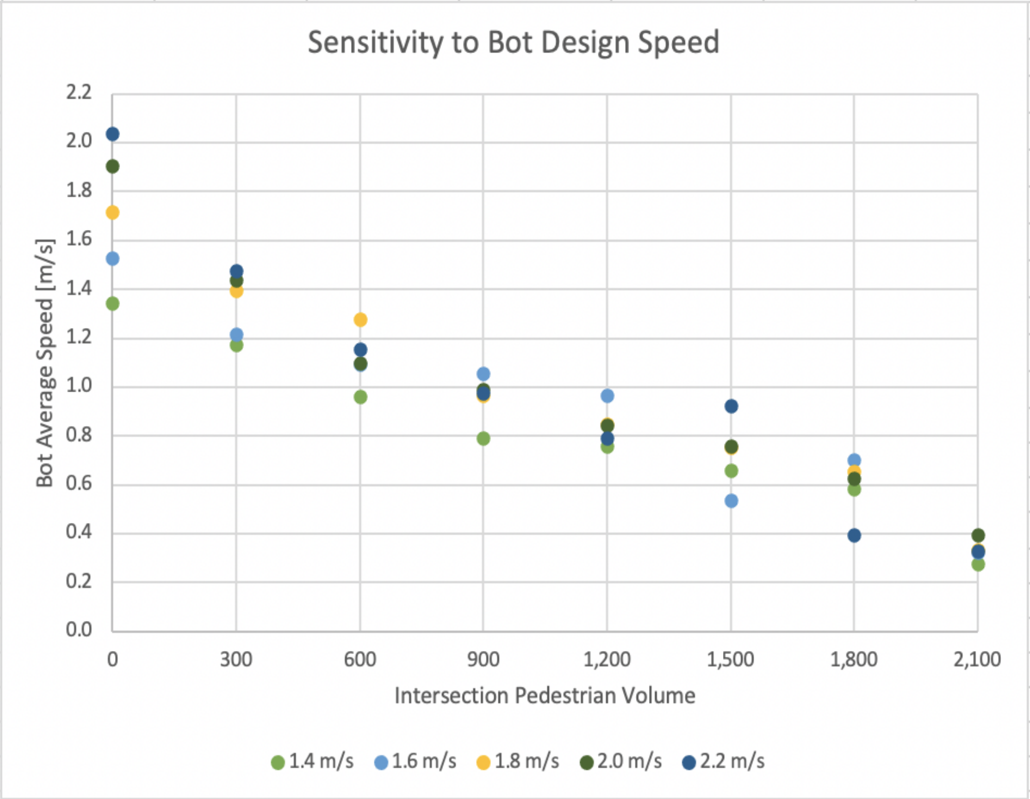
Simulation Results

Scenario II: Design Speed

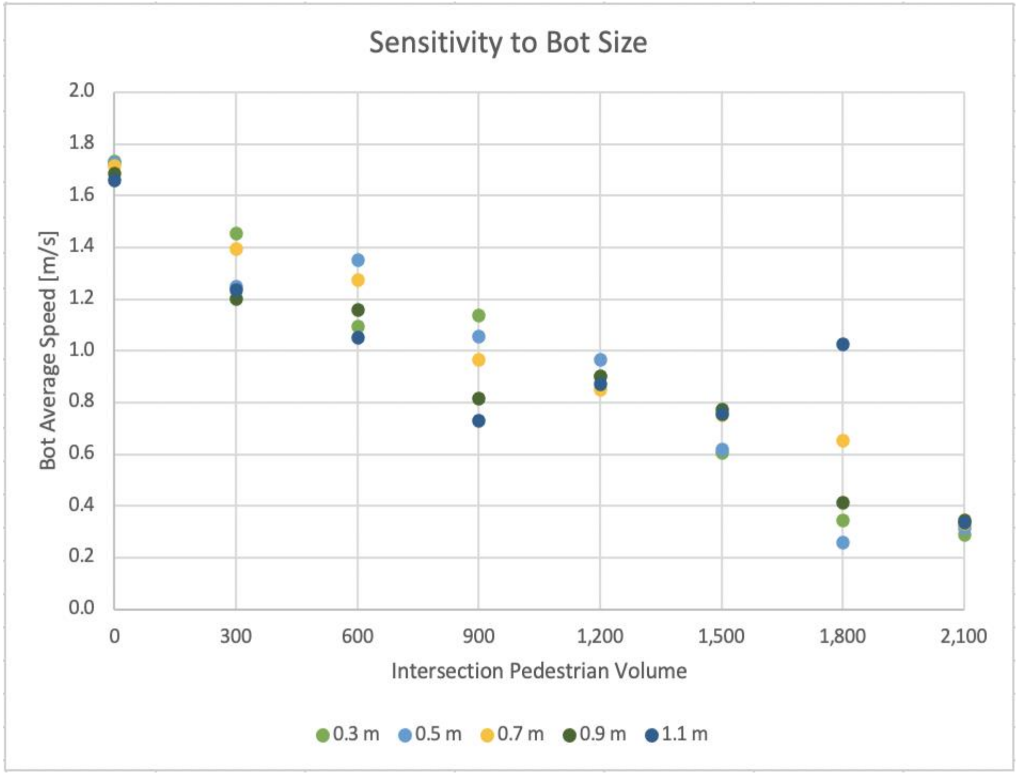
- The greater the design speed, the less attainable it becomes.
- Regardless of the design speed, the bot's average speed is decreased as the crowded density increases.
- When the volume is below 1500 and above 1800, the average speed increases as the design speed increases.
- The bot's average speed does not follow a particular trend when the intersection volumes is between 1500 and 1800.
- The bot's size and space are fixed at 0.7m and 0.4m, respectively.



Simulation Results

Scenario II: Bot Size

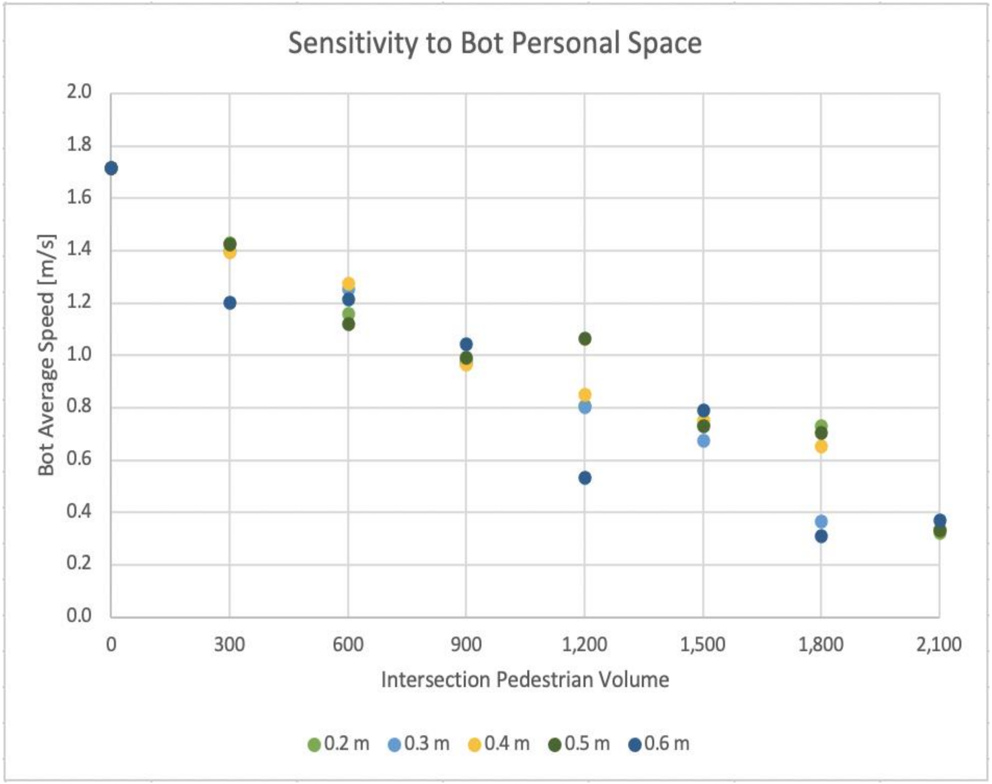
- Regardless of the bot size, the bot's average speed is decreased as the crowded density increases.
- At lower density regimes (300, 600), the average speed drops as the bot size increases
- When intersection volumes above 900, the average speed increases as the bot size increases from 0.3m to 0.7m, but decreases as the size further increases
- The bot's design speed and space are fixed at 1.8m/s and 0.4m, respectively.



Simulation Results

Scenario II: Personal Space

- Given a fixed personal space value, there is a negative correlation between average speed and pedestrian density.
- For a certain crowd level, the space requirement does not have a clear impact on the bot's average speed.
- Bot's performance is governed by random variation in the model.
- The bot's design speed and size are fixed at 1.8m/s and 0.7m, respectively.



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Project Limitation & Future Research

Project Limitation & Future Research

Limitations

- Lack of data
  - Pedestrian Counts (Volume & Direction)
  - Pedestrian Profile
- Uncertainty:
  - Congestion & Randomness
  - Bot's path

Further Improvements

- Path-Based Tests
- Different Effectiveness Metrics
  - Number of times the bot freezes
  - Delay Time
  - Go-to success rate
  - ……

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Questions

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