JENSEN HUGHES

RAIL CAR OPERATIONAL ENVIRONMENT EVACUATION STUDY
Fire and Evacuation Modeling Technical Conference 2024

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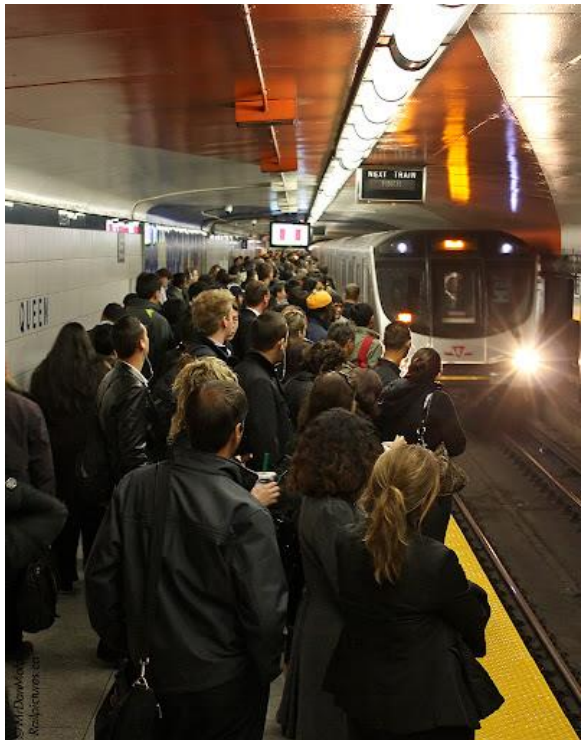
Outline

- Motivation
- Literature Review
- Egress Model Development
- Modeled Scenarios
- Results
- Conclusions and Recommendations

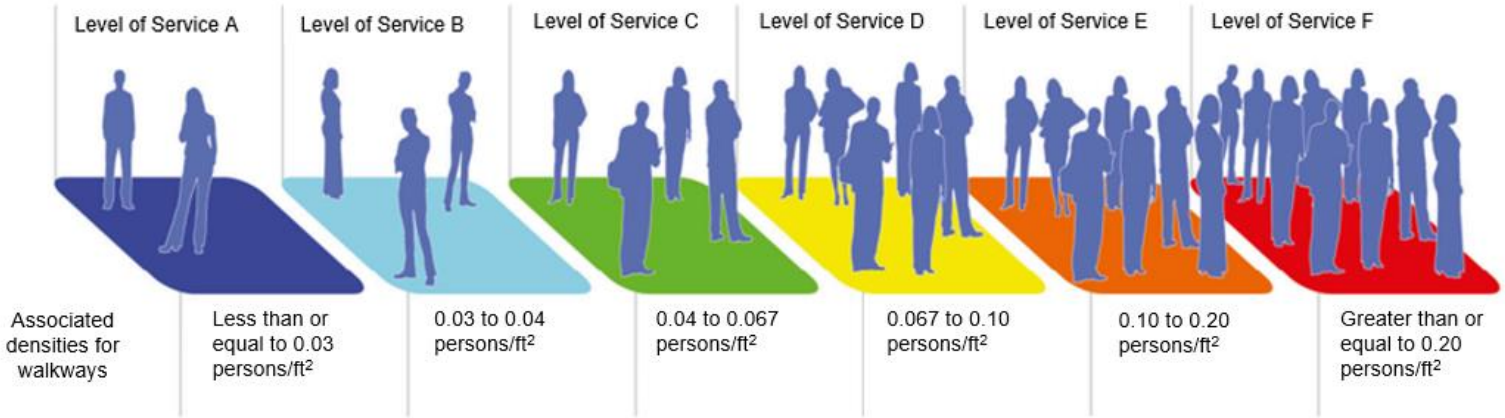
Motivation

- Congestion within the operational environment
- Understand egress from rail car in a tunnel and in a station using Pathfinder



Literature Review

- John J. Fruin's Pedestrian Planning and Design, 1971
  - Level of service concept
- SFPE Handbook of Fire Protection Engineering, Chapter 59, Employing the Hydraulic Model in Assessing Emergency Movement
  - Unimpeded walking speed when density < 0.05 persons/ft^2
    - Speed based on level of service A – C
- NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems
    - Speed based on level of service E and F



Model Development Background

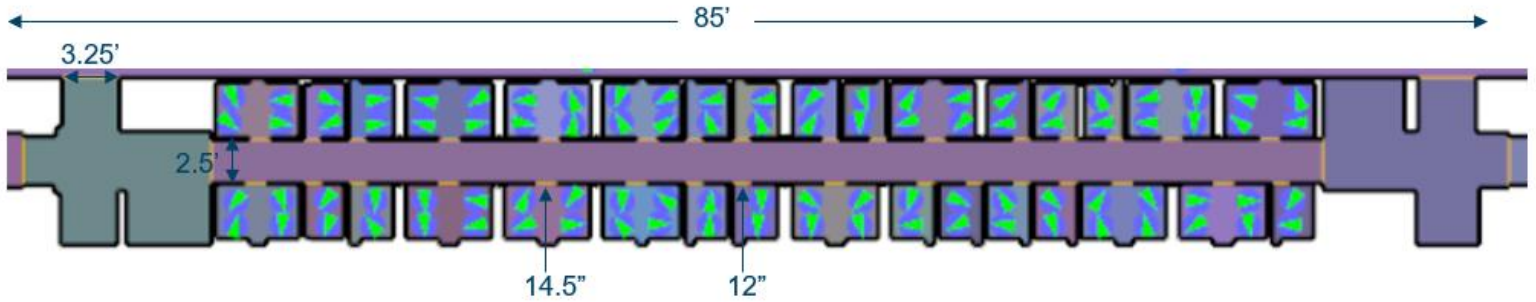
- Pathfinder Version 2023.2.0816
- Monte Carlo Method
  - Pathfinder is a deterministic model
  - Vary a parameter to see impact of stochastic characteristics and decision making
- Steering Mode
  - Collision handling
  - Occupant interaction
  - Localized density effects

Run 1

Run 2

Rail Car Geometry

- Six cars per train
- Rooms to represent seat location
- 92 occupants per car
- 552 total occupants per train
- Reduce diameter to move through narrow geometry (11-inches) when capturing narrow aisles

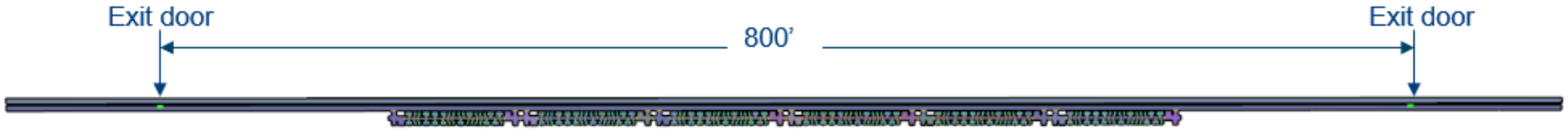


Single car

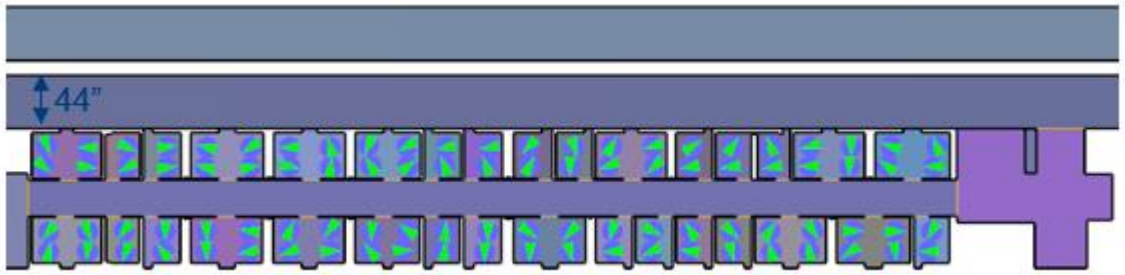
Six car length rail car

Tunnel Geometry

- Based on NFPA 130 requirements
- Contains one train
- Total of 552 occupants
- 800 ft between exits
- Platform is 44 inches



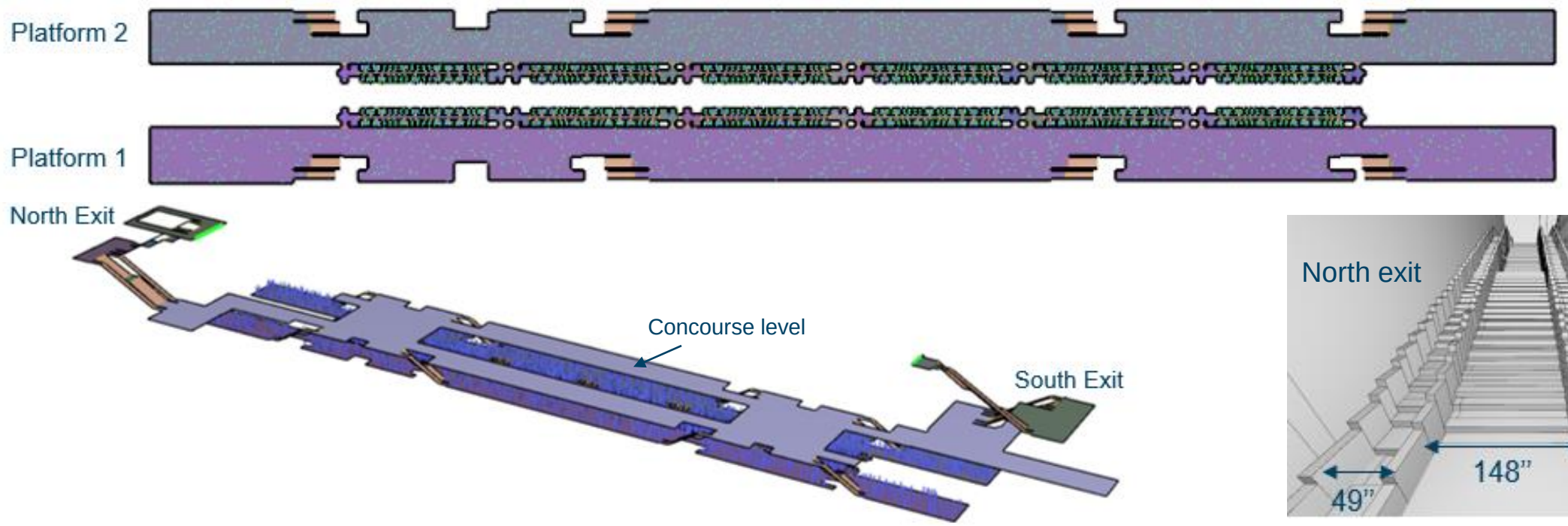
Total tunnel



Platform width

Station Geometry

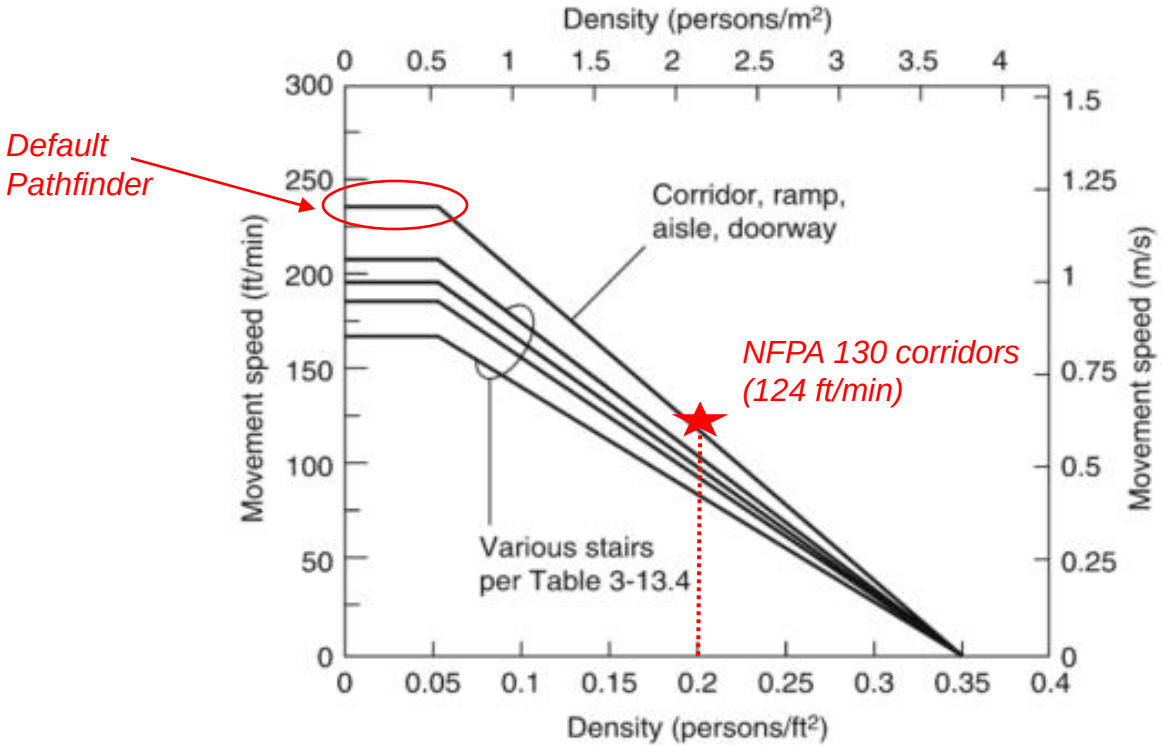
- Based on NFPA 130 requirements
- 2 trains in station
- 8 stair/escalator sets from platforms to concourse
- Consider maximum occupant loading
  - 552 occupants waiting on each platform
  - Additional 552 occupants on platform 2 to account for missed headway due to disruptions and delays (§5.3.2.5 of NFPA 130)
  - Total of 2,760 occupants



	Scenario	Maximum Walking Speed	Diameter	Height	Wall boundary layer	# of runs
Base Scenario	Pathfinder Default (D)	3.9 ft/s	17.9 in	6 ft	0.49 ft	25
Walking Speed	Fruin Distribution	**Normal Distribution [1.9-5.9 ft/s] μ: 3.39 ft/s σ: 0.65 ft/s**	17.9 in	6 ft	0.49 ft	25
	Simplified Distribution (SD)	**F: 3.9 ft/s (50%) M: 4.5 ft/s (50%)**	17.9 in	6 ft	0.49 ft	25
	NFPA 130 Default	**2.06 ft/s**	17.9 in	6 ft	0.49 ft	25
Additional Parameters	Diameter (D)	3.9 ft/s	**17.9 in – 24 in**	6 ft	0.49 ft	25
	Height (D)	3.9 ft/s	17.9 in	**5 ft 3 in – 6 ft**	0.49 ft	25
	Boundary Layer (D)	3.9 ft/s	17.9 in	6 ft	**0 – 0.66 ft**	25
	Diameter (SD)	F: 3.9 ft/s(50%) M: 4.5 ft/s (50%)	**17.9 in – 24 in**	6 ft	0.49 ft	25
	Height (SD)	F: 3.9 ft/s(50%) M: 4.5 ft/s (50%)	17.9 in	**5 ft 3 in – 6 ft**	0.49 ft	25
	Boundary Layer (SD)	F: 3.9 ft/s(50%) M: 4.5 ft/s (50%)	17.9 in	6 ft	**0 - 0.66 ft**	25
All	All Parameters	**Normal Distribution [1.9-5.9 ft/s] μ: 3.39 ft/s σ: 0.65 ft/s**	**17.9 in – 24 in**	**5 ft 3 in – 6 ft**	**0 - 0.66 ft**	25

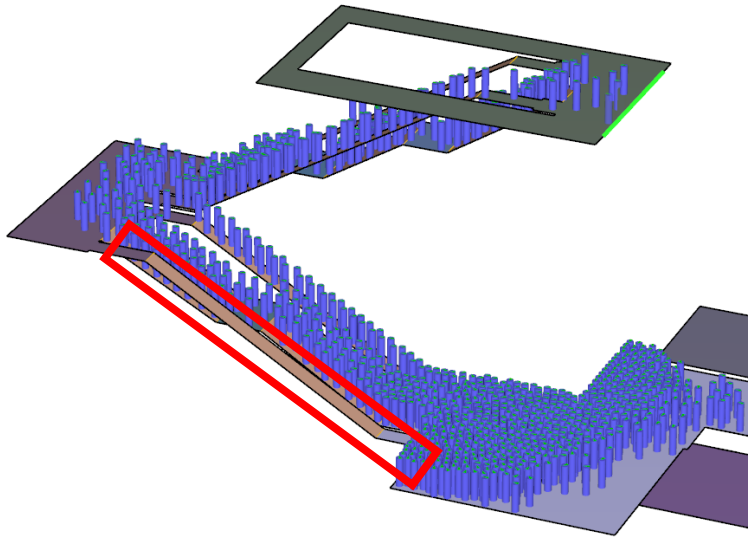
Egress Model Results

- Average egress time is 117% greater when using NFPA 130 compared to Pathfinder default
  - Speeds accounts for high density (Level of service E or F)
  - NFPA 130 walking speed (2.06 ft/s) yields unrealistic results and is not recommended for use in Pathfinder

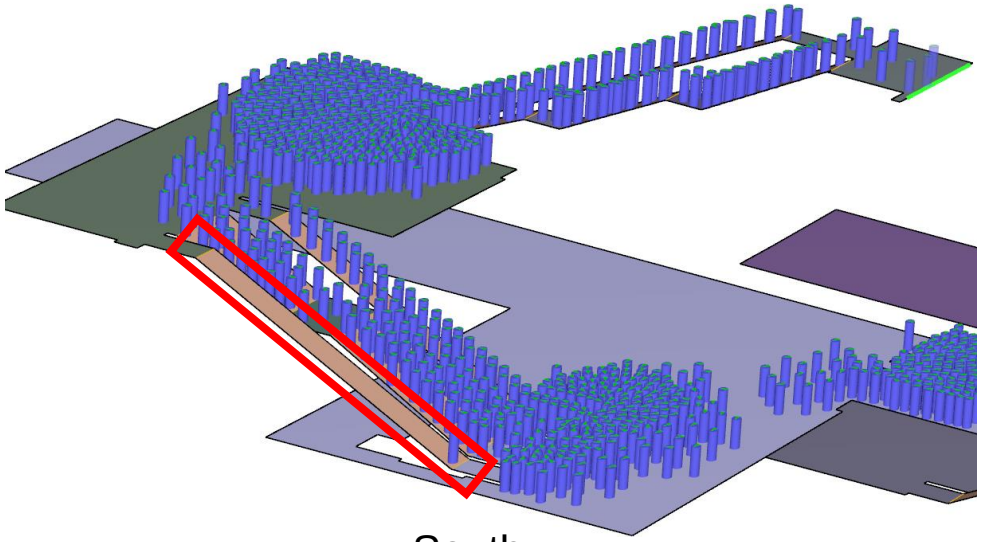


Station Specific Input

- Assume escalators shut down upon fire alarm activation
  - Treat escalators as stairs in Pathfinder
- Occupants do not equally distribute between means of egress
- Consider parameters that factor into cost (function of distance and time)



North

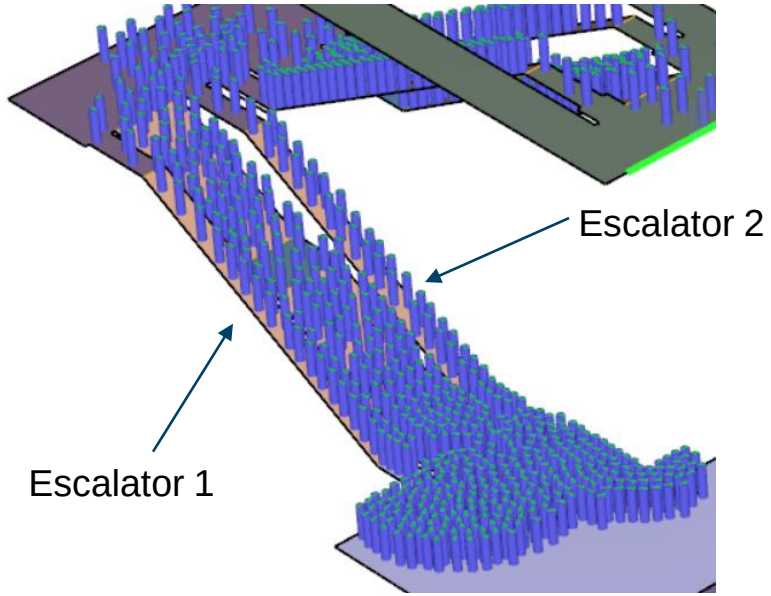


South

Station Specific Input

- Current Room Distance Penalty
  - Basic implementation of fatigue
  - Default 35 m (114.83 ft)
  - Recommend to change to 0
  - Eliminates decision making as a function of concourse length
- Equal distribution of occupants on escalator

	North Escalator			South Escalator			
Parameter	Distribution 1 (%)	Distribution 2 (%)	Total usage (persons)	Distribution 1 (%)	Distribution 2 (%)	Total usage (persons)	Total evacuation time (s)
Default	9	91	358	30	70	524	1197.3
Room Distance Penalty = 0	47	53	543	47	53	568	1131.8



Variation in Evacuation Time

Scenario	Environment	Minimum Egress Time (sec)	Average Egress Time (sec)	Maximum Egress Time (sec)	[A] % Variation between min and max egress time	[B] % Variation relative to default value
Walking Speeds						
Pathfinder Default (D)	Tunnel	334	359	392	17.0	0
	Station	892	906	918	3.0	0
Fruin Distribution	Tunnel	345	366	398	15.0	1.9
	Station	1125	1145	1165	3.5	26.4
Simplified Distribution (SD)	Tunnel	303	332	367	21.0	-7.5
	Station	855	864	877	2.6	-4.6
Additional Parameters						
Diameter (D|SD)	Tunnel	341 | 325	348 | 331	355 | 345	4.1 | 6.1	-3.1 | -0.3
	Station	968 | 917	983 | 926	999 | 940	3.2 | 2.5	8.5 | 7.2
Height (D|SD)	Tunnel	326 | 310	358 | 333	390 | 357	19.6 | 15.2	-0.27 | 0.3
	Station	898 | 853	910 | 863	922 | 876	2.6 | 2.8	0.49 | -0.09
Boundary Layer (D|SD)	Tunnel	305 | 285	346 | 315	444 | 356	46 | 16.7	-3.6 | -5.1
	Station	853 | 805	864 | 822	884 | 832	3.6 | 3.4	-4.5 | -4.9
All	Tunnel	349	367	402	15.0	2.1
	Station	977	995	1019	4.2	9.8

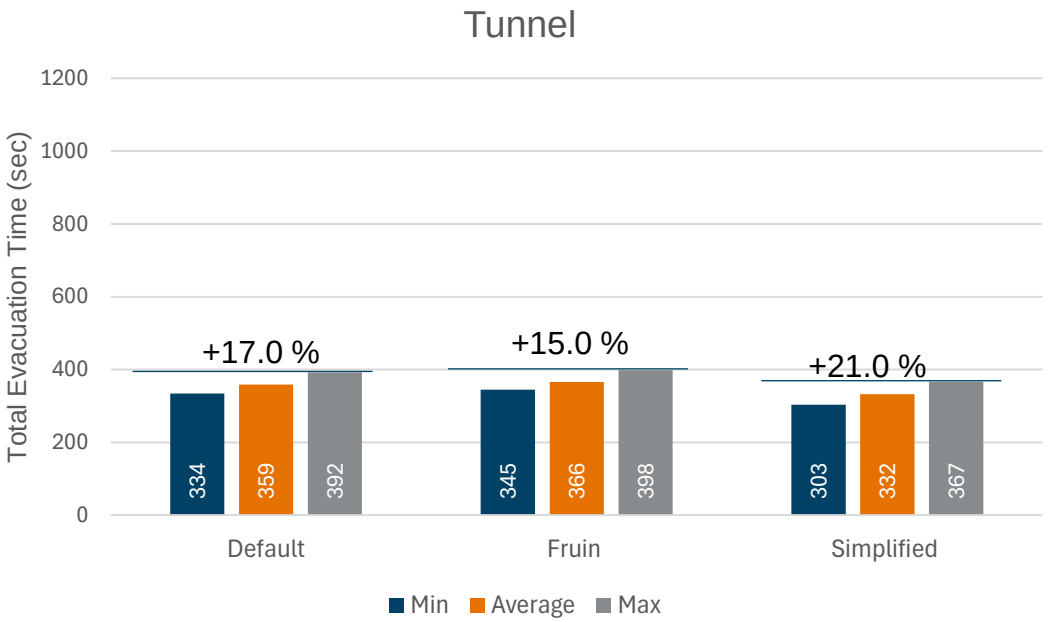
[A] $\% = \frac{t_{max} - t_{min}}{t_{min}} * 100$

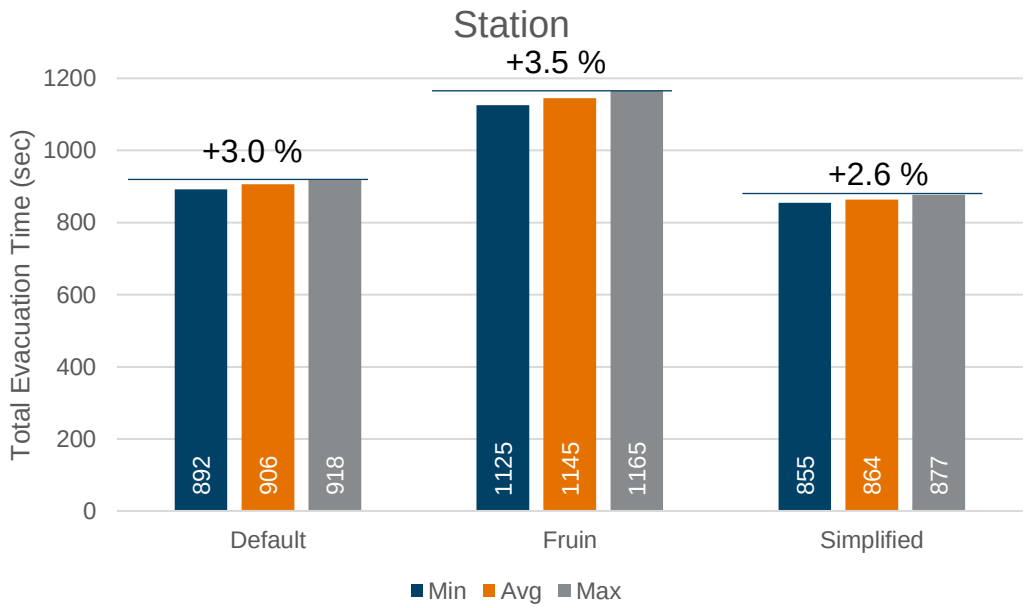
[B] $\%D = \frac{t_{average,X\ scenario} - t_{average,D}}{t_{average,D}} * 100$

$\%SD = \frac{t_{average,X\ scenario} - t_{average,SD}}{t_{average,SD}} * 100$

Individual Variation – Walking Speed

- 17% variation in total egress time with the default Pathfinder inputs for tunnel geometry
- 3.0% expected variation for the station geometry
- Variation shows the importance of performing a sensitivity analysis
- Similar conclusion for two operational scenarios utilizing Fruin and Simplified distributions

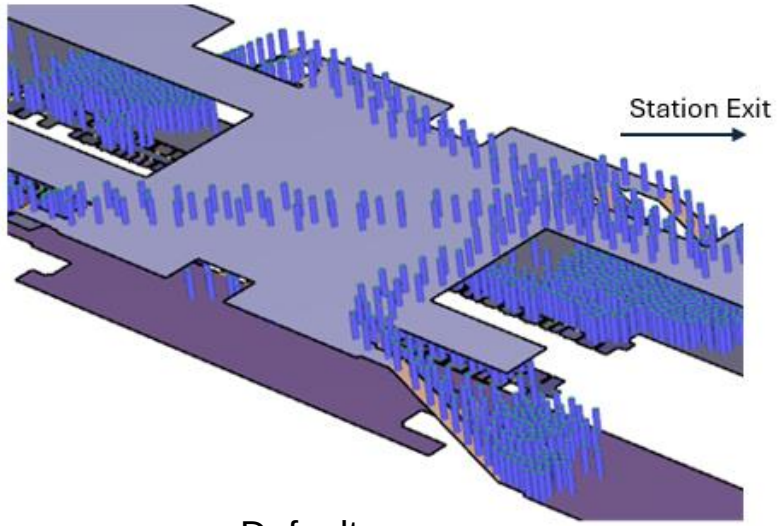




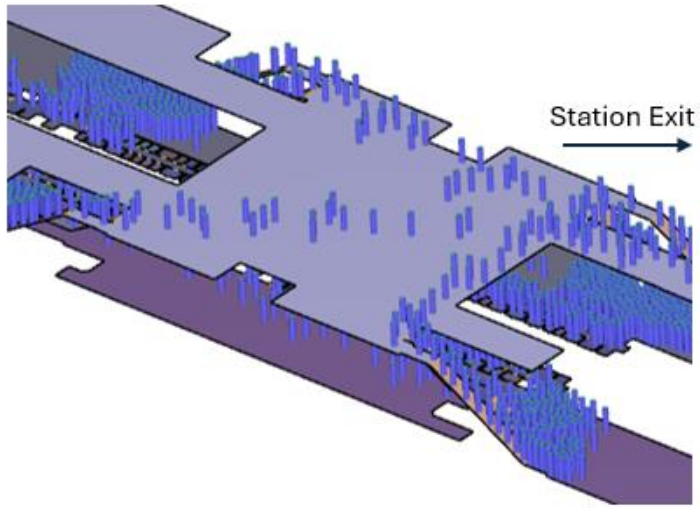
Default vs Scenario Average – Walking Speed

- Total evacuation time is driven by slowest person in the group
  - 50% of occupants are moving at speeds less than 3.93 ft/s for Fruin
  - Average walking speed is 4.2 ft/s for the simplified distribution
- Minimum speed from Fruin impacts the station more
- Larger variation in Fruin walking speed distribution for station compared to tunnel

Scenario	Tunnel Variation (%)	Station Variation (%)
Default	0	0
Fruin	+ 1.9	+ 26.4
Simplified	- 7.5	- 4.6

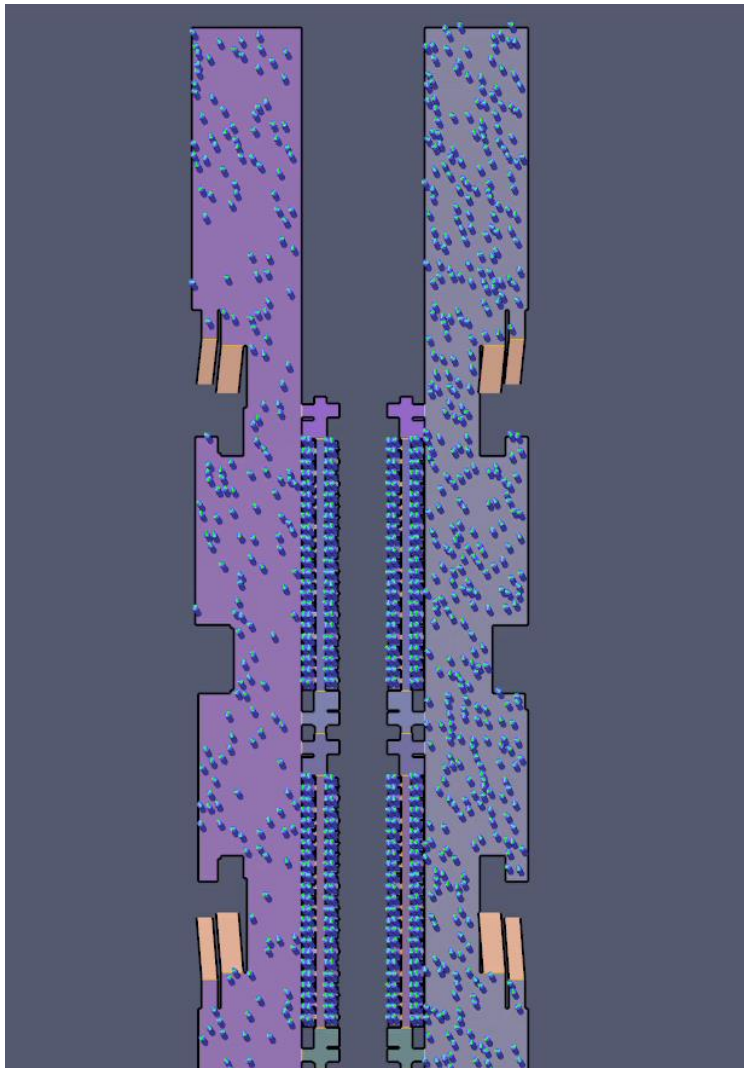


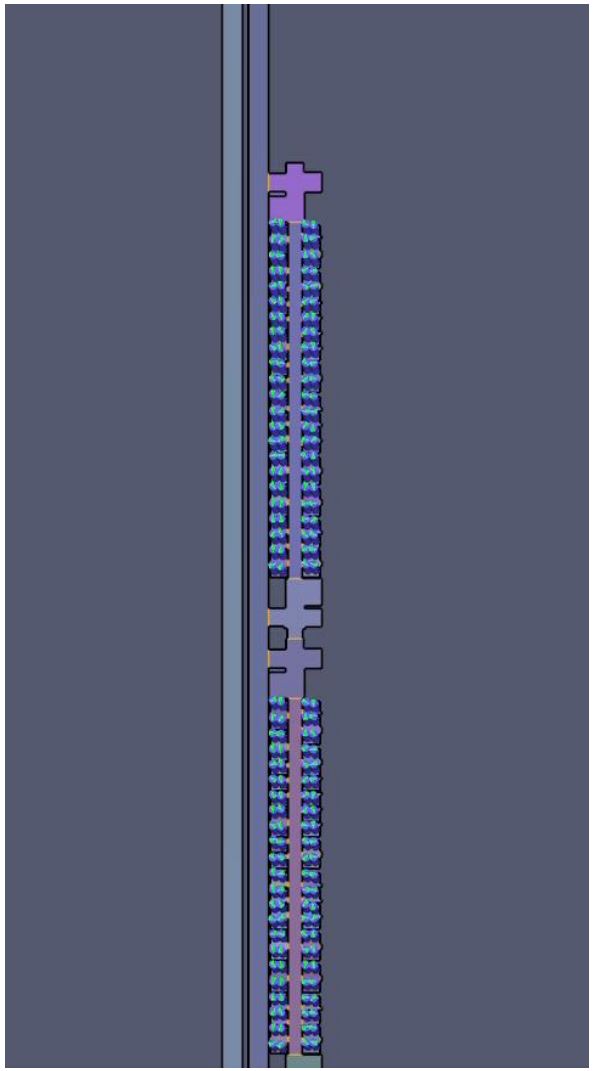
Default



Fruin Distribution

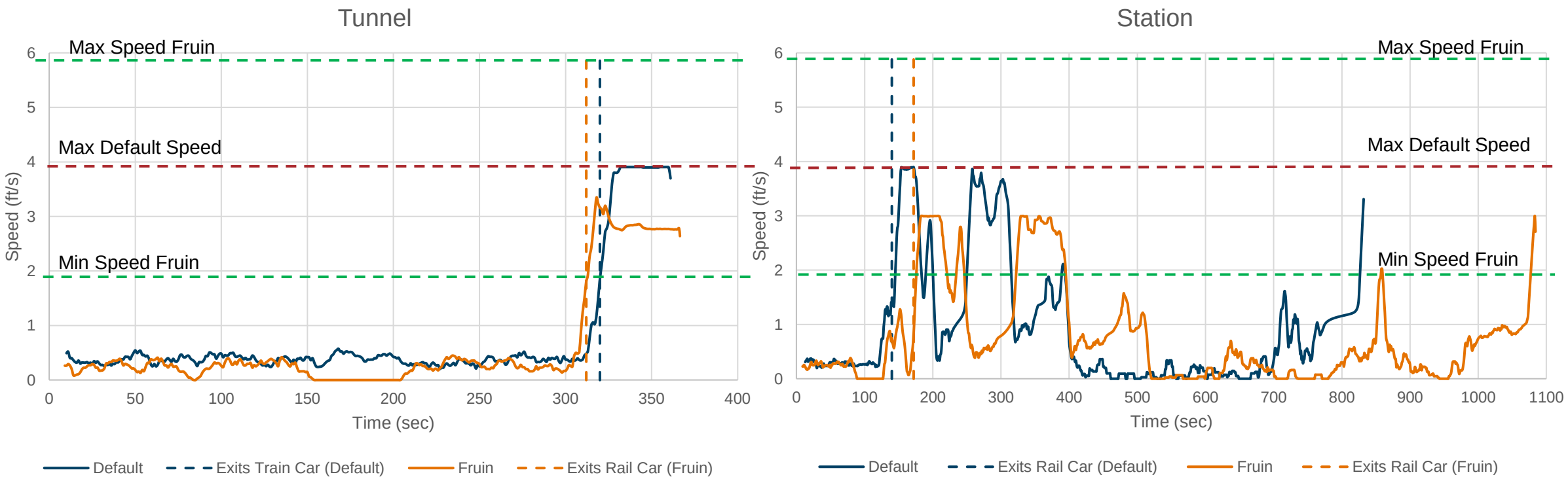
Station vs. Tunnel – Fruin Distribution





Default vs Fruin Comparison for Station vs Tunnel

- Impact of different occupant speeds are not seen until the occupants are out of the rail car
  - Tunnel is driven by the congestion in the rail car
  - Variation in station is driven by egress elements
- Greater deviations between Default and Fruin averages in the station because congestion in rail car isn't the primary impact



Single Parameters + All Parameters

- Single Parameters
  - Average diameter of occupant is increased
    - Impacts collision handling and increases the overall evacuation time
  - 75% of occupants have a smaller boundary layer
    - Increases walking space and allows for more efficient egress
    - Decreases total egress time
  - Height does not impact occupant egress in the environments that were studied
  - Similar conclusions can be drawn for diameter, boundary layer and height when using simplified distribution
- All Parameters
  - Similar variation for tunnel
  - Reduced magnitude of variation seen with Fruin distribution in station

Scenario	Environment	% Variation relative to default value
Diameter (D|SD)	Tunnel	-3.1 | -0.3
	Station	8.5 | 7.2
Height (D|SD)	Tunnel	-0.27 | 0.3
	Station	0.49 | -0.09
Boundary Layer (D|SD)	Tunnel	-3.6 | -5.1
	Station	-4.5 | -4.9
All	Tunnel	2.1
	Station	9.8

Preliminary Conclusions and Recommendations

- Results only apply to distinct operational environments
- Inputs
  - Recommend to set current room distance penalty = 0
  - Do not recommend to use NFPA 130 walking speed of 2.06 ft/s
- Sensitivity analysis is important
  - Utilize Monte Carlo Method
- Differences in egress times in operational environments attributed to geometry
  - Occupants cannot reach unimpeded speeds until leaving the rail car
  - Congestion effects in rail car propagate in tunnel
  - Impact of means of egress and queuing in the station results in stochastic walking speeds

Thank You!

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