Authenticating Crowd Models for Stadium Design

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Fire and Evacuation Modeling Technical Conference

Thursday September 10, 2020

Introduction and Motivation

Why stadium design?

- Tens of thousands of people
- Mass onset of ingress and egress
- Stadium design is growing in capacity


TSN 1200
TSN 1200
TD PLACE
Fury FC vs
U
V

Introduction and Motivation

Crowd Simulation Tools

- Tool for practitioners in the validation and verification process of designing a safe usable space
- Used to model and assess pedestrian dynamics
  - Regular circulation
  - Ingress
  - Egress
  - Full and partial evacuations
  - Emergency situations

Introduction and Motivation

Crowd Simulation Tools

- Social force model
- Industry standard metrics
  - (i.e. Fruin Distribution)
  - Defines speed based on density of the crowd
  - Produced in 1971
- Project-specific data input
  - Lack diversity in movement representation
  - Relatively unavailable

Research Questions

- How accurate are current crowd modelling methods and computational modelling tools for stadium design?
- How can we increase reliability of their functions and outputs for practitioner use?

Stadium

- Tennis stadium located in York University, Toronto, Canada
- Built in 2004 (16yo at time of study)
- Capacity of 12,500
- Studied the events at an annual 7-day tennis tournament

Objectives

- Configure comparative crowd simulation models to analyse the impact of authenticating models with project-specific data versus using industry standard metrics
- Analyse the crowd to establish set of agent profiles and demographic distributions

- Profile parameters
  - Speed
  - Radius
- Demographic distribution
  - Proportion of different profiles prevalent in the crowd

Agent Profile	Speed (m/s) Min	Max	Mean	SD	Radius(m)
Default Profile					
Fruin Commuter	0.65	2.05	**1.35**	0.25	**0.25**
Able-Bodied Profiles					
Child	0.34	2.35	**1.45**	0.75	**0.15**
Young Adult	0.71	2.75	**1.61**	0.58	**0.25**
Adult	0.67	2.85	**1.64**	0.59	**0.25**
Senior	0.40	2.52	**1.32**	0.48	**0.25**
Mobility-Limiting Impairment Profiles					
Cane	0.21	1.68	**0.91**	0.28	**0.35**
Crutches	0.35	1.22	**0.68**	0.34	**0.35**
Person Req. Assist	0.16	2.02	**0.98**	0.41	**0.40**
Walking Stick	0.14	1.68	**1.01**	0.41	**0.35**
Overweight and Obese Profiles					
Adult & Young Adult	0.60	2.42	**1.30**	0.54	**0.35**
Senior	0.46	2.21	**1.21**	0.63	**0.35**
Other Mobility-Limiting Profiles					
Oversize Luggage	0.08	2.72	**1.50**	0.55	**0.40**

Profile Parameters

- Input speed and radius details

Agent Profile	Speed (m/s) Min	Max	Mean	SD	Radius(m)
Default Profile					
Fruin Commuter	0.65	2.05	**1.35**	0.25	**0.25**
Able-Bodied Profiles					
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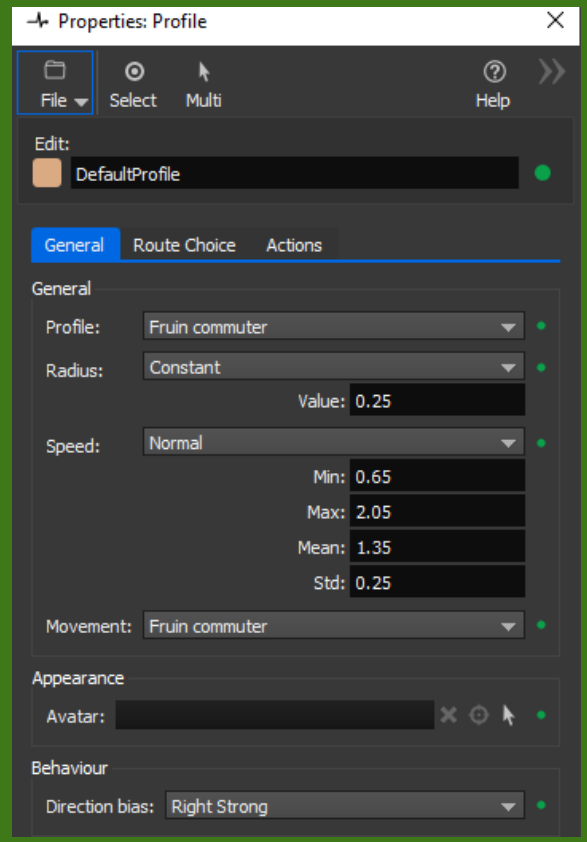
Other Mobility-Limiting Profiles					
Oversize Luggage	0.08	2.72	**1.50**	0.55	**0.40**

Profile Parameters

- Industry standard metric
- Default profile from the software



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Oversize Luggage	0.08	2.72	**1.50**	0.55	**0.40**

Profile Parameters

- Project-specific data
- Acquired from previous studies conducted at the stadium
- Developed for the SFPE foundation on Movement and Anthropometry report [1]

[1] J. Gales, J. M. Ferri, G. Harun, C. Jeanneret, and T. Young, “Anthropometric Data and Movement Speeds,” Society of Fire Protection Engineers, Toronto, 2020

Demographic Distribution

- Uses previously defined agent profiles
- Assigns proportions of each demographic
- Total population is 6250

	Model 1 (Default)		Model 2 (Average)		Model 3 (Observed)		Model 4 (Forecasted)	
Agent Profile	**Frequency**		**Frequency**		**Frequency**		**Frequency**	
Default Profiles								
Fruin Commuter	100%	6250	-	-	-	-	-	-
Total	100%	6250	0%	0	0%	0	0%	0
Able-Bodied Profiles								
Child	-	-	15%	938	15%	938	14%	875
Young Adult	-	-	25%	1563	15%	938	12%	750
Adult	-	-	35%	2188	25%	1563	11%	688
Senior	-	-	25%	1563	10%	625	3%	188
Total	0%	0	100%	6250	65%	4063	40%	2500
Mobility-Limiting Impairment Profiles								
Cane	-	-	-	-	0.06%	4	2.82%	176
Crutches	-	-	-	-	0.01%	1	0.47%	29
Req. Assist.	-	-	-	-	0.09%	6	4.19%	262
Walking Stick	-	-	-	-	0.03%	2	1.40%	87
Total	0%	0	0%	0	0.19%	12	8.87%	554
Overweight and Obese Profiles								
Adult	-	-	-	-	22.58%	1411	34.95%	2184
Senior	-	-	-	-	11.00%	688	14.95%	934
Total	0%	0	0%	0	33.58%	2099	49.90%	3119
Other Mobility-Limiting Profiles								
Oversize Luggage	-	-	-	-	1.23%	77	1.23%	77
Total	-	-	-	-	1.23%	77	1.23%	77
Combined Total	100%	6250	100%	6250	100%	6250	100%	6250

Note:

- All models represent standard egress scenarios
  - Low motivation principles
  - Not reflective of emergency evacuations
- Models are not for validation purposes
  - Configured to illustrate the increasing importance of including project specific data

	Model 1 (Default)		Model 2 (Average)		Model 3 (Observed)		Model 4 (Forecasted)	
Agent Profile	**Frequency**		**Frequency**		**Frequency**		**Frequency**	
Default Profiles								
Fruin Commuter	100%	6250	-	-	-	-	-	-
Total	100%	6250	0%	0	0%	0	0%	0
Able-Bodied Profiles								
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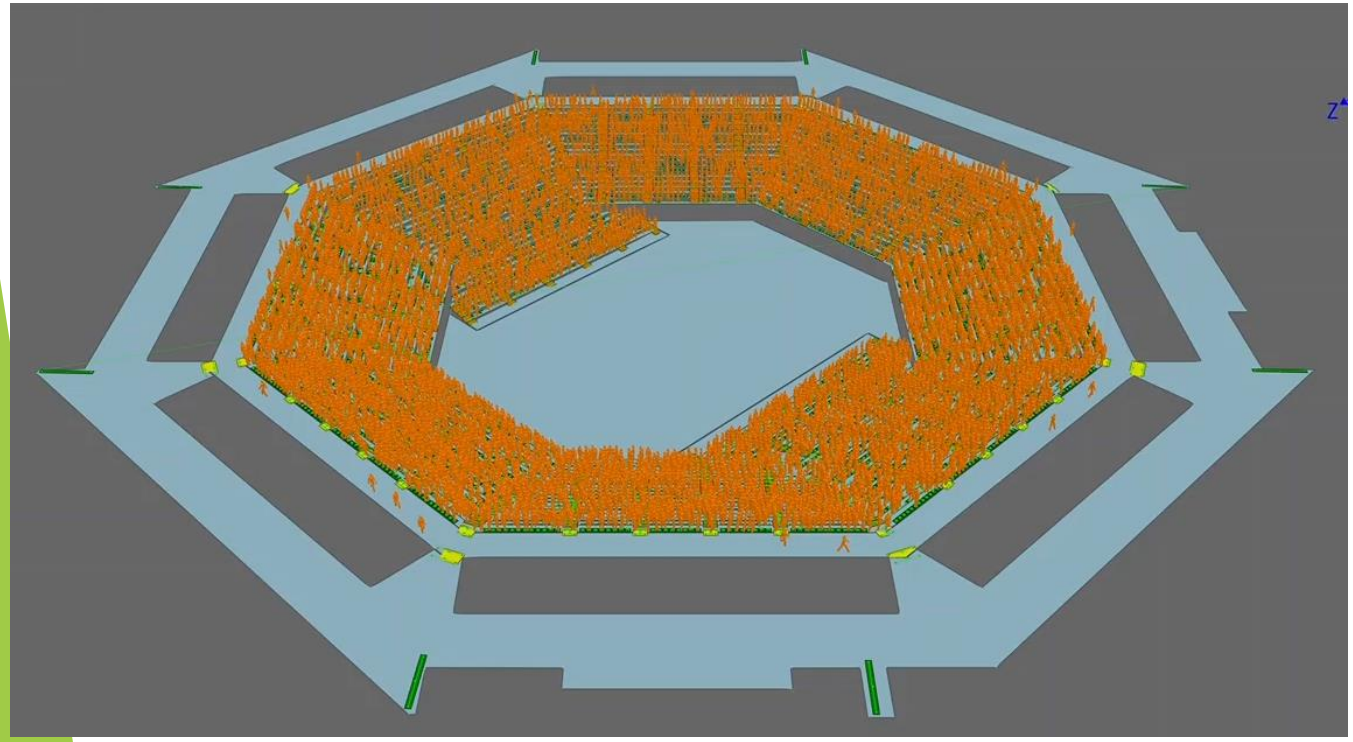
Total	-	-	-	-	1.23%	77	1.23%	77
Combined Total	100%	6250	100%	6250	100%	6250	100%	6250

Model 1
Current Default Parameters

- Does not include project-specific data
- Adopts only default parameters provided by the software



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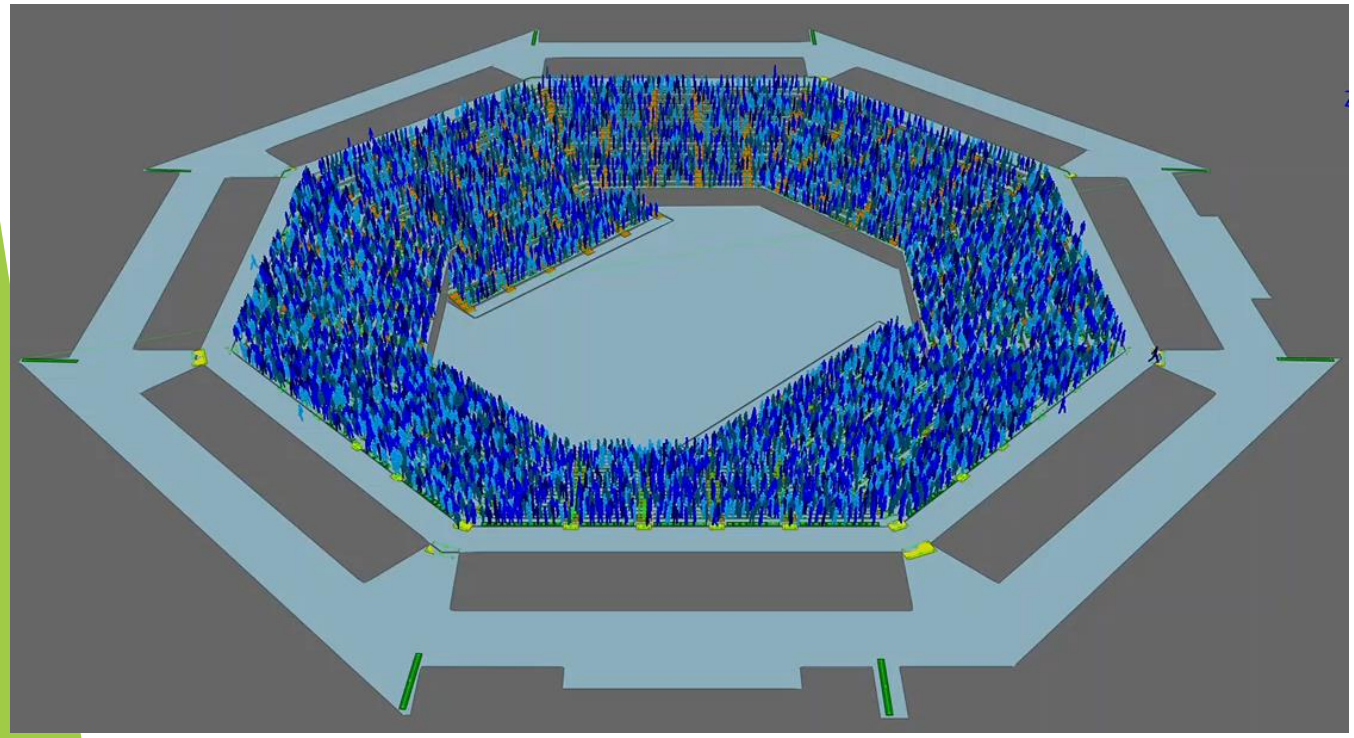
Combined Total	100%	6250	100%	6250	100%	6250	100%	6250

Model 2
Manual Input Parameters for Average Population

- Based on observation of demographics present at the event
- Not inclusive of more complex profiles



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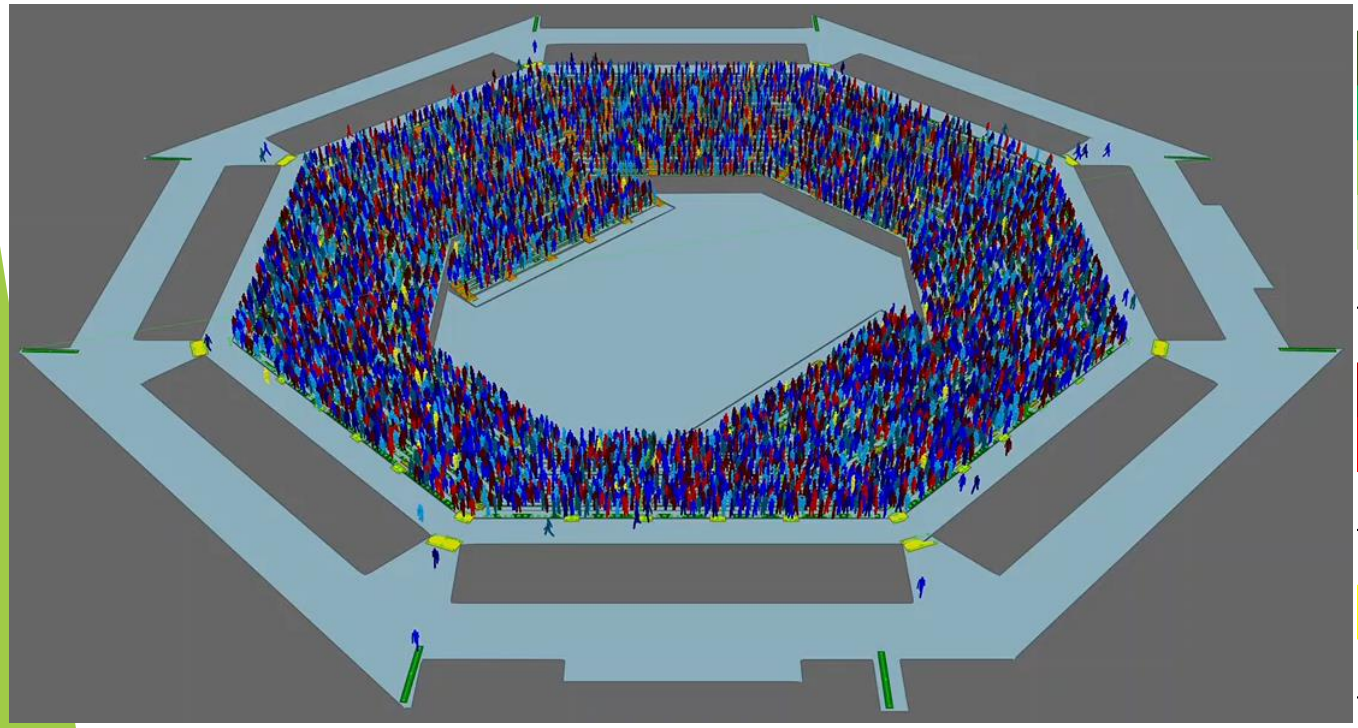
Other Mobility-Limiting Profiles								
Oversize Luggage	-	-	-	-	1.23%	77	1.23%	77
Total	-	-	-	-	1.23%	77	1.23%	77
Combined Total	100%	6250	100%	6250	100%	6250	100%	6250

Model 3
Manual Input Parameters for Observed Population

- Based on observed population
- Includes most diverse set of profiles
- Inclusive of mobility-limiting cases



	Model 1 (Default)		Model 2 (Average)		Model 3 (Observed)		Model 4 (Forecasted)	
Agent Profile	**Frequency**		**Frequency**		**Frequency**		**Frequency**	
Default Profiles								
Fruin Commuter	100%	6250	-	-	-	-	-	-
Total	100%	6250	0%	0	0%	0	0%	0
Able-Bodied Profiles								
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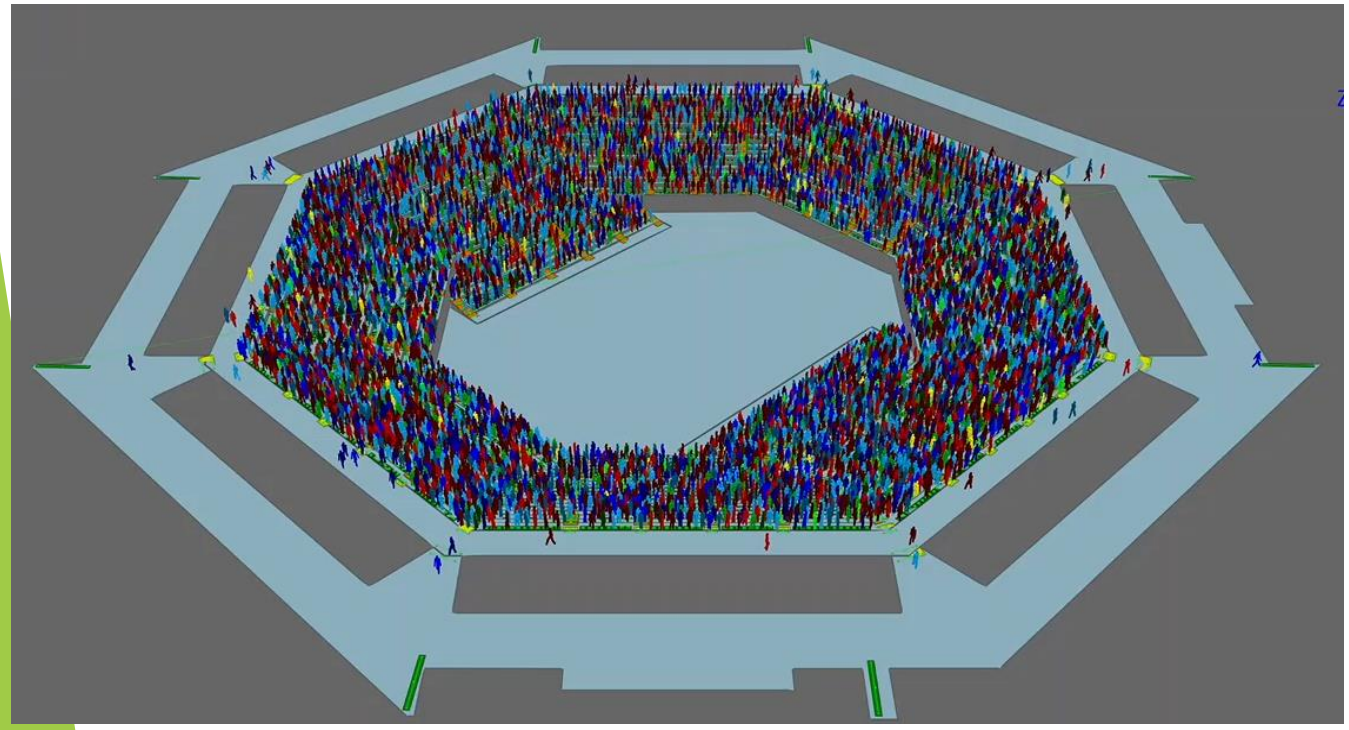
Oversize Luggage	-	-	-	-	1.23%	77	1.23%	77
Total	-	-	-	-	1.23%	77	1.23%	77
Combined Total	100%	6250	100%	6250	100%	6250	100%	6250

Model 4
Manual Input Parameters for Forecasted Population

- Based off Canadian national statistics
- Gives insight to inclusive design
- Uses expected percentages of all cases



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Total	100%	6250	0%	0	0%	0	0%	0
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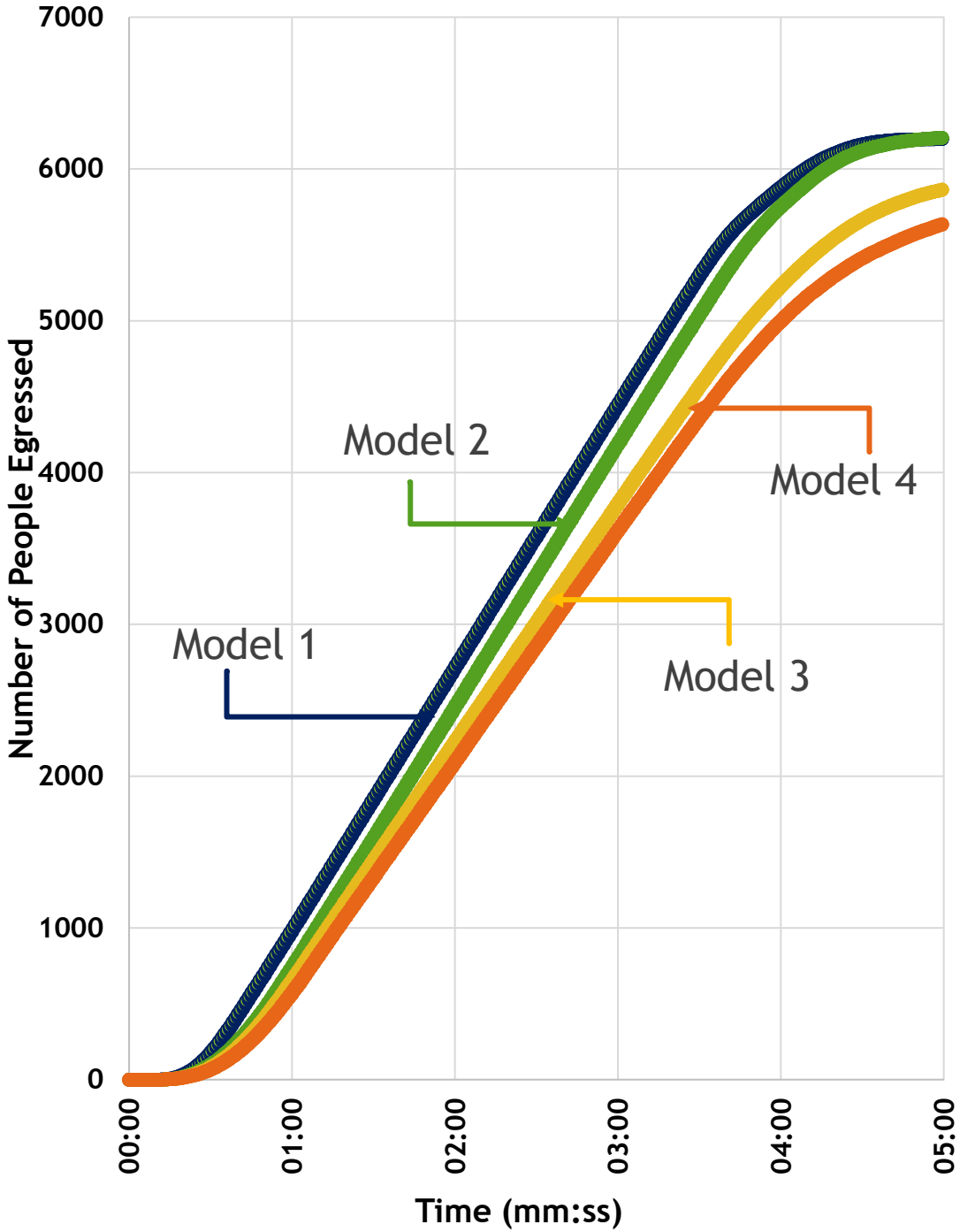
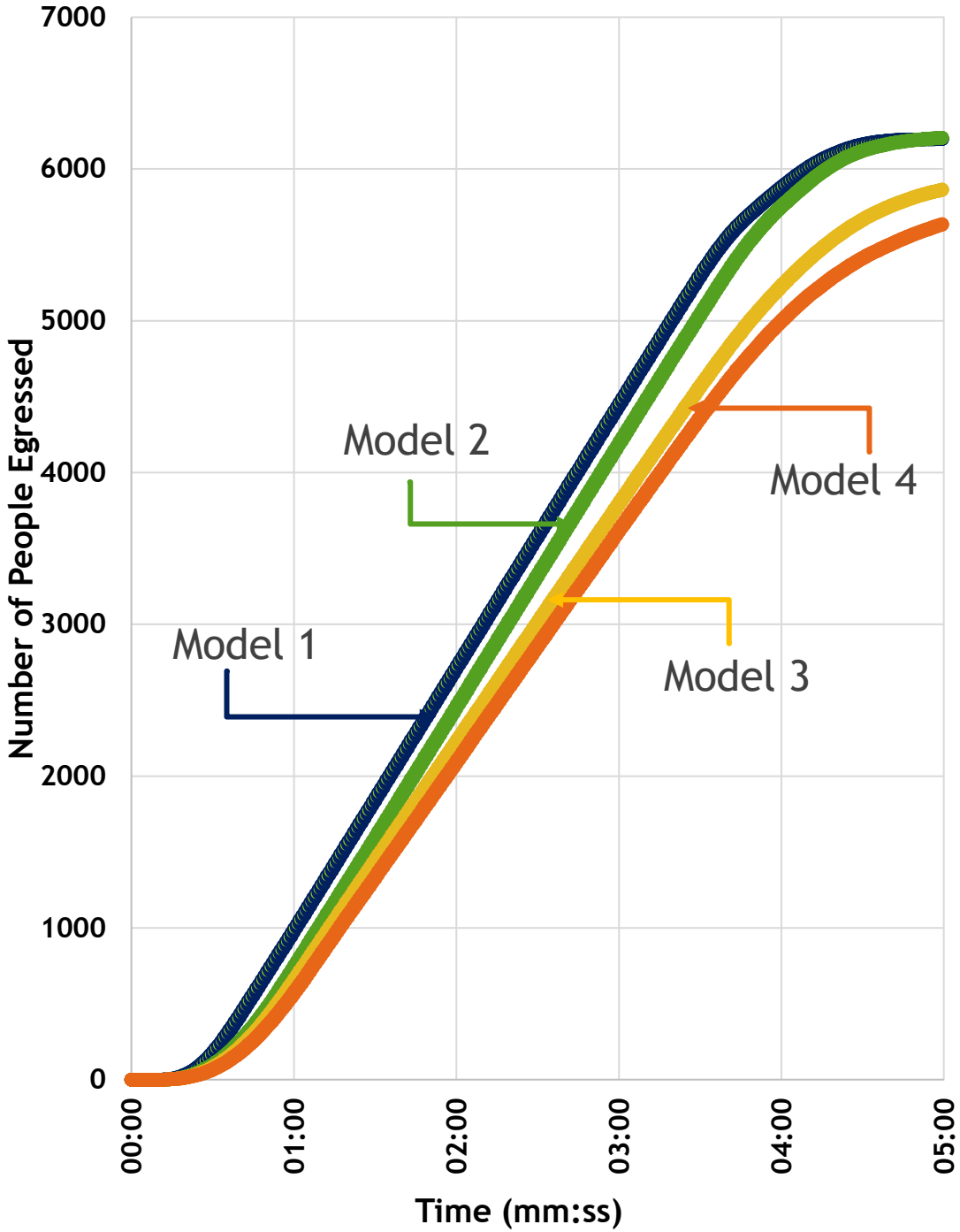


Preliminary Results

- Introductory models
- Subject to modifications

Time	Percent Population Egressed			
(m:ss)	Model 1	Model 2	Model 3	Model 4
1:00	16%	12%	10%	9%
2:00	44%	40%	36%	34%
3:00	71%	67%	61%	58%
4:00	94%	92%	84%	80%
5:00	99%	99%	94%	90%



Preliminary Results

- Model 1
  - Shows the fastest egress

Time	Percent Population Egressed			
(m:ss)	Model 1	Model 2	Model 3	Model 4
1:00	16%	12%	10%	9%
2:00	44%	40%	36%	34%
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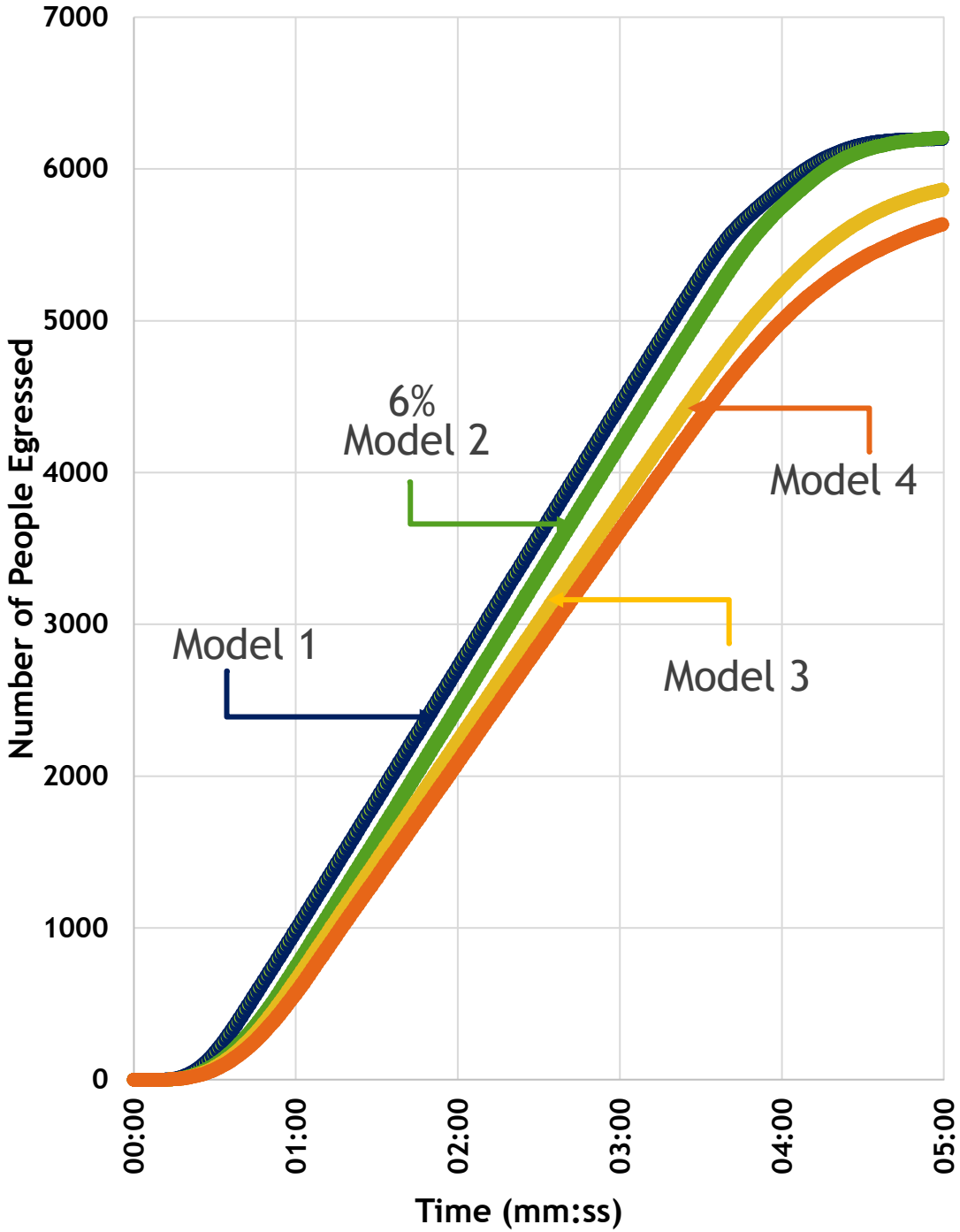
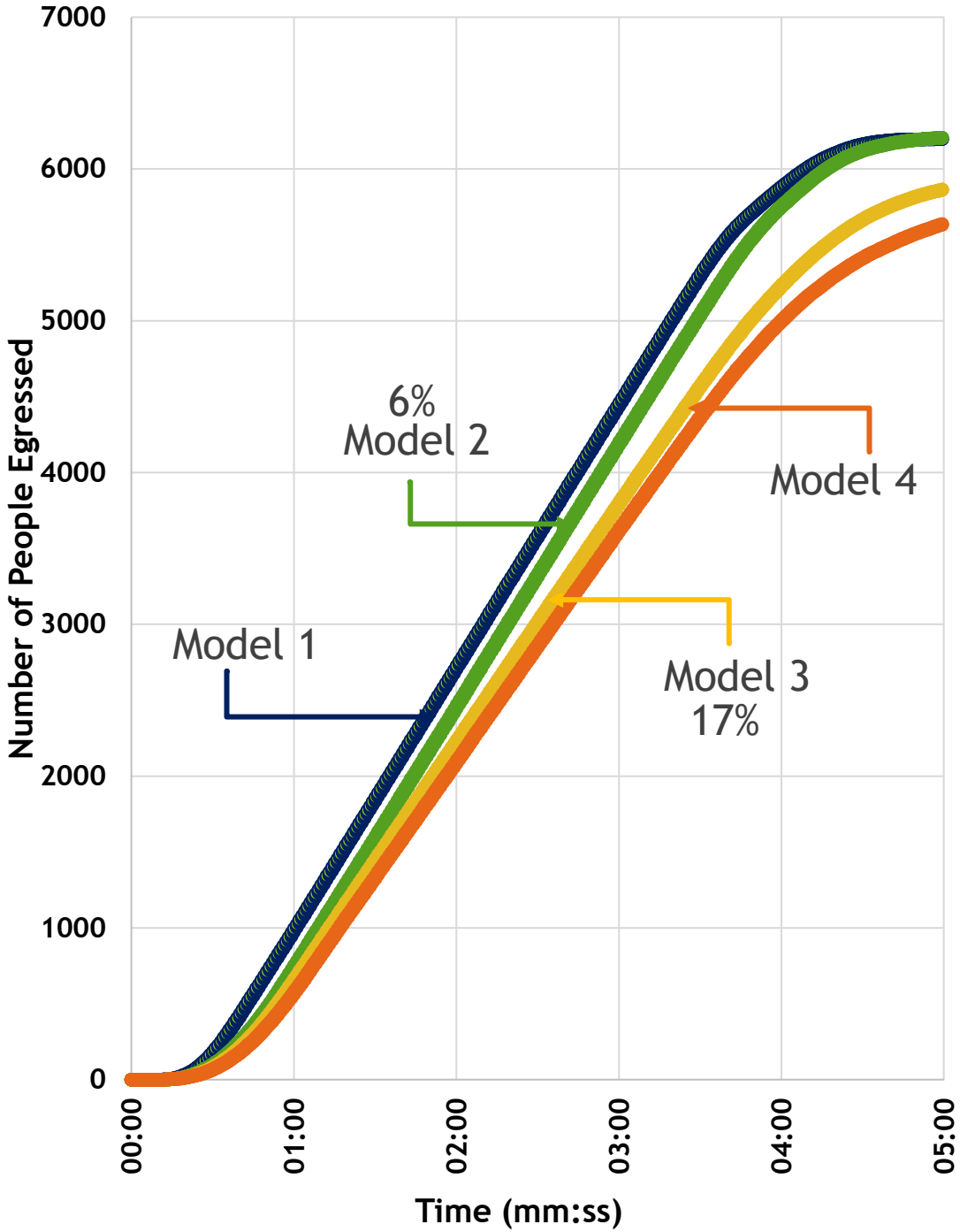


Preliminary Results

- Model 2
  - Similar trend as Model 1
  - Slower egress time

Time	Percent Population Egressed			
(m:ss)	Model 1	Model 2	Model 3	Model 4
1:00	16%	12%	10%	9%
2:00	44%	40%	36%	34%
3:00	71%	67%	61%	58%
4:00	94%	92%	84%	80%
5:00	99%	99%	94%	90%



Preliminary Results

- Model 3
  - Slower overall egress
  - Due to slower speeds and greater radii
  - Most authentic model

Time	Percent Population Egressed			
(m:ss)	Model 1	Model 2	Model 3	Model 4
1:00	16%	12%	10%	9%
2:00	44%	40%	36%	34%
3:00	71%	67%	61%	58%
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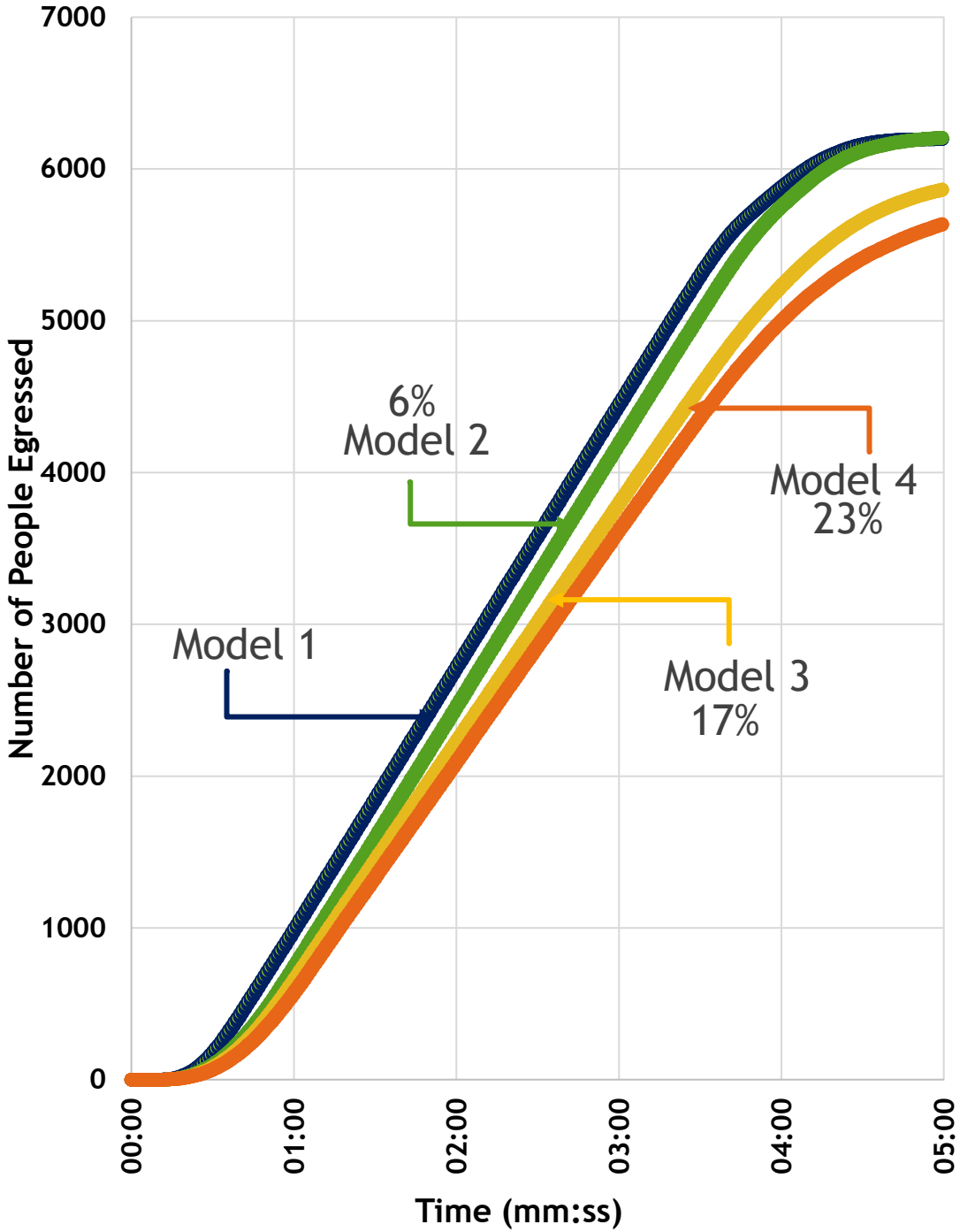
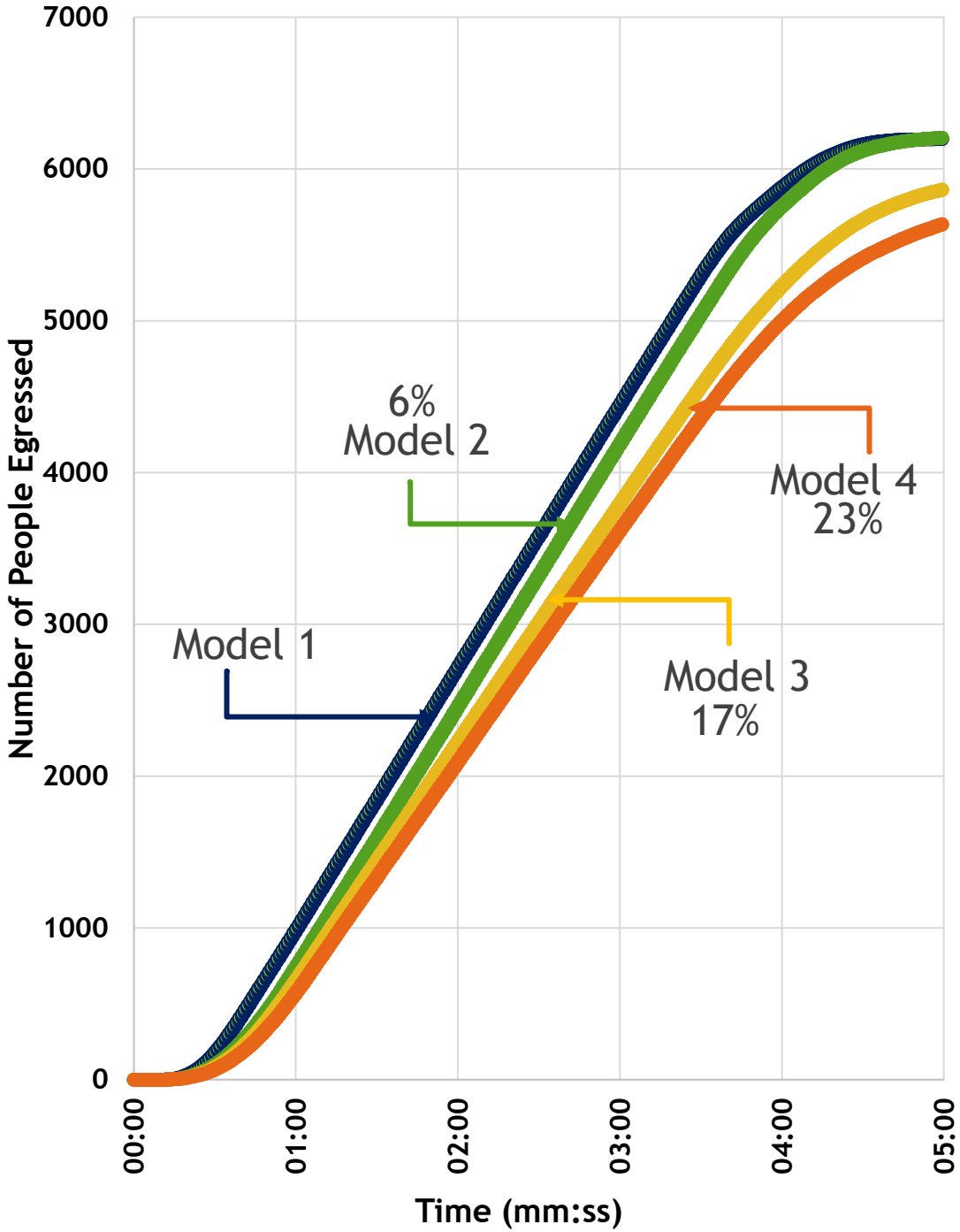


Preliminary Results

- Model 4
  - Shows the slowest egress
  - Due to even higher percent of profiles with slower speeds and greater radii

Time	Percent Population Egressed			
(m:ss)	Model 1	Model 2	Model 3	Model 4
1:00	16%	12%	10%	9%
2:00	44%	40%	36%	34%
3:00	71%	67%	61%	58%
4:00	94%	92%	84%	80%
5:00	99%	99%	94%	90%



Limitations

- Does not include all mobility limitations
- Crowd size set to 6250
- Relatively short travel distances
- We anticipate that egress times would increase when increasing diversity of profiles, crowd size, and travel distances

Time	Percent Population Egressed			
(m:ss)	Model 1	Model 2	Model 3	Model 4
1:00	16%	12%	10%	9%
2:00	44%	40%	36%	34%
3:00	71%	67%	61%	58%
4:00	94%	92%	84%	80%
5:00	99%	99%	94%	90%

Preliminary Conclusions

- Using industry standard metrics can underrate the outputs of crowd simulation tools
- Using project-specific data for profile parameters and demographic distributions can increase the authenticity and reliability of the models

Future Research

- Validate models against observed egress scenarios
- Analyse demographic behaviors independently
- Compare simulations with a range of modelling software
- Expand on the diversity of movement profiles

Thank you

Acknowledgements

- ARUP Human Behavior and Evacuation Skills Team, and Accessible Environments Team
- Lund University
- SFPE foundation