Pedestrian Dynamics at Transit Stations: A Hybrid Pedestrian Flow Modeling Approach

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Introduction

Modeling Framework

Numerical Results

Conclusions

TGF 2015, The Netherlands, October 2015
Federal officials will assume responsibility for Metro safety

By Lori Arstid and Paul Duggan

Metro now is the first U.S. subway system placed under direct federal supervision for safety lapses under a plan announced late Friday by Transportation Secretary Anthony Fox.
Objectives

• Consider an integrated modeling approach that captures pedestrian walking behavior in congested and uncongested conditions in transit stations
• Combine concepts from previously existing pedestrian behavior models
• Simulate scenarios that can be compared to real world data
• Explore model results for a transit station application
Modeling Framework

Social Force Model:
attractive and repulsive
force structure

(Helbing, Buzna, Johansson
and Werner, 2005)

Materials Science:
multi-body potential
molecular interactions

(Karamouzas, Skinner
and Guy; 2014)

Behavioral Heuristics:
Incorporating cognitive and
physiological pedestrians
characteristics

(Moussaïd, Helbing and
Theraulaz; 2011)
\[ b = 0.5 \cdot \sqrt{\left( \frac{1}{v^2} \right) + \left( \frac{1}{v^2} \right)} \]

\[ V_0 \beta \equiv \text{constant parameter} \]
\[ \alpha \equiv \text{velocity of pedestrian} \]
\[ \beta \equiv \text{time change used to determine step width of pedestrian} \]

\[ f_{\text{rep}}(r_{ab}) = -\frac{1}{r_{ab}^2} \]

\[ f_{\text{attract}}(r_{ab}) = \frac{1}{r_{ab}^2} \]

\[ f_{\text{rep}}(r_{ab}) = -\frac{1}{r_{ab}^2} \cdot V_{ab}(\|r_{ab}\|) \]

\[ U_{ab}(\|r_{ab}\|) = U_{ab} \cdot \frac{1}{\|r_{ab}\|} \]

\[ R \equiv \text{constant parameter} \]

\[ v_0 \equiv \text{velocity of pedestrian} \]
\[ a \equiv \text{direction of motion of pedestrian} \]
\[ \Delta \tau \equiv \text{time change used to determine step width of pedestrian} \]

\[ F_0 = \left( \frac{v_0}{a_0} - v_0 \right) \]

\[ a = 1 \]

\[ a_0 = 1 \]

\[ v_0 = 1 \]

\[ v_0 = 1 \]

\[ t_a = \text{relaxation time of pedestrian} \]

\[ v_a \equiv \text{actual velocity of pedestrian} \]
\[ a_a \equiv \text{desired direction of pedestrian} \]
\[ a_a \equiv \text{desired velocity of pedestrian} \]

Social Force Model

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Behavioral Heuristics

Walking Direction

\[ \overline{e}_{\alpha}(t) = d_{\text{max}}^2 + r(e)^2 - 2d_{\text{max}}r(e)\cos(e_0 - e) \]

\[ \overline{e}_{\alpha}(t) \equiv \text{desired direction of pedestrian } \alpha \]

\[ d_{\text{max}} \equiv \text{sight distance of pedestrian } \alpha \]

\[ r(e) \equiv \text{distance to first collision} \]

\[ e_0 \equiv \text{direction of destination} \]

\[ e \equiv \text{direction within field of view considered by pedestrian} \]

Field of View
Molecular interactions can be modeled by taking into account directly neighboring molecules. Requires “social force” calculations between multiple bodies within the corresponding field of view.

\[
\text{Total Force Felt by Pedestrian} \; \alpha \\
= \sum_{i=1}^{3} F_\alpha^0(v_\alpha, v_\alpha^0 e_\alpha) + f_{\alpha\beta_i}(r_{\alpha\beta_i}) + f_{\alpha B_i}(r_{\alpha B_i})
\]
Numerical Analysis

Experimental Results (Courtesy, TU Delft)

• One directional flow
• Two directional flow
• Crossing
• Wide Bottleneck
• Narrow bottleneck

Simulation

• Alternative Crossing Scenario
• Transit Application
Experimental Results: 1-D Flow (A vs. B)
Experimental Results: 2-D Flow (C vs. D)
Experimental Results: Crossing (E vs. F)
Experimental Results: Wide and Narrow Bottlenecks

- **Wide Bottleneck**
  - Length: 10m
  - Width: 4m
  - Height: 2m

- **Narrow Bottleneck**
  - Length: 10m
  - Width: 4m
  - Height: 1m
Experimental Results: Wide Bottleneck

Data

Model
Experimental Results: Narrow Bottleneck

Data

Model
Transit Application
Transit Layout

EXITING PEDESTRIANS
ENTERING PEDESTRIANS
Transit Trajectories & Space Usage

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Conclusions

- Feasible modeling approach: flexible and computationally efficient
- Basic validity analysis (i.e. macro analysis)
- Realistic trajectory patterns

- Next steps:
  o Flow-density analysis \(\rightarrow\) traffic flow theory based study
  o Additional trajectory data specific to transit related pedestrian dynamics
  o Microscopic calibration capturing heterogeneity
  o Real-time application: predictive tool
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