

Modelling and Simulation of Rail Passengers to Evaluate Methods to Reduce Dwell Times

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MAS 2015

Content

- Introduction
- Modelling Theory
- Modelling Practice
- Model Implementation
- Experimentation
- Future Work

Introduction



Problem Statement

- The rail network in the UK is fast approaching maximum capacity and passenger numbers are growing 6-7% per year
- One relatively simple (and therefore cheap) way to increase capacity of the rail network is to reduce loading/unloading times (dwell time)



Aim and Approach

- Aim: Test the feasibility of using agent based modelling for assessing novel methods of reducing dwell times
- Approach: Using Xi's Extended Social Force Model (ESFM) together with a novel decision making algorithm for passengers' door choice

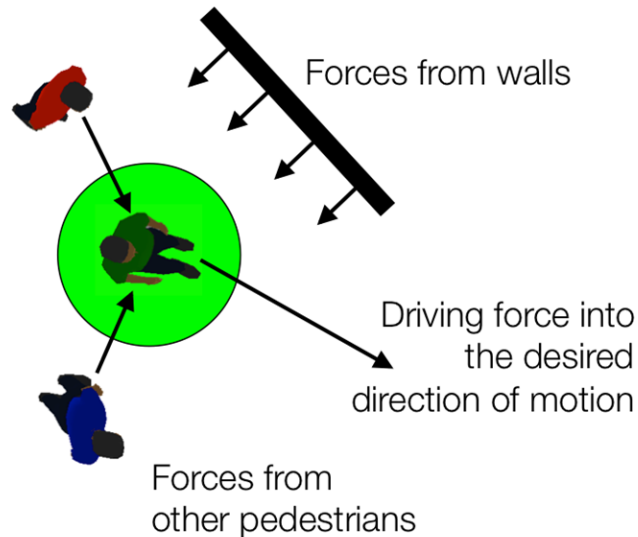


Modelling Theory



Social Force Model (SFM)

- The "social force model" (Helbing and Molnar 1995) assumes that the acceleration, deceleration and directional changes of pedestrians can be approximated by a sum of different forces, each capturing a different desire or interaction effect.



<http://futurict.blogspot.it/2014/12/social-forces-revealing-causes-of.html>

Agent-Based Modelling

- In Agent-Based Modelling (ABM) a system is modelled as a collection of autonomous interacting decision-making entities called agents.
- Each agent individually assesses its internal and external situation and makes decisions on the basis of a set of rules.
- ABM is well suited to modelling systems with heterogeneous, autonomous and proactive actors, such as human-centred systems.

Modelling Practice



Base Model

- SFM was implemented by computing the force on an agent at each time step, using the model provided by Xi et al. (2010).

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0(t) e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_W \mathbf{f}_{iW}$$
$$\mathbf{f}_{ij} = \mathbf{f}_{ij}^{psy} + \mathbf{f}_{ij}^{phy}, \quad \mathbf{f}_{ij}^{psy} = A_i \exp\left(\frac{r_{ij} - d_{ij}}{B_i}\right) \mathbf{n}_{ij}$$
$$\mathbf{f}_{ij}^{phy} = k g(r_{ij} - d_{ij}) \mathbf{n}_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ji}^t \mathbf{t}_{ij}$$

Base Model

- To add some novelty we decided to incorporate the Extended Social Force Model (ESFM) proposed by Xi et al. (2010) which adds "vision" to the SFM.
- A simple way of considering vision is to use a "form factor" coefficient which modifies the psychological force felt by a passenger.
- We also developed a novel decision making algorithm which is based on a passenger's knowledge of the station, as well as their environment.

Base Model

- From this, the parameters used in the SFM could be calibrated in order to produce realistic behaviour (using trial and error).
- Four behaviours are to be expected: (Helbing and Molnar, 1995; Helbing et al. 2000)
 - Clogging at bottlenecks
 - Lane formation
 - Oscillations at doorways
 - Freezing by heating (pedestrians' high desired velocity resulting in slower overall movements)

Passenger Types

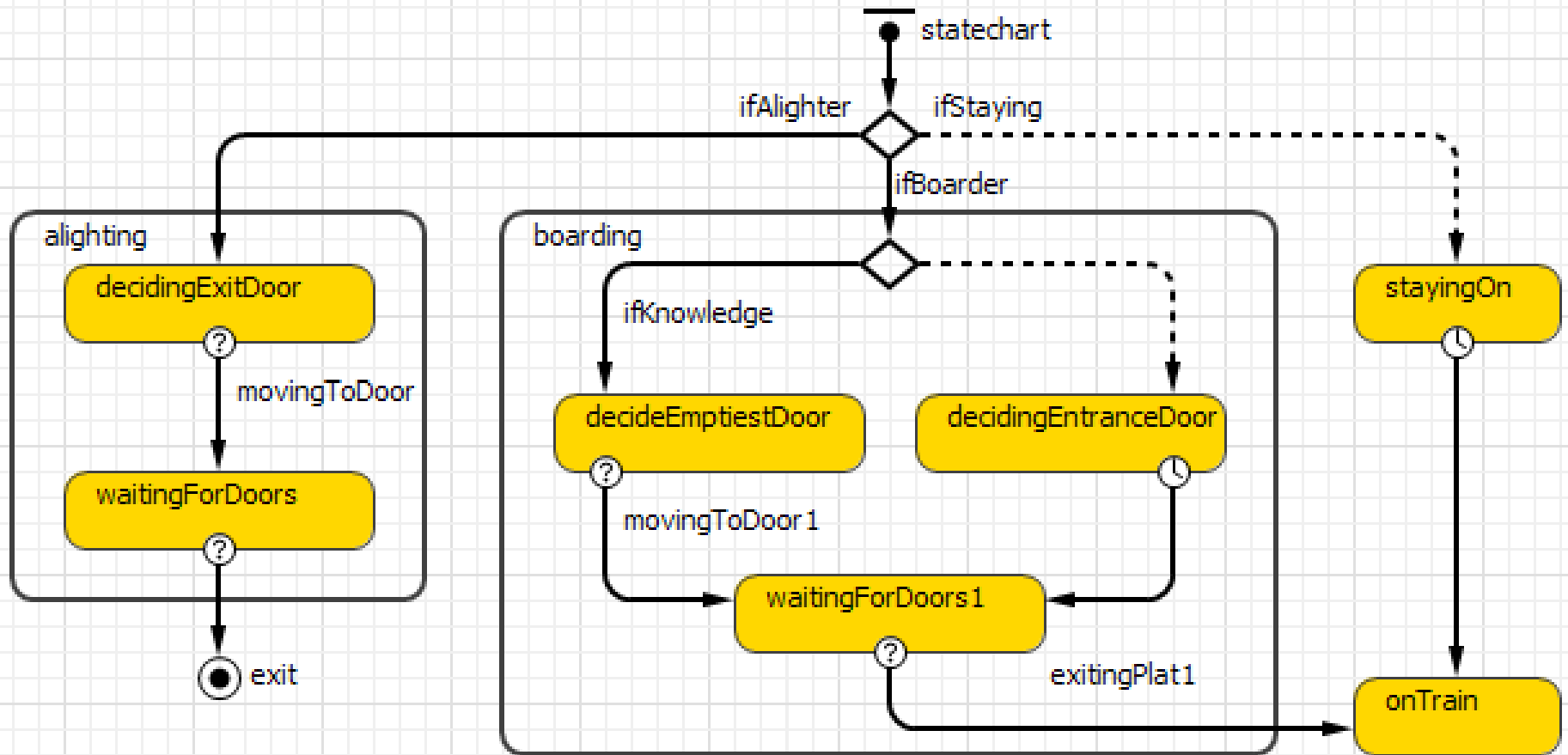
- Passenger decision-making process depends on "knowledge"
 - If a passenger has knowledge of the station they base their decision on the least crowded door.
 - If a passenger does not have knowledge of the station, there are two different decision-making processes, depending on their arrival time relative to the train's arrival time.
 - Early arrivals will move towards the nearest anticipated door area.
 - Late arrivals pass by each door in turn. If the crowdedness at a door is under a specified threshold, the passenger will choose that door to enter.

Passenger Types

- For simplicity, it was also assumed that boarders do not wait for alighters before they start moving, and instead it is left to the social force to decide which group moves, hopefully oscillating, depending on relative group sizes.



Passenger States



Model Implementation



Pre Train Arrival

SFM : Simulation - AnyLogic University [EDUCATIONAL USE ONLY]

passengers[110] | 110

```

statechart
    [*] --> statechart
    statechart --> ifAlighter
    statechart --> ifStaying
    statechart --> ifBoarder
    ifAlighter --> alighting
    ifStaying --> stayingOn
    ifBoarder --> ifKnowledge
    ifBoarder --> decidingEntranceDoor
    ifKnowledge --> decideEmptiestDoor
    decideEmptiestDoor --> movingToDoor1
    movingToDoor1 --> waitingForDoors1
    waitingForDoors1 --> exitingPlat1
    decidingEntranceDoor --> exitingPlat1
    exitingPlat1 --> onTrain
    alighting --> decidingExitDoor
    decidingExitDoor --> movingToDoor
    movingToDoor --> waitingForDoors
    waitingForDoors --> exit
    
```

type boarder
 target (335.5967541862913, 64.323480...)
 target1 (335.5967541862913, 64.323480...)
 target2 (469.8571459833327, 60.294417...)
 target3 (536.1898784722695, 57.570228...)
 target4 (666.9987644006043, 60.453386...)
 target5 (747.3818888158375, 55.836662...)
 C1pop 0
 C2pop 0
 C3pop 0
 C4pop 0
 C5pop 0

vOParam
 40.468
 v0 2
 Tau 1
 A 200
 B 8.178
 k 38
 K 300
 Twor 4.634
 A1 3.000
 B1 6
 k1 190
 K1 3.000

initial
 (100.39586528060443, 122.2662... false
 colour blue
 m 61.767
 connectionRange 20
 connectionRangeWalls 20

knowledge
 targetTemp
 emptiestDoor 1.000
 doorThreshold 18
 shortestDist 0
 timeOfStartup 14.168
 targetReached false

px 335.597
ri 2.317
ux 3.939
vx 3.847
vjx 0.683
x 276.615
xj 790
nijx 0.923
tijx -0.384
sumForcex -113.593
nearestPointx 0
nearestPoint 0

py 64.323
ry 3.135
uy 4.134
vy 3.948
vjy 0.302
y 87.184
yj 50
nijy 0.384
tijy 0.923
sumForcey -229.643
nearestPointy 0

dip 63.421
rij 5.452
dij 515
deltaVx 1.25
deltaVy -3.538
rijdij 0
ridij -17.427
physx 0
psycx 21.394
physy 0
psycy 40.755
exx 0.937

destx 59.275
desty -22.555
lambda 0.1
cosAB 0.045
formFac 0.57

Run: 0 Paused | **Time:** 20.55 | **Simulation:** Stop time not set | **Date:** Sep 20, 2015 11:30:48 AM | **Memory:** 52M of 910M

Train arrival

SFM : Simulation - AnyLogic University [EDUCATIONAL USE ONLY]

passengers[201] 201

```

statechart
    [*] --> alighting
    alighting --> exit : exit
    alighting --> boarding : ifAlighter
    boarding --> alighting : ifStaying
    boarding --> onTrain : ifBoarder
    boarding --> boarding : ifKnowledge
    boarding --> waitingForDoors1 : movingToDoor1
    waitingForDoors1 --> boarding : exitingPlat1
    onTrain --> stayingOn : L
    stayingOn --> onTrain : L
  
```

alighting (highlighted in red box):

- decidingExitDoor (state with ?)
- movingToDoor (transition)
- waitingForDoors (state with ?)
- exit (final state)

boarding:

- decideEmptiestDoor (state with ?)
- decidingEntranceDoor (state with L)
- waitingForDoors1 (state with ?)
- exitingPlat1 (transition)

stayingOn (state with L)

onTrain (state with L)

Parameters:

- vOParam: 24.901
- v0: 24.901
- Tau: 1
- A: 200
- B: 8.891
- k: 38
- K: 300
- Twor: 6.142
- px: 638.805
- ri: 3.071
- ux: 1.809
- vx: 1.902
- vjx: 0.181
- x: 632.679
- xj: 790
- nijx: 0
- tijx: 1
- sumForcex: 151.686
- nearestPointx: 0
- nearestPoint: 0
- py: 98.029
- rj: 2.856
- uy: 10.111
- vy: 10.736
- vjy: 1.66
- y: 37.114
- yj: 36.34
- nijy: 0
- tijy: 0
- sumForcex: 1.023.299
- nearestPointy: 0
- initial: (631.7372462703067, 32.148151... true)
- colour: yellow
- m: 81.877
- connectionRange: 20
- connectionRangeWalls: 20
- knowledge: true
- targetTemp: (896.802841302367)
- emptiestDoor: 1.000
- doorThreshold: 20
- shortestDist: 276.314
- timeOfStartup: 20
- targetReached: false
- dip: 62.006
- rij: 5.927
- dij: 157.459
- deltaVx: 1.809
- deltaVy: 0
- rijdij: -2.819
- ridij: -10.588
- physx: 0
- psycx: 0
- physy: 0
- psycy: -265.699
- exx: 0.181
- destx: 6.264
- desty: 61.689
- lambda: 0.1
- cosAB: -0.073
- formFac: 0.517

Simulation Status:

- Run: 0 Paused
- Time: 20.55
- Simulation: Stop time not set
- Date: Sep 20, 2015 11:30:48 AM
- Memory: 40M of 910M

Train Stop Time

SFM : Simulation - AnyLogic University [EDUCATIONAL USE ONLY]

passengers[150] | 150

```

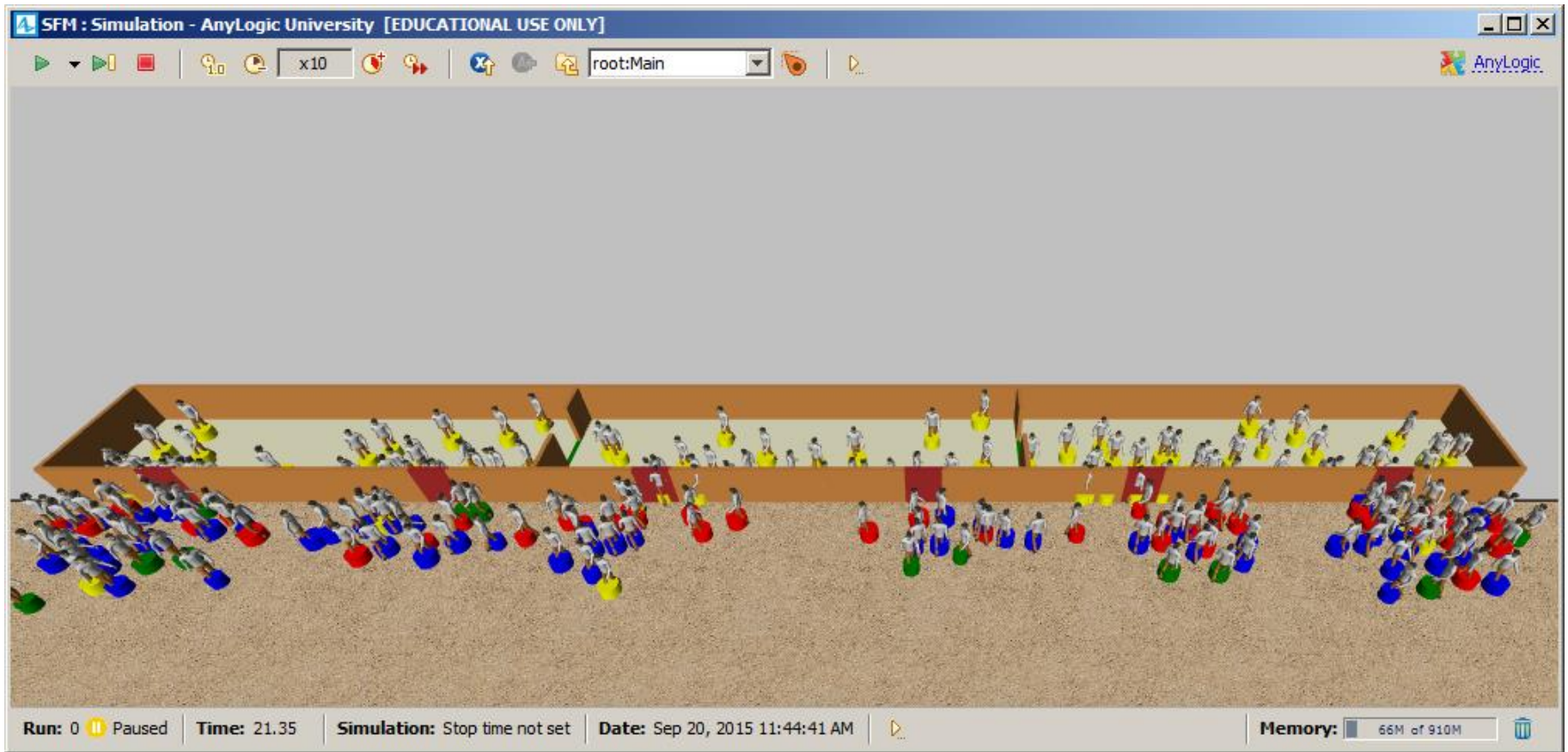
stateDiagram-v2
    [*] --> statechart
    statechart --> alighting : ifAlighter
    statechart --> stayingOn : ifStaying
    statechart --> boarding : ifBoarder
    alighting --> alighting : decidingExitDoor
    alighting --> waitingForDoors : movingToDoor
    waitingForDoors --> exit : 
    boarding --> boarding : ifKnowledge
    boarding --> decideEmptiestDoor : 
    decideEmptiestDoor --> waitingForDoors1 : movingToDoor1
    waitingForDoors1 --> boarding : 
    boarding --> decidingEntranceDoor : 
    decidingEntranceDoor --> waitingForDoors1 : 
    waitingForDoors1 --> onTrain : exitingPlat1
    stayingOn --> onTrain : 
    
```

Variables:

- vOParam: 2.849
- v0: 2.849
- Tau: 1
- A: 200
- B: 8.651
- k: 38
- K: 300
- Twor: 5.495
- px: 543.937
- ri: 2.748
- ux: 0.504
- vx: 0.526
- vjx: 2.032
- x: 513.015
- xj: 790
- nijx: 0
- tijx: 1
- sumForcex: 33.608
- nearestPointx: 0
- nearestPoint: 0
- initial: (499.9975788179482, 40.30640...false)
- colour: yellow
- m: 73.254
- connectionRange: 20
- connectionRangeWalls: 20
- py: 98.309
- rj: 3.019
- uy: 0.397
- vy: 0.414
- vjy: 0.137
- y: 31.522
- yj: 31.492
- nijy: 0
- tijy: 0
- sumForcex: 24.405
- nearestPointy: 0
- knowledge: false
- targetTemp: (881.9600375502864, 122.16696...)
- emptiestDoor: 1,000
- doorThreshold: 20
- shortestDist: 390.636
- timeOfStartup: 20
- targetReached: false
- dip: 73.642
- rij: 5.767
- dij: 277.023
- deltaVx: 0.504
- deltaVy: 0
- rijdij: -11.603
- ridij: -15.76
- physx: 0
- psycx: 0
- physy: 0
- psycy: -114.532
- eax: 0.47
- destx: 30.96
- desty: 66.817
- lambda: 0.1
- cosAB: -0.049
- formFac: 0.528

Run: 0 Paused | Time: 37.35 | Simulation: Stop time not set | Date: Sep 20, 2015 11:31:05 AM | Memory: 61M of 910M

3D Display



Experimentation



Experimentation

- Four scenarios are considered
 - Scenario 1: The "standard" generic scenario.
 - 600 passengers (split evenly between boarders, alighters, and stayers)
 - Normal distribution of desired walking speeds (mean = 1.3m/s; standard deviation = 0.2m/s)
 - 10% of passengers have "knowledge" of emptiest door
 - Scenario 2: The "rush hour" scenario in which the majority of the passengers are expected to be middle-aged commuters.
 - 1200 passengers (split equally between boarders, alighters and stayers)
 - Normal distribution of desired walking speeds (mean = 1.47m/s; standard deviation = 0.2m/s)
 - 50% of passengers have "knowledge" of the emptiest door

Experimentation

- Scenario 3: "OAP day out" in which a large number of passengers are elderly passengers.
 - 600 passengers (split evenly between boarders, alighters, and stayers)
 - Normal distribution of desired walking speeds (mean = 1.0m/s; standard deviation = 0.5m/s)
 - 10% of passengers have "knowledge" of emptiest door
- Scenario 4: The "Emergency" scenario, to assess how well the train and platform can be cleared, including a higher desired velocity representing panic.
 - 400 passengers (all of which being alighters)
 - Normal distribution of desired walking speeds (mean = 3.0m/s; standard deviation = 1.0m/s)
 - 10% of passengers have "knowledge" of emptiest door

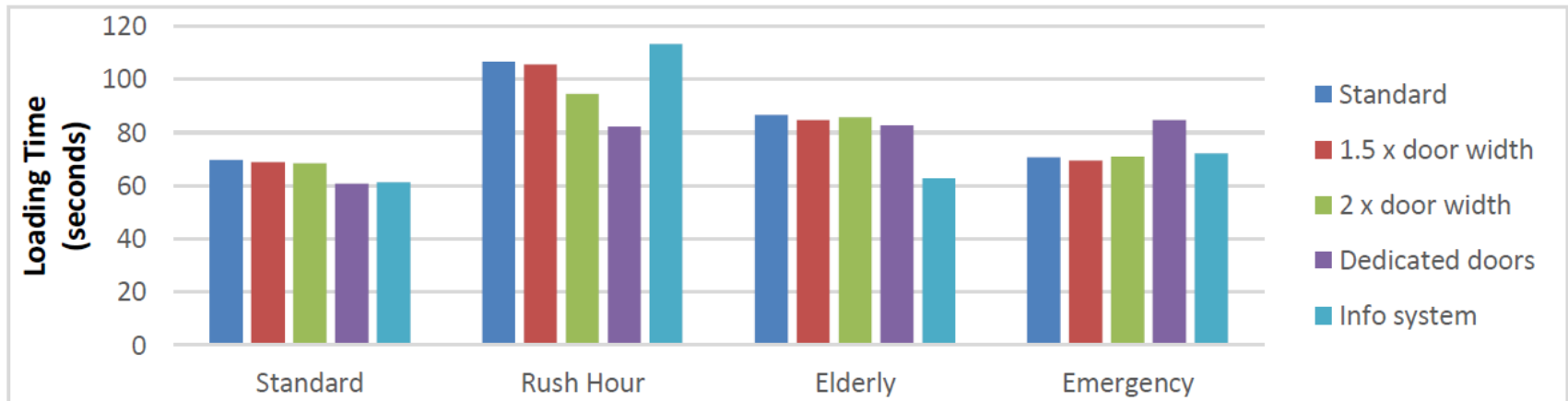
Experimentation

- For the four scenarios we compare five strategies:
 - Base case
 - 1.5x wider doors
 - 2x wider doors
 - Designated boarding and alighting door
 - An active passenger information system

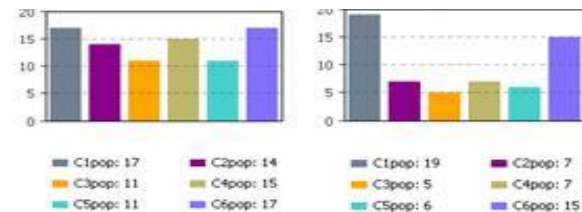


Results

- The quantitative output was total loading time



- There are a number of other numerical outputs available
 - Separation of Boarding and alighting times
 - Door utilisation dynamics



Future Work



Future Work

- This was just a feasibility study!
 - There are still bugs



- Next steps:
 - Modelling the interior of the train
 - Modelling groups: The ESFM also includes a socially attractive force between members of a group
 - Adding rules to let alighters off first (as it is the rule in Britain)
 - Adding agent learning

References

- Aristotle (BC) Aristotle quotes [<http://www.online-literature.com/aristotle/>]
- Helbing, D., & Molnar, P. (1995). Social force model for pedestrian dynamics. *Physical Review E*, 51(5), 4282.
- Helbing, D., Farkas, I., and Vicsek, T. (2000). Simulating dynamical features of escape panic. *Nature*, 407(6803), 487-490.
- Xi, H., Son, Y. and Lee, S. (2010). An integrated pedestrian behavior model based on Extended Decision Field Theory and Social Force model. In: 2010 Winter Simulation Conference. IEEE, pp.824 - 836.