

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

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# 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





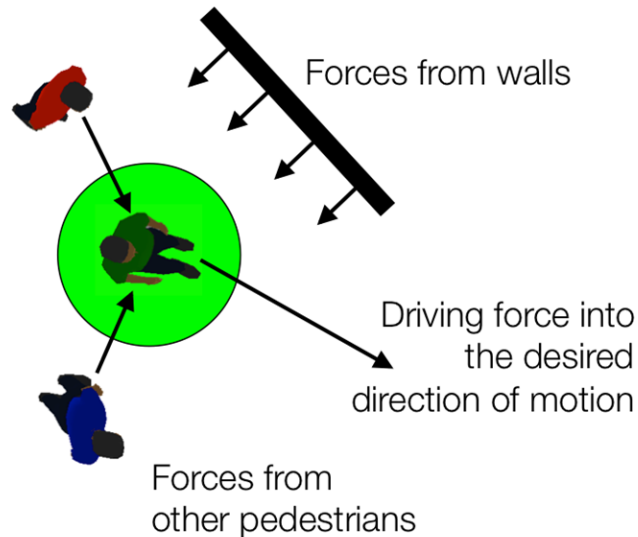


# Modelling Theory



# 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

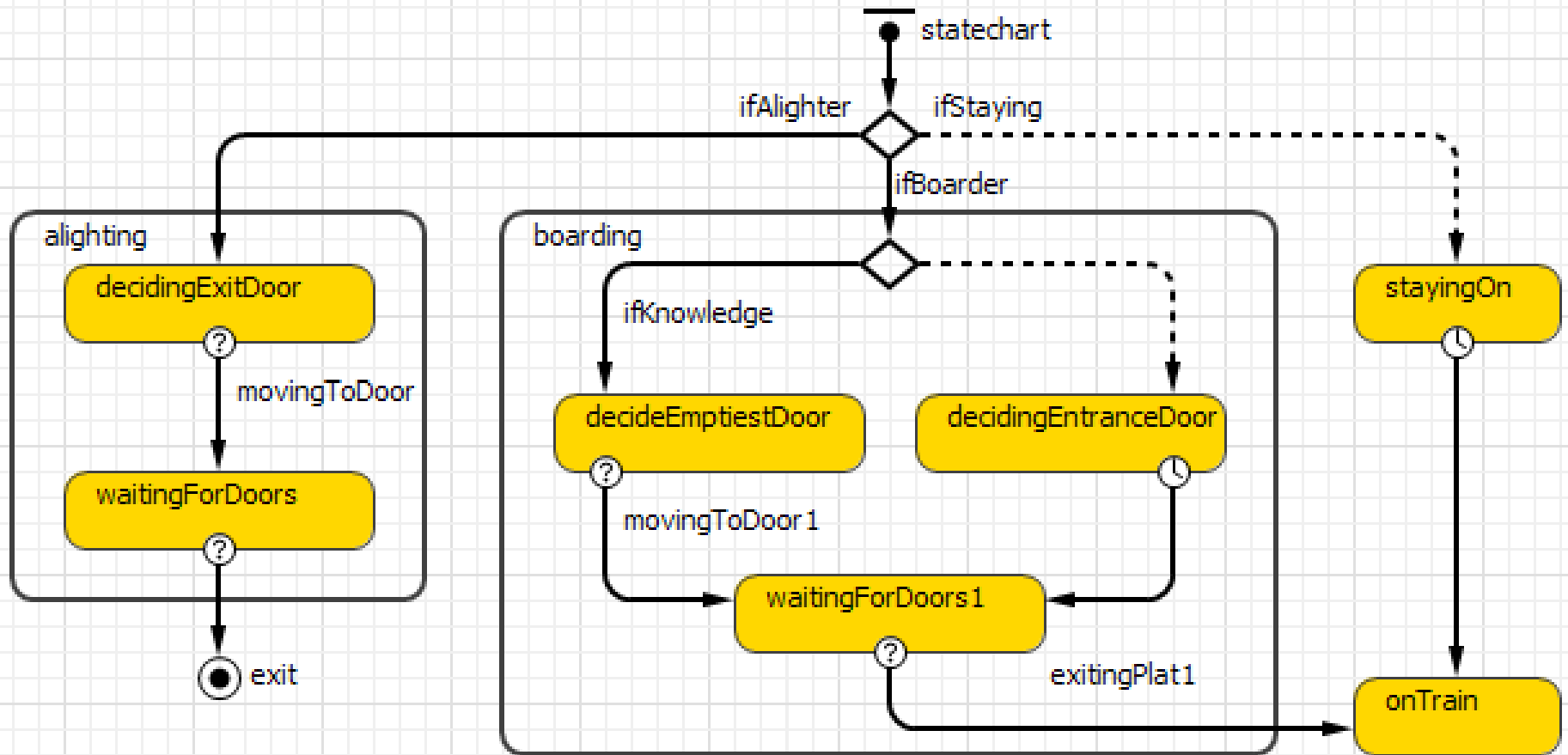
- Passenger decision-making process depends on "knowledge"
  - If a passenger has knowledge of the station they base their decision on the least crowded door.
  - If a passenger does not have knowledge of the station, there are two different decision-making processes, depending on their arrival time 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  
 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**

**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** -10.67  
**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 --> decidingExitDoor
    decidingExitDoor --> waitingForDoors
    waitingForDoors --> exit
    alighting --> boarding
    boarding --> ifKnowledge
    ifKnowledge --> decideEmptiestDoor
    decideEmptiestDoor --> movingToDoor1
    movingToDoor1 --> waitingForDoors1
    waitingForDoors1 --> exitingPlat1
    exitingPlat1 --> onTrain
    boarding --> decidingEntranceDoor
    decidingEntranceDoor --> onTrain
    boarding --> stayingOn
    stayingOn --> onTrain
    onTrain --> [*]
  
```

type alighter  
 target (638.8053310279482, 98.029207...)  
 target1 (896.8028413023677, 110.18449...)  
 target2  
 target3  
 target4  
 target5  
 C1pop 0  
 C2pop 0  
 C4pop 0  
 C5pop 0

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

initial (631.7372462703067, 32.148151... true)  
 colour yellow  
 m 81.877  
 connectionRange 20  
 connectionRangeWalls 20  
 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  
 sumForcey 1.023.299  
 nearestPointy 0

knowledge  
 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  
 eox 0.181  
 destx 6.264  
 desty 61.689  
 lambda 0.1  
 cosAB -0.073  
 formFac 0.517

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

```

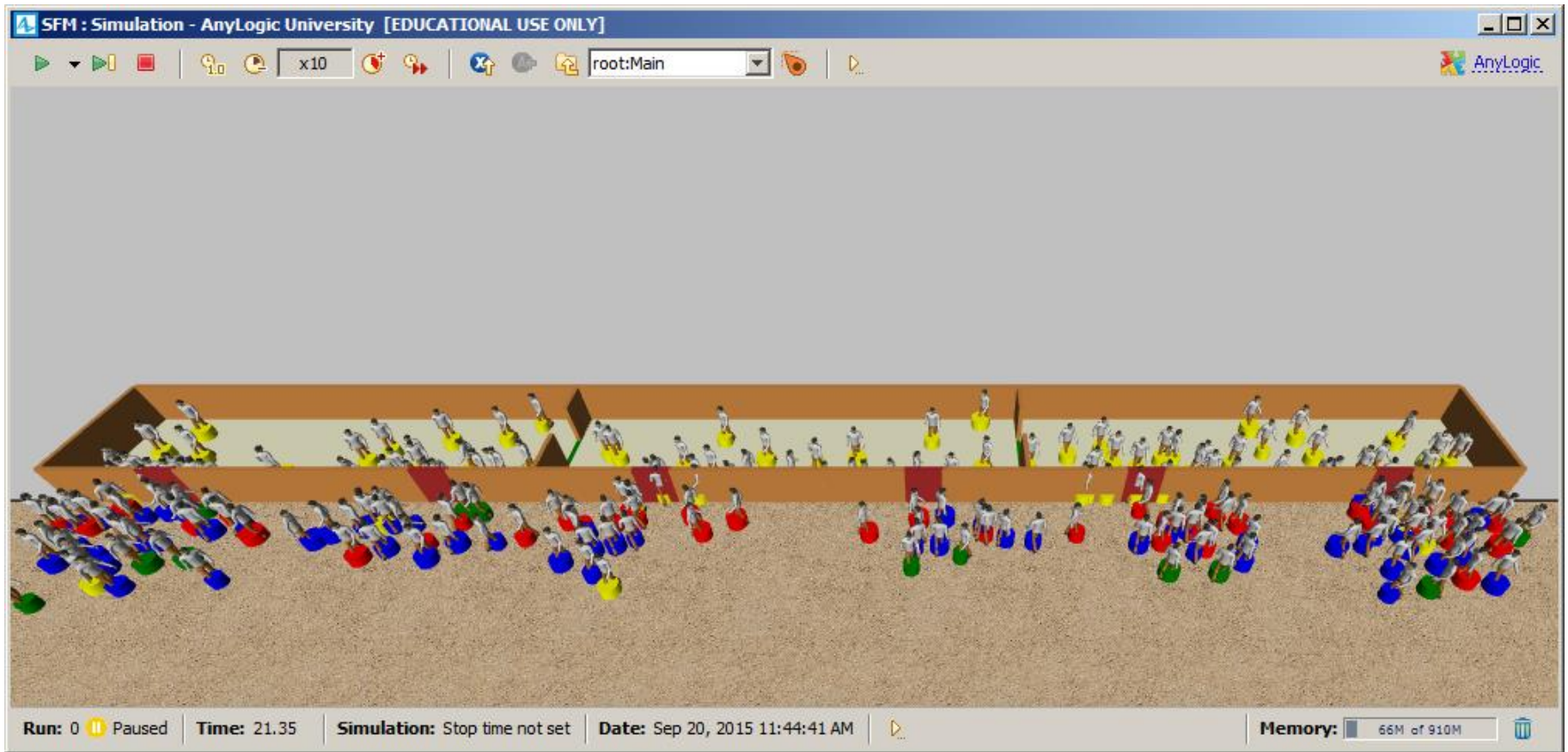
statechart
    [*] --> statechart
    statechart --> alighting : ifAlighter
    statechart --> boarding : ifBoarder
    statechart --> stayingOn : ifStaying
    alighting --> alighting : decidingExitDoor
    alighting --> waitingForDoors : movingToDoor
    waitingForDoors --> exit : ?
    boarding -->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

**Parameters:**

- 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
- 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
- initial: (499.9975788179482, 40.30640...)
- colour: yellow
- m: 73.254
- connectionRange: 20
- connectionRangeWalls: 20
- 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

**Simulation Status:** 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

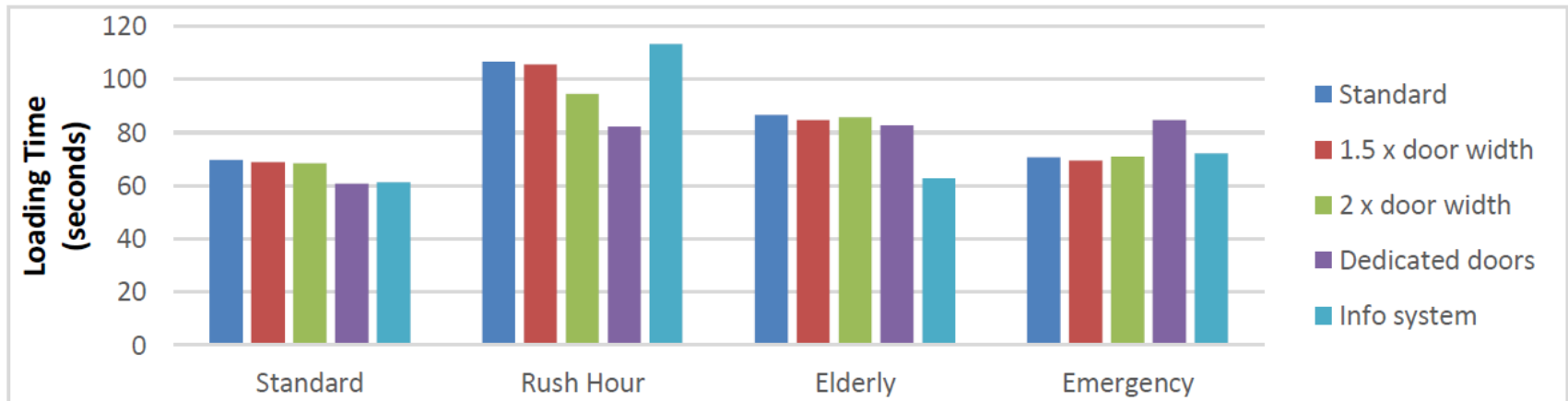
# Experimentation

- 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

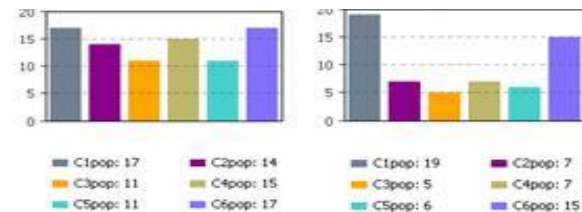


# Results

- 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.