Modelling of pedestrian flows during dwelling: development of a simulator to evaluate rolling stock and platform flow performance

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1. Introduction

In mass transit railway or commuter rail systems, dwelling times are usually long and chaotic, which can lead to tardy trains and a decrease in the system efficiency, especially during peak hours. For more efficient and robust schedules and improvement of passengers’ comfort, a train operator must take care of the passenger movements in the train and on the platform and improve the design of both trains and platform in order to optimize pedestrian flows.

The objective of SNCF is to develop a tool in which the user can easily model the design of each passenger coach, to run simulations and derive statistics about the efficiency of the coach architecture and interior design (as seats arrangement or configuration of the area around the doors) proposed by train manufacturers. Parametric studies could furthermore be carried out upstream from new trains projects to help to write their specifications.

There exist several commercial on-the-shelf software tools that simulate pedestrian movement in public facilities but they usually suffer from the following limitation: the default behaviour correspond to the movement of a crowd in a large space. Therefore, in order to reproduce the alighting and boarding behaviour of the passengers, the modeller must add many “functional areas” so that the simulation becomes realistic. Then, the modelling task is very tedious and the result of the simulation heavily depends on the way the environment is modelled.

In order to overcome this issue, we designed a new tool with a strict separation between the spatial representation of the environment (that is the geometry of the train and the platform) and the behaviour of the passengers. Our study focuses on the alighting and boarding process subject to several environmental variants: width of the door, height of the platform, presence of steps, arrangement of the seats…

The train editor is used to model single or double-decker coaches in 3D and provide facilities to arrange seats and locate other train interior components (that are stored in a library). A similar editor is provided to model the platform.

The simulator is based on a specialized software library developed by GOLAEM that provides functionalities to simulate complex human behaviours through a programming language. For example, boarding passengers choose their position on the platform according to the position of the doors of the train but their behaviours are balanced by their willingness of boarding (which depends on the density of people) and their education (most people leave space for alighting passengers).
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Observation of passengers' behaviours during alighting and boarding and their usage of the different train and platform area have been collected on-site for different stations and different train architectures. These qualitative data completed with quantitative ones (dwelling time, speed of alighting and boarding) allow the calibration of the simulator. This simulator will be used in the future by SNCF to evaluate rolling stock and platform design performance in terms of flow efficiency.

Section 2 presents a literature study that explains the choice of our modelling approach. Our behavioural model is details in Section 3 and preliminary experimental results are shown in Section 4.

2. State of the art

As surveyed in a report of the Rail Safety and Standards Board (2003), there exist several commercial off-the-shelf software tools that simulate pedestrian movement in public facilities: BuildingEXODUS (Fire Safety Engineering Group), EGRESS (AEA Technology plc), Legion (Legion International Ltd.), MYRIAD (Crowd Dynamics), PAXPORT (Halcrow Group Ltd.), SIMULEX (Integrated Environmental Solutions Ltd.), STEPS (Mott MacDonald) and TermSIM (Airport Research Center GmbH). Other popular tools can be added to this list such as SimWalk (Savannah), Vissim (PTV). The capabilities of these tools to fit our requirements have been evaluated.

In the recent years, the tools have become useful decision support tools for architects and designers in order to optimize the location and the size of stairs, corridors or any new facility when a public building is designed or upgraded. Simulating flows is also very instructive when a public venue is partly closed for renovation in order to share the space between the public and the construction zones. Another current application is the simulation of pedestrian crowds in evacuation situations in order to assess the safety of buildings such as stations, airports or stadiums (Helbing et al., 2002).

In all these generic tools, the behaviour of the people is quite simple. By default, each pedestrian wants to go from a starting point to a target point following an “optimized” path. However, such behaviour is not fit for our purpose because the behaviour of the passengers is very special in the dwelling time. For example, boarding passengers mostly let the alighting passengers leave the train before they go aboard. Moreover, the gap crossing between the platform and the train must be carefully modelled. The models built with pedestrian simulation tools can be tuned with the help of “functional areas” in order to modify, slow down or speed-up the paths of the people. However, from our experience, such an approach is very difficult for our aim because it requires a lot of such “areas”. Moreover, the outcome of the simulation is very related to these areas, their size and the associated parameters and can not be simply predictable for another train configuration. By contrast, in our approach, the model is only an objective description of the physical environment and is completely separated from the behavioural model. Therefore, different train designs may be more efficiently and more objectively compared.

In the literature, special attention is devoted to the modelling for the alighting and boarding process and for the calculation of dwelling times. Wiggenraad (2001) analyses data collected at seven Dutch railway stations and concludes that the alighting or boarding time per passenger is about 1 second and that larger doors reduce this time. Based on data collections, statistical models can be built using regression methods. Very recent models are proposed by Buchmueller et al (2010) in cooperation with the Swiss Federal Railways (SBB) and by Chengxiang et al (2009).

The statistical models have a limited number of parameters, typically the number of passengers or the size of the doors. Simulation-based models use a more detailed description of the environment and are therefore more relevant to describe the influence of the location of seats, bars or stairs in the train or on the platform. Qi et al (2008) propose a simple cellular automata model that is improved by Chi et al (2010). The simulation model is based on a division of the space into square cells in which there is at
most one pedestrian, which is a very strong assumption. For example, the width of the door is exactly equal to the length of three sides of the square cells. By contrast, our model is continuous, which means that the coordinates of the simulated agents are real numbers.

As above-mentioned, the modelling of the gap crossing between the platform and the train is very important. Daniel and Rotter (2009) analyse the risks caused by this gap and propose an observational study of the passengers boarding trains. Fujiyama and Tyler (2010) study regression models to estimate the walking speed on stairs. They consider several parameters related to the person (weight, height, the leg extensor power) and to the stair (gradient, riser height, tread depth), calibrate of the model with their own measures and compare it to other models and studies. Fernandez et al (2010) propose a laboratory study in view of application to the bus case.

Biomechanics-based models, in which the gait of each pedestrian is precisely described, could be very useful for our problem. They are very popular for game and animation applications and some research work are dedicated to climbing and descending stairs (Wu and Popovic, 2010). However, simulating the gait of hundreds of interacting pedestrians requires too much CPU time and is too expensive for the purpose of our project. Therefore, our model is based on a trade-off between simulation and statistics in which

- the pedestrians are represented by their coordinates and orientation,
- the free individual speeds are calibrated by statistical models,
- the real speeds are derived from the behavioural model.

3. **Our model**

3.1 **Behaviors**

The population of passengers is decomposed into 4 different behavioral groups:

- Passengers present on the platform staying there to wait for another train;
- Passengers present on the platform wishing to get in the train;
- Passengers on board of the train wishing to get off the train;
- Passengers on board of the train wishing to stay in.
Those groups of passengers are performing different activities but can share some of them, as illustrated in figure B. To model those passenger behaviors, we are using Golaem Activity which is an authoring tool allowing to model cognitive activities and to connect them to low level actions performed by passengers.
3.2 Navigation

To manage the reactive navigation, which means the way each passenger will avoid obstacles and other pedestrians on its journey, we are mixing different algorithms depending on the context. Indeed, each algorithm has its validity domain and is not suited to manage all passenger interaction configurations. Inside the train, density is higher and collision avoidance possibilities are scarcer, so we use a predictive collision avoidance algorithm mixed with the Social Force Model. When getting in/getting off the train, passengers switch to the Social Force Model only because we want them to be able to push other passengers and force the way through the crowd. To navigate on the platform, where there is plenty of space for collision avoidance, they will only need the predictive collision avoidance algorithm.

3.3 Description of the passengers activity

Passengers getting off the train have an initial placement in the train that can be either seated, standing up in a corridor, in stairway, near a grabbing bar or a door. They stay at their place until the train approach their destination. When the train approaches the train station, passengers will progressively leave their place to reach an exit door. The choice of the door is done individually depending on different criteria (distance to each door, density of people on the way). When the train is stopped, passengers should leave the train. If needed, one of the passengers should activate the opening of the door and wait for the complete opening. The alighting time depends on different parameters (stair height, length, individual speed). When reaching the platform, each passenger has to choose an exit (if not already known) and reach it. The rate of each exit can be configured depending on its configuration (depending on the width of stairs for example).

Passengers wishing to get in the train will be initially located somewhere on the platform, waiting for the train approach. The distribution of population on the platform can be configured differently depending e.g. on the weather conditions. When the train is approaching, passengers are starting to move to reach a door of the train. However, the estimation of the location of the door is not easy while the train is still
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Moving. The door selection is done individually and will start very late when the train is almost stopped. When the door is chosen, passengers are moving toward its area.

Figure D: (a) ongoing passengers wait near the door before entering the train (b) two different behaviours in the Simulator for the ongoing passengers.

When the passenger is located in the area allowing it to get in the train, he still has to decide to do it and this decision will depend on different criteria: number and density of people still getting off the train, time since the train stopped, politeness. (cf figure D). When the signal announcing the closing of the door is ringing, individual stress of passengers will increase and they will become less polite.

Once in the train, each passenger has to choose its place amongst unoccupied ones. Passengers may have preferences on where to seat in the train. As shown on figure E.a, one criterion is the moving direction (red triangle for concerned passengers); a second one is the social distance: in a block of seat, sit down on the seat farthest of the already sat person (yellow line for concerned passengers). A third criterion is the distance of the exit. All those behaviors have been implemented and can be balanced, as illustrated in figure E.b. Several passengers may compete for the same seat, and if the chosen seat has been taken by another passenger, the passenger will have to choose another one. When there is no seat still available, a passenger will choose an area to stay upright.

Passengers who are staying in the train may have to move from their current place when the train is approaching a station to let other passengers reach the exit. They can search for an empty seat before other passengers get in the train. If they are located near an exit and cannot move inside the train to a place which is not in conflict with passengers that are getting off the train, they will have also to get off, wait near the door and reenter the train.

Passengers who are staying on the platform should avoid the location in the part of the platform concerned by the passenger exchange. If this is the case, they will move to a more quiet area and will stay there to wait for their train.
3.4 Cost/Decision functions

Most of the behaviors previously described are depending on the individual characteristics of each passenger. It is then necessary to express how each parameter will influence each behavior. For example, the behavior that consists in reaching a door to get off the train requires two parameters: the choice of the door and the time to start the behavior. Both parameters are linked together as the distance to the door has an impact on the determination of the departure time to reach it, and the departure time will also have an impact on the choice of the door as the density of population in the different parts of the train is evolving. Thus another notion is also important: the passenger’s anticipation. To sum up, a cost function (depending on the distance to the door and the density of population in front of this door) is used to evaluate which door is the most appropriate, then a decision function (parametrized by the distance to the selected door, the individual anticipation factor and the density of population in front of this door) is used to determine if it is the time to start the displacement to the exit. The same algorithm is used to compute all decisions made by the passengers. However the parameters taken into account may vary.

4. Experimental results

4.1. Software tool

This behavioral model was implemented in the simulation module of a complete software suite. This suite is also composed by a configuration editor and a result analyser.
The configuration editor is composed of several submodules. Two dedicated 3D modelers are respectively devoted to the design of coaches and platforms. They give the possibility to import existing 3D models or to build new ones. Each editor contains a catalog of objects and the users move and rescale these objects in the model with the mouse. Both 2D and 3D views are available. In a preprocessing phase, the simulator automatically computes the topological representation of the whose scene from the train and platform models. A functional tag, such as “door”, “seat”, “stair”, “bar” is assigned to most objects in the catalog. In the model, these tags have a direct impact on the behavior of the passengers. Conversely, untagged objects are interpreted as obstacles.

The configuration of a simulation also consists in defining the population size, distribution and characteristics (age, diameter, comfort speed, mobility capabilities). The simulator generates the population, and configure each individual passenger with its own behavior and objectives. A log file is used to record at each time step all the result material that will be used after for replay and data analysis.

The simulation analysis module is dedicated to build statistics tables and graphs from the simulation. In particular, it computes the number of passengers that have entered or left the train for each time point of the simulation, for each door and for each coach.

4.2. Calibrating the simulator

The simulation model contains several parameters for each class of passengers which are used by the preprocessor to populate the model (speed, size, aggressiveness, time to cross the vertical and horizontal gaps).

A first calibration of major parameters has been done by using data from the literature like speed to come up stairs. Figure G shows the results of simulations using these first basic calibration compared to data obtained in a station in Paris suburb by counting exchange time at doors for several trains. Comparison is encouraging.
A more complete experimental campaign has been recently carried out. Different train and platform configuration have been chosen to allow the evaluation of major parameters on the flow (width of doors, height of vertical gaps, effect of grabbing bars, position of stairs for double-decker trains, ...). Observation of passengers' behaviour have also be done for as shown in figure H. Exploitation of these results will improve the calibration of passengers' behaviour in the tool.

5. Conclusion

The article has presented a behavioral model and a simulation software suite dedicated to the evaluation of the dwelling times for trains. The main innovation in our approach is the complete separation between
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the environmental 3D model that contains both trains and platforms and the behavioral model of the passengers. With such a separation, it becomes easier and faster to model because the end-user does not have to care about any “functional area” to model the behavior of the passenger. Even more interestingly, the influence of the train design (and especially the size of the doors and the layout of the seats) is more fairly evaluated because the behaviour of the passengers does not depend on “modeling tricks”. This simulation software will be used tomorrow by the rolling stock department of SNCF as a decision aid to evaluate new train proposal and then improve train operation in dense areas and passenger’s comfort.

6. References


