

The Possible Use of Evacuation Modelling Tools for the Rolling Stock

Guillaume CRAVEUR¹, Patrick GUYET²

Summary

Evacuation modelling technology offers designers and regulators of train new opportunities to rigorously test designs and theories in order to improve the passengers' safety. This paper deals with the opportunity to use these tools for the railway industry.

The FDS+Evac and buildingEXODUS softwares are used to model and simulate the evacuation of rolling stock. Firstly, in order to demonstrate the reliability of these tools to calculate the complete evacuation time, a comparative study was achieved between a real test, simulations done with FDS+Evac and simulations done with buildingEXODUS. Multiple simulations are performed to capture the stochastic variations in egress times. The philosophy of this comparative study is to realize the real test in one hand, and to use evacuation modelling tools with the incoming data (population, train geometry, initial position of the people, and known characteristics of the population) of the real test in another hand. The goal is not to stall the simulations results with the real test but to analyze the results of calculations by themselves.

The following study highlights the interest of using evacuation modelling for the railway industry and shows their reliability in order to satisfy the TSI RST HS 2008/232/CE and the future TSI LOC&PAS. A confrontation „modelling – full-scale test” is presented and analysed.

Keywords: evacuation, modelling, FDS+Evac, building EXODUS, safety

1. Context

Evacuation modelling technology offers designers and regulators of train new opportunities to rigorously test designs and theories in order to improve the passengers' safety. However, before evacuation modelling can be used effectively it needs to be understood by the regulatory and train industry and validated. This work has been already done by the maritime industry. Indeed, the IMO in Guidelines for evacuation analysis for new and existing passenger ships (MSC / Circ.1238)

¹ Fire Safety Engineer; Rolling Stock Engineering Centre; France.

² Fire Safety Expert; Rolling Stock Engineering Centre; France.

presents the method to determine the travel time by simulation tools for the advanced evacuation analysis and the guidance on validation / verification of evacuation simulation tools. This paper deals with the opportunity to use these tools for the railway industry.

The FDS+Evac and buildingEXODUS softwares are used to model and simulate the evacuation of rolling stock. A brief description of these tools will be made later in this paper. Firstly, in order to demonstrate the reliability of these tools to calculate the complete evacuation time, a comparative study was achieved between a real test, simulations done with FDS+Evac and simulations done with buildingEXODUS. Multiple simulations are performed to capture the stochastic variations in egress times. The philosophy of this comparative study is to realize the real test in one hand, and to use evacuation modelling tools with the incoming data (population, train geometry, initial position of the people, known characteristics of the population) of the real test in another hand. The goal is not to stall the simulations results with the real test but to analyze the results of calculations by themselves.

The problems are important and are submitted to lawful requirements. European regulation (TSI RST HS 2008/232/CE) imposes: „The number of the doors and their dimensions shall allow the complete evacuation within three minutes by passengers without their baggage in a situation where the train is stopped alongside a platform. It is permitted to consider that passengers with reduced mobility are to be assisted by other passengers or staff, and that wheelchair users are evacuated without their wheelchair. Verification of this requirement shall be made by a physical test with a normal load as defined in clause 4.2.3.2 and under normal operating conditions”. The objective of the work presented below is to show that it is possible to replace the full-scale test imposed by the TSI RST HS 2008/232/CE by digital simulations of evacuation.

The following study highlights the interest of using evacuation modelling for the railway industry and shows their reliability in order to satisfy the TSI RST HS 2008/232/CE and the future TSI LOC&PAS. A confrontation „modelling – full-scale test” is presented and analysed.

2. Full-scale Test

A full-scale test was carried out around a TGV double deck on April 14th 2011 in Le Mans railway station in order to demonstrate the conformity of the evacuation time prescribed in the TSI RST HS 2008/232/CE. To validate the representativeness of this test, travelers were placed in coach TGV R8 (coach TGV which contains the most of passengers with 92 places) and half of the high room of coach TGV R7 (26 places). The full number of participants in this test is thus

of 118 people. The visualization of this train and the emplacement of the people are in the following picture (Figure 1).

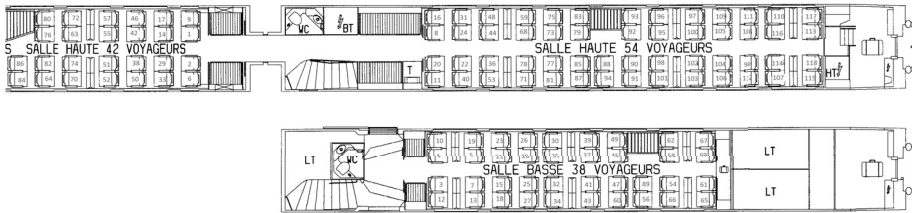


Fig. 1. View of the train and emplacement of people

The travelers of coach TGV R7 had the obligation to borrow the exit of coach TGV R8 to create a bottleneck starting from the top of the staircase to the door [1]. In order to represent as closely as possible this full-scale test, we had to analyze the incoming data. It was therefore necessary to identify each passenger who participates to this test so as to have corpulence and age in adequacy between the real test and modellings. In addition, it was necessary to know the initial position of each person in order to represent as closely as possible the initial configuration of the test. The output data is the total evacuation time which is 126 seconds.

3. Simulations With FDS+Evac

The study is only based on the incoming data which are the diagram of the TGV double deck and the panel of population who participate to the evacuation test. The goal is to use these data with an aim of obtaining an evacuation egress time using numerical simulations. FDS+Evac is the evacuation simulation module for Fire Dynamics Simulator (FDS). FDS+Evac is a combined agent-based egress calculation model and a Computational Fluid Dynamics (CFD) model. In this software, the agents egress is based on an assumption of continuous space and time, but the geometry of the train is fitted to an underlying rectilinear mesh [2].

The geometrical modelling of the high part of coach TGV R7 and coach TGV R8 is based on the creation of a mesh, i.e. by the space discretization of a continuous medium. The mesh created with FDS is copied on a Cartesian rectilinear grid. This rectilinear discretization and the use of the code itself imply the respect of different criteria [3]:

- objects to be modeled must conform to the grid,
- the grid must satisfy the constraint of the Poisson solver.

To find a space division which satisfies the whole of these criteria and also makes possible to represent accurately the geometry of the coaches (Figure 2), a study of sensitivity was conducted on the grid cells dimensions. The goal of this sensitivity study was to obtain the best compromise between the geometry, the computing time and the validity of the result.

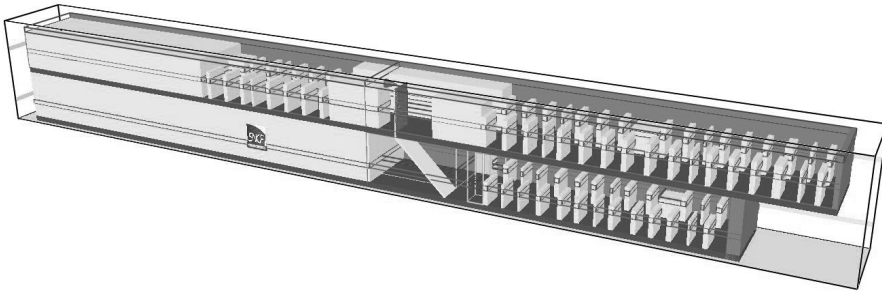


Fig. 2. Modeling of the train with FDS

However, although the model tries to be the most realistic, many assumptions were made. The first is relative to the coaches geometry. Indeed, the coaches are represented by parallelepipeds, which is an approximation especially on the level of the ceiling which is curved. This does not pose a concern because this assumption has no influence on the dynamic of evacuation under the respect of the criteria of the TSI RST HS 2008/232/CE. The mesh of the geometry would have to be more precise for a study on the tenability conditions in case of a fire. For the same reasons, overhead luggage racks are not modeled. The parts of the coaches where nobody is present and where nobody can go are not modeled, the associated space is then filled in the simulation data by what is called an obstruction. It permits to spare CPU time. In the simulation, the seats are present. But only the file of the seats is modeled because it constitutes the real obstacle at the evacuation which enforces the passengers to use the corridor. Otherwise, if the base of the seat is modeled, nobody can be located at this place in FDS+Evac, because it needs a minimum space on the ground in order to put a person. So, the base of the seat is not represented. However, the position of the files and thus the relative distance between two seats are correct. Another assumption made in the model concerns the width of the corridor. A constraint imposed by FDS+Evac is that spaces in which a person is allowed to circulate must be at least of 0.7 meters. However, the real corridors width is 0.45 meters. The width of the corridors is thus increased in order to satisfy the software constraint and permit the „numerical” people circulations. The corridor width increase imposes a decrease of the seats width as the coach width is fixed. It has to be noted that this assumption does not affect the dynamics of evacuation because the number of units of passage is not modified. An unit

of passage is the minimum width where a person can walk. As concerns the internal doors, the assumption is that they stay open during the evacuation test. Thus, they are not modeled. The staircase is defined with the command &EVSS. This command does not represent a real staircase but a ramp which allows defining coefficients of acceleration or slowdown for the people standing in the staircase are defined.

FDS+Evac treats each evacuee as a separate entity which has its own personal properties and escape strategies. The movement of the people is simulated using two-dimensionnal planes representing the floors. The basic algorithm behind the egress movement solves an equation of motion for each person in a continuous 2D space and time. The shape of the human body is approximated by a combination of three overlapping circles (Figure 3). R_p , R_d and R_s are the different radii which are used in FDS+Evac in order to determine the space occupied by a person.

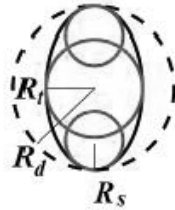


Fig. 3. Shape of the human body in FDS

Body dimensions and speeds travel are, by default, distributed randomly from a uniform distribution for each generated person. The method of Helbing's group is used as the starting point of the agent movement algorithm of FDS+Evac, where a so-called „social force” is introduced to keep reasonable distances to walls and other people [3]. FDS+Evac is based on the laws of mechanics to compute the trajectories of the people during the calculation. Each person follows his own equation of motion:

$$m_i \frac{d^2 x_i(t)}{dt^2} = f_i(t) + \xi_i(t)$$

Where:

- $x_i(t)$ – is the position of agent i at time t ,
- $f_i(t)$ – is the force exerted on agent i by the surroundings,
- m_i – is the mass,
- $\xi_i(t)$ – is a small random fluctuation force.

It is possible to choose the body type which is directly linked to the walking speed (Table 1).

Table 1

The body sizes and walking velocities of the people in FDS

Body type	R_d [m]	R_l/R_d	R_s/R_d	d_s/R_d	Speed [m/s]
Adult	0.255±0,035	0.5882	0.3725	0.6275	1.25±0.30
Male	0.270±0,020	0.5926	0.3704	0.6296	1.35±0.20
Female	0.240±0,020	0.5833	0.3750	0.6250	1.15±0.30
Child	0.210±0,015	0.5714	0.3333	0.6667	0.90±0.30
Elderly	0.250±0,020	0.6000	0.3600	0.6400	0.80±0.30

It is possible to generate randomly all the population but in our case it is not good to use this method because we want to impose the real localization, age, gender of the full-scale test population. Concerning the reaction time, it can be imposed, i.e. it is possible to define an interval of time in which we want the people begin to evacuate. In our case, this time is imposed at 0 second, it means that people will move directly in order to reproduce what has been done in the real test.

In order to place numerical people in the coach, we have to use „evac boxes”, which are areas where you can put people at the beginning of the simulation. For each people, you can choose the orientation the person will have in the „evac box”. By default, the orientation of each person is randomly chosen. Here, for each person, we define an orientation, which corresponds to the orientation of the seat occupied by this person. So, people are oriented in our case at an angle of 0° or 180° according to the length of the coach.

4. Results With FDS+Evac

Due to the fact that FDS+Evac uses stochastic properties for the people characteristics and for the initial localization of the people, a lot of simulations have to be completed. Here, 100 simulations have been performed. With 100 simulations, the convergence of the results is well-defined and it is possible to make a statistical study. The average time of evacuation for these 100 simulations is 131 seconds. For recall, the evacuation time monitored during the real test is 126 seconds. Thus, the average variation with the real test is 4%, the maximum variation with the real test is 14,3% and the minimum variation with the real test is 0% (it corresponds to a time of 126 seconds). These results will be discussed later.

On the following picture (Figure 4), we can see the modelling realized with FDS+Evac. It shows the initial location of people in the coaches. Women are in red and men are in yellow.

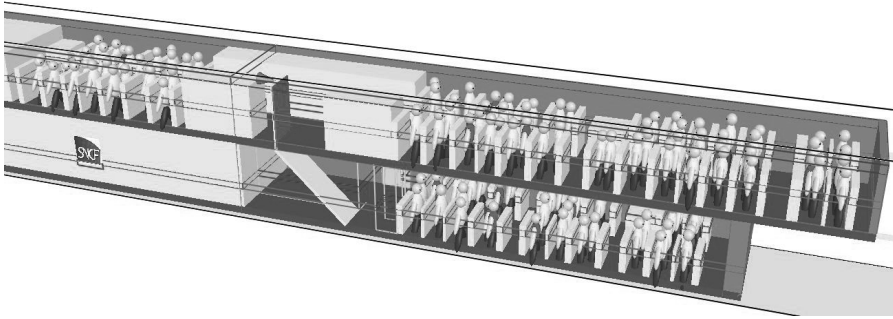


Fig. 4. Geometry and localization of the people in the modeling made with FDS+Evac

5. Simulations With BuildingEXODUS

The software computes the trajectory of each person according to the path of evacuation which they chose to borrow at each step time. The geometry and the grid defined in buildingEXODUS is well adapted to the real coach geometry. In buildingEXODUS, the entire space of the geometry is covered with a grid of nodes which are generally spaced by intervals of 0.5 meters. At any time, only one person can occupy one node. It implicates a conflicts management based on several parameters like the traveling time, the parameter „drive” which measures the capacity for a person to win a node against another, etc...

There are different types of nodes: „free space nodes” which allow unhindered movement and represent unobstructed horizontal terrain, „seat nodes” which represent seating area and either force occupant to engage in hindered movement, „stair nodes”, „external exit nodes” [4] for those which interest us. A person can pass from one node to one of the neighborhood nodes connected by arcs. The arcs have a physical length, i.e. the distances between all the nodes are the real distances of the geometry. Moreover, arcs have a specific parameter called „obstacle” which defines the difficulty of passing from one node to the other. The walking speed on an arc is then defined by the value $Walk / Obstacle$ where Walk is the speed of standard walk of a person. Therefore, more the value of the parameter obstacle is high (it is the case for arcs between seats) more the time to pass from one node to the other is important. The localization of the various nodes has to be representative of the possible ways followed in the trains (Figure 5).

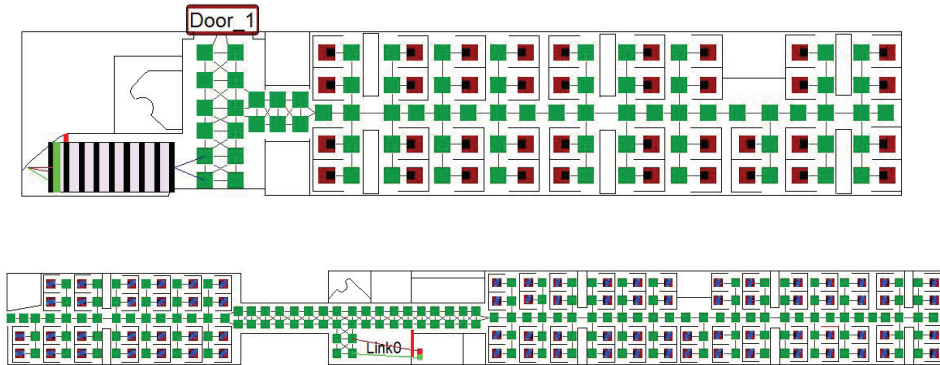


Fig. 5. Modelling realized with buildingEXODUS

Indeed, there can be one maximum occupant in the width of the corridor like using the exit door. The units of passage are respected in all the sites of the train. Concerning the modelling of the staircase, it is made via a specific tool (Figure 6).

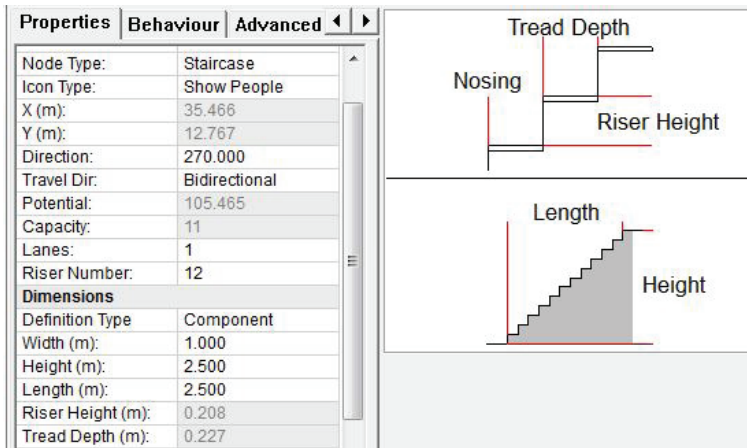


Fig. 6. Modelling of the staircase in buildingEXODUS

Thus, the staircase modeled is representative of the real staircase with a full description of the stairs (length, height, the number of steps...). Among a large number of modifiable parameters (Figure 7), only the gender, the age, the weight and the size of each person were fixed with respect to the real people. All the others parameters are randomly defined according to the previous parameters and the associated databases.

Fig. 7. Parameters for each person in buildingEXODUS

The vrEXODUS tool is used in order to see 3D representation of the evacuation (Figure 8). On the following picture (Figure 9), it is the modelling realized with buildingEXODUS. It shows the congestion in front of the door during the evacuation.

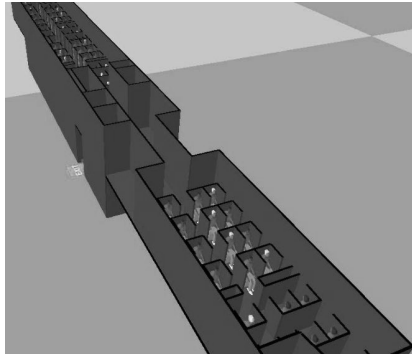


Fig. 8. Representation of the modelling in vrEXODUS

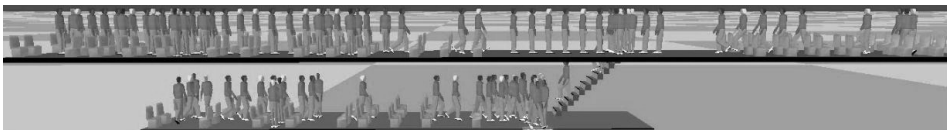


Fig. 9. View of the congestion in front of the door during the evacuation

6. Results With BuildingEXODUS

The results being able to vary from a simulation to another because of the randomness of many parameters, one hundred simulations were carried out to compare with the FDS+Evac results. The average time of evacuation for these 100 simulations is 124,7 seconds. For recall, the evacuation time of the real test is 126 seconds. Thus, the average variation with the real test is 1%, the maximum variation with the real test is 3,9% and the minimum variation with the real test is 0% (it corresponds to a time of 126 seconds). These results will be discussed in the next paragraph.

7. Comparison of Results

We saw that very good results were obtained. The following graph (Figure 10) shows all the simulation results obtained with the tools FDS+Evac, building EXODUS and the full-scale test.

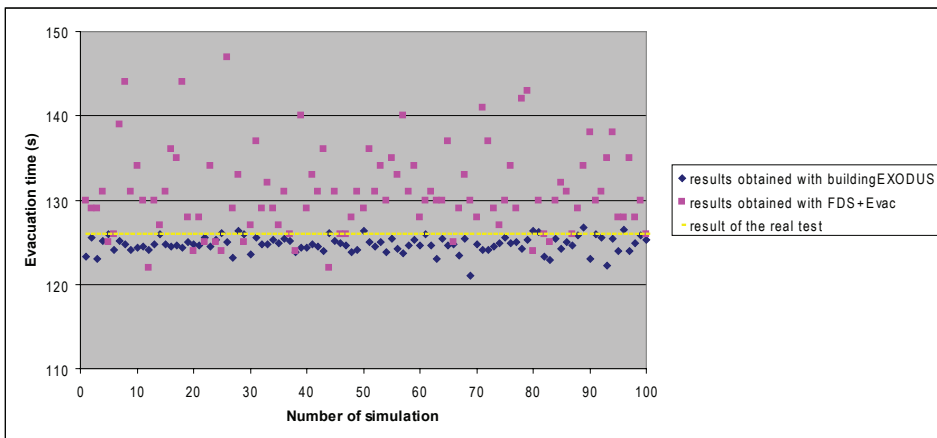


Fig. 10. Presentation of the results obtained

We can see on that graph that we have two different results according to the software used. Indeed, the results obtained by buildingEXODUS and plotted in blue are almost under the result of the real test while the results obtained by FDS+Evac in pink are almost above the result of the real test. However, which is important here is the fact that all the results are close to the real test evacuation time. The standard deviation is used to measure the dispersion of a data set. The weaker it is, the more the values are gathered around the average. The results

obtained with buildingEXODUS have a standard deviation equal to 0.95 whereas results obtained with FDS+Evac have a standard deviation equal to 5.04. This point shows that besides having a better average time of evacuation, buildingEXODUS has a weaker standard deviation. This point is due to the difference between the CFD model of FDS+Evac and the «node-to-node» system of buildingEXODUS which is less permissive. Another point which can be compared is the calculation time. The average calculation time for each of the 100 simulations made with FDS+Evac is around 713 seconds whereas the average calculation time for each of the 100 simulations made with buildingEXODUS is around 7 seconds on the same computer.

8. Conclusions / Prospects

These results obtained from the numerical study achieved by the CIM show that a very good agreement was obtained between the two softwares which are buildingEXODUS and FDS+Evac. Moreover the evacuation times performed by simulations are very close to the time monitored during the real evacuation test. It seems that for this application, buildingEXODUS allows nevertheless to have better results, with a better reproducibility.

Otherwise, the acceptability criterion of TSI RST HS 2008/232/CE which imposes the complete evacuation under three minutes of the rolling stock is satisfied. So, the correlation between experimental data and simulations makes possible to validate the use of evacuation modelling in order to fulfil the requirements of the TSI RST HS 2008/232/CE.

Finally, this study shows advantages of evacuation modelling which allows realizing a lot of different simulations by changing the incoming data and which is less expensive than a real scale test (it does not need the immobilization of a train, hundreds of volunteers and a platform of station) which does not give any information about average time and standard deviation.

To note that in the case of an invitation to tender, the numerical simulation makes possible to test upstream if the specifications are respected. Thus, it will be possible to compare diagrams during the design phase of the project. Moreover, with these tools, it is possible to compare train's architecture, to compare the evacuation time in function of the population, to simulate the evacuation with or without luggage, to simulate panic movement, to simulate fire propagation with the effects of smoke, heat. All those items have an influence which obviously can not be really tested but which can be computed, which is a main advantage of numerical simulation. Specialized tools exist nowadays and have reached an important level of reliability. Some of them are of general purpose so are used in various fields (aeronautics, naval industry, civil engineering and building

industry). Very high level trainings are now available for engineers already familiar with numerical simulation, especially in the field of CFD and finite element simulation for mechanical structures.

The numerical results the CIM got could have important implications for rail safety because the application of evacuation modelling could supplant a part of the real tests imposed by the regulations. The work to do now is to achieve others real evacuation tests (with others populations, trains, platforms) and compare them to simulations. If, in any case, the simulation time is very close to the real evacuation time, we could imagine that we can restrict the real tests and use the evacuation modelling as a viable tool to satisfy the criteria of the TSI RST HS 2008/232/CE.

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