U.S. Department of Transportation
Federal Railroad Administration

RESEARCH RESULTS
FRA OFFICE OF RAILROAD POLICY & DEVELOPMENT

RR 15-35 | October 2015

Passenger Rail Car Egress Computer Model

SUMMARY

The Office of Research, Development, and Technology of the Federal Railroad Administration (FRA) is investigating ways to enhance regulatory requirements that address the safe, timely, and effective evacuation of occupants from passenger rail vehicles in various emergency scenarios. Several evacuation concepts, strategies, and techniques are currently being investigated and evaluated for applicability to U.S. passenger rail cars.

FRA is also interested in determining the feasibility of applying performance-based emergency evacuation time-based requirements to passenger rail cars. The requirements would be similar to minimum evacuation times specified by the Federal Aviation Administration (FAA) (e.g., 14 CFR Part 25.803 stipulates as part of its certification process that occupants can be evacuated within 90 seconds).

However, it is necessary to assess how long it would take for passengers to egress from passenger rail cars to different locations using exit designs and configurations present in the unique railroad-operating environment. Therefore, FRA provided partial funding to the Fire Safety Engineering Group (FSEG), University of Greenwich, United Kingdom, to develop a new prototype railEXODUS® software model that is designed to accurately predict passenger rail car egress times for a variety of emergency scenarios.

BACKGROUND

With the exception of the FAA 90-second requirement for aircraft emergency evacuation, U.S. regulatory agencies do not currently mandate evacuation times for passengers and crews from public transportation vehicles. This is because of numerous variables, such as vehicle configuration, number of passengers, and the operating environment, which affect the length of time necessary for passengers and crew to leave a public transportation vehicle in an emergency evacuation.

Review of past passenger train accidents identified several issues in emergency evacuation situations that influence the way in which individuals will behave and the resulting human dynamics. For example, the flow rate of occupants traversing passenger rail car door exits will be affected:

- If side-door exits are used, where the vertical drop may vary from no distance (high-platform) to several feet (m) down to the right-of-way (ROW), or egress is through inter-car end-door exits to an adjacent car; or
- If low levels of visibility exist due to smoke, dust, and failure of emergency lighting, all of which may hamper individual and group movement.

In addition, passenger rail car design-specific features, such as aisle and exit widths; movement rates along passenger rail car aisles; the presence of obstacles such as baggage; and passenger exiting behaviors, etc., all affect passenger egress speed.

Currently, the only way to validate passenger rail car occupant egress time prediction is to conduct actual simulated emergency evacuations or egress experiments. However, such demonstrations have significant cost, as well as safety and health risks, including slipping, tripping, and/or falling by the participants.

Accordingly, the use of computer models that simulate egress behavior could reduce the number of actual evacuation tests that need to be performed to determine egress times for various passenger rail car designs.

Furthermore, using an egress computer model, rather than hand calculations, may permit many more passenger rail car emergency egress designs to be evaluated in a far shorter time period and at less cost.

FRA provided partial funding to the Fire Safety Engineering Group (FSEG), University of Greenwich, United Kingdom, to develop a new prototype railEXODUS® software that has the capability to estimate U.S. passenger rail car egress times for various types of door exits under different conditions, such as low-level or non-existent emergency lighting. This new software depicts and illustrates how passengers behave when exiting from a passenger rail car under varied scenarios and the resulting human dynamics unique to the passenger train-operating environment [1].

EXODUS®

EXODUS® is a suite of software tools designed to simulate the evacuation and circulation dynamics exhibited by large numbers of persons within complex enclosures, such as high-rise buildings and underground transportation stations (buildingEXODUS®); transportation vehicles, including aircraft (airEXODUS®); and ships (maritimeEXODUS®).

The EXODUS® software takes three types of interactions into consideration:

- People-people,
- People-structure, and
- People-fire.

The EXODUS® software is written in the C++ programming language and uses object-oriented techniques and rule-based technology to control the simulation. Therefore, the behavior and movement of each agent (occupant) is determined by a set of heuristics or rules. For additional flexibility, these rules are categorized into five interacting submodels: **OCCUPANT, HAZARD, MOVEMENT, BEHAVIOUR,** and **TOXICITY** (see Figure 1).

These submodels operate in a region of space defined by the **GEOMETRY** of the enclosure. The EXODUS® software is able to track the route of each occupant as he or she moves around the enclosure **GEOMETRY**.

In evacuation applications involving fire, the software can also predict when occupants will be affected by fire hazards such as heat, smoke, and toxic gases.

EXODUS® produces a range of outputs, both graphical and textual.

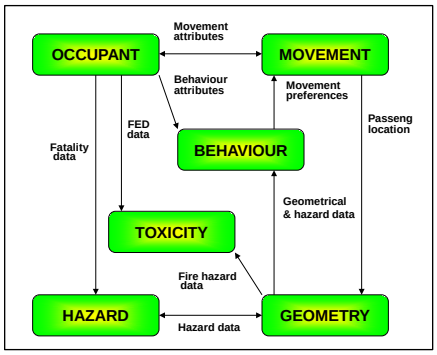

Figure 1. EXODUS® Component Interaction

APPLICATIONS

A wide range of potential applications exist for the validated prototype railEXODUS® software for passenger rail car egress:

- **Design Applications**. Passenger rail car design engineers could use the software in the early stages of design to optimize the level of evacuation safety built into new vehicles. For example, the location, type, and number of exits could be evaluated.
- **Regulatory Applications**. Regulatory agencies, in consultation with industry groups, could use the software to define performance-based evacuation requirements for different types of railroad-operating environments.
- **Certification Applications**. Industry groups could use the software to determine whether new passenger rail car designs comply with performance-based egress requirements.
- **Passenger Train Crew Training and Emergency Management Aid**. Passenger train operating agencies could use the software (with its virtual reality graphical capabilities) as an aid in the evacuation safety training of crews. The software could also be used to assist these agencies in the development of operating procedures for passenger train emergency scenarios. In addition, the software could help emergency response organizations plan their response to such situations.
- **Accident Investigation**. Accident investigators could use the software to assist in the analysis of train accidents and other emergency situations.

- **Normal Operations**. Passenger rail car design engineers, train operating agencies, and station managers could use the software to simulate normal operations, including the train-station interface and the efficiency of passenger disembarkation.

NEW railEXODUS® PROTOTYPE SOFTWARE DEVELOPMENT

FSEG previously developed a prototype passenger rail car railEXODUS® egress software. However, this software did not consider the behavior of passengers exiting under all of the unique conditions and circumstances of the railroad-operating environment, such as egress from a passenger rail car to a low-platform location or the ROW; or egress from a rail car at an adverse inclination.

To generate realistic egress time predictions of for passenger rail cars, the new prototype railEXODUS® software is able to simulate occupant egress for a variety of emergency scenarios, and is capable of addressing how rail passengers behave and the resulting human dynamics [1].

Data Analysis

To characterize the egress performance of individuals in the actual U.S. passenger train operating environment, the new prototype railEXODUS® software incorporated data from 2005 and 2006 egress experiments conducted by the John A. Volpe National Transportation Systems Center (Volpe Center) using upright commuter rail cars under normal and emergency lighting conditions [2].

The data include interior aisle occupant travel speeds and flow rates through the various exits, as well as occupant exiting behaviors.

In addition, passenger car geometry data were derived from commuter rail car drawings provided by Volpe Center.

New railEXODUS® Prototype Software Capabilities

From a modeling perspective, passenger rail car emergency egress environments and scenarios share many similarities with egress situations in the building, maritime, and commercial aviation environments.

Accordingly, a simulation tool capable of modeling passenger train emergency egress situations would share many of the basic capabilities of the airEXODUS®, buildingEXODUS®, and maritimeEXODUS® models, which:

- Represent space and time;
- Represent the target population of occupants and their movement capabilities;
- Modify the movement rates of individuals in crowds;
- Represent main behavioral responses such as overtaking capabilities, exit selection, occupant response times, etc.; and
- Incorporate fire data into the evacuation simulation and determining the impact of fire products (e.g., toxic gases and heat) on the exposed population.

The original prototype railEXODUS® software was expanded to incorporate the capability to simulate occupant egress from U.S. passenger rail cars for the following types of scenarios:

- Exit from one or two side doors onto high platforms in normal or emergency lighting conditions;
- Exit from one or two side doors in normal lighting conditions to:
  - Low-platforms, and
  - ROW;
- Inter-car end-door exit into the adjacent car in normal or emergency lighting conditions; and
- Movement of passengers in car aisle subjected to adverse angle of roll.

Figure 2 shows an example of the passenger rail car egress routes as modeled in the new prototype railEXODUS® software.

Figure 2. railEXODUS® – Egress Routes

Figure 3 illustrates the virtual reality (vr) feature of the new railEXODUS® prototype software.

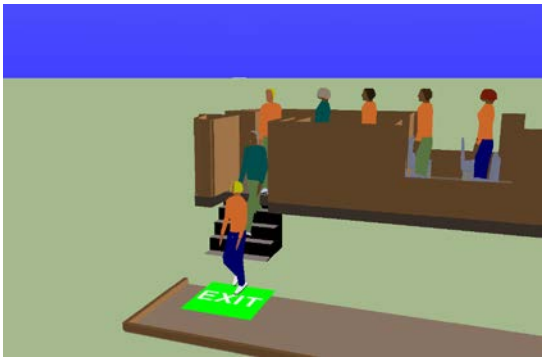

Figure 3. railEXODUS® vr – Egress to Low Platform

Validation and Verification

As part of the validation and verification process for the new prototype railEXODUS® software, the distribution of numerical predictions for the time occupants took to traverse the various exits were directly compared with those measured in the Volpe Center egress experiment trials. Using the average exit time from multiple computer simulations, the predictions were within 10 percent of the egress trials in all cases.

The new prototype software was also verified for adverse angle of roll egress time predictions for passenger rail cars. However, it was not possible to validate the software simulations for those egress times because the only available adverse angle egress data were from maritime egress experiments.

The new prototype railEXODUS® software is currently in "alpha" version, since it has only undergone in-house testing by FSEG and has been subjected only to limited external third-party "beta" testing.

For information on licensing railEXODUS, contact:

Professor Ed Galea, PhD
Director
Fire Safety Engineering Group
University of Greenwich
Old Royal Naval College
30 Park Row
Greenwich SE10 9LS
London UK

RELATED RESEARCH

See also Research Results RR06-06, RR06-07, and RR11-23.

Volpe Center staff have entered numerous U.S. passenger rail car designs into the new prototype railEXODUS® software to develop egress time predictions for a variety of passenger equipment.

Volpe Center staff have also conducted egress demonstrations for FRA, the railroad industry, and other participants that included exiting under different angles of rail car inclination, as well as under darkness and smoke conditions, with the Rollover Rig Evacuation Simulator.

REFERENCES

[1] Galea, E.R., et.al. *Passenger Train Emergency Systems: Development of Prototype railEXODUS Software for U.S. Passenger Rail Car Egress.* Final Report. Prepared by Fire Safety Engineering Group, University of Greenwich (United Kingdom) for FRA/U.S. DOT. DOT/FRA/ORD-14/35.

[2] Markos, S.H. and Pollard, J.K. *Passenger Train Emergency Systems: Single-Level Commuter Rail Car Egress Experiments*. Prepared by Volpe Center for FRA/U.S.DOT. Final Report. Report no. DOT/FRA/ORD-15/04

CONTACT

Melissa Shurland
Federal Railroad Administration
Office of Research and Development
1200 New Jersey Avenue, SE – Mail Stop 20
Washington, DC 20590
Tel: (202) 493-1316
Melissa.Shurland@dot.gov

KEYWORDS

Emergency egress, egress time modeling, egress time prediction, evacuation, passenger train, passenger rail, passenger train emergencies