U.S. Department of Transportation
Federal Railroad Administration

RESEARCH RESULTS
FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

RR 22-27 | **September** 2022

TRAIN-TO-TRAIN IMPACT TEST: WHEELCHAIR SECUREMENT EXPERIMENTS

SUMMARY

Researchers crash-tested off-the-shelf wheelchair securement devices in a train-to-train impact test at the Transportation Technology Center (TTC) in Pueblo, Colorado, on August 11, 2022. Two wheelchair securement devices and one backboard (baseline experiment) were each tested with a Hybrid III 50th percentile male (H3-50M) anthropomorphic test device (ATD), i.e., a crash test dummy, seated in a wheelchair.

Figure 1 shows the train-to-train impact test. The moving consist housed the three occupant experiments inside two passenger railcars behind the leading locomotive of the moving consist, which was equipped with a retrofit crash energy management (CEM) system [1]. The passenger railcar immediately behind the CEM locomotive contained Experiment 1, and the trailing passenger rail car contained Experiments 2 and 3.

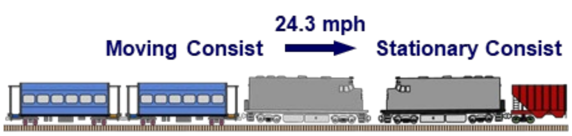

Figure 1. Train-to-Train Impact Test

The main objective of this test program was to evaluate the effectiveness of off-the-shelf securement systems from transit buses in protecting wheelchair occupants in a passenger train collision. As a starting point, researchers used safety performance criteria already used for passenger rail seats [2] and workstation tables [3] to evaluate the performance of the wheelchair securement systems. The performance criteria include requirements for structural integrity, attachment, occupant compartmentalization, and occupant injury.

BACKGROUND

In a train collision, a secondary impact occurs when an unrestrained occupant launches from its initial position and impacts an interior structure. Depending on the deceleration of the train during the collision and the interior configuration, secondary impacts can cause significant injuries and fatalities. Rapid deceleration of the train and a long travel distance for an occupant can result in a high secondary impact velocity (SIV).

Through accident investigations, the Federal Railroad Administration (FRA) has identified rigid, low-back seats and thin, rigid workstation tables as causal mechanisms of secondary impact injuries. It has funded research to develop seats and tables that improve compartmentalization and minimize secondary impact injuries. Compartmentalization is an interior design strategy that aims to contain occupants between rows of seats or between seats and tables during a collision, preventing occupants from traveling over seats or tables and impacting other passengers and hazardous objects. FRA has also worked with the rail industry to develop improved regulations and safety standards for seats and tables to better protect train passengers from secondary impacts with seats [2] and tables [3].

Train passengers seated in wheelchairs may be exposed to greater hazards. They require larger spaces to maneuver, which can lead to higher secondary impact velocities in an accident. Wheelchairs can also be hazards for other passenger train occupants, since some power wheelchairs can weigh as much as 600 lbs. An unrestrained wheelchair can act like a heavy projectile during a train accident, compounding the secondary impact forces experienced by a passenger. Effective securement of wheelchairs and compartmentalization of passengers seated in them can improve collision safety for all passengers. Currently, there are no requirements for wheelchair users, or the wheelchairs themselves, to be restrained while riding on passenger railcars.

OBJECTIVES

1. Test three off-the-shelf wheelchair securement devices in a train-to-train collision as a proof-of-concept.
2. Evaluate the performance of the securement devices with regards to human injury, compartmentalization, structural integrity, and attachment per the APTA seat [2] and workstation table [3] safety standards.

METHODS

In the train-to-train impact test, a CEM locomotive pulling two passenger rail cars impacted a standing conventional locomotive backed by two hopper cars at 24.3 mph. Inside the moving passenger railcars, researchers conducted three wheelchair securement device experiments. For each experiment, they seated a H3-50M in a wheelchair. Researchers wanted to use rigid surrogate wheelchairs (SWCs) meeting RESNA WC-4, Section 18 [4] in all experiments, but were only able to acquire two SWCs for the test. A commercially available lightweight wheelchair was used in Experiment 1 because the wheelchair was not actively restrained and therefore did not need to be rigid.

Researchers instrumented the railcars and H3-50Ms to collect data during the test. They also recorded each occupant experiment using overhead and side-facing, high-speed video cameras.

- **Experiment 1** was a baseline experiment using a rear-facing backboard with no active restraint (i.e., securement). Researchers seated a H3-50M in a lightweight folding wheelchair (Quickie QXi). Figure 2 (left) shows the pre-test setup of Experiment 1.
- **Experiment 2** used a Q'Straint Quantum securement system consisting of a rear-facing backboard which actively held a rigid surrogate wheelchair (SWC) in place with side grips. A three-point seat belt restrained the H3-50M. Figure 2 (middle) shows the pre-test setup of Experiment 2.
- **Experiment 3** used a Q'Straint One securement system which held a forward-facing SWC with four floor-mounted straps. A three-point seat belt restrained the H3-50M. Figure 2 (right) shows the pre-test setup of Experiment 3.

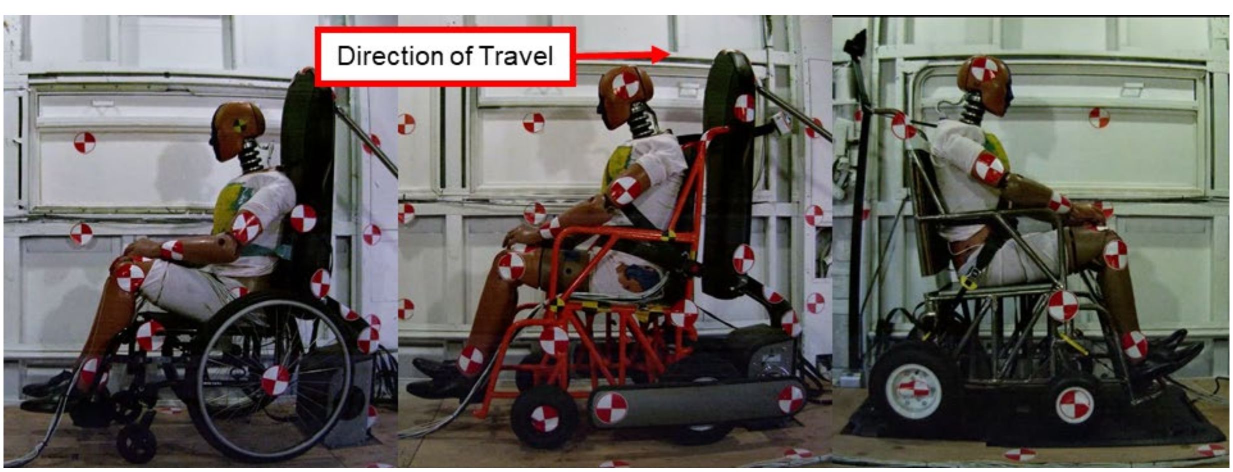

Figure 2. Pre-test Video Snapshots (-0.04 s) of Experiments 1 (Left), 2 (Middle), and 3 (Right)

RESULTS

The train-to-train impact occurred at 24.3 mph. All three wheelchair securement devices maintained their structural integrity and remained attached to the carbodies during the test. The wheelchairs and ATDs were compartmentalized in each experiment. The injury values measured by the H3-50Ms met the performance requirements specified in the APTA seat and table standards.

Figure 3 shows SIVs calculated from the measured decelerations of the passenger rail cars alongside SIVs calculated from the idealized crash pulses in the APTA (U.S.) and GM/RT 2100 (U.K.) safety standards. While the APTA crash pulse only has a minimum requirement, the GM/RT 2100 has a lower and upper bound, both of which are plotted. The SIVs for the occupant experiments were generally between the APTA and GM/RT 2100 minimum requirements.

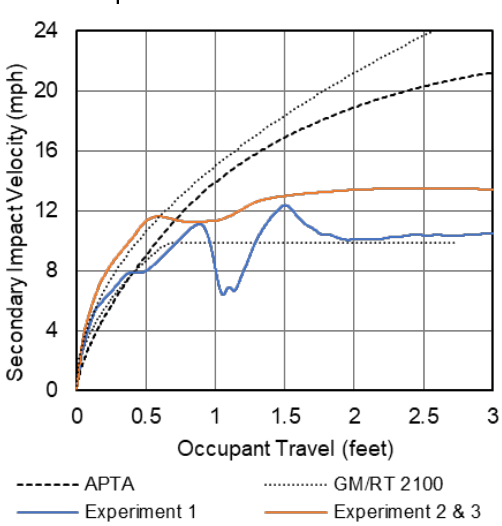

Figure 3. Secondary Impact Velocities

Researchers generated the curves by integrating the crash pulse once to calculate change in velocity (i.e., SIV) and again to calculate relative displacement (i.e., occupant travel). They measured the accelerations of the passenger railcars using accelerometers on the underframes of the carbodies and filtered them using a CFC60 low-pass filter, per SAE J211-1. The SIVs presented in Figure 3 were derived using the average value obtained for the two passenger railcars.

Figure 4 shows the post-test position of the H3-50M and wheelchair for each experiment. The images were captured from the side-facing, high-speed videos approximately 2 seconds after the impact of the locomotives. After reviewing the high-speed video footage, the researchers determined the wheelchair securement devices compartmentalized the ATDs and wheelchairs and remained attached.

Figure 4.Post-test Video Snapshots (2 s) of Experiments 1 (Left), 2 (Middle), and 3 (Right)

Table 1 summarizes the injury performance for each occupant experiment. All injury values were well below the performance limits. The values are listed in terms of percent of the performance limit, so that values less than 100 percent meet the APTA requirements [2, 3].

Table 1. Injury Criteria for Occupant Experiments

Experiment #	1	2	3
HIC15	3%	2%	5%
Neck Tension	12%	8%	20%
Neck Compression	6%	24%	7%
Nij	15%	26%	26%
Chest Acceleration 3ms	18%	35%	26%
Chest Compression	32%†	9%	31%
Left Femur Compression	4%	10%	4%
Right Femur Compression	6%	9%	4%

† Spike in chest compression due to signal noise

CONCLUSIONS

The occupant experiments demonstrated the feasibility of using off-the-shelf wheelchair securement devices in a passenger railcar. The train-to-train impact at 24.3 mph resulted in SIVs that were generally between the idealized crash pulses from APTA and GM/RT 2100. The wheelchair securement devices retained their structural integrity, remained attached to the carbody, compartmentalized the ATDs, and resulted in injury values that are likely survivable for an occupant.

FUTURE ACTION

The researchers did not intend to evaluate a worst-case scenario for occupant injury in this test due to safety concerns associated with a full-scale test. Future sled testing of wheelchair securement devices is planned with a more severe crash pulse meeting the requirements (8g) of the APTA standards along with companion finite element analysis.

REFERENCES

[1] P. Llana, K. Jacobsen, and R. Stringfellow. (2020). Locomotive Crash Energy Management Vehicle-to-Vehicle Impact Test Results. *Proceedings of the 2020 Joint Rail Conference, JRC2020-8030*.

[2] American Public Transportation Association. (March, 2021). APTA PR-CS-S-016-99, Rev. 3 – Standard for Passenger Seats in Passenger Railcars.

[3] American Public Transportation Association. (October 2015). APTA PR-CS-S-018-13, Rev. 1 – Fixed Workstation Table in Passenger Rail Cars.

[4] Rehabilitation Engineering and Assistive Technology Society of North America. (November, 2017). WC-4, Section 18 – Wheelchair Tiedown And Occupant Restraint Systems For Use In Motor Vehicles.

ACKNOWLEDGMENTS

Engineers at the Volpe National Transportation Systems Center developed the test requirements and analyzed the test results. Engineers and technicians at MxV Rail (formerly TTCI) conducted the tests. Thanks to Q'Straint for their donated wheelchair securement equipment and support of this research effort.

CONTACT

Jeff Gordon
Program Manager
Federal Railroad Administration
Office of Research, Development, and Technology
1200 New Jersey Avenue, SE
Washington, DC 20590
(617) 494-2303
Jeffrey.Gordon@dot.gov

KEYWORDS

Crashworthiness, train-to-train test, anthropomorphic test device, ATD, rail passenger safety, wheelchair securement, wheelchair

CONTRACT NUMBER

DTFR5311D00008L/693JJ619F000102

Notice and Disclaimer: This document is disseminated under the sponsorship of the United States Department of Transportation in the interest of information exchange. Any opinions, findings and conclusions, or recommendations expressed in this material do not necessarily reflect the views or policies of the United States Government, nor does mention of trade names, commercial products, or organizations imply endorsement by the United States Government. The United States Government assumes no liability for the content or use of the material contained in this document.