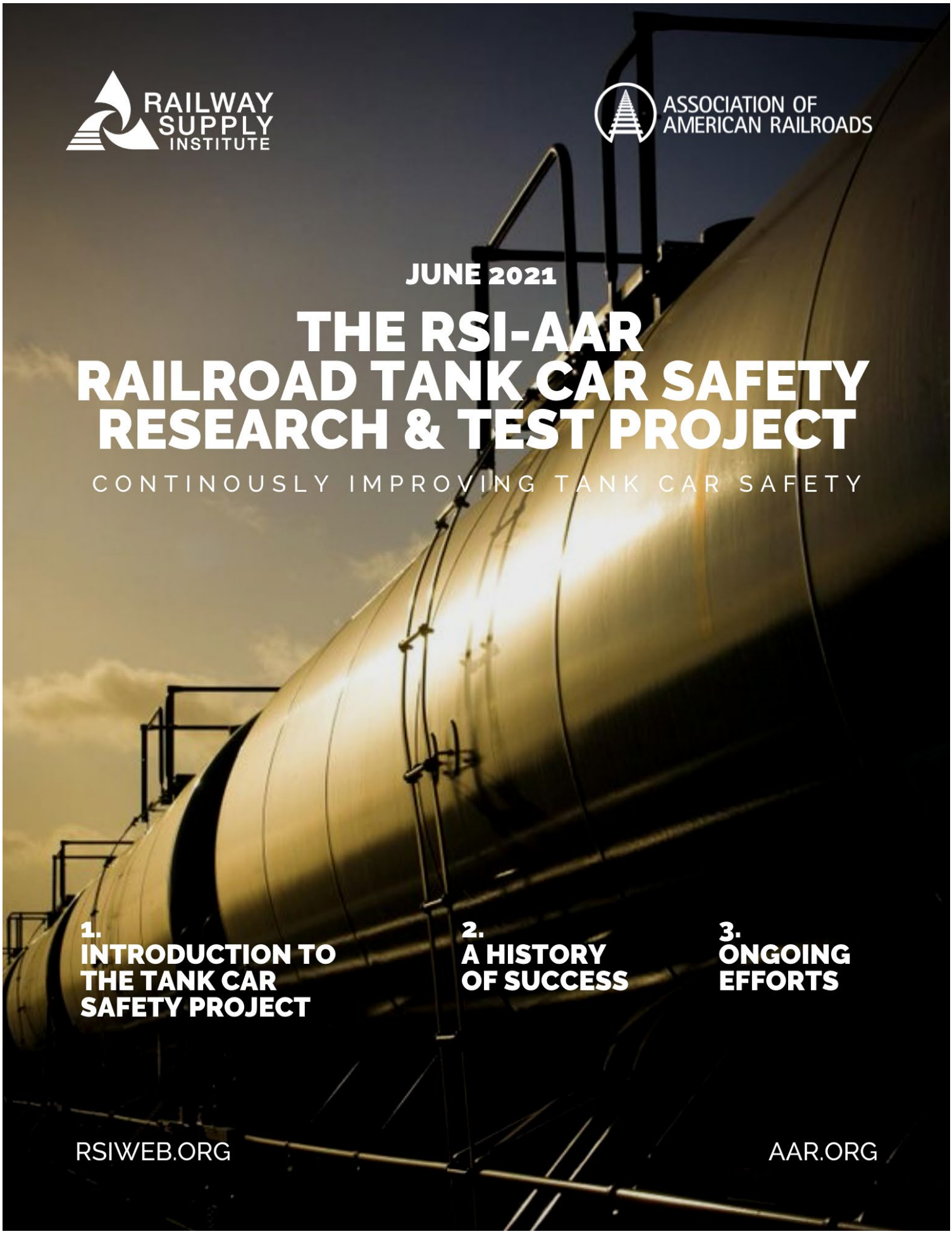

RAILWAY SUPPLY INSTITUTE

ASSOCIATION OF AMERICAN RAILROADS

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THE RSI-AAR RAILROAD TANK CAR SAFETY RESEARCH & TEST PROJECT

CONTINOUSLY IMPROVING TANK CAR SAFETY

1. INTRODUCTION TO THE TANK CAR SAFETY PROJECT

2. A HISTORY OF SUCCESS

3. ONGOING EFFORTS

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1. Introduction to the Tank Car Safety Project

An effective safety program focuses on continuous improvement, which can only be driven by the best data. Through a cooperative research program, the Railway Supply Institute (RSI) and its partner, the Association of American Railroads (AAR), have achieved great success in this regard over the last five decades.

In 1970, RSI's predecessor (the Railway Progress Institute) and AAR established the RSI-AAR Railroad Tank Car Safety Research and Test Project (the "Safety Project") to conduct research and testing to identify and evaluate design concepts for improving the damage resistance of tank cars involved in accidents. The Safety Project's mission is to conduct scientific and engineering analyses of railroad tank car safety, and especially accident safety. This research is carried out in support of the mutual goal of its sponsors: continuous improvement in tank car safety. When RSI and AAR established the Safety Project, they began collecting data on how tank cars and their safety systems have performed in accidents. The resulting database has made it possible to offer robust quantitative information on dozens of tank car safety questions.

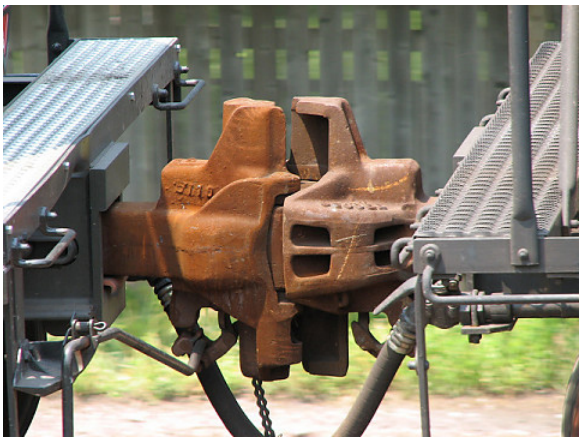
Since 1970, the partners have invested more than $20 million in the Safety Project, while also investing hundreds of millions of dollars in safety improvements to the tank car fleet. The two associations jointly fund the work, set priorities, and approve research projects. These investments have yielded significant safety improvements that are reflected in modifications to existing tank cars, construction of new tank cars with improved designs, and quantitative decision-making tools such as risk analyses and cost-benefit analyses. Research by the Safety Project has led to now-common tank car safety features, including head shields, shelf-couplers, and thermal protection on tank cars carrying hazardous materials. The Safety Project continues to play a critical role in identifying tank car safety issues, developing potential solutions, and evaluating their effectiveness.

2. A History of Success

The Safety Project's origins are attributable to RSI and AAR's mutual interest in identifying and addressing the failures of tank cars carrying propane and liquefied petroleum gas (LPG) that occurred in the 1960s and early 1970s. In the 1970s, the Safety Project was established to play a lead role in determining the failure mechanisms to the cars and the best means to engineer solutions to prevent a recurrence. A joint industry/federal task force depended on the Safety Project's support to find the best solutions.

Using its data on tank cars in accidents to determine the causes of the releases, and a series of full-scale tests to select among various approaches to head protection, fire survival, and prevention of coupler over-ride that led to many tank head punctures, the Safety Project made recommendations that were implemented by the U.S. Department of Transportation in its Docket HM-144 rulemaking in 1977. The resulting application of head shields, shelf couplers, and thermal protection to the cars in LPG service mitigated coupler override and puncture issues identified at that time and these enhancements are now seen as major successes in advancing tank car safety.

Considering the success of improving the safety of cars carrying LPG, RSI and AAR agreed to turn the Safety Project into an ongoing program dedicated to continuous improvements in tank car safety. The Safety Project next turned its focus to protecting bottom fittings on non-pressure tank cars. Design options were tested for impact survival and fatigue resistance, allowing the industry to select effective designs and initiate requirements. The Safety Project later confirmed the effectiveness of these designs with a study of the collected accident data.



Top and bottom shelf couplers, introduced during the effort to protect LPG cars in the 1970s following Safety Project research, to prevent coupler override in an accident and resulting tank head punctures. Today, shelf couplers are required on all tank cars carrying hazardous materials.

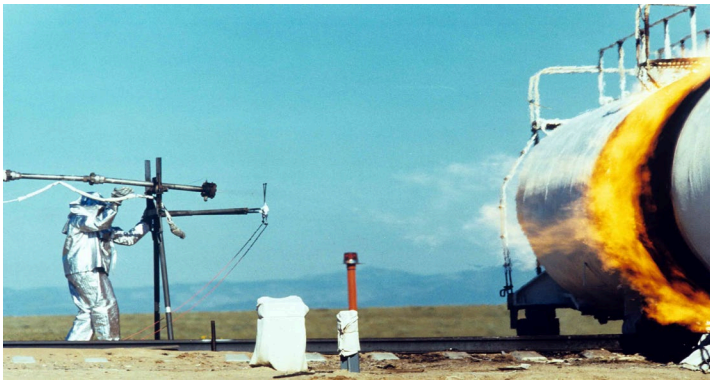
Along with the focused testing in the early days of the Safety Project, the sponsors set up a database of information regarding tank cars that were damaged in accidents known as the "Tank Car Accident Database" (TCAD). TCAD is populated and analyzed on an ongoing basis, which has made it a tremendous asset to the industry from the start. Through analyzing TCAD data, the Safety Project has been able to verify and quantify the benefits of safety improvements, including those arising out of its research programs.

Bottom fittings on tank cars are protected with skids that deflect impacts with the ground, rails and other freight cars during a derailment.

The Safety Project's ability to quantify the effects of key safety proposals has contributed to the resolution of a variety of issues in recent years. The Safety Project's landmark report RA-05-02, "Safety Performance of Tank Cars in Accidents: Probabilities of Lading Loss" (published 2006), and its recent update, RA-19-01, "Conditional Probability of Release (CPR) Estimates for Railroad Tank Cars in Accidents" (published 2019), provide quantitative information on the accident performance of a wide variety of tank car configurations and safety features. CPR is the probability that a single tank car of a given design releases lading when it is derailed in an accident. The CPR estimates in these reports provide robust quantitative performance information which has been used to create improved packaging specifications for tank cars carrying flammable liquids, materials poisonous-by-inhalation ("PIH"), and other hazardous materials.

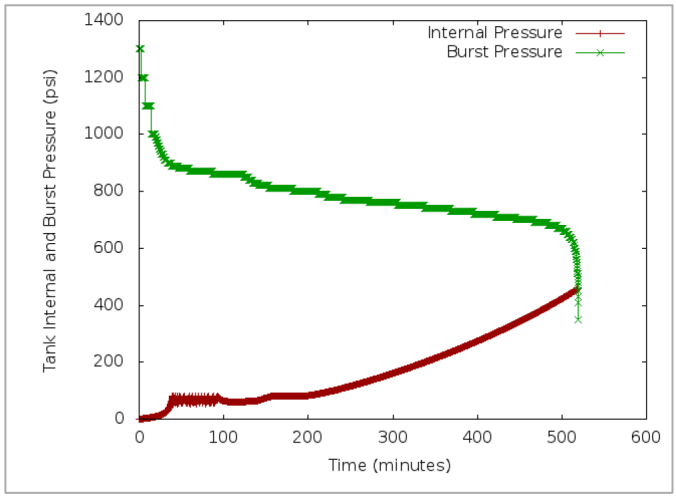
In 2002, for example, the industry set out to identify requirements for hazardous materials tank cars that would operate at more than 263,000 pounds of gross rail load. The goal was to use a third of the weight above that threshold for safety improvement and the rest for lading. CPRs drawn from Safety Project data were key tools in choosing the best approaches for allocating that weight. In the 1990s, and again in 2005, the industry considered packaging improvements for chemicals that are specifically hazardous to the environment. The earlier effort led to a rulemaking that substantially upgraded the specifications for tank cars carrying halogenated-organic compounds and some other materials while the latter found that there were no additional chemicals needing these requirements. In both cases, Safety Project CPR estimates helped to quantify the benefits of the various options.

A CPR analysis was at the core of a 2016 industry petition that asked DOT to allow the 2009 interim standards for tank cars transporting PIH materials to become a permanent standard. Using CPRs, the industry petition demonstrated that the cars that complied with the interim standard provided a significant improvement over prior designs. Other research by the Advanced Tank Car Collaborative Research Program, an industry and government research coalition supported by the Safety Project, concluded that the interim standard should become permanent.



Example of full-scale testing in the early 1970s of an LPG tank car exposed to fire. Such tests, jointly conducted by the Safety Project and the Federal Railroad Administration, helped quantify the rate of heat transfer into a tank under intense fire conditions and led to thermal protection requirements for flammable gas tank cars and eventually additional tank car types.

With the steep rise in shipments of ethanol and crude oil, and following some derailments of trains carrying those commodities, the industry sought to enhance the packaging standards for these materials. The Safety Project provided robust quantitative information about the benefits of the various design specification changes. Safety Project CPR estimates informed the industry's recommendations and standards for flammable liquid transportation, which culminated in DOT promulgating the new DOT-117 tank car specification.



AFFTAC trace of pressure versus time for a fire scenario for an ethanol car equipped with a ceramic fiber thermal blanket. Source: Safety Project Report RA-16-01.

Going forward, the CPR information developed by the Safety Project will continue to support industry efforts to improve the performance of tank cars damaged during accidents.

The release of product resulting from impacts is not the only facet of accident performance. Derailed tank cars can be exposed to fires of temperatures of over 1500°F, which may cause the tank steel to weaken and the lading to heat up. The tank car must be designed to retain the pressure for certain periods of time until emergency responders can mitigate the fire. Fire tests were part of the original LPG-car improvement research program, and more recently, the Safety Project has conducted high-temperature tensile and stress-rupture tests of tank steels to refine its understanding of how tank cars behave when subjected to intense heat. The Safety Project developed a physics-based model, AFFTAC ("**A**nalysis of **F**ire e**F**fects on **TA**nk **C**ars"), to simulate how a tank car and the product carried therein behave when exposed to fire. The AFFTAC model estimates tank survival time, tracks behavior of the lading in the tank and the pressure relief system, and compares differences among commodities and fire protection systems. AFFTAC was originally based on the Federal Railroad Administration's (FRA) 1984 research study, thermal model and accompanying 1998 User's Manual, to conduct thermal analysis in order to understand the fire performance of thermal protection systems and tank car designs.

A recent example is the study summarized in report RA-16-01, "An Analysis of Tank Cars with Flammable Commodities," which investigated the expected tank survival times with various car designs and levels of thermal protection while loaded with a variety of types of crude oil and ethanol.

The Safety Project also has contributed to areas other than accident performance. With assistance from the FRA and Transport Canada, in 2009, the Safety Project completed the Tank Car Operating Environment over-the-road research test. This test assisted tank car builders in improving the design of cars to withstand the rigors of rail transportation. The data on loads imparted into the underframes of the test cars serve as the basis for the tank car stub sill design load spectrum in the AAR's *Manual of Standards and Recommended Practices* that governs new car construction. **The Safety Project also developed a database to accumulate the results of stub sill inspections, and funded an industry-wide database (known as the Tank Car Integrated Database, or "TCID") of stub sill and tank inspection data that facilitates monitoring the health of tank cars.** Individual car owners can use TCID to conduct analysis of their fleets. TCID is managed by Railinc, and the Safety Project continues to supply analytical support as needed.

3. Ongoing Efforts

Now celebrating its 50th anniversary, the Safety Project maintains its ongoing commitment to continuous improvement that was the vision of its founders. The TCAD database has been continuously populated with new data since 1970, with assistance from Sims Professional Engineers and the University of Illinois at Urbana-Champaign. TCAD currently contains records on over 50,000 tank cars damaged in over 31,000 different accidents since 1970. There are three categories of information in TCAD, each with multiple fields describing: (1) the car and its features and lading; (2) what happened to the car, such as the nature of the damage, lading lost, and casualties; and (3) the accident that caused the tank car to be damaged.

The task of populating this database with information regarding tank cars, the accident in which a tank car was involved, and the resulting damage from that accident, is complex, often requiring information from over 20 sources of data. In some instances, the Safety Project sends an independent observer to a derailment to collect data that are then integrated into the TCAD database. To analyze a tank car's performance during a derailment and develop the data for TCAD, the analysts at Sims assemble a picture of what occurred from a variety of sources, depending on what is available for a particular car or accident. This requires interpreting conflicting data and navigating gaps in the information, which is an intricate and specialized investigative process conducted by tank car experts with years of experience.

The Safety Project has augmented TCAD over time to ensure it remains useful for data analysis. For example, new fields have been added and others refined to describe: what type of train derailed; whether there was fire and whether a given car was exposed to it; the type of top fittings protection with which a tank car was equipped; and, whether the bottom outlet valve had a handle securement system. These fields are now collected for new accidents, and existing records have been backfilled to expand the sample of accidents and to enable a robust analysis of these data.

The AFFTAC fire model is similarly reviewed on a regular basis and adapted as necessary. The Safety Project uses fire test data and other research to validate the AFFTAC model results, and to help identify any appropriate adjustments.

For fifty years, the Safety Project has reflected its sponsors' cooperation and commitment to ongoing improvement in tank car safety; creating a program and a legacy that is unmatched in any other hazardous materials transportation mode.