Enhanced Tank Car Design Improves the Safety of Transporting Crude Oil and Alcohol by Rail

CHRISTOPHER P. L. BARKAN, XIANG LIU, AND M. RAPIK SAAT

Barkan is Professor of Civil and Environmental Engineering and Executive Director of the Rail Transportation and Engineering Center (RailTEC), University of Illinois at Urbana–Champaign. Liu is Assistant Professor of Civil and Environmental Engineering, Rutgers University. Saat is Research Assistant Professor in Railway Engineering, Department of Civil and Environmental Engineering and RailTEC, University of Illinois at Urbana–Champaign.

The nation's quest for energy self-sufficiency has led to a dramatic increase in the transport of flammable liquids by rail. In the first decade of the 21st century, the rail transport of alcohols not otherwise specified (NOS) increased 10-fold from approximately 30,000 tank carloads per year to more than 300,000 in 2010. As the alcohol traffic stabilized, an even more dramatic increase in the transport of petroleum crude oil began with the boom in shale oil production.

Rail transport of petroleum crude oil increased more than 50-fold from approximately 9,500 carloads in 2008 to 500,000 in 2014, with further growth expected (*1*). Railroad safety improved in the same period, declining from 4.39 accidents per million train miles in 2004 to approximately 2.25 in 2014, a 49 percent reduction (Figure 1, below) and the lowest level since the Federal Railroad Administration (FRA) began recording these statistics in 1975.

Problem

Despite the reduction in the accident rate, the substantial growth in flammable liquid traffic raised concern about the risk of accidents producing large spills. The new traffic was moving differently, often in unit trains of 80 to 120 cars from origin to destination. Damage to conventional, nonjacketed DOT-111 tank cars, combined with thermally caused failures in large, multiple tank car derailments, resulted in several dramatic—and two fatal—train accidents.

The accidents galvanized industry, public, and government attention on the topic. The rail industry faced a paradoxical situation: train safety was improving, but the risk was increasing with the dramatic growth in traffic.

Solution

Improving the safety and reducing the risk involve three key elements:

- Railroad accident prevention,
- Improved tank car safety design, and
- Enhanced emergency response capabilities.

The research on tank car safety design—the focus of this article—was a collaborative, multiyear effort by several organizations, including the Railway Supply Institute (RSI)–Association of American Railroads (AAR) Railroad Tank Car Safety Research and Test Project, the U.S. Department of Transportation (DOT) FRA, the U.S. DOT National University Rail Center, the Rail Transportation and Engineering Center (RailTEC) at the University of Illinois at Urbana–Champaign (UIUC), and several other individuals and companies (*2*).

Safety-Related Questions

The research started by addressing two questions:

- How effectively do different tank car safety design features prevent releases?
- What is the optimal combination of design features?

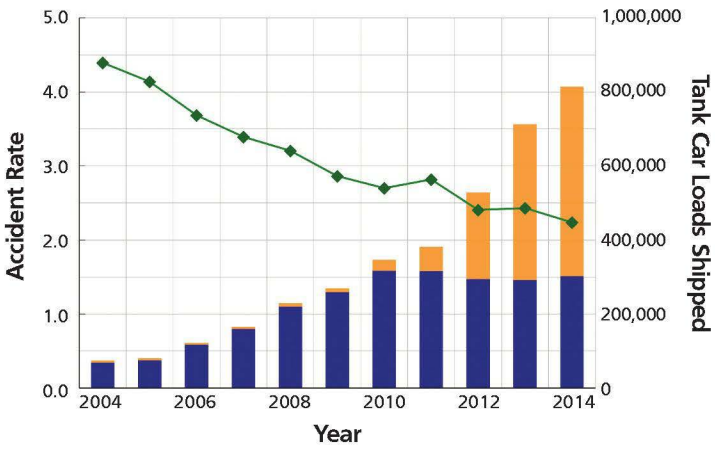

FIGURE 1 Reportable train accidents per million train miles (green) and growth in railroad tank car shipments of alcohol NOS (blue) and petroleum crude oil (orange) in the United States, 2004–2014. [Sources: For accident data: Federal Railroad Administration: http://safetydata.fra.dot.gov/officeofsafety/publicsite/summary.aspx (2014 data are preliminary); for traffic data: Association of American Railroads.]

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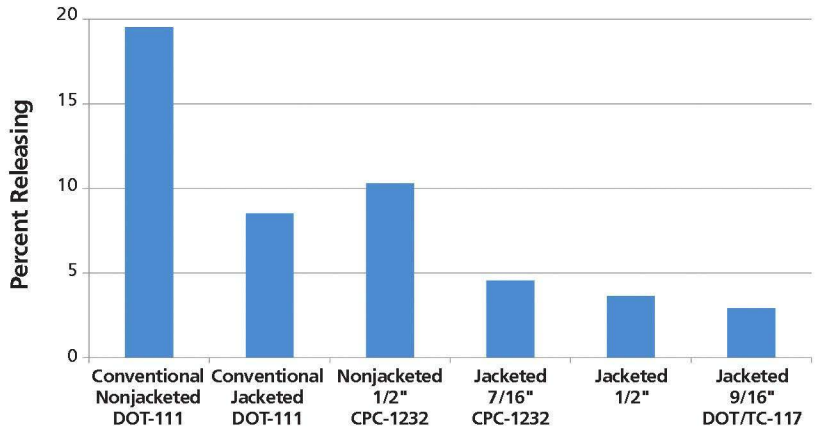


FIGURE 2 Percentage of tank cars of various designs expected to release 100 or more gallons (CPR_{100}) from physical impacts in FRA-reportable accidents (*4*).

The RSI-AAR Tank Car Safety Project analyzed data on tank car safety performance (*3*), quantifying the effect of different tank car design features on the likelihood of a release in accidents (*4*). Researchers at UIUC then used these statistics and other data to develop an optimization model for a tank car safety design (*5*). The researchers quantified the safety benefit of each design change element, along with its associated impact on tank car weight, to determine which combinations of design enhancements were most effective and efficient.

The changing nature of rail traffic, however, with increased movement by unit trains, raised new safety-related questions:

- Do unit trains derail at a rate different from that of conventional trains?
- What is the likelihood of large, multiple car releases?
- What was the effect of fire on tank car failures?

UIUC developed an integrated risk model for hazardous materials transportation to evaluate railroad infrastructure, operating practices, tank car design, and routing and to investigate the most efficient combination of measures to reduce risk (*6*). A preliminary analysis suggested that the derailment rate for unit trains was not significantly different from that of other types of freight trains. Research on this topic is continuing, but given the declining accident rate, the most plausible explanation for the increased number of incidents is the dramatic increase in unit train traffic.

Multiple Car Accidents

The RSI-AAR data enabled a statistical estimate of how each particular tank car design would perform in accidents (Figure 2, left); however, the substantial increase in unit train traffic led to concern about the occurrence of large, multiple-car release accidents. UIUC therefore used a new risk model to estimate the probability of release events of various magnitudes for different tank car designs.

The findings indicated that even relatively small differences in the probability of individual car releases yielded large differences in the probability of multiple car releases (*7*). For example, a design improvement that resulted in a 20 percent reduction in release probability for a single derailed car offered a 74 percent reduction in the probability that five or more derailed cars would release.

The risk model was used to calculate how the different tank car designs affected the relative expected time intervals between events of various magnitudes (Figure 3, below left). The most important finding was that even small differences in an individual car's probability of release diverged geometrically when the probability of larger numbers of cars releasing was calculated (compare Figure 2 with Figure 3). This result was influential in the industry's decision to support a more robust tank car design.

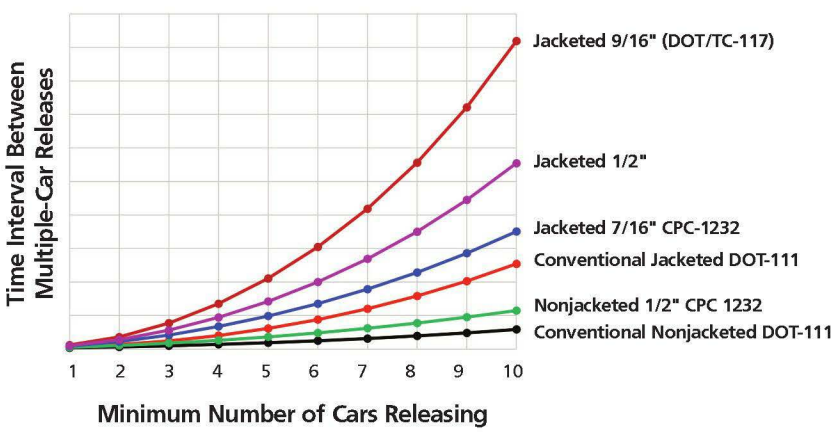
Protection from Fires

Although the improved damage resistance reduced the incidence of cars failing from the initial, physical impacts of a derailment, another aspect of unit train derailments emerged and gained importance. Even if only a few cars release their contents, a fire may ensue.

The fire can engulf other derailed tank cars that had not released in the initial derailment. The product inside the cars would heat up, increasing the pressure inside the tank, while the fire impinging on the tank would thin and weaken the steel on the upper side, reducing its strength. If the rising internal pressure exceeds the strength of the weakening tank, a separation—known as a thermal tear—could occur in the tank steel, and a large quantity of product would suddenly release, triggering the vertically directed fireballs sometimes seen in these incidents.

Industry and government had sponsored the development of a research tool known as Analysis of Fire Effects on Tank Cars (AFFTAC) to evaluate increases in thermally induced pressure and the effectiveness of

FIGURE 3 Illustration of the effect of tank car design on the geometric divergence of the expected interval between occurrences of multiple car release incidents of varying magnitude.



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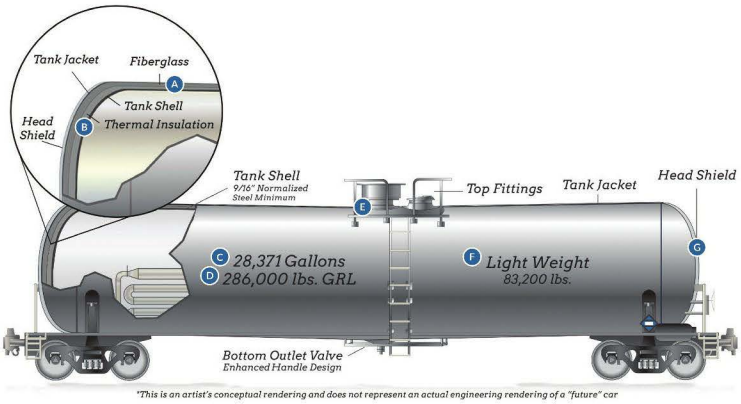

FIGURE 4 Illustration of the new safety features on tank cars for transporting petroleum crude oil and alcohol NOS. (Drawing courtesy of Railway Supply Institute)

designs for pressure relief devices (*8*). The industry used AFFTAC to develop a thermal protection system to extend the survivability of petroleum crude oil and alcohol NOS tank cars in fires as long as possible, ideally preventing the tank cars from failing altogether.

Researchers identified a twofold solution:

- First, place a layer of thermal insulation around the tank and encase the insulation in a steel jacket to reduce the rate of heat flux into the tank and to improve resistance to damage in derailments—in Figure 2, for example, compare the jacketed with the nonjacketed versions of the conventional DOT-111.
- Second, equip cars with appropriately sized pressure-relief valves to reduce internal pressure more effectively in a controlled manner.

Benefits

The research described here was used to inform the development of the enhanced tank car safety design features proposed by the rail industry for transporting petroleum and alcohol NOS:

- A thicker, more puncture-resistant tank constructed of stronger steel;
- Full-height head shields;
- Robust top-fittings protection; and
- A thermal protection system encased in a steel jacket (Figure 4, above) (*9*).

This tank car is expected to reduce the average probability of a release caused by the impacts of an accident by an estimated 85 percent compared with the probability of a release by the current nonjacketed DOT-111 car; moreover, the enhanced design is expected to reduce considerably the likelihood of secondary failures caused by fire.

U.S. DOT and Transport Canada recently promulgated regulations to incorporate these features into the new DOT-TC-117 tank car (*10, 11*). When fully implemented, these cars will improve substantially the safety of transporting petroleum crude oil and alcohol NOS by rail in the United States and Canada.

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EDITOR'S NOTE: Appreciation is expressed to G. P. Jayaprakash and Amir Hanna, Transportation Research Board, for their efforts in developing this article.

Suggestions for Research Pays Off topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, Keck 488, 500 Fifth Street, NW, Washington, DC 20001 (202-334-2956; gjayaprakash@nas.edu).

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