Safe Placement of Train Cars:
A Report

U.S. Department
of Transportation
Federal Railroad
Administration

Report to the Senate Committee on Commerce, Science and Transportation and the House Committee on Transportation and Infrastructure

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REPORT TO THE SENATE COMMITTEE ON COMMERCE, SCIENCE AND TRANSPORTATION AND THE HOUSE COMMITTEE ON TRANSPORTATION AND INFRASTRUCTURE

Introduction

Section 111 of the Hazardous Materials Transportation Authorization Act of 1994 (see box) requires a report on two related, but distinct, issues: first, make-up of trains in such a manner as to prevent derailments caused by in-train forces and, second, placement of hazardous materials cars in trains so as to avoid harm to crew members or interaction of hazardous materials, should a train accident or other unintended release occur.

> *Section 111 of the Hazardous Materials Transportation Authorization Act of 1994 (P.L. 103-311) provides:*
>
> **SEC. 111. SAFE PLACEMENT OF TRAIN CARS**
>
> The Secretary of Transportation shall conduct a study of existing practices regarding the placement of cars on trains, with particular attention to the placement of cars that carry hazardous materials. In conducting the study, the Secretary shall consider whether such placement practices increase the risk of derailment, hazardous materials spills, or tank ruptures or have any other adverse effect on safety. . . .

Essentially, train makeup is not an issue that focuses on hazardous materials but on the distribution of power, braking effort, and weight throughout a train and the effect of each on train handling. From the point of view of train makeup, whether or not heavy cars belong at the front of a train is independent from whether or not those cars are carrying hazardous materials, just as, from the perspective of hazardous materials safety, whether or not hazardous materials cars belong at the rear of the train is independent from how many empty cars are in the front of the train. The reality, of course, is that both considerations are vital and FRA's (Federal Railroad Administration) stewardship of railroad safety requires that rules written in one area not overlap into another, to the detriment of either.

Train make-up remains a matter under active consideration by the FRA as this report is prepared. While this report provides the current status of our activities, analysis in this area is ongoing. FRA will continue to use data gathered in this effort in conjunction with all our data while making decisions about focusing our safety resources.

Train placement of hazardous materials has been thoroughly reviewed with appropriate consideration for possible regulatory change. For reasons set forth in this report, FRA currently sees no merit in disturbing established and very effective requirements already embodied in the Department of Transportation's Hazardous Materials Regulations. Although there is a theoretical basis for adoption of various refinements to train placement requirements, in no case is it apparent that their implementation would offer advantages sufficient to offset the costs involved–particularly the safety risk associated with additional switching of cars.

Train Make-Up

Train make-up refers to the distribution within the train of railroad cars that are empty or loaded, short or long, or that have other characteristics affecting their ability to negotiate railroad track while subject to "draft" (stretching) forces and "buff" (compressive) forces within the train. Improperly assembled trains are more susceptible to derailment, depending upon grade, curvature, train handling (use of the throttle, independent brake, dynamic brake and automatic braking system), and other factors.

FRA has no regulations directly governing train make-up. Since the 1970s, FRA and the AAR (Association of American Railroads) have conducted extensive joint research that led to industry guidelines for track-train dynamics, including distribution of cars within a train by weight and other characteristics.[1] The resulting book, the *Train Make-up Manual*, suggests that certain in-train configurations, combined with certain operating territory conditions, do not lead to problems. Essentially, according to that research, no special consideration for train make-up need be given for general merchandise trains composed of average length railroad cars[2] where the total train weight is less than 4,000 tons, the maximum gradient is less than 2 percent, and the maximum curvature is less than 8 degrees.[3] Where the train exceeds 4,000 tons, long car/short car combinations are, ideally, to be restricted within the consist so as not to exceed maximum trailing tonnage for the ruling grade/curvature combinations set forth in the *Manual.*

> AAR's Vehicle Track Systems "no-problem" train:
> - ✓ Less than 4,000 tons total train weight;
> - ✓ Less that 2% maximum gradient; and
> - ✓ Less than 8° maximum curvature.

IN-TRAIN FORCES

Understanding the development of the forces acting within a train[4] requires, in turn, understanding four factors that produce those forces: First, *train resistance*, or the force gained by adding grade resistance, curve resistance, acceleration (or deceleration), and rolling resistance. Second, *tractive effort*, or the force generated by the locomotive at the coupler to overcome train resistance. Third, *braking*, or the force necessary to overcome the momentum of

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[1] See, for instance, Lovette, P.M. and Thivierge, *Train Make-up Manual*, Report R-802, Association of American Railroads Research and Test Department, AAR Technical Center, Chicago, 1992.

[2] An "average length railroad car" is one 40 - 50 feet long.

[3] *Train Make-up Manual*, p. 2.

[4] *Train Make-up Manual*, pp. 3-9.

the train–whether from rolling inertia or down-grade acceleration–and to slow or stop the train. Braking is accomplished by dynamic braking, by use of the automatic brake, and by use of the independent brake. Dynamic braking is a process by which the traction motors are electrically converted to become generators. The current they develop is then dissipated, or "wasted," through resistor grids. A very loose, imperfect analogy to dynamic braking is the use of engine compression braking to retard a car or truck as it moves down a hill. Because dynamic braking almost always starts from the head end of a train, the retarding forces will concentrate, or "pile-up," at the front.[5] The automatic brake controls the application, and release, of brake shoes against the wheels of a train, controlled by the operation of a brake valve in the locomotive. Once automatic braking has been established, retardation is applied to each car and there is no steady state concentration of braking forces in the train.[6] The independent brake controls brake applications at the locomotive only. As with dynamic braking, use of the independent brake causes retardation forces to concentrate at the front of the train.

Development of slack as train length increases.

TRAIN LENGTH	TOTAL SLACK
50 cars	50 feet
100 cars	100 feet
150 cars	150 feet
200 cars	200 feet

Slack represents the range of longitudinal travel of a coupler relative to the car to which it is attached. Most, but not all, common freight cars are equipped at each end with AAR standard knuckle couplers attached to the car through a "draft gear." The coupler - draft gear system is designed so that the coupler may travel through a particular distance when a draft or buff force is applied to the coupler. A small amount of free movement is found between and within the couplers themselves, but most of the travel is found in and controlled by the draft gear. Draft gears are designed to permit that limited travel, and to control shocks by absorbing energy as the travel reaches its limit.

[5] Of course, where mid-train auxiliary power is used, the forces from dynamic braking will "spike" behind each set of locomotives and where a rear pusher locomotive stays on a train as it moves down off the crest of a hill, the effect of its braking action, whether dynamic or not, will tend to create slack ahead of the locomotive.

[6] Brake application is not instantaneous throughout the train because the air "signal" that moves down the brake pipe travels at the speed of sound, rather than of light, the way an electric signal does. The signal takes 2-3 minutes to travel the length of a 100-car train. While the brakes are applying, forces tend to concentrate at the head of the train, although mid-train power, helper engines, and two-way end of train brake devices, each of which can initiate a brake application from its location, are able to establish steady-state braking significantly faster than with head end power alone.

Travel in one draft gear can reach six inches, depending on the force on the coupler and the rate of application of that force. The connection between any two cars may therefore contribute nearly twelve inches of slack, so that the total slack in a train may approach one foot for every car in the train. The cumulative amount of slack in a train is proportional to the length of the train. A 150 car train of common freight cars can have almost 150 feet of total slack.

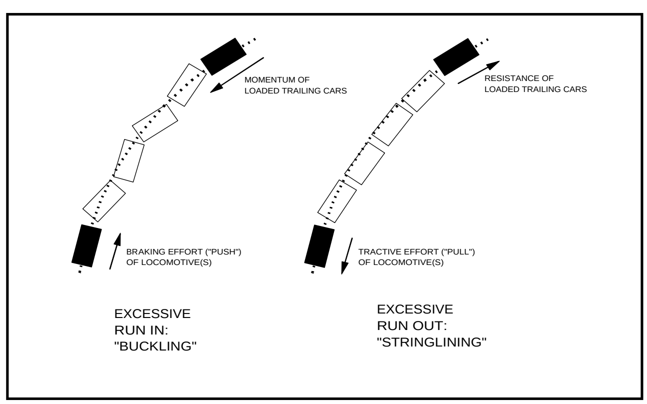
Draft gears are designed so that a locomotive starting a train will effectively start the train car-by-car, rather than starting the train as one solid mass. The standing inertia and friction in the wheels and bearings of a standing car is much higher than that of a car which is moving, even slowly. It is therefore necessary to "break the train loose" one car at a time to reduce the tractive effort and draft forces that would otherwise be required if all cars in the train were to be started simultaneously. Even with the force absorbing properties of the draft gear, a rapid rate of slack travel through a train can develop excessive draft or buff forces that could damage or derail the train. Some cars are designed with much lower coupler or draft gear travel, including such devices as sliding center sills or semi-permanent couplers without conventional draft gear, but a majority of common freight cars will permit the slack travel as described above. Conversely, some cars are equipped with end-of-car cushioning devices, which permit greater ranges of coupler travel than do conventional draft gears.

Excess train forces–steady state

Excessive train forces can break equipment, cause a rail to turn over, or cause a car to climb a rail. Steady state forces are those that are applied for a relatively long period of time such as the pull up a grade or the compressive forces of descending a grade under dynamic braking.[7] High steady state forces can cause three problems:

Train separation occurs when unreasonably high draft forces exceed the physical strength of the materials used in a car's draft system and the train breaks in two. The coupler knuckle is the intended weak link, to protect the draft gear and end sill assemblies.

Stringlining, *buckling*, and *jackknifing* are similar phenomena, that is, reactions to forces that depend on the direction of the force. Draft forces below the maximum

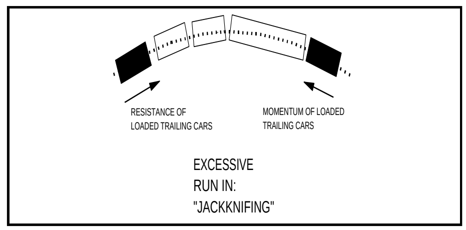


[7] *Train Make-up Manual*, p. 10.

described above tend to stretch the train into a straight line, (a “stringline”) thus causing severe lateral loads along the inside of the curve. Track is designed to withstand these forces under normal conditions, but combinations of cars with a high center of gravity or with light loads may have a higher lateral load than the track or the car can resist. Several failure possibilities exist under these conditions: The lower rail may roll over, the whole track structure may be pulled from the ballast towards the center of the curve’s arc, the wheels on the high side of super-elevated[8] track may lift and derail, or the cars may tip off the rail on the low side. It is even possible for the cars in the train to be “picked up” and deposited in the inside of the curve with few, if any, marks on the rails to determine the exact point of derailment.

Buckling is the opposite of stringlining, where forces in buff cause cars to skew off the tracks. Both stringlining and buckling are aggravated when the cars under force vary between loaded and empty.

Jackknifing, like buckling, happens when forces within the train act towards each other at levels greater than the vehicle/track combination can handle safely. Cars pushing against each other attempt to fold like a jackknife and coupler angles can create lateral forces similar to, but in the opposite direction of, stringlining. Typically, the rail car does not turn over (initially) but a wheel climbs over the rail or a rail turns over and eliminates the ability of the track structure to contain the train. Jackknifing is often exacerbated by combinations of long and short cars coupled together.



Excess train forces–transient

Transient forces, by definition of short duration, also play a role in optimizing train make-up.[9] They are primarily the result of train operations over changing grades or during acceleration or deceleration. The most certain way to avoid excess transient forces in terrain with a changing contour is to evenly distribute tonnage throughout the train; failing that, tonnage

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[8] Track is “super-elevated” when the outside rail is raised above the inside to compensate for the centrifugal forces of higher speed movements.

[9] *Train Make-up Manual*, p. 11.

should be concentrated at the head end. The worst case scenario places concentrated tonnage to the rear of empty or lightly loaded cars. A brief look at terrain features known to induce transient forces will further explain the potential dangers:

Crests are changes in gradient from uphill to downhill, adjusting the free play (slack) in the train from slack-out to slack-in and causing a transient force to run through the train as the slack runs in.[10] If the transient forces exceed the ability of the track vehicle system to contain it, cars may jackknife and derail. Crest transient forces are magnified by larger differences in gradient, higher train speeds, faster rate of brake application (train or dynamic) at the crest, and tonnage concentrated toward the rear of the train. A crest has the effect of adding the force of the cars toward the front of the train on the descending grade to the tractive force of the locomotive, so the cumulative forces might exceed the capacity of the draft system unless the locomotive tractive effort is reduced on the descending grade.

Sags are the opposite of crests and cause slack to adjust from running-in to running-out. Excess transient forces here can break a coupler knuckle or, if the train is in a curve, derail a car by stringlining. Sag transient forces are magnified by the same conditions as magnify the forces induced by crests.

Undulating terrain combines the worst of crests and sags and may place a long train in each such state at several points along its length. Optimum train make-up and skillful train handling are vital to safe and successful operations across undulations; power and brake applications must be small and gradual. Problems with pulling (draft) forces and pushing (buff) forces can also happen to trains where the cars are either all loaded or all empty. Experience with the Tropicana Orange Juice unit train and with unit trains of coal or grain proves the proposition.[11] In uneven terrain (and railroads that are table-top flat are the extreme exception), the rolling of the land can induce significant draft and buff force peaks at almost any point in the train which, if they get high enough to overcome the inertial forces holding the train on the track, can lead to derailments.

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[10] *Ibid.*, p. 12.

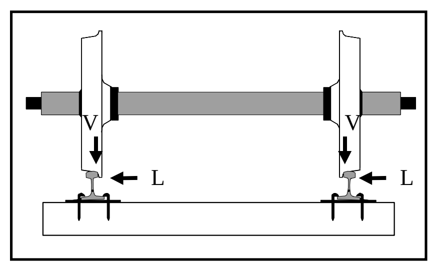
[11] Recognized references include: Powers, R.G. and Stephenson, J.G., "Train Action Measurements in the Tropicana Unit Train," ASME Paper No. 73-WA/RT-9, November 1973 and Fahey, W.R., et al., "Derailments on a Heavy Haul Railway," Session 315, Paper 3.4, Heavy Haul Railways Conference, Perth, Western Australia, September 1978.

DIFFICULT CAR TYPES

Certain types of cars,[12] physically different from conventional cars, are known to require special consideration if they are to move over the road safely. "Difficult cars" can cause dilemmas even in AAR's "no-problem" train.

Multiple platform cars fall into two types: those with stand-alone two-truck platforms joined either by a drawbar or a non-operable conventional coupler and those with articulated platforms sharing a common truck. Both types have conventional couplers at the nether ends. Only the articulated platform cars require special analysis in train make-up; they require a consideration of trailing tonnage at the articulated connection between two platforms, at the coupler connecting two such cars, and at the coupler connecting a multiple platform car to a conventional car. The *Train Make-up Manual* includes formulas for making the necessary calculations (beyond the scope of this report) but the make-up problems are not the result of articulation but of light (empty) weight. The truck and car geometry of articulated shared cars are actually an improvement over conventional cars, but the reduced vertical loads increase L/V ratios and may be the limiting condition.[13]

Single axle cars can be considered as normal cars when using the formulas in the *Manual*, but special note must be taken that these cars have extremely low light (empty) weights. Entraining them ahead of heavier cars may lead to adverse L/V ratios, as can sharp vertical curves common to crests in yards and at crossovers, which may contribute to wheel unloading.



Long car/short car combinations can become critical in crossovers where there is less than one car length of track in between the lead curves of the switches, and the

[12] *Ibid.*, p. 37.

[13] "L/V ratios" are a calculation of the lateral (sideways) forces acting on a rail car divided by the vertical forces. Vertical forces are typically generated by weight, although there may be a minor, transient increase in V forces at the bottom of a sharp dip. As a gross over-simplification, where lateral forces exceed vertical forces, cars tend to be pulled (or pushed) off the rails.

dilemma gets worse the sharper the turnout. The problem stems from the long overhang of these cars, that is the distance from the truck center at either end to the coupler pulling face at that same end. Known problem areas are probably best handled by re-routing. The phenomenon is also critical on sharp curves, where the discrepancy in car lengths causes the coupler geometry to impart unusually high lateral and overturning forces on the joined cars.

End of car cushioning is designed to reduce the shocks and resulting lading damage from high draft or buff forces, especially in rail yards. The detrimental effect of these devices on train make-up is the extra slack they contribute to total train length. No firm guidelines exist for optimizing operations in trains containing these cars, but some major carriers limit the number of EOC-equipped cars in a single block; another common practice is to entrain such cars after loaded cars with conventional draft gears.

HARMONIC MOTION

Train make-up may be influenced by three different types of harmonic movement, a condition very sensitive to train speed, but usually unaffected by train length or trailing tons.

Truck hunting is an instability that usually occurs at speeds in excess of 45 miles per hour in cars that are empty or lightly loaded. Worn trucks can cause hunting as slowly as 35 miles per hour. This type of harmonic is observed as yawing and twisting of the carbody around the center of the car and it may cause sufficiently high lateral and low vertical forces to cause a wheel to climb up over the rail (wheel climb). The great irony of truck hunting is that it most often is worst on what seems to be the best track—tangent track with welded rail—and curves as low as one degree may suppress hunting. Poor track alignment and surface decrease the potential for truck hunting, but increase the likelihood of a derailment if a "hunting" car is in the consist. Certain car series are known hunting bad actors and most railroads maintain speed restrictions on such cars.

Pitch and bounce tend to occur at speeds greater than 45 miles per hour and are seen as extreme vertical displacement at the ends of the car, with the ends of the car either in-phase (both rising at the same time) or out-of-phase (one end rises while the other falls) depending on whether the car is in pitch or bounce mode. Pitch and bounce are most often observed on loaded cars with insufficient suspension damping. Short cars such as ore jennies and a group of tank cars known colloquially as “beer can” cars[14] are more prone to this condition than long cars. Railroads maintain a list of such cars for review before a planned high speed operation.

Harmonic roll is a low speed (10-25 miles per hour) harmonic motion associated with heavily loaded, high center-of-gravity cars on less than prime track. Sometimes called “rock and roll,” the condition happens most frequently on half-point staggered jointed rail where the truck centers of the car are close to the joint spacing. Because the classic rail length is 39 feet—the length that would fit in a 40-foot gondola car—the typical “rock and roller” is a short 50-foot long, high sided, covered hopper car loaded with grain or other dry-flowing material. In a train handling such cars, harmonic roll can be effectively prevented by operating outside the 10-25 mile per hour speed range.

RESEARCH

The industry itself, through the Association of American Railroads, has continued research and evaluation efforts particularly related to new types of equipment as the equipment has been introduced. The AAR, through the Transportation Technology Center, Inc. (TTCI), has also continued to develop a computer-based model used to analyze and predict in-train forces, known currently as the Train Operations and Energy Simulator (TOES).

FRA’s Office of Research and Development is conducting a study of train make-up considerations. The goals of the study are:

- assess train make-up guidance describing “good practice” as it is available in the open literature,
- review individual railroads’ operating rules relating to train make-up,
- review railroads’ train make-up practices in the field, and
- review records of accidents attributed to improper train make-up.

In order to better understand the operating rules and field practices, the study has begun with a review and analysis of train accidents attributed to train make-up and train handling.

[14] They are short but maintain the same approximate diameter as a standard tank car and look remarkably like a very large version of their namesake.

From here, it will move to a review of the written policy, as expressed in the operating rules, and the field practices. Finally, the research will “run” actual railroad consists on a train operations simulator to determine whether the particular trains could traverse varied terrain safely.

This research has been arrested by the unavailability of a suitable computer model for analysis of in-train forces. Although it has offered to conduct analyses for the FRA, AAR has declined to license the TOES model to FRA. AAR explains that control of the model is maintained “to ensure the model is run properly.”[15] With encouragement from staffs of the NTSB (National Transportation Safety Board) and Transport Canada, in Fiscal Year 2003 FRA initiated development of a new computer-based model called ATTIF (Analysis of Train/Track Interaction Forces) to accomplish this work. The new model is being designed as a public-domain code and will be available for use by other government agencies and members of the public. It is currently under development through a joint collaboration with the University of Illinois at Chicago.

During the initial development phase ending September of 2004, the structure of the code and the main subroutines required for solving the system equations have been fully generated along with detailed 3-dimensional elements for accurate prediction of wheel/rail contact and interaction forces. An algorithm for modeling braking and traction forces has also been developed and implemented within the new code. While generally similar in functionality to TOES, the new model, due to its advanced wheel/rail contact treatment, will allow for considerably more accurate prediction of lateral to vertical load ratios that are key for assessing derailment tendencies. This will also greatly reduce the time needed for conducting detailed safety studies where currently additional codes must be run in conjunction with TOES in order to generate the more accurate wheel/rail forces. It is anticipated that by the end of 2005, the new code will begin to be used for conducting safety and risk evaluations of various train operation and make-up scenarios. Other future potential applications include accident investigations, energy consumption and train operation studies, ride quality evaluation, as well as new and current equipment safety evaluations.

During the next phase, which began in October of 2004 and will end in September of 2006, more detailed coupling elements such as draft gears, end-of-car cushioning devices, draw bars and articulated connectors will be developed and added to the code library and a more user-friendly interface will be added.

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[15]Letter of November 1, 2002, from AAR President Edward R. Hamberger to FRA Administrator Rutter.

FUTURE ACTIONS

FRA, the NTSB (National Transportation Safety Board), and the railroads continue to identify train accidents attributed to train make-up. In any given year railroads now report approximately 40 derailments using a train make-up "cause code," down from as many as 80 in the early 1990's. These totals include code H599, "other causes relating to train handling or train make-up." Over the period 1992-2002, these events resulted in approximately $37 million in harm to persons and railroad property (2002 dollars). Included in this amount are costs associated with no fatalities, five (5) injuries, and the evacuation of 2,300 people. A majority of these events occurred in yards,[16] and two-thirds occurred on Class 1 track (maximum authorized speed 10 mph). It should be noted that the rate of these events has declined more steeply than their absolute numbers, given the growth in train miles over the period.

Additional accidents attributed to improper use of power brakes, improper train handling, and other causes may also be related in part to train make-up where the combination of grade and curvature together with less-than-ideal train make-up creates an excessive challenge for the locomotive engineer. On an annual basis over 100 derailments are reported under these cause codes. Although most of these events are minor in nature, over the period of 1992-2002 they accounted for $102 million in harm to persons and railroad property (2002 dollars). It is not known how many of these events, if any, might have been prevented with better train make-up.

Better train make-up practices may lead to further reductions in the train accident rate. However, in evaluating options for improved train make-up, it will be important to consider the costs, and especially the safety costs, associated with more extensive switching of cars. The most common cause of fatalities to railroad employees is being crushed or run over in switching operations. According to the Switching Operations Fatality Analysis (SOFA) Working Group, there were 114 such fatalities in the period 1992-2002. Although every effort is being made to reduce these numbers, and some success is being achieved, increasing the exposure of train and yard crews to these hazards should be carefully weighed.

Further reductions in adverse train make-up and train handling events are possible under existing rules and practices. More extensive use of empty/load brake valves (evening out the rate of deceleration of cars in the train when brakes are applied) and distributed power (with additional locomotives in the middle of the train under radio control from the lead engine) should make it somewhat easier for locomotive engineers to control in-train forces. Running counter to

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[16] This may indicate misuse of the code or simply that the derailment occurred as the train was departing or arriving a yard location.

this influence, however, is the more extensive use of pre-blocking of cars to destination and the trend toward heavier-tonnage trains.

Over the long term, the development of Electronically Controlled Pneumatic (ECP) braking, with its more even brake applications and graduated brake release, offers promise for better management of in-train forces (at least buff forces). However, despite the apparent readiness of the technology, and despite successful demonstration of ECP train brakes, there is presently no established timetable or implementation plan for applying ECP brakes to either the existing fleet or new fleet segments. FRA has awarded a contract for an 18-month study into the costs and potential benefits of ECP brakes, with the hope of identifying a plausible migration path to ECP brakes and encouraging industry action.

In-Train Placement of Hazardous Materials Cars

Current in-train placement rules generally require a "six-deep" separation between a hazardous materials carrying tank car and a locomotive or occupied caboose. These rules grew out of "good practices" established at a time when railroads used steam locomotives that produced hot cinders and carried freight, including explosives, in wooden box cars. Some separation between hazardous materials cars and the parts of trains occupied by humans is intuitively correct, but research by FRA and others points out that the risk of incompatible chemicals mixing in a derailment is small and must be balanced against the risk of crew injuries during any extra switching required by stringent car placement rules.

Regulations: Just after the turn of the 20th century, Congress directed the Interstate Commerce Commission to formulate and publish "Regulations For The Transportation Of Explosives" to promote the safe transportation in interstate commerce of explosives and other dangerous articles. As the only nation-wide transportation system, the railroads played a large role in the early framing of the rules and created the Bureau for the Safe Transportation of Explosives and Other Dangerous Articles (later called the Bureau of Explosives) within the AAR to inspect shipments and methods of manufacture and packing.

Impetus for the early laws and regulations was provided by a number of accidents relating to shipments of black powder. It is thus not surprising that the first train placement rules dealt with cars containing explosives. These early regulations required cars of explosives to be placed near the center of the train, and at least 16 cars from the engine and 10 cars from the caboose, when the length of train would permit. The "16 deep" rule was chosen because it was considered to be a "safe distance" during a time when railroads used steam locomotives that produced hot cinders and carried freight, including explosives, in wooden box cars.

By 1922, regulations were in effect to require cars placarded INFLAMMABLE[17] to be placed in trains at least five cars from the engine and five cars from the caboose. When the length of the train did not permit this placement, the hazardous materials car was to be placed near the middle of the train, separated from the engine or an occupied caboose by at least one car, and the engine crew was to be informed of its presence and location in the train. Under no circumstances could an INFLAMMABLE car be placed next to a car transporting explosives.

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[17] The term "INFLAMMABLE" was confused with "unflammable" or "non-flammable" and the class name was changed to FLAMMABLE.

The current in-train placement requirements[18] are founded on no more rigorous a scientific basis than were the original. They are, rather, based on the empirical evidence of history and on a sense of what "ought" to be, driven by concerns for the safety of crew members. This is not intended as criticism. The current in-train placement and separation regulations seem to have served the cause of safety well, and no body of evidence has emerged from the analysis of accidents or incidents to suggest the need for sudden or drastic overhaul.

Position in Train of Placarded Cars
Transporting Hazardous Materials

RESTRICTIONS	Placard Group 1	Placard Group 2		Placard group 3		Placard Group 4
	Rail Car	Tank Car	Rail Car	Tank Car	Rail Car	Rail Car
1. When train length permits, placarded car may not be nearer than the sixth car from the engine or occupied caboose.	X	X		X		
2. When train length does not permit, placarded car must be placed near the middle of the train, but not nearer than the second car from an engine or occupied caboose.	X	X		X		
3.An open-top car when any of the lading protrudes beyond the car ends or if shifted would protrude beyond the car ends.	X	X		X		
4. Loaded flat car except closed TOFC/COFC equipment, auto carriers, and other specially-equipped cars with tie-down devices for handling vehicles. Permanent bulk head flat cars are considered the same as open-top cars.	X	X		X		
5. Any rail car, transport vehicle, or freight container with temperature control equipment or internal combustion engine in operation.	X	X		X		
6. Placarded cars may not be placed next to each other based on the following:						
Placard Group 1		X	X	X	X	X
Placard Group 2	X			X	X	X
Placard Group 3	X	X	X			X
Placard Group 4	X	X	X	X	X	

Placard Group:
Group 1: Divisions 1.1 and 1.2 (Class A explosive) materials.
Group 2: Division 1.3, 1.4, 1.5 (Class B and C explosive), Class 2 (compressed gas; other than Div 2.3, PG I, Zone A), Class 3 (flammable liquid), Class 4 (flammable solid), Class 5 (oxidizing), Class 6 (poisonous liquid; other than Div 6.1 PG I, Zone A), and Class 8 (corrosive) materials.
Group 3: Divisions 2.3 (PG I, Zone A; poisonous gas) and 6.1 (PG I, Zone A; poisonous liquid) materials.
Group 4: Class 7 (radioactive) materials.

* Where an "X" appears at the intersection of a Placard Group column and a Restriction row, the corresponding restriction applies.

[18] The current regulations, at 49 CFR § 174.85, use a table to graphically display requirements that, until December 1990, were contained in §§ 174.85 through 174.93.

The regulations now specify a 6-deep / middle of the train / buffer car requirement. That is, loaded placarded cars (other than those placarded combustible) may not be placed nearer than the sixth car from the locomotive or occupied caboose, if the length of the train permits it. If 6 deep is not possible, then loaded placarded cars must be placed in the middle of the train and separated from the locomotives or occupied caboose by at least one nonplacarded car. The regulations also require the segregation of certain cars from other cars. The chart, reproduced above from § 174.85, provides the details.

In some limited cases, hazardous materials transportation has been permitted without a "buffer" or "spacer" car. Unit trains transporting sulfuric acid are currently operating in Canada[19] without buffer cars under specific regulatory endorsement. However, in the United States there are a very few nearly-unit trains of hazardous materials, and they operate with a buffer between the loaded placarded cars and the occupied locomotive and caboose.

Cabooseless train operations are now common and FRA is considering whether or not to require segregation of loaded placarded hazardous materials cars from the rear of such trains. At least part of the impetus for an amendment is a recommendation (R-87-17) to that effect from the National Transportation Safety Board. The purpose of the recommendation was to protect the engine crew on following trains from striking hazardous material cars that could be positioned on the rear-end of a leading train.

Issues: In-train placement of hazardous materials presents at least three categories of issues: (1) employee versus public safety, (2) the potential for chemicals to mix with adverse reactions versus the proximity of chemical-laden cars to sources of ignition, and (3) train placement versus train make-up. The following section is a brief description of some of the dimensions of the issues, including a discussion of supporting research studies.

The safety of the public is enhanced when the number of accidents is reduced or when the consequences of any given accident are lessened. "Optimum" performance of a system for placing hazardous materials cars in trains, then, would be achieved when these cars were so marshaled (to use the Canadian term) that an accident to one would not affect another. For instance, if 10 cars of liquefied petroleum gas were scheduled to be moved in a 110-car train,

[19] Unit trains, so named because they move one commodity in a single train directly from shipper to consignee, have been successful in moving tremendous tonnages of grain and other agricultural products, lumber, and coal. More recently, beginning in 1967, a major Canadian producer of sulfuric acid has proven that unit trains can move large quantities of this basic industrial chemical safely. The hazardous materials regulatory body in Canada granted this unit train an exception; regulations in effect in both Canada and the United States at the time were nearly identical in requiring at least one buffer car.

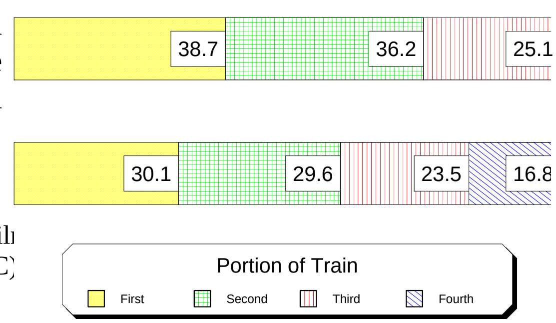
they could be inserted as every tenth car. This would separate each one from all others and would require the derailment of more than 10 cars before 2 such cars would become involved. However, this plan would require 10 times more switching than moving the cars as a solid block and, if any part of the train derailed, this plan would essentially guarantee that a liquefied petroleum gas car would be involved.

On the other hand, switching railroad cars involves the risk of accidents and employee injury. If the goal is a reduction in accidents and injuries during switching operations, railroad workers would be protected, and "optimum" performance would thus be achieved, when the cars are marshaled to reduce the number of switching movements. Because the whole system for moving hazardous materials safely by railroad has such a good safety record, FRA is reluctant to attempt to "improve" safety by issuing regulations that will markedly increase the switching movements for cars of hazardous materials. Switching also involves the risk of overspeed impact, and–historically–some of the most catastrophic rail accidents involving hazardous materials have been in classification yards, with effects into the adjacent or nearby neighborhoods. Accordingly, a tradeoff of more highly refined train placement requirements could be more numerous incidents involving release of hazardous materials. Maximum total safety is not achieved by asking one group of "at risk" people to accept more risk so that another group will endure less. Despite the controversy woven throughout this issue, there is, effectively, universal agreement that the hazardous materials in a train should be separated from the portions of the train carrying people.

A hazardous materials train derailment theoretically could create a "witches brew" of chemicals that react to produce reactions more volatile, and fumes more toxic, than any of the individual products. In-train placement regulations do consider both reducing the likelihood of a tank puncture -- by prohibiting a hazardous materials tank car next to a load of telephone poles, for instance -- and reducing the lethal effects of the post accident scene -- by requiring, for instance, that poison gas and explosives cars not be coupled to each other.

Research: The Transportation Systems Center (now, the Volpe National Transportation Systems Center) published a study in March of 1979 exploring the idea that most derailments involve cars placed towards the front of a train.[20] TSC's analysis grew from a determination of the in-train location of all derailed units in reportable accidents for the years 1975, 1976, and 1977. After eliminating what it called

Position in Train of Derailed Cars
(Transportation Systems Center)

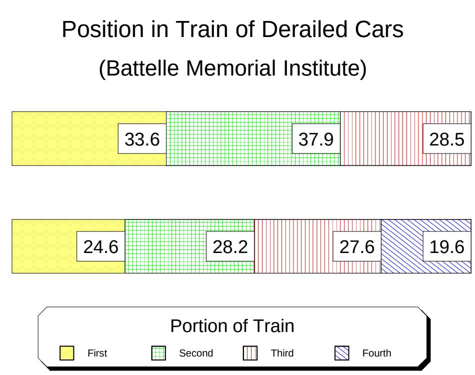


[20] Fang, Paul Ching-I and Reed, H. David, "Strategic Positioning Of Raili
Derailment," Internal Staff Study, Transportation Systems Center (DOT/TSC)

"bad data," for instance, reports where the number of cars derailed equaled a greater number than the length of the train, TSC was left with over 22,000 derailments over the three-year period.

Dividing the train into thirds, TSC found that 38.7 percent of the cars derailed were in the first third of the train, 36.2 percent were in the middle third, and 25.1 percent were in the last third. Splitting the train into quarters showed 30.1 percent of the cars derailed were in the first quarter, 29.6 in the second, 23.5 in the third, and 16.8 in the last quarter of the train. The data also appear here as a bar graph. The study concluded that the risk of derailment is higher in the forward section of the train than in the rear third or rear quarter of the train.

Under contract with FRA, Battelle completed a more recent study.[21] Because Battelle concentrated on identifying opportunities for reducing the number and severity of hazardous materials car derailments, it selected only derailments on "main track" involving "freight trains" and "mixed trains," and it eliminated any derailment associated with a "short train," that is, a train with 10 or fewer cars and locomotives. As with TSC, Battelle weeded out "bad data" and developed a final total of 5,451 derailments in 1982 through 1985.[22] The three- and four-section analysis of derailments in this study is similar to the earlier TSC project, and appears in the accompanying bar graph. Both studies show that the risk of derailment is significantly less in the rear of the train. The Battelle study also shows that the next safest section of the train is the front and the four section analysis indicates that, except for the rear of the train, "...there is little difference in the relative safety of the first three quarters."[23]



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[21] Thompson, R.E., Zamejc, E.R., and Ahlbeck, D.R., *Hazardous Materials Car Placement In A Train Consist*, Final Report, Technical Task No. 6, Contract No. DTFR53-86-C-00006, 1989. The study is in two volumes: Volume I, Review and Analysis, and Volume II, Appendices.

[22] An analysis by Battelle, within its report, demonstrates that mainline, long-train derailments constitute approximately the same percentage of incidents during the years included in the TSC study as in the years examined by Battelle. The more recent study simply focuses on a subset of the overall statistics.

[23] Battelle study, Vol. I, p. 11. Battelle attributes the relatively minor statistical differences between its study and the TSC work to the examination by TSC of derailments on all types of track, rather than on mainline track only. Battelle also excluded "short" trains and this may well have given a clearer picture of the relationship between each of the thirds or quarters of the train. (The average length in Battelle's study was 81 cars and locomotives. In the VNTSC work, it was 65.)

If mainline track operations were all that needed to be considered and, if avoiding derailments were the overwhelming priority, a hazardous materials placement strategy concentrating on the rear portion of the train would seem wise. However, train marshaling is not that simple. Another FRA study[24] concluded that the preferred location for loaded cars is towards the front of the train because, under braking, heavy cars decelerate more slowly than empty cars and, if placed towards the rear, would "push" the more rapidly decelerating empty cars in front of them and generate high buff forces. Another danger of placing extended strings of light cars ahead of loads is the "stringline" effect.[25] Analysis of the July 14, 1991 accident at Dunsmuir, California,[26] shows that the pulling force of the engines combined with the drag of heavy loads may cause a group of light cars (especially long, light cars) to be pulled off the tracks and towards the inside of a curve. The tighter the curve, the more pronounced the possible effect.

Yet another set of complications arises in the consideration of hazardous materials incompatibility. Battelle reviewed the top 100 hazardous materials transported by rail, ranked by number of tank car shipments.[27] Each commodity on the list was paired with every other and the pairs were considered "incompatible" if the combination produced greater lethal effects than either of the individual components. The research chemists evaluating the commodity pairs regarded the following effects as particularly dangerous:

- Toxic chemical releases,
- Fireballs,
- Unconfined vapor cloud explosions,

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[24] Nayak, P.R. and Palmer, D.W., "Issues and Dimensions of Freight Car Size: A Compendium," Report No. FRA/ORD-79/56, January 1980.

[25] “Stringlining” was discussed earlier in this report.

[26] An earlier example is the November 9, 1977, accident at Pensacola, Florida where a derailment, at least partly attributable to the "stringline" effect, lead the puncture of a tank car of anhydrous ammonia and the resulting gas cloud caused 2 deaths, many injuries, and the evacuation of 1,000 people.

[27] A list is published each year by the Bureau of Explosives of the Association of American Railroads. The Battelle study used the 1986 list; the most recent list available is in *Annual Report of Hazardous Materials Transported by Rail, Year 1995*, Report BOE 95-1, Bureau of Explosives, Association of American Railroads, Washington, D.C., September 30, 1995. From year to year, the rankings of the commodities are remarkably consistent. The report uses data garnered from the second generation of the AAR's TeleRail Automated Information Network (TRAIN II), the industry's rail car interchange data base.

- Condensed phase explosions, or
- Pool fires - thermal radiation hazards, toxic combustion products.

Battelle ranked the pairs of chemicals on the basis of both their potential consequences and their risk. Chemical mixtures with the worst consequences include:

- Oleum with organic chemicals: Can produce toxic emissions, fire balls, and unconfined vapor cloud explosions;
- Fuming nitric acid with organic chemicals: Can yield toxic emissions, fire balls, and unconfined vapor cloud explosions;
- Hydrogen peroxide with organic chemicals: Can give off toxic emissions and undergo condensed-phase explosions;
- Sodium metal with commodities containing water: May result in fire ball or unconfined vapor cloud explosion; and
- ASTM Group 1 (Nonoxidizing mineral acids) with ASTM Group 2 (oxidizing mineral acids): Toxic emission consequences.

Consequence-based ranking yielded an interesting sidelight; according to the report,

> It is interesting to note that mixing of chemicals will generally mitigate the toxic emission consequences of highly toxic chemicals such as hydrocyanic acid, chlorine, anhydrous ammonia, and hydrogen fluoride. An exception is the combination of hydrocyanic acid with chlorine, which may form cyanogen chloride, a tear gas. In the case of hydrogen fluoride, all combinations resulted in either the same or reduced consequences as compared with the unmixed chemicals.
>
> Similarly, mixing will generally mitigate the consequences (fireballs and UVCE's) of highly flammable chemicals including hydrocyanic acid, acetaldehyde, and ethylene oxide.[28]

This serendipitous mitigation of the consequences of chemical releases is especially interesting in a "real world" transportation situation, where safety and risk decisions are interlaced with economic and traffic-flow decisions and where the overall safety of rail borne hazardous materials transportation is already very good.

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[28] Battelle study, p. 76.

When calculating the risk-based rankings, Battelle combined the consequences of mixing an incompatible chemical pair with the yearly number of tank car movements of the commodities. The reasoning was that the volume of movements gives an indication of the potential frequency for the chemicals to be involved in the same derailment; this reasoning is admittedly imperfect because it does not allow for different patterns of distribution for various chemicals or for seasonal patterns in their transportation volumes.[29]

Normalized risk was established by dividing the risk of each pair by the risk of the lowest contributor in the pair.[30] Of the commodity pairs in the study, the lowest combination was hydriodic acid and acrylic acid, and this was assigned a normalized risk equal to one. All other combinations were ranked relative to how much greater their risk was than the lowest. The combination of hydrochloric acid with sulfuric acid has the greatest risk, and it is over five times the risk of hydriodic acid with acrylic acid. According to the Bureau of Explosive's annual report of hazardous materials transportation, over 70,000 tank cars of sulfuric and hydrochloric acids moved in 1992, compared with fewer than 4,000 for the pair with the lowest risk ranking. The Battelle report attributes more than 50 percent of the risk to the following combinations:

- Oleum with sodium hydroxide, methyl alcohol, denatured alcohol, or fuel oil;
- Sulfuric acid with hydrochloric acid, methyl alcohol, denatured alcohol, vinyl chloride, hydrofluorosilicic acid, carbon tetrachloride, or benzene;
- Sodium hydroxide with styrene, acetic acid, or carbon tetrachloride; and
- Chlorine with anhydrous ammonia or hydrocyanic acid.

Based on its findings thus far, Battelle went on to consider car-to-car separation within a train. "The minimum segregation distance," according to the report, "is the spacing distance between HAZMAT rail tank cars which is required to prevent mixing of incompatible chemicals during train accidents involving derailments."[31] The distance cannot be defined precisely because of the varying effects of terrain, natural and constructed drainage systems, and the surface adsorption of liquids. Individual hazardous materials spills can also be affected by the weather at the time of the accident. Recognizing these limitations, Battelle concludes that a

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[29] As just two examples, anhydrous ammonia, an important agricultural fertilizer, moves most heavily during the growing season and the largest volumes of liquefied petroleum gas move during the heating season for homes and industries.

[30] "Risk," for these purposes, is a concept developed by combining the consequences of a particular chemical and the surface area over which those consequences are likely to be felt. A more complete discourse is given in the Battelle study.

[31] Battelle report, p. 78.

complete spill of a 100-ton tank car onto flat, "normally" adsorptive soil would affect a roughly circular area with a radius of about 40 meters (±132 feet).

During derailments, tank cars often turn at right angles to the track and stack up - not unlike a stack of firewood.[32] The September 28, 1982, derailment on the Illinois Central Gulf Railroad at Livingston, Louisiana,[33] is considered by the Battelle study as a "worst case" example. In that accident, 42 railroad cars, nearly all of them tank cars loaded with hazardous materials, derailed and most of them lost all or part of their contents. The tank cars stacked up so severely that 30 were compressed into an area about 265 feet long, or only about 5 car lengths. A spill from the first car in the stack could, assuming Battelle's 40-meter affected area, have mixed with a spill from the 30th car. If the spill from each car affected a 40-meter circle, then the separation distance after a derailment would have to be 80 meters, and to accomplish that at Livingston would have required a separation distance of 30 cars.

Because the Livingston derailment is considered a worst case, the study determined the average maximum number of derailed cars is 13 and concluded that a 15-car separation would provide the 40-meter post-derailment clear zone to minimize commingling of incompatible chemicals.

Canadian authorities have also evaluated risks to train crews and the general public associated with position and separation distances of hazardous materials in a train. A March 1991 research study reported an investigation made by the Institute of Guided Ground Transport[34] to determine:

(1) extent to which regulatory restrictions governing the train placement of hazardous materials interfere with the recommended practices of train make-up for safe train handling; and

(2) whether more compatible regulations involving train handling will improve the overall safety and efficiency of the movement of hazardous materials by railroad.

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[32] These derailments are also called "accordion" derailments.

[33] The National Transportation Safety Board report on the accident is number NTSB/RAR/83/05, "Derailment of Illinois Central Gulf Railroad Freight Train Extra 9629 East (GS-2-28) and Release of Hazardous Materials at Livingston, Louisiana, September 28, 1982."

[34] English, G.W., Cattani, T.K., and Schweir, C., "Assessment of Dangerous Goods Regulations in Railway Train Marshalling," a working paper prepared for Transport Canada by the Canadian Institute of Guided Ground Transport, Queen's University at Kingston, Ontario, March 1991.

As noted, the Canadian regulations are similar to those promulgated by RSPA. The most notable exceptions deal with unit trains of placarded tank cars--no buffer cars are required--and with a five-car separation requirement between cars carrying Division 2.1 (flammable gases) and loaded tank cars transporting chlorine, anhydrous ammonia, or sulfur dioxide.[35]

Neither of the major Canadian railroads has had an incident where hazardous materials placement specifically contributed to a train handling derailment. Canadian National Railways, with relatively flat and straight routes, pointed out that, while a concentration of heavy cars at the rear of the train might be troublesome, a concentration of empty cars there is not necessarily preferred, and might cause more problems than randomly distributed empty cars. The Canadian study also noted that the separation requirements for hazardous materials cars required extra switching moves and a consequent increased exposure to accidents or injuries when performing them.

The Canadian Institute of Guided Ground Transport (Institute) took a long look at the segregation analysis made by Battelle and noted that the risk rankings there do not consider the frequency at which commingling might be expected to occur. Some idea of the frequency of a specific hazardous material being involved in a specific derailment, sometimes known as the exposure risk, can be gathered using the following steps:

> Divide the hazardous materials carloads by the total carloads, multiply that result by the average ratio of loaded car moves to total car moves, then multiply by the probability of release upon derailing, and then multiply by the average number of cars derailing in a derailment.

Making the calculations, the Institute determined that the probability of two common acids both being present and both releasing is on the order of 5.5×10^{-8} or about 55 chances per billion derailments. Performing the same calculations on Battelle's highest risk pair, hydrochloric acid and sulfuric acid, creates a combined probability 2,643 times smaller than the individual probabilities. The Institute also notes that these rough assessments have not considered the probability of effective mixing of the two commodities, nor the probability that the derailment would happen anywhere near a populated area.

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[35] The major railways operating in Canada have argued that this requirement to separate Division 2.1 from the other named gases is a knee-jerk reaction to a massive derailment and fire at Mississauga, Ontario, (near Toronto) in which the presence of a tank car of chlorine in the midst of a conflagration of liquefied petroleum gas cars led to an evacuation of nearly 500,000 people. It was later determined that the chlorine car had indeed been breached and most of its contents had escaped in the thermal plume.

Using actual traffic patterns through an area of suburban Toronto and using any "oxidizing or poisonous substance" combined with any other hazardous materials shipment, the Canadian study calculated that the chances of a derailment with a combined release are between 0.0042 per million and 0.0017 per million derailments.

Finally, the Canadian study noted that many of the worst consequence combinations carry the same placard (hydrochloric acid and sulfuric acid are both in Class 8, formerly corrosive materials) and current regulations in either Canada or the United States do not require buffer cars between commodities of the same class. By contrast, the Canadian restriction of five-car separation between Flammable Gases (Class 2.1) and chlorine, anhydrous ammonia, and sulfur dioxide is enforced on commodities not considered incompatible (in that the combination was not more lethal than either individual chemical), while chlorine and anhydrous ammonia themselves were not required to be separated even though they are considered to present an explosion hazard.

The Institute study mentions a British Railways study[36] performed by Bowring Protection Consultants. The purpose of the British study was to identify the risks associated with the existing segregation requirements for dangerous goods and to explore the possibility of either relaxing or strengthening them. In some instances the British regulations are less restrictive than those of Canada and the United States. For instance, no buffer car is required between occupied rail cars and cars transporting hazardous materials. British regulations, however, tend to be more restrictive in the area of compatibility requirements. For example, there are more combinations, which require single car buffers and, under some conditions, hazardous materials cannot be transported in the same train regardless of separation. The study concluded that the probability of dangerous combinations happening on British Rail is low enough under a random marshaling strategy that it is not an immediate cause for concern.

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[36] Considine, M., A Risk Based Approach to the Segregation of Dangerous Goods on the Railways, Bowring Protection Consultants, prepared for British Railways Board, Contract No. RE21090, March 1988. The Canadian Institute notes that this is a confidential report and it was furnished by Transport Canada. FRA has not read and evaluated the report text itself. The comments included here are those of the Canadian Institute of Guided Ground Transport.

Conclusion

Each year, railroad switchmen are injured, equipment is damaged, and hazardous materials are released in switching accidents, and at least some of that switching happens in order to satisfy the requirements for positioning placarded rail cars in trains. "In-train placement" involves issues of separating hazardous materials cars from parts of the train occupied by people and segregating hazardous materials cars, one from the other; it differs from train make-up, where the goal is to place cars into a train such that they balance the forces within the train.

The issue of train make-up to control improper weight distribution and the consequent imbalance of forces within the train present complex technical problems that have been the subject of extensive research supported by FRA and the industry over two decades. The railroad industry has used the products of FRA's research to develop and implement guidelines for train make-up, and FRA intervenes to encourage more conservative train make-up practices where the need to do so is apparent. Development of more formal Federal policies or requirements has been delayed by the unavailability for independent analysis of an appropriate train dynamics simulator. However, a new modeling tool is currently under development through FRA's Office of Research and Development, and when it is available in a validated form it should permit FRA to more closely evaluate the industry's performance in maintaining appropriate train make-up.

Existing regulations regarding train placement of hazardous materials cars have been fashioned through long experience and have functioned well. The requirement that tank cars carrying hazardous materials be place at least six deep provides suitable protection for train crews without creating excessive issues regarding train make-up (e.g., location of loaded cars). Use of a buffer car at the back of each train containing hazardous materials may have some merit to reduce the consequences of rear end collisions, but thus far the use of cabooseless trains (which itself reduces risk to crew members who would have been riding the relatively fragile caboose) has not resulted in significant additional exposure to head-end crews; and, as discussed in this report, additional switching results in safety as well as economic costs. Risk analysis regarding product combinations has not indicated any compelling need to alter existing requirements that provide for separation of certain commodities to limit, insofar as is practical, undesirable interactions should the train derail. Accordingly, existing in-train placement requirements appear to provide for an appropriate level of safety.