U.S. Department
of Transportation

**Federal Railroad
Administration**

REPORT TO THE HOUSE AND SENATE APPROPRIATIONS COMMITTEES: THE SAFETY OF PUSH-PULL AND MULTIPLE-UNIT LOCOMOTIVE PASSENGER RAIL OPERATIONS

JUNE 2006

Office of Safety
Office of Railroad Development

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Acronyms, Trade Names, Etc.

ACE	Altamont Commuter Express Authority
Amtrak	National Railroad Passenger Corporation
APTA	American Public Transportation Association
ARR	Alaska Railroad
BPM	billion passenger miles
BNSF	BNSF Railway Company
CAS	Collision Avoidance System
CEM	crash energy management
CSXT	CSX Transportation, Inc.
E.O. 20	Emergency Order No. 20
ETMS	Electronic Train Management System
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HRI	highway-rail intersection
IODS	Intruder and Obstacle Detection System
ITS	Intelligent Transportation System
LIRR	Long Island Rail Road
MBTA	Massachusetts Bay Transportation Authority
Metra	Northeast Illinois Regional Commuter Railroad Corporation
Metrolink	Southern California Regional Rail Authority
MU	multiple-unit
NICTD	Northern Indiana Commuter Transportation District
NJT	New Jersey Transit
NPRM	notice of proposed rulemaking
NSC	National Safety Council
NTSB	National Transportation Safety Board
PTC	positive train control
RAIRS	Railroad Accident Incident Reporting System
RSAC	Railroad Safety Advisory Committee
ROW	right-of-way
SEPTA	Southeastern Pennsylvania Transportation Authority
SIV	secondary impact velocity
SUV	sport utility vehicle
SOA	state-of-the-art
TRE	Trinity Railway Express
Tri-Rail	Tri-County Commuter Rail Authority
UP	Union Pacific Railroad Company
Volpe Center	Volpe National Transportation Systems Center

EXECUTIVE SUMMARY

This report responds to a request contained in the Report of the House Committee on Appropriations on the Departments of Transportation, Treasury, and Housing and Urban Development, The Judiciary, District of Columbia, and Independent Agencies Appropriation Bill, 2006 (H. Rept. 109-153; June 24, 2005), which stated as follows:

> *Push-pull operations*—The Committee is concerned about the safety of passenger rail operations with the use of cab cars as the forward car in the push-pull mode or self-propelled locomotives with passenger seating (MU locomotives), particularly after the tragic and deadly Metrolink train derailment in Glendale, California in January. Previous studies have noted that occupants of the relatively exposed cab car, including the engineer, are vulnerable to serious injury or fatality in the event of a collision with either a road vehicle at a grade crossing or with another train. Current railroad requirements must be reassessed to ensure the safety of passengers occupying the leading car. In light of these concerns, the Committee directs FRA to conduct a definitive study regarding the use of cab cars during the push-pull mode or in MU locomotives as compared to standard passenger locomotives as leading vehicles in passenger trains, to include a review of the following: the relative frequency and severity of accidents, with special emphasis placed on the differences associated with derailments; the efficacy of crashworthiness features; and a review of the FRA's Emergency Order No. 20 and its effectiveness in increasing passenger safety. FRA should report to the House and Senate Committees on appropriations no later than June 1, 2006.

Equipment Types and Service Types

Most commuter railroads generally operate one or both of two types of passenger train service: multiple-unit (MU) locomotive and push-pull. An MU locomotive is a self-propelled rail vehicle that is designed to transport and be occupied by passengers. MU locomotives can be either electric or diesel. MU locomotives typically operate semi-permanently coupled together as a pair or triplet with a control cab at each end. During peak commuting hours, multiple pairs or triplets of MU locomotives, or a combination of both, are typically operated together as a single passenger train in MU service.

In contrast, push-pull service is passenger train service typically operated with a conventional locomotive in the rear of the train pushing the consist (the "push mode") with a cab car in the lead position of the train, and with the conventional locomotive in the lead position of the train pulling the consist (the "pull mode") with the cab car in the rear of the train. A cab car is both a passenger car and a locomotive in that it has a control cab from which the engineer can operate the train. Control cables run the length of the train, as do electrical lines providing power for heat, lights, and other purposes. Structurally, MU locomotives and cab cars built in the same period are very similar, and both are designed to transport and be occupied by passengers. The principal distinction is that cab cars do not have motors to propel themselves. Unlike MU locomotives and cab cars, conventional locomotives are not designed to be occupied by passengers—only operating crewmembers—conventional locomotives are designed to move other rail equipment.

Historically, MU locomotive commuter service using power derived from an overhead catenary or ground-level third rail has predominated in the Northeast, but some electric MU locomotive service is also provided in northern portions of Illinois and Indiana.[1] As commuter service has grown outside the Northeast, commuter authorities have generally chosen to use diesel-powered MU locomotive service or push-pull service. Locomotives used for push-pull commuter service are generally diesel-electric, but in the New York City region some are dual powered (capable of taking power from a third rail or operating from energy developed by a diesel prime mover).

Long-distance intercity passenger trains are generally operated in the pull mode exclusively with conventional locomotives in the lead, but State-financed intercity service over relatively shorter distances sometimes utilizes push-pull arrangements. Approximately 94 percent of National Railroad Passenger Corporation (Amtrak) service is operated exclusively in pull service with conventional locomotives in the lead. The rest is in push-pull service. Amtrak also operates some trains with what are commonly known as "cabbage cars," which are de-powered locomotives used as cab cars but without passenger seating. This report categorizes such service as pull because these cars behave structurally like conventional locomotives, not cab cars. Most Amtrak trains in the Northeast Corridor, from Washington to New York to Boston, use conventional, electric locomotives. Elsewhere throughout the country, Amtrak trains use conventional, fossil-fueled locomotives.

Definition of Concern

Accidents and incidents involving trains and their occupants include train-to-train collisions, highway-rail grade crossing collisions, collisions with obstructions on the right-of-way (ROW), and derailments. These occurrences may result in train occupant injury or death from such causes as loss of occupant volume (due to structural crushing), fire and smoke, occupant ejection from the train, and occupant impact(s) with the interior. The type of risk faced by occupants is different depending on service type.

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[1] Service provided by the Northern Indiana Commuter Transportation District (NICTD) is a remnant of the extensive electric inter-urban service once provided in many locations across the Nation.

This report addresses the following two questions of concern. (1) Based on recent accidents, is there any difference in the likelihood of derailment between a conventional locomotive-led train and a cab car- or MU locomotive-led train resulting from a highway-rail grade crossing collision? (2) Assuming that a collision or derailment occurs, is there any difference in the severity of accident consequences between a conventional locomotive-led train and a cab car- or MU locomotive-led train?

The Safety Record

The Federal Railroad Administration (FRA) reviewed fatal accidents over the 20 calendar years of 1986–2005 and focused more specifically on all serious accidents occurring during the past 10 calendar years (1996–2005).

FRA did note a higher fatality rate in the push mode than in the pull mode for commuter push-pull service. The bulk of the fatalities stemmed from two collisions in February of 1996 (Secaucus, NJ; Silver Spring, MD) and three events in southern California involving the Southern California Regional Rail Authority (Metrolink) commuter service (Placentia, Burbank, Glendale). Loss of occupant volume due to structural crush during a collision has resulted in a total of 22 fatalities in the past 10 years. Ten of these fatalities occurred on conventional locomotive-led trains, while 12 have occurred on cab car-led trains.

By contrast, MU service—with an occupied passenger-carrying locomotive in the lead at all times—compiled a superior safety record over the past 20 years and over the past 10 years experienced a fatality rate less than conventional locomotive-led intercity service or any competing mode of transportation, including scheduled airlines.

FRA examined the question of whether a cab car- or MU locomotive-led train is more likely to derail than a conventional locomotive-led train, assuming collision with an object such as a motor vehicle at a highway-rail grade crossing. Each type of service experienced a low number of derailments in relation to the number of collisions. Although the analysis tended to favor pull service for resistance to derailment on the raw numbers, comparisons of the derailment histories of these modes of operation show no statistically significant differences in the propensity to derail.

Engineering Analysis of Derailment Propensity

The historical record for passenger trains derailing in a collision matches well with expected outcomes. With technical assistance from the Volpe National Transportation Systems Center (Volpe Center), FRA analyzed and compared the likelihood of post-collision derailment of cab car- and MU locomotive-led trains and conventional locomotive-led passenger trains. Fundamentally, the potential for derailment is related to the ratio of the vertical and lateral forces acting between the equipment and the track [1]. Assuming that the suspension is well designed for the equipment's weight, the lateral forces that develop during a highway-rail grade crossing collision increase in concert with the vertical forces as the equipment weight increases. As car weight increases, the lateral forces required to cause derailment also increase, but the ratio of the lateral to vertical forces which lead to derailment remain constant. With adequately designed suspensions, the expected tendency to derail is the same for conventional locomotives and cab cars and MU locomotives. As noted above, analysis of 10 years of data does not establish any greater propensity for cab car- or MU locomotive-led trains to derail than conventional locomotive-led trains.

Analysis of the Safety Issues

Safety is achieved through prevention (avoid an incident if possible), mitigation (do not let an incident turn into something worse), and response (be prepared to deal with an incident-related emergency). For example, MU service is most concentrated in the Northeast, where many of the lines are equipped for cab signals and automatic train control and where development of the transportation infrastructure has emphasized grade separation of the railroad from other public transportation. It is not surprising that these factors, which prevent incidents or mitigate their consequences, support a low accident rate. By contrast, the only MU service to experience a fatal collision over the past 10 years (one highway-rail grade crossing collision) does not have automatic train control and has many grade crossings on its line—some used by large volumes of heavy trucks.

This report details many of the actions that FRA and passenger railroads have been taking to reduce risk to passengers and crew. They range from wider deployment of positive train control (PTC) systems and various improvements in highway-rail grade crossing safety, to advances in crashworthiness, to better emergency preparedness (in other words, better prevention, mitigation, and response). Taken as a whole, these actions have already begun to reduce the risk reflected by the incidents described in this report.

By contrast, a narrow focus on one aspect of the safety issues (cab car- or MU locomotive-led operations versus conventional locomotive-led operations) could result in simply shifting risk from one place to another. Compared to cab car or MU locomotive-led trains, conventional locomotive-led trains may reduce the number of fatalities due to loss of occupant volume at the colliding interface; however, in more serious events the structural crush is passed back to other areas of the train. Conventional locomotives absorb very little collision energy [2], while adding energy to the initial impact because of the difference in mass between a cab car or MU locomotive and a conventional locomotive. The added collision energy may exacerbate the occurrence of lateral buckling of the train, increasing the likelihood of subsequent collisions with objects on or near the wayside or with other trains.

The Glendale Incident

The Committee specifically referenced the Glendale, CA, incident of January 26, 2005, as one reason for requesting this report. This incident was deliberately triggered by an apparently criminal act. Further, it involved enormous quantities of kinetic energy. Events of this kind almost invariably produce outcomes that would have been difficult to predict, let alone to control. Other incidents, such as the Chase, MD, collision of January

7, 1987, or the Bourbonnais, IL, grade crossing collision followed by a derailment and collision with standing freight cars on March 15, 1999—both involving *conventional locomotive-led trains*—had previously illustrated the point that some events are sufficiently severe that it is not realistic to focus on mitigation. Thus, in addressing events of this kind, the focus needs to be on prevention.

In the case of the Glendale incident, three trains were involved: a cab car-led passenger train, a standing freight train, and a conventional locomotive-led passenger train. During the incident, after striking a stationary sport utility vehicle (SUV) situated approximately 150 feet from the highway-rail grade crossing and straddling the rails, the cab car-led passenger train derailed. As a result of the impact with the SUV, the lead truck of the cab car encountered a hard object from the SUV, causing the cab car to be guided down a siding, which resulted in an impact at an approximate speed of 49 miles per hour with the standing freight train. After the collision with the standing freight train, the rear end of the lead cab car buckled laterally, fouling the ROW of the oncoming, conventional locomotive-led passenger train. The rear end of the cab car raked the side of the conventional locomotive-led train, which was moving at an approximate speed of 51 miles per hour, causing intrusion into occupied areas of that train.

Eliminating cab car-led passenger trains and always having a conventional locomotive in the lead have been suggested as a strategy for improving crashworthiness. In the case of the Glendale incident, results from computer simulations, which assume that a conventional locomotive would have derailed in the same manner as the cab car (which appears very likely, given that the SUV had dug into the track structure), indicate that having a conventional locomotive in the lead would not have reduced the total number of fatalities. These simulations indicate that, had a conventional locomotive been in the lead, fatalities would have been reduced but not eliminated in the second collision involving the standing freight train. However, the actual cab car-led train buckled during the incident and sideswiped the conventional locomotive-led passenger train. The simulations indicate that a conventional locomotive in the lead would have amplified the buckle and aggravated the sideswipe, likely increasing the fatalities resulting from the third collision with the conventional locomotive-led passenger train.[2]

Crashworthiness Research

Crashworthiness research employs knowledge of historical accident consequences to determine the risk factors that passengers and crewmembers are subjected to and to develop alternative design strategies to address those factors. The principal goals of crashworthiness research include preserving the space for passengers and crewmembers to ride out an event and ensuring that the secondary impact environment during the ride-out phase maintains the forces the occupants are subjected to within survivable levels.

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[2] The initial collision with the SUV was not simulated. Whether the initial collision would have resulted in derailment, and if so, whether such derailment would have resulted in the subsequent collision with the freight train cannot be determined with the information available from the incident.

Initial phases of crashworthiness research focused on the characteristics of the then-current cab car and MU locomotive designs with the objective of strengthening the forward end structure to best withstand collision forces, consistent with the longitudinal strength of the passenger vehicle. This effort identified collision post and corner post enhancements that are intended to optimize vehicle performance short of collapse of the vehicle's underframe. These results are incorporated in all new cab cars and MU locomotives delivered for service. Recent research has focused on specifying criteria, both static and dynamic, for graceful deformation of the end structure to better absorb and control collision energy. FRA is presently preparing a proposed rule to make these criteria mandatory.

To further improve cab car and MU locomotive crashworthiness in train-to-train collisions, FRA has been pursuing the strategy of crash energy management (CEM). CEM improves the crashworthiness of the entire train by absorbing the collision energy in a controlled progressive manner in designated crush zones, as well as managing the inter-car interactions at coupled and colliding interfaces. These crush zones are designed to collapse in a controlled fashion during a collision, distributing the crush among the normally unoccupied areas of the train's cars. This design strategy protects the occupied spaces in the train and limits the decelerations of the occupant volumes. Research results indicate that passenger train crashworthiness can be incrementally increased by first incorporating CEM in the cab car, then by modifying the coach cars with couplers designed to push back and absorb energy, and finally by incorporating structural crush zones in all of the coach cars.

These concepts were successfully demonstrated through full-scale crash testing in March 2006 at the Transportation Technology Center, Pueblo, CO. Recognizing the acceptance of CEM principles internationally, Metrolink has awarded a contract for a new generation of passenger equipment that will utilize CEM research results. The result will be a significantly safer fleet less susceptible to loss of occupant volume and more likely to remain on track and in line, whether the collision occurs in the push or pull mode. Metrolink views this approach as much more cost effective than converting to a pull-only operation.

FRA Efforts to Improve the Safety of Cab Car- and MU Locomotive-Led Trains

Although the historical record does not indicate that passenger safety is significantly compromised by use of cab car- or MU locomotive-led trains, there are types of events, such as head-on collisions between conventional locomotive-led freight trains and cab car-led trains, that involve somewhat greater hazard for cab car occupants. This concern is particularly relevant to older cab cars, which were constructed with the same end strength characteristics as passenger coaches. Beginning in the early 1990s, FRA began efforts to mandate improvements in cab car design. FRA has also sought to improve railroad operating practices involving push-pull service and to ensure that all rail passenger service is accompanied by effective emergency planning.

FRA's approach to increasing the safety of rail passenger travel has included research and development of safety technology, technical support for industry specifications and standards, and, when necessary, development of regulations. Overall, the likelihood of a rail passenger being injured or killed is low, and FRA has sought to progressively reduce the risks to rail passengers.

Targeted actions, many of which were taken in cooperation with the American Public Transportation Association (APTA), manufacturers of rail equipment, and labor organizations representing passenger rail employees, include:

- Improved operating practices under Emergency Order No. 20 (E.O. 20) (since February 1996).
- Strengthened collision posts and end material on new cab cars and MU locomotives ordered on or after September 8, 2000, or placed in service on or after September 9, 2002, under the Passenger Equipment Safety Standards, and strengthened corner posts under APTA's industry standards (developed with FRA assistance).
- Designs for CEM that will close the perceived gap between conventional locomotive- and cab car-led trains with respect to head-on collisions, now incorporated into Metrolink's current cab car procurement.
- Concepts for improved seats and tables now being demonstrated through full-scale tests.
- Improved emergency egress from existing and new cars, with additional proposals pending.
- Mandatory emergency preparedness programs, drills, and debriefs since 1998 under the Passenger Train Emergency Preparedness rule.

FRA continues to progress research, discussed immediately above, and rulemaking in many of these areas.

FRA is also actively working to spur innovative approaches to highway-rail grade crossing safety and the introduction of PTC systems that can prevent train-to-train collisions. PTC is a reality on portions of the Northeast Corridor and on Amtrak's Michigan line, as well as on the New Jersey Transit's (NJT) Pascack Valley line, and rapid progress is now being made in revenue demonstration of a PTC architecture that may be suitable for application across the freight rail system, including those portions shared with commuter service. PTC technology can prevent train-to-train collisions, overspeed derailments, and impacts with track personnel and machinery. Events such as those that occurred at Gary, IN; Secaucus, NJ; Silver Spring, MD; and Placentia, CA, can be reliably prevented.

Recognizing that risks do not manifest themselves in the same way in every region and on every railroad, FRA is also working with commuter railroads to enhance their ability to conduct hazard analysis and to identify and address risks particular to their operating environments. The Tri-County Commuter Rail Authority (Tri-Rail), southern Florida's commuter rail service, has conducted a pilot collision hazard analysis with assistance from APTA and FRA. APTA and FRA will be working to make available guidance material and training for application on the other commuter rail properties. Careful analysis of hazards can help to identify and correct conditions, such as those present at the highway-rail grade crossing in Burbank, CA, that can result in harm to passengers.

Finally, FRA is working with Metrolink to help develop and demonstrate a sealed corridor approach, adapted with security concerns in mind, to help reduce the risk of events like the 2005 Glendale incident.

Conclusion

Commuter rail service is provided by State or local governments or by public benefit corporations acting on their behalf. Since funding implies control, a particular State or local body funding commuter rail service can elect to provide exclusively conventional locomotive-hauled service. There is no Federal law or regulation *requiring* push-pull or MU locomotive service. However, Appendix D describes the costs that would be associated with abandonment or restriction of push-pull or MU locomotive service on the Nation's rail system. In most cases, these costs could not be borne within existing funding levels without reduction of rail service or without forgoing expansion of service.

Both intercity passenger and commuter rail service are very safe, and are becoming safer. They are much safer than use of personal motor vehicles (the likely alternative for commuters in large urban areas). FRA, therefore, recommends continued emphasis on progressive improvement of passenger rail safety as a whole, rather than abandonment of push-pull service. FRA emphasizes that public authorities providing MU locomotive service have generally succeeded in providing extraordinarily safe transportation with a passenger-occupied vehicle in the lead at all times, and a similarly high level of safety is possible where push-pull service is provided. FRA remains committed to working with passenger rail service providers and their employees, suppliers, and communities with the goal of driving down risk and providing safe and effective solutions to the challenges that confront transportation today.

1. Introduction

In 1996, FRA evaluated the safety of push-pull and MU locomotive operations following two major accidents (Silver Spring, MD, and Secaucus, NJ) and issued E.O. 20. E.O. 20 required more effective communication among crew members with respect to restrictive signals, imposed a delayed in block rule that is intended to prevent mental errors regarding previous signal aspects, required development of interim system safety plans, and required the marking and testing of emergency exits. The interim plans have since been superceded by comprehensive system safety plans under a program sponsored by APTA and supported through monitoring by FRA, but the remainder of the order remains in full effect and is codified in part in FRA's regulations.

The Passenger Train Emergency Preparedness rule, which was based on research, guidelines, and a 1997 notice of proposed rulemaking (NPRM), was published on May 4, 1998. As Chapter 4 explains, this rule focuses on emergency systems, planning, training, and use of drills and debriefs to verify and sharpen readiness.

The Passenger Equipment Safety Standards rule, which was preceded by an Advance Notice of Proposed Rulemaking issued in 1996 and an NPRM issued in 1997, was published on May 12, 1999. The Standards contain extensive requirements for the design, inspection, and testing of rail passenger equipment, including improved structural standards for cab cars and MU locomotives. Work continues through the Passenger Safety Working Group of the Railroad Safety Advisory Committee (RSAC) to improve and update the standards based on operating experience and research results.

On July 1, 1999, APTA issued its initial Manual of Standards and Recommended Practices for rail passenger equipment, complementing the FRA regulations. The APTA standards have introduced additional innovations in passenger train safety. APTA's parallel effort is supported by rail labor organizations and FRA as a rapid means of introducing new concepts and a coordinated means of providing details required for specifications in passenger car procurements.

As a result of the impact at Glendale, CA, where a motor vehicle was deliberately placed on a Metrolink main line immediately prior to the arrival of a commuter train in the push mode, FRA developed an interim report dated July 1, 2005, on the safety of passenger-occupied vehicles leading train movements. This final report, which was requested by the House Committee on Appropriations, seeks to use up to 20 years of safety experience and 16 years of passenger safety research to provide an assessment of safety performance in the principal service modes, as well as to document steps taken to improve that performance.

The report consists of the following elements: analysis of the safety data (Chapter 2); an engineering analysis of cab car crashworthiness issues, including implications for the Glendale incident of 2005 (Chapter 3); and a description of additional actions that are being taken to improve passenger rail safety (Chapter 4). Appendix A describes the methodologies and assumptions used in analysis of the safety data. Appendix B reviews the fatal passenger train accidents that occurred in the period 1986–1995. Appendix C provides detailed information on the passenger train accidents involving fatalities and/or injuries during the period 1996 through December 2005. Appendix D sets forth a review of the implications of prohibiting or restricting cab car- or MU locomotive-led service. Appendix E provides a list of reference documents used in this report.

2. Safety Analysis

2.1 Introduction

This chapter reviews rail incident frequency and severity, both of which are important factors for determining risk. The 20-year period between 1986 and 2005 is reviewed in two parts. First, the entire period is reviewed generally. Then, the most current 10-year period is analyzed in greater detail. For the first 10 years of the period, certain relevant operational information is not readily available, and certain accident information is inconsistent, making it very difficult to conduct a more detailed analysis of that period. Furthermore, many commuter rail push-pull operations were not in service during that time period. The first 10-year period is also less reflective of current operating conditions. Appendix B presents details regarding incidents that occurred between 1986 and 1995. Information reported to FRA beginning in 1997 and information available from an FRA-sponsored field study of causal mechanisms of occupant casualties since 2000 conducted by the Volpe Center and its contractor allow for a more in-depth analysis of the more recent 10 years of the study period (1996–2005).

This chapter also compares (1) the likelihood of derailment, a proxy for frequency of serious incidents, between conventional locomotive-led trains and passenger-carrying locomotive-led trains (i.e., cab cars and MU locomotives); (2) the severity of consequences resulting from such operations; and (3) the relative safety of passenger train operations and other modes of passenger transport.

2.2 Historical Accident Review: 1986–2005

A review of incidents that have occurred in the last 20 years illustrates the level of risk that passenger train occupants are exposed to and highlights the factors that pose the greatest risk to them. Railroads are required to report train accidents with property damages exceeding a railroad property damage threshold (currently $7,700) to FRA. During the 20-year period, 2,736 such incidents involving passenger trains were reported. These were classified by type. Figure 1 depicts a chart where the number of incidents for the 20-year period is plotted against the type of incident.[3] Many incidents classified as collisions and grade crossing incidents also resulted in derailment. Even so, the two categories of incidents that comprise the largest number of incidents are derailments and highway-rail grade crossing collisions.

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[3] Incidents are classified by type according to the occurrence of the initial event. That is, a grade crossing collision that results in derailment is classified as a grade crossing incident and not a derailment.

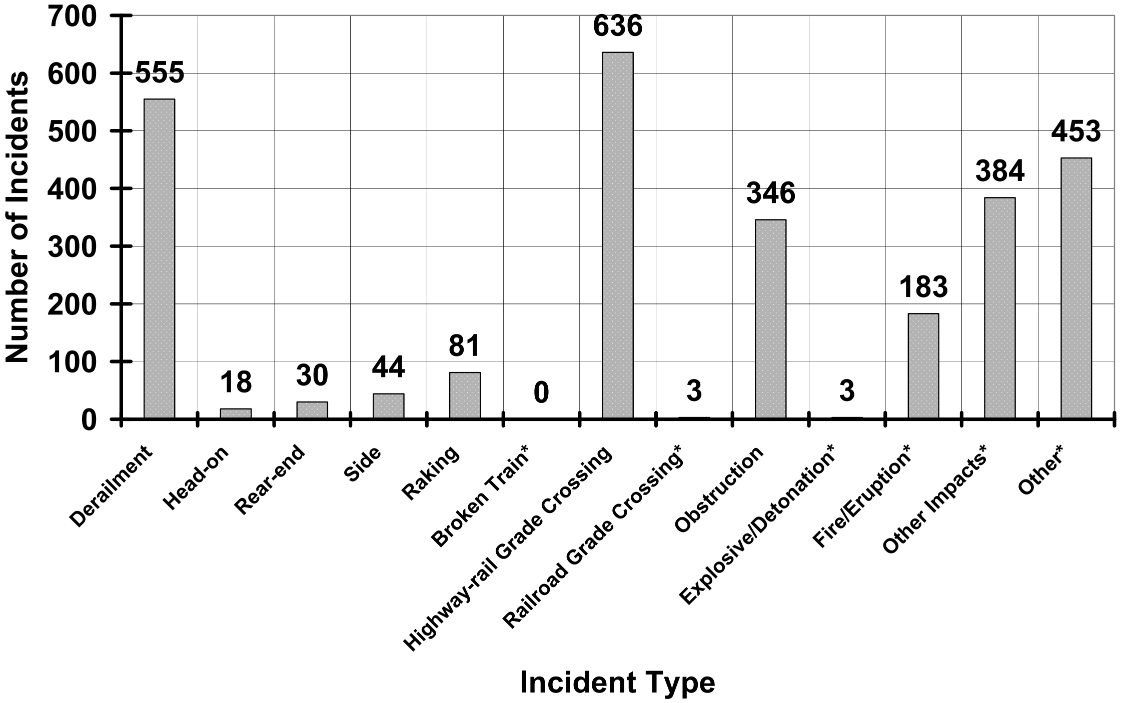

Figure 1. Number of Incidents versus the Incident Type from Railroad Accident Incident Reporting System (RAIRS) 1986-2005

To demonstrate the severity associated with these types of incidents, Figure 2 depicts the number of passenger train occupant fatalities resulting from each type of incident reported. The figure presents three bars, one for the total number of fatalities and the individual breakdown by whether the fatality was a crewmember or passenger. The total number of fatalities is listed explicitly for each incident type. From the figure it would appear that fatalities from derailments are the highest risk; however, 42 of the passenger fatalities occurred in a single event where a barge struck a bridge and caused a misalignment of the track, which led to the derailment. These fatalities cannot be attributed to either vehicle or track defects. The bridge's misalignment resulted in the lead vehicle falling into the river, and the fatalities were due to drowning. Not including these fatalities, the number of fatalities resulting from derailment is comparable to the number of fatalities resulting from grade crossing collisions. The 2005 incident that occurred in Glendale is classified as a head-on collision for the cab car-led train and a raking collision for the conventional locomotive-led train.

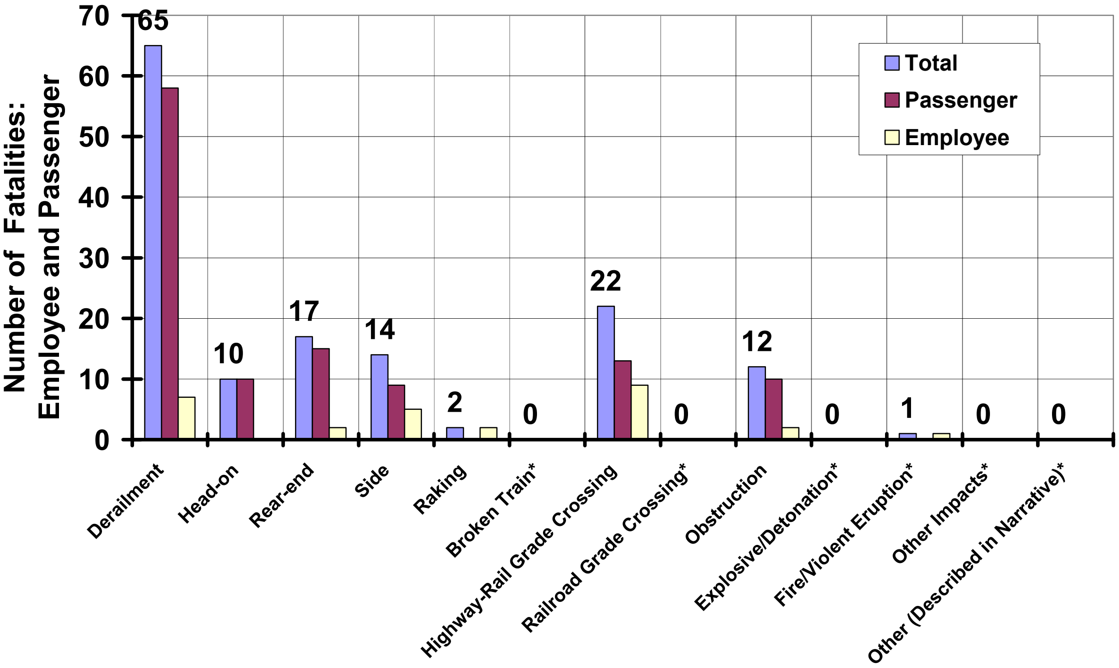

Figure 2. Number of Employee and Passenger Fatalities versus Incident Type from RAIRS 1986-2005

Collisions are a significant risk due to the direct loading onto the carbody structures that results in possible loss of survivable space for occupants. Collisions can be further broken down into either in-line collisions, including head-on and rear-end, and impacts with obstructions, for a total of 39 fatalities, or offset collisions, including side and raking collisions, for a total of 16 fatalities. This greater frequency of in-line collisions has driven the goals of FRA passenger rail crashworthiness research.

As noted earlier, the goals of FRA crashworthiness research include, first and foremost, preservation of normally occupied volume and, second, the minimization of secondary impact forces that occupants are subjected to as they ride out an incident. Causes of fatality can be classified into a number of categories, including loss of occupied volume, fires from ruptured locomotive fuel tanks, ejection, and occupant impacts with interior structures. Categorizing the cause for fatalities experienced for this dataset is difficult because of inconsistent reporting from various sources. The next section will discuss in greater detail a subset of the dataset (1996–2005), where greater detail into causal mechanisms for injury and fatality are available from an FRA-sponsored accident field investigation study.

2.3 Grade Crossing Collisions Resulting in Train Derailments or Other Serious Consequences to Passenger Train Occupants (1996–2005)

Although the Glendale event was not accidental at its inception, and the motor vehicle in question did not occupy a road crossing, some have raised concern regarding the safety of push-mode operations with respect to highway-rail grade crossing exposure. Grade crossing collisions are the most common type of accident that passenger trains experience. All grade crossing collisions are reportable to FRA. Between January 1996[4] and December 2005, 1,986 grade crossing collisions between motor vehicles and passenger trains (intercity and commuter) occurred involving the first unit of the train. This includes both instances where the train struck the highway vehicle and instances where the highway vehicle struck the train. These were distributed as follows:

• Commuter service	
o Pull (conventional locomotive leading)	290
o Push (cab car leading)	218
o MU	105
• Intercity service	
o Amtrak/Alaska Railroad (ARR)	1,373

In commuter service, more accidents occur in the pull mode than in the push mode, despite the fact that the exposure is very similar. This may be attributed to the time of day, as passenger trains experience more grade crossing collisions during the evening rush when they predominantly operate in the pull mode than during the morning rush when they predominantly operate in the push mode. Statistics for highway vehicle accidents also indicate that more accidents occur during the evening rush than during the morning rush. Appendix A presents motor vehicle crash rates by time of day.

Most grade crossing collisions result in no significant damage to the passenger train or harm to its occupants. Highway-rail grade crossing collisions with property damage in excess of a specified threshold[5] are also reportable separately as train accidents. Of the 1,986 grade crossing collisions, 438 were also reported as train accidents (damage exceeded threshold). These were distributed as follows:

• Commuter service	
o Pull	62
o Push	48
o MU	21
• Intercity service	
o Push – State of California	19

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[4] Amtrak operates trains in commuter service for several commuter railroads. Prior to 1997, Amtrak commingled reports of commuter rail and intercity accidents/incidents. Thus, it is difficult to accurately isolate all commuter rail accidents/incidents that occurred prior to 1997 for purposes of this analysis. FRA analysts used their best judgment.

[5] Currently the threshold is $7,700, as noted above.

- Pull - State of California 47
- Remaining Amtrak/ARR 243

In conducting the analysis, FRA noted that some cab cars and MU locomotives were involved in low speed collisions, resulting in no structural damage to the rail car frame, but nonetheless triggered filing of the equipment report by virtue of their design (e.g., use of an outer shell of easily damaged fiberglass to enhance appearance and air flow over the car body). Similar collisions involving other cab cars and MU locomotives may not trigger filing of the equipment report. Assuming crossing collisions that result in derailments triggered filing of the accident report by causing significant damage, most serious events should be captured in this data. Therefore, it is more appropriate to rely on derailments resulting from all grade crossing collisions with motor vehicles involving the first unit of the train for purposes of comparing the propensity for derailment of MU and cab car-forward and conventional locomotive-led operations.

Twenty-six grade crossing accidents were reported to have resulted in derailments. FRA has added the collision on NICTD at Portage, IN, to this group because of its fatal consequences and the fact that it did occur at a crossing (but did not involve derailment of the MU locomotive consist). Table 1 presents the distribution of these derailments and resulting casualties by train makeup.

Table 1. Grade Crossing Train Accidents Resulting in Damage Exceeding Accident/Incident Reporting Threshold (Rates per Billion Passenger Miles (BPM)) January 1996–December 2005[6]

	Commuter Rail			Intercity (Amtrak-ARR)		
	Pull (rate per BPM)	Push (rate per BPM)	MU (rate per BPM)	Amtrak–ARR (rate per BPM)	Push for CA*	Pull for CA*
Derailment Resulted	2 (0.09)	3 (0.14)	1 (0.02)	20 (0.37)	3	0
Train Fatalities	**0/0**	**1 (0.05)**	**0 (0)**	**12 (0.22)**	**0**	**0**
Train Injuries	24 (1.07)	26 (1.18)	0 (0)	162 (2.99)	9	0
Including Portage, Fatal Accident with No Derailment (See Below)			1 (0.02)			
Train Fatalities			**3 (0.07)**			
Train Injuries			1 (0.02)			

* Passenger mile information for Amtrak operations for the State of California is not available for years before 2000. These incidents are also included in the overall intercity statistics in fifth column to allow for comparison of intercity and commuter operations.

Commuter Service. During this period, the two pull (conventional locomotive forward) collisions with derailment involved the Massachusetts Bay Transportation Authority

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[6] Over the study period (1996–2005), commuter railroads logged 460 million passenger train miles, provided 4.2 billion passenger trips, and accumulated 86.8 billion passenger miles.

(MBTA) in Wakefield, MA (1996), and Metrolink in Glendale, CA (2000). The MBTA collision derailed the locomotive and resulted in 15 serious occupant injuries and 21 minor occupant injuries. The Metrolink collision with derailment involved coaches; the locomotive did not derail. The injuries that resulted were minor.

The three push (cab car forward) collisions with derailments involved Metrolink in Burbank, CA (2003), Tri-Rail in Boca Raton, FL (2001), and MARC Train in Hanover, MD (1996). The fatality in the push mode derailment was to a passenger at Burbank. The passenger, age 76, was initially treated and released from a local hospital but then died 15 days later from internal injuries that were probably sustained during the accident. The passenger was riding in the lower level of the cab car. Twenty-two non-fatal injuries resulted from a single incident, the Metrolink collision in Burbank. Two of the injuries were to Metrolink employees, and the remaining 20 injuries were to passengers. Injuries occurred throughout the train. According to the National Transportation Safety Board (NTSB) report of the incident, 12 train occupants were transported to area hospitals. The most serious injury was to a female passenger seated at a workstation table in the cab car mezzanine whose spine was crushed after she was thrown from her seat, resulting in lower-body paralysis. Four passengers were injured in the MARC incident.

The single MU service derailment involved a Long Island Rail Road (LIRR) train in New York, NY (1996), with no passengers on board. One of two crewmembers was injured. In Table 1, FRA has specially accounted for the fatal, non-derailment event on the NICTD (collision on a private crossing between an electric MU locomotive consist and a tractor-trailer carrying steel coils, 1998). The three fatalities in this incident were to occupants in the forward end of the lead cab car where the steel coil rolled through.

Arguably, this is not enough information from which to make a determination as to which arrangement results in more derailments or other serious consequences following a grade crossing collision. It does, however, demonstrate that such derailments are very rare for commuter rail whether in push, pull, or MU service.

Intercity Service. Amtrak and ARR have limited push-pull operations. Three Amtrak grade crossing accidents in Ventura County, CA, involved push operations and resulted in derailment. In Moorpark in 2000, the first one resulted in derailment of three cars and injuries to five train occupants. In Camarillo in 2001, the second one resulted in derailment of the lead truck of the cab car and injury to one passenger. In Somis in 2005, the third one resulted in derailment of the lead truck of the cab car and injuries to three occupants. Eleven fatalities resulted from an incident in Bourbonnais, IL, in 1999 and another from an incident near McIntosh, GA, in 2003—both in the pull mode of operation.

A meaningful comparison of intercity push-pull operations should focus on corridors that have push and pull operations with similar exposure. Amtrak operates along four corridors where trains travel in push mode in one direction along the route and in pull mode in the other direction. Three of these operations are in California. The other is a portion of the Regional Service in the Northeast. Amtrak maintains 5-year records of passenger mile data for the three corridors in California, but such data is not maintained separately for the push-pull portion of the Regional Service.

Amtrak passenger mile data for the push-pull corridors in California is only available for the years 2000 and onward. A change in the direction of push and pull operations occurred in the late 1990s along one of the California corridors, as well as a change in the type of cab cars used along one of the corridors.[7] This analysis is thus limited to the 6-year period 2000 through 2005, which includes the three derailments that occurred during the 10-year period of the analysis for this report. This shorter time frame, coupled with the fact that all three derailments involved push-mode operations, results in considerably less favorable statistics for Amtrak push-mode operations in California.

2.4 Other Fatal Train Accidents

In addition to grade crossing accidents that resulted in derailment and triggered an equipment report, FRA also reviewed data for other passenger train accidents that triggered an equipment report and that involved either a passenger or crewmember fatality on board.

The data for the types of passenger rail equipment involved appear in Table 2.

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[7] Single-level Pacific Surfliner corridor cab cars were replaced with bi-level cab cars.

Table 2. Fatal Non-Grade Crossing Train Accidents (Rates per BPM) January 1996–December 2005

	Intercity		Commuter Rail		
	Amtrak Push & ARR–Other Service	Amtrak Pull (rate per BPM)	Pull (rate per BPM)	Push (rate per BPM)	MU
Total Events	0	3 (0.06)	2 (0.09)	5 (0.23)	0
Train Fatalities	0	6 (0.11)*	4 (0.18)	25 (1.13)***	0
Serious Train Injuries	0	221 (4.08)	24 (1.07) **	83 (3.76)***	0
Notes	--	Nodaway, 2001; Crescent City, 2002; and Flora, 2004, which were all derailments.	NJT raking collision at Secaucus, NJ, resulting in one fatality on board the locomotive-led train. Metrolink secondary raking collision at Glendale, CA, (Train #901) resulting in three fatalities.	Metrolink head-on collision with BNSF train at Placentia, CA, and Glendale, CA primary collision /derailment/ collision (Train #100). Metra derailment in Chicago, IL. NJT and MARC train head-on collisions at Secaucus, NJ, and Silver Spring, MD.	--

* Distribution of fatalities: Nodaway, IA–1; Crescent City, FL–4; Flora, MI–1.
** Distribution of serious injuries: Secaucus, NJ–4;[8] Glendale, CA–20.
***Distribution of fatalities: Placentia, CA–3; Glendale, CA–8; Chicago, IL–2; Secaucus, NJ–2; and Silver Spring, MD–11.
Distribution of serious injuries: Placentia, CA–37; Glendale, CA–24; Chicago, IL–15; Secaucus, NJ–4; and Silver Spring, MD–3.

Two of the fatalities in the Silver Spring accident were due to loss of occupied space. The other nine were due to smoke inhalation and burns. NTSB noted that the nine fatalities due to fire might have been avoided had "proper and immediate egress from the

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[8] The NTSB report was unclear as to which train the eight injuries that occurred were in. Since the level of severity was similar for each train and there was no indication of the total passengers on each train, the total was divided evenly so as not to cause bias in either direction.

car been available.” FRA has since issued Passenger Train Emergency Preparedness standards that require commuter and intercity passenger railroads to mark emergency exits with luminescent material and post operational instructions. These railroads are also required to test emergency window exits periodically. FRA further requires that each powered exterior side door in a vestibule that is partitioned from the passenger compartment of a passenger car have a manual override device located adjacent to the door that can be operated without the use of a tool or other implement. Older cars without the relocated override device have been retrofitted.

The two fatalities in the Secaucus cab car-led train were the engineer and a passenger riding in the cab car. The third fatality in this incident was the engineer of the conventional locomotive-led train.

Two of the fatalities in the Metrolink collision at Placentia were passengers seated at workstations facing the direction of travel who received severe trauma injuries to the chest and upper abdomen. The third fatality was a 77-year old woman who was traveling in the third car and was hospitalized until she died almost 2 months after the accident. Although her initial injuries were not life threatening, she died from pneumonia and similar complications.

Although some uncertainty exists regarding the precise, initial locations of occupants that were fatally injured in the Glendale incident, eight fatalities were occupants in the cab car of the cab car-led train (Train #100) that collided with the highway vehicle—some were in the rear of the car and others in the front of the car. The three remaining fatalities were occupants of the conventional locomotive-led train (Train #901) that was subsequently struck by coach cars of the cab car-led train (Train #100) that had jackknifed. Accordingly, in Table 2, three of the 11 fatalities from this incident are shown as involving occupants of a commuter train in the pull mode.

Both of the fatalities resulting from the Chicago derailment were due to loss of occupied space in one of the trailing coaches when the entire train derailed. The only occupant in the cab car, which was closed to passengers that day, was the engineer, who rode out the derailment.

2.5 Comparison of Pull Service with Push Service and MU Service

Concern has been raised that cab cars and MU locomotives are more prone to derailment than conventional locomotives. In a limited way, cab cars and MU locomotives may be compared with some freight cars, which have a greater tendency to derail when not loaded [3]. The weight of a loaded freight car may be 500 percent greater than the weight of the same car without the load. Freight cars sit on the same mechanical spring suspension whether loaded or unloaded. When the cars are not loaded, these suspensions can have difficulty distributing equal vertical loads to all of the wheels in response to perturbations in the track. Relatively small vertical perturbations in the track can reduce the vertical load on a wheel to the point where there is insufficient vertical force to prevent the wheel from climbing the rail and derailing the car. In contrast, a typical fully loaded cab car is approximately only 25 percent heavier than an empty cab car. In addition, cab cars generally ride on airbag suspensions designed to change stiffness of the air springs between the carbody and the truck in response to load. These suspensions are effective in distributing equal vertical loads among all of the wheels despite perturbations in the track, for the limited range of loads experienced by cab cars.

FRA has reviewed from a statistical point of view the safety record of pull service, push service, and MU service with respect to susceptibility to derailment. Although fatal non-grade crossing events do not provide sufficient data points for a meaningful comparison, collisions at highway-rail grade crossings do. In conducting this analysis, FRA had to elect whether to compare all events involving derailment or only events exceeding the threshold for railroad property damage. As discussed above, some cab cars and MU locomotives were involved in low speed collisions resulting in no structural damage to their frames, but nonetheless triggered filing of the equipment report by virtue of their design. Similar collisions involving other cab cars and MU locomotives may not trigger filing of the equipment report. It is therefore more appropriate to rely on the percentage of derailments resulting from all grade crossing collisions with motor vehicles involving the first unit of the train to compare the safety of cab car-led, MU locomotive-led, and conventional locomotive-led operations.

Table 2-3 presents the proportion of highway-rail grade crossing collisions that resulted in derailment for each mode of operation as well as some combinations of scenarios that may be of interest.

Table 3. Proportion of Highway-Rail Grade Crossing Collisions Resulting in Derailment 1996–2005

Type of Service	Mode of Operation	Proportion of Collisions Resulting in Derailment
Commuter	Pull	0.0069
	Push	0.0138
	Push + Glendale	0.0183
	MU	0.0095
	Push + MU	0.0124
	Push + Glendale + MU	0.0154

Table 4 presents the percentage point differences between the proportions of highway-rail grade crossing collisions that resulted in derailment. The table also notes whether such differences are statistically significant or not. A difference that is not statistically significant may be due to chance alone.

Table 4. Differences in Proportion of Highway-Rail Grade Crossing Collisions Resulting in Derailment 1996–2005

Type of Service	Modes of Operation Compared	Difference in Proportion Derailed (Percentage Points)	Statistically Significant?
Commuter	Push & Pull	0.69	No
	(Push + Glendale) & Pull	1.14	No
	MU & Pull	0.22	No
	(Push + MU) & Pull	0.55	No
	(Push + Glendale + MU) & Pull	0.85	No

A comparison of the difference between the proportion of grade crossing accidents that results in derailment occurring in the push mode and the pull mode[9] of operation indicates that such difference (0.69 percentage points) is not statistically significant. Including the intentional derailment of the cab car-forward commuter train at Glendale, which arguably could have occurred at a crossing, would not affect that conclusion.

A comparison of the difference between the proportion of grade crossing accidents that result in derailment occurring in pull mode and MU operations favors pull mode operations. The differences, however, are not statistically significant among these modes of operation.[10]

Moreover, including in the analysis the Glendale incident and combining MU incidents with push incidents results in a difference with pull mode of 0.85 percentage points, which is also statistically not significant at conventional levels.

In summary, taking the most unfavorable comparison of cab car- and MU locomotive–led trains with conventional locomotive-led trains, the chance that a train will derail following an impact at a highway-rail grade crossing may be at worst 1.14 percentage points greater in the push mode (including Glendale) than in the pull mode.

Amtrak push-pull operations in California are commingled with long-distance pull-only train operations. Using information, such as number of units in a train, train number, identification number of first unit of train involved in an incident, and direction of travel, the California Department of Transportation was able to use its expertise to reasonably classify the type of service and mode of operation of trains operating along the Amtrak push-pull corridors in California that were involved in reportable highway-rail grade crossings accidents that triggered accident reports. Unfortunately, the train number and identification number of first unit of train involved in an incident are not reported on the grade crossing report, making it difficult to determine with certainty which incidents involved push, pull, or long-distance trains. Focusing on simply those grade crossing incidents that triggered accident reports, 19 accidents occurred in push mode and 47 in

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[9] Push mode = 3/218; Pull mode = 2/290.

[10] Pull mode = 2/290; MU = 1/105.

pull mode. As reflected in Table 4, three of the push mode collisions resulted in derailment, while none of the pull-mode collisions resulted in derailment. Although a statistical comparison would clearly favor pull mode, such a comparison may not be very meaningful due to the small size of the dataset.

FRA is aware that when a collision does occur, whether at a crossing or with other rail rolling stock, passengers in a cab car or MU locomotive may be more vulnerable than passengers riding in a coach trailing a conventional locomotive.[11] It is also likely, however, that severity outcomes in high-energy events, such as the Glendale intentional derailment, are more likely to be influenced by chance circumstances rather than by placement of a conventional locomotive in the consist. The discussion below regarding safety mitigations further explores this set of issues. Before addressing mitigations, however, it is important to put the issues into perspective.

The fatality rates for passengers in push-pull, MU, and conventional locomotive service may be compared with other modes of transportation using statistics assembled by the National Safety Council (NSC). For the 10-year period 1994 through 2003 (the last year for which normalizing statistics were available), the average annual fatality rates *for passengers* were as follows:

	Rate per BPM
Passenger autos	8.55[12]
Buses (transit, intercity)	0.35
Scheduled airlines	0.28[13]

When combining *passenger and employee* fatalities from grade crossing collisions and other fatal train accidents and normalizing by BPM in the particular class of service, the following lists the results for the 10-year period 1996 through 2005 (rates from the two charts may not add up precisely due to rounding):

	Rate per BPM	Total Occupant Fatalities	
Commuter push and MU	0.47[14]		
Commuter push	1.2	27	Silver Spring (11) Secaucus (2) Burbank (1) Placentia (3) Glendale (8,Trn #100)

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[11] For example, see *Crashworthiness of Passenger Trains*, DOT/FRA/ORD-97/10 (Volpe National Transportation Systems Center, February 1998).

[12] Note that this is the rate for passengers, an NSC category that includes the operator of the vehicle for passenger autos but not taxis, buses, or airlines. This category does not include SUVs, vans, and pickup trucks.

[13] Note that the scheduled airline rate excludes fatalities resulting from the terrorist acts of September 11, 2001.

[14] Excluding the fatalities from Glendale, which was a deliberate act, and the fatalities from Silver Spring due to smoke inhalation, the fatality rate for commuter push would be 0.77, and the combined rate for commuter push and MU service would be 0.20.

			Chicago (2)
MU	0.07	3	Portage
Amtrak push	0.00	0	
Commuter pull	0.18	4	Glendale (3,Trn #901) Secaucus (1)
Amtrak pull	0.34*	18	Bourbonnais (11) Flora (1) Crescent City (4) Nodaway (1) McIntosh (1)

* This is an approximation, because passenger train miles are not available in separate form for push and pull mode operations prior to 2000.

Note that, in the interest of conservative analysis, these comparisons are structured to be less favorable to rail travel. While the NSC data includes only passengers, the data displayed above includes employees serving as crewmembers of trains. While the NSC data excludes fatalities from criminal acts (e.g., September 11, 2001), the rail data includes the 2005 incident at Glendale.

Seven trains with conventional locomotives in the lead and seven trains with either a cab car or an MU locomotive in the lead were involved in incidents resulting in occupant fatalities during this period. Loss of occupant space was the most frequent cause of fatality in both modes of operation. Fire was the second most frequent. Ejection and secondary impact caused the remaining fatalities. Thus, FRA's research activities have focused on strategies to mitigate the most frequent causes of occupant fatality.

The distribution of occupant fatalities by location differs between passenger trains operating with conventional locomotives in the lead and those with cab cars or MU locomotives in the lead. With the exception of the 2005 Chicago incident, all fatalities in cab car- and MU locomotive-led trains have occurred in the lead vehicle and have resulted from head-on or near-head-on collisions.

In contrast, many of the fatalities resulting from pull-mode operations did not occur in the first passenger car (including intercity service transition crew cars) and resulted from non-collision derailments. Only three resulted from head-on collisions.

The same number of cab car- and MU locomotive-led trains and conventional locomotive-led trains were involved in fatal incidents, which was seven each. A comparison of fatalities per incident shows that 30 occupants died in trains with cab cars or MU locomotives in the lead, whereas 22 occupants died in trains with conventional locomotives in the lead.

As is evident from these data, MU service during the period exhibited very good safety performance, notwithstanding the fact that occupied passenger-carrying locomotives were in the lead for every movement. Commuter push service significantly exceeded typical fatality rates for public transportation, but about two thirds of the fatalities occurred in two events. One was a non-accidental event (Glendale), as Metrolink did experience a very unusual and difficult period. The other event involved circumstances that are no longer present in commuter or intercity rail operations (inability to egress in Silver Spring). All else being equal, if the same circumstances were present today, nine fatalities due to smoke inhalation in the Silver Spring accident would likely not occur. Nonetheless, all categories of passenger rail transportation were safer than the average for passengers in private passenger automobile transportation when computed on a national level.

3. Efficacy of Crashworthiness

The objective of rail crashworthiness research and testing is to improve the safety of vehicle occupants. Existing rail vehicles, including traditional cab cars, are robust and very crashworthy in typical encounters with highway vehicles and in low-speed impacts with other rail vehicles. Enhancements in cab car and MU locomotive designs mandated by FRA regulations and provided for in APTA standards have further improved the ability of newer cars to withstand collision forces. Incorporation of advanced concepts, such as CEM, can make cab cars and MU locomotives highly crashworthy in moderate-energy collisions of the kind that conventional locomotive-led passenger trains withstand well.

There are practical limits, however, on the ability of both conventional locomotive-led trains and cab car- and MU locomotive-led trains to withstand extreme events, such as the Chase, MD collision of 1987, the Bourbonnais crossing collisions with derailment of 1999, or the 2005 Glendale, CA incident. Events of this kind involving very large amounts of energy are not manageable using crashworthiness strategies. On average, outcomes are unlikely to be influenced by where the locomotive was positioned when the event began to unfold.

This chapter describes what can and is being done to progressively improve the passenger fleet through crashworthiness research. The following chapter will describe in greater detail (1) how the research is being incorporated into regulations, standards, and specifications and (2) what actions are being taken to prevent serious accidents and incidents from occurring.

FRA has been continuously conducting research on passenger rail equipment crashworthiness since 1989. The primary purpose of this research has been to develop the base of technical information needed to promulgate passenger rail equipment safety regulations [4, 5, 6]. The results of the research have also been used in the development of railroad procurement specifications [7, 8] and industry standards [9, 10].

In designing for crashworthiness, the primary objective is to preserve sufficient volume for the occupants to ride out the collision without being crushed. Excessive forces and decelerations also present a potential for injury to the occupants. Relatively large forces and decelerations can occur when an unrestrained occupant strikes the interior. Occupant impacts with the interior or collisions between occupants and loose objects thrown about during the collision are usually termed secondary collisions. The second objective of crashworthiness is to limit these secondary collision forces and decelerations to survivable levels.

Preserving occupant volume during train collisions and/or derailments relies on the strength of the structure. If the occupant compartment is sufficiently strong, there will be sufficient space for the occupants. Secondary effects can be mitigated by a combination of structural crashworthiness and occupant protection measures. Allowing portions of the vehicle to crush in a predetermined manner can control the deceleration of the cars. Occupant protection measures include the use of restraints, such as seatbelts and shoulder harnesses, and strategies, such as compartmentalization [11, 12, 13, 14]. How hard the occupant strikes the interior depends upon the deceleration of the train itself during the collision and the degree of "friendliness" of the interior.

A tradeoff exists between increased occupant volume strength and secondary impact velocity (SIV). If a single car has uniform crush strength, increasing the crush strength increases the speed at which occupants impact the interior. For a train of cars the issue is more complex. The cushioning of the cars ahead and the pushing of the cars behind influence the deceleration of any particular car. In general, any crashworthiness strategy that better preserves the occupant volume will make the secondary impacts more severe for the occupants in the interior. The effects of secondary impacts can be mitigated through the strategic modification of interior features (i.e., rear-facing seats, padded seats).

The principal focus of passenger rail equipment crashworthiness research has been the development of structural crashworthiness and interior occupant protection strategies. Two collision scenarios have been addressed in passenger rail equipment crashworthiness research: a cab car/MU locomotive to conventional locomotive train-to-train collision and a cab car/MU locomotive to steel coil grade crossing collision [15, 16]. These two collision scenarios represent likely incidents [17] during which the passenger compartment may be compromised, but for which improved occupant protection can be achieved through design modifications of conventional rail cars. Prototype designs were developed, and full-scale passenger rail equipment impact tests have been conducted to allow direct comparison of conventional and alternative crashworthiness strategies [18, 19]. Relatively simple models are initially developed to plan the tests. If these models do not provide sufficient detailed information, more complex models are used to address specific issues. The models are refined using the test results and are used to extrapolate from the test results.

Structural crashworthiness strategies developed by the research include:

- Optimized cab car and MU locomotive end frames that increase the survivable speed by 50 percent in grade crossing collisions [20].
- Carbody structural crush zones that double the survivable speed (i.e., the maximum collision speed for which all of the occupants are expected to survive) for cab car/MU locomotive-to-conventional locomotive collisions [21, 22].

Of course, structural crashworthiness strategies are also focused on keeping the rail equipment in-line and upright in a collision, as discussed below.

Occupant protection strategies developed include:

- Improved workstation tables that limit abdominal loads to survivable levels [13, 23, 24].

- Optimized commuter seats that minimize head decelerations, neck loads, and chest decelerations, both forward-facing and rearward-facing [14].

3.1 Train-to-Train Collisions

Cab car- and MU locomotive-led trains present a challenging situation in collisions. The presence of passengers in locomotives of lighter weight and lower strength in comparison with conventional locomotives presents a potential hazard in the event of a collision. In order to address this exposure, FRA has conducted research on strategies intended to improve the crashworthiness of cab cars and MU locomotives [20, 22, 25, 26, 27, 28].

Cab cars, MU locomotives, and conventional coach cars are required to support an 800,000-pound longitudinal static load applied at the buff stops without permanent deformation. See 49 C.F.R. 238.203 [6]. This requirement assures a minimum strength of the vehicle's occupied volume. The buff stops are located approximately 6 feet from the end of the vehicle and support the compressive longitudinal loads from the coupler. Meeting this requirement using conventional design practices has resulted in structures that are nearly uniform in their axial strength. These structures are as strong at the ends as at the mid-length.

When a cab car, MU locomotive, or a conventional coach car is loaded longitudinally, the structure of the vehicle's body is initially very stiff. As the load is increased, deflections of the vehicle body remain relatively small until a critical load is reached, and the body begins to cripple. Once crippled, its ability to further support a longitudinal load is compromised. As a result, a much lower load is required to deform the vehicle body longitudinally, and the deflections of the vehicle body increase significantly. Because the longitudinal force develops in the impacting cars first, once the peak force is attained and the vehicle body cripples, the colliding vehicle of a train will lose the ability to transmit significant longitudinal forces rearward to the trailing cars. In a collision, a colliding vehicle that performs in this manner will singularly absorb much of the collision energy as the occupied volume is crushed. If the collision is extreme, this situation can result in the colliding vehicle being destroyed.

Research has shown that passenger rail equipment crashworthiness can be significantly increased if the force/crush behavior is engineered to take place in a controlled manner. Sacrificial crush zones can be designed into unoccupied locations in the rail vehicles, such as brake and electrical service closets and bicycle storage areas, as well lightly occupied areas, such as vestibules and stairwells. These crush zones are designed to crush gracefully, with a lower initial force and increased average force. With such crush zones, multiple vehicles share energy absorption during the collision, consequently preserving the integrity of the occupied areas by managing the collision energy.

The approach of including crush zones is termed CEM, and it extends from current conventional crashworthiness design practice. The 800,000-pound buff strength requirement prescribes the strength of the structure that supports the crush zone. By doing so, current practice controls the force required for crushing the crush zone, which in turn influences the amount of energy absorbed. Greater buff strength allows greater crushing forces to be supported, and, in turn, greater energy can be absorbed for a given crush distance.

Figure 3 is a schematic of the concept of CEM, with crush zones at the ends of all of the train's cars. By controlling the structural crushing in the CEM zones of the trailing cars, occupant volumes can be preserved. Severity of the secondary impacts can be limited by managing the deceleration of the occupied volume with controlled structural crushing.

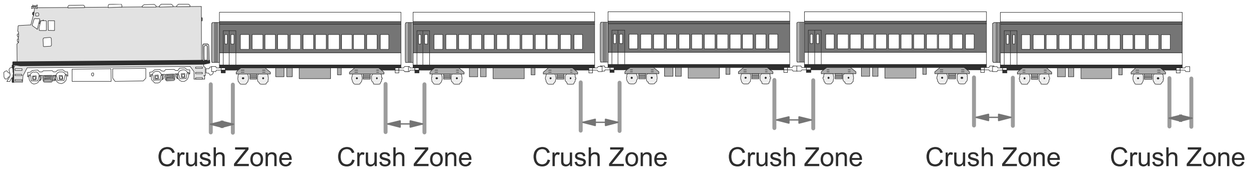

Figure 3. Schematic Illustration of Crush Zone Locations in Commuter Rail Passenger Train Used in Push-Pull Service

In cab cars and MU locomotives, measures are required to provide protection for the train operator, who is located closest to the impact in a train-to-train collision. One alternative is to move the operator back from the end of the cab car/MU locomotive, inboard of the crush zone. Similar interior measures as used for the passengers can be used to protect the operator. Another alternative is to keep the operator at the end of the cab car/MU locomotive, ahead of the crush zone. In this alternative, the operator's cab is surrounded by a structure that can slide back as the energy dissipation elements are crushed. The area behind the operator is unoccupied but could be used as a utility closet for brake or electrical equipment. This arrangement allows for preservation of the operator's volume in the event of a collision but exposes the operator to higher deceleration than the passengers. To protect the operator in this arrangement, additional measures, such as seatbelts, airbags, or other inflatable structures, may be necessary. Figure 4 shows schematic illustrations of the alternative arrangements for protecting the operator.

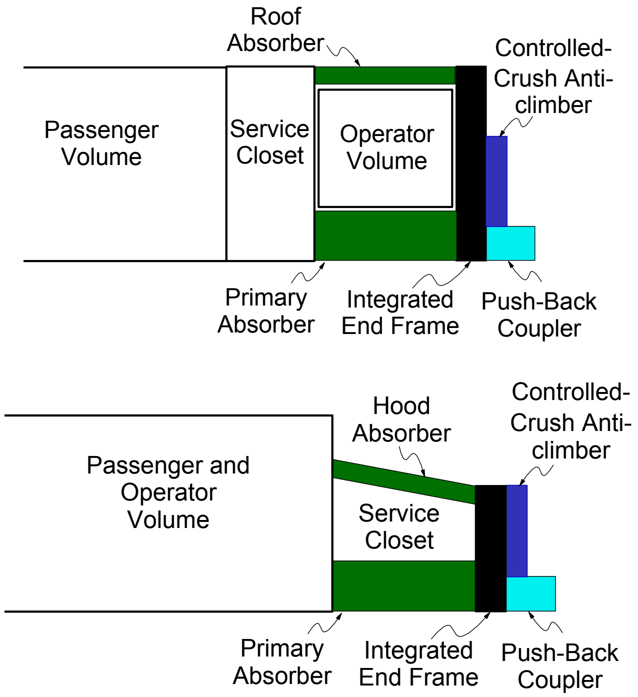

Figure 4. Schematic Illustrations of CEM Cab Car Arrangements

A series of six tests have been conducted to measure the crashworthiness performance of existing equipment and to measure the performance of equipment incorporating CEM features. The collision scenario addressed by these tests is a cab car-led passenger train colliding with a conventional locomotive-led passenger train. The tests conducted for each equipment type include:

1. Single-car impact into a fixed barrier
2. Two coupled car impact into a fixed barrier
3. Cab car-led train collision with standing conventional locomotive-led train

The overall objectives of these tests are to demonstrate the effectiveness of:

- Improved crashworthiness cab car and MU locomotive structural designs
- Improved crashworthiness coach car structural designs
- A variety of occupant protection strategies

This arrangement of the tests allows comparison of the existing equipment's performance with the performance of improved-crashworthiness equipment. The sequence of impact tests allows an in-line train-to-train collision to be studied in incremental levels of complexity. These tests are intended to measure the crashworthiness of a single car, then the interactions of two such cars when coupled, and finally the behavior of complete trains, including the interactions of the colliding cars.

The results from these tests show that the CEM design has superior crashworthiness performance over existing equipment. In the single-car test of existing equipment [29] at a closing speed of 35 mph, the car crushed by approximately 6 feet, intruding into the occupied area. As a result of the crippling of the carbody structure, the car lifted by about 9 inches, raising the wheels of the lead truck off the rails. Under the single-car test conditions at a closing speed of 34 mph, the CEM car crushed about 3 feet, preserving the occupied area. As a result of the controlled crush of the carbody structure, its wheels remained on the rails [30].

In the two-car test of existing equipment [31] at a closing speed of 26 mph, the impact car again crushed by approximately 6 feet. No crush of the trailing car occurred. The crippling of the carbody structure again caused the car to lift about 9 inches. The conventional couplers caused the cars to buckle laterally. As a result of this misalignment of the coupled cars, the trucks immediately adjacent to the coupled connection derailed. In the two-car test of CEM equipment, at a closing speed of 29 mph, the cars preserved the occupant areas. The impact car crushed at the front and rear, and the trailing car crushed at the front. The pushback couplers allowed the cars to remain in-line with all of the wheels on the rails [32].

In the train-to-train test of existing equipment [33] at a closing speed of 30 mph, the colliding cab car crushed by approximately 22 feet. There was no crush imparted to any of the trailing equipment. Due to the crippling of the cab car structure, the cab car overrode the conventional locomotive. The space for the operator’s seat and for approximately 47 passenger seats was lost. During the train-to-train test of CEM equipment, at a closing speed of 31 mph, the front of the cab car crushed by approximately 3 feet, and the crush propagated back to all of the unoccupied ends of the trailing passenger cars. The controlled deformation of the cab car prevented override. All of the crew and passenger space was preserved. Figure 5 includes frames from high-speed movies recorded at the train-to-train test of existing equipment and the train-to-train test of CEM equipment.

Figure 5. Frames from Train-to-Train Test Movies of CEM and Existing Equipment

While computer simulation models are not necessary to describe the results of the full-scale tests, they are critical to their conduct. Such models were used to determine the impact speed and measurements to be made, as well as to predict the behavior of the equipment during the test. In turn, these models have been refined using the test measurements. The results of the first three tests were especially useful in refining the models. For the fourth and subsequent tests, the pre-test predictions have been within the repeatability of the test. These models can then be used to predict the results of similar collision scenarios with varying initial conditions.

Figure 6 shows simulation results from a model developed as part of the full-scale test effort [34]. This figure shows the amount of occupant volume lost in the impact cab car for closing speeds up to 40 mph, for a cab car-led train collision with a conventional locomotive-led train of equal weight. Loss of occupant volume is the principal cause of fatality in cab car-led passenger train accidents. The plot does not address ejection, occupant impacts with the interior, or fire. The passenger equipment modeled is single level with end vestibules. This figure contains plots for an all-conventional train (i.e., a train comprised of existing equipment not utilizing a CEM design); a train with a CEM cab car and conventional coach cars; a train with a CEM cab car and conventional coaches modified with pushback couplers; and an all-CEM train. By changing only the cab car from an existing design to a CEM design, the crashworthy speed (the maximum speed for which no occupant volume crush exists) increases from 15 mph to 25 mph. A substantial increase in crashworthiness can be achieved by including crush zones on the first car in the train. By further changing the coach cars to have pushback couplers, but otherwise conventional structures, the crashworthy speed can be further increased to 28 mph. A pushback coupler allows for a relatively modest amount of energy absorption under collision conditions. This result suggests that a further increase in crashworthiness can be achieved by relatively minor modification to existing equipment. The fourth plot on the graph shows that an all-CEM train has a crashworthy speed of 38 mph.

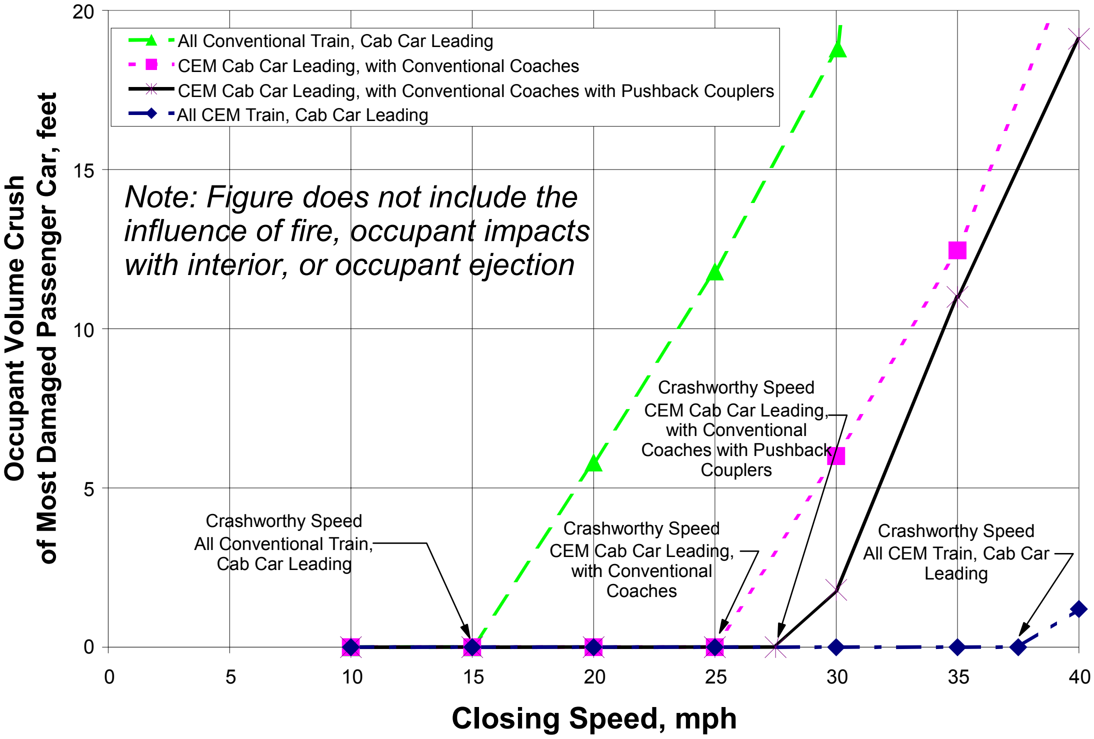

Figure 6. Occupant Volume Crush Results for Varying Closing Speeds of Cab Car-Led Trains[15]

Figure 7 shows simulation results for the amount of occupant volume lost in the first passenger car (including a cab car) for conventional locomotive-led and cab car-led passenger trains not utilizing a CEM design in collisions with conventional locomotive-led trains. This figure focuses on the primary cause of fatality, which is loss of occupied volume; this figure does not address other causes of fatality, such as fire, ejection, and occupant impacts with the interior. As in Figure 6, the equipment modeled is single level with end vestibules. By substituting a conventional locomotive for the cab car, the crashworthy speed increases from 15 mph to 25 mph. For speeds above 25 mph, crush will occur in the first coach car. The conventional locomotive is stronger than the coach cars and hence absorbs little energy [2]. Figures 6 and 7 show that a CEM cab car provides the same crashworthy speed as substituting a conventional locomotive for single level equipment with end vestibules. An all-CEM train has a crashworthy speed that is greater than the crashworthy speed of a conventional locomotive-led train.

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[15] For purposes of Figures 6 and 7, the term “conventional” is used to distinguish passenger rail equipment not utilizing a CEM design from that equipment with a CEM design.

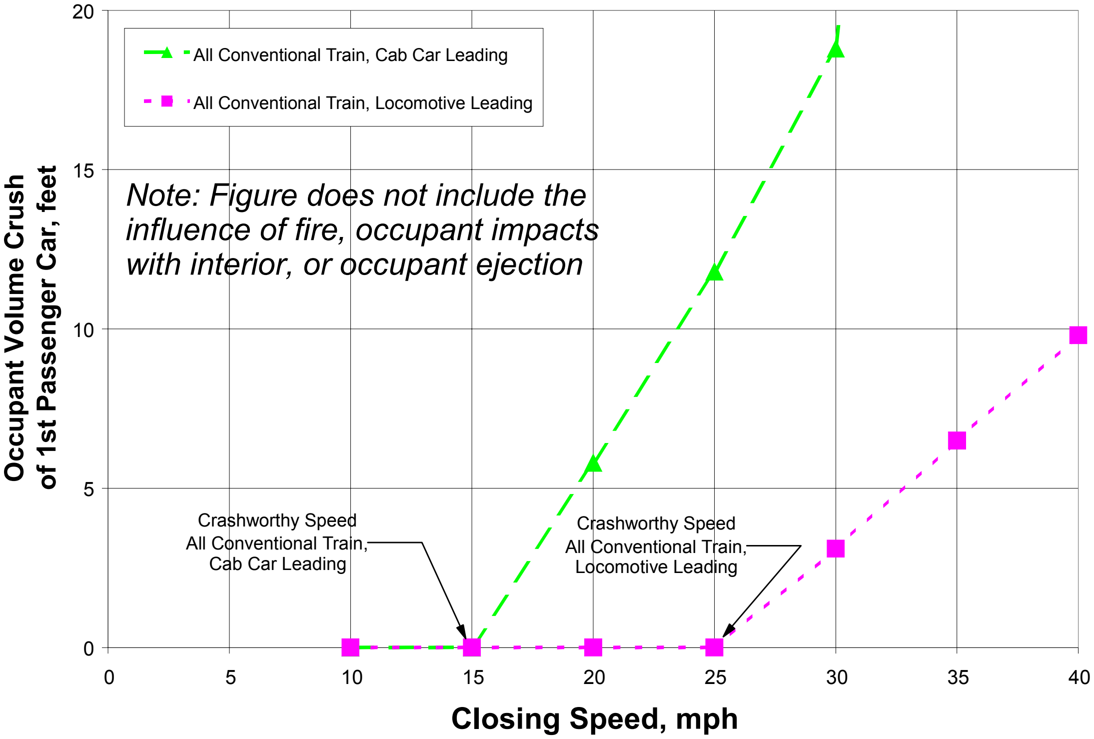


Figure 7. Occupant Volume Crush Results for Varying Closing Speeds

These research results suggest that a railroad can incrementally increase structural crashworthiness as it purchases and overhauls equipment. When new equipment is purchased, existing cab cars can be replaced with CEM cab cars. When existing equipment is overhauled, relatively minor modifications can be made to retrofit the equipment with pushback couplers. After the existing cab cars are replaced with CEM cab cars, the coach cars can be replaced with CEM coach cars.

3.2 The Glendale Incident

Figure 8 shows a photograph of the Glendale incident. Eight of the 11 fatalities occurred in train 100, the southbound cab car-led passenger train. Three of the fatalities occurred in train 901, the northbound conventional locomotive-led passenger train. The trailing cab car from train 901 is on its side, shown in the middle right side of the photograph. The passenger equipment is multi-level with quarter-point doors. This incident was investigated as part of FRA's ongoing field study of injury and fatality in passenger train accidents [24].

Figure 8. Aerial Photograph of Glendale Incident

Train 100, traveling south at 62 mph, collided with an SUV, which was situated perpendicular to the track with its front wheels between the rails. This impact occurred approximately 150 feet southeast of the grade crossing at Chevy Chase Drive. The SUV was lower than it would have been at a grade crossing, with the wheels of the SUV on the ties and ballast, below the running surface of the rails. This situation made it easier for some part of the SUV to get under the cab car and derail it. The Glendale incident involved three collisions:

1. The initial collision of train 100 with the SUV. Some part of the SUV–the engine block, transmission, differential, or other solid piece–became trapped under the cab car. The cab car then encountered special trackwork, the switch components. The solid piece from the SUV interacted with the switch components in such a way that the front end of the cab car entered a siding. The back end of the cab car and the trailing equipment remained on the main line track.
2. These events led to a collision of train 100 with the freight train parked in the siding. The front of the cab car impacted a six-axle freight locomotive coupled to a second six-axle freight locomotive in turn coupled to a number of cars loaded with ballast. The impact with the freight locomotive crushed the front end of the cab car, shortening the cab car by more than 26 feet. Prior to impact with the locomotive, the cab car was skewed. That is, the lead truck of the cab car derailed and was guided by the rails of the siding track into the freight locomotive, while the rear truck of the cab car appears to have stayed on the main line track, so that the cab car was traveling with the front on one track and the back on another

track. The impact with the freight locomotive appears to have caused the back of the cab car to derail and swing out further, into the ROW of the adjacent second main line track.

3. These events led to a raking collision of trains 100 and 901. As the back end of train 100's cab car swung around, it impacted the side of train 901, which was traveling north at 51 mph. The back end of train 100's cab car and the front end of train 100's first trailer car first impacted the side of train 901's middle passenger car and proceeded to rake down the side of train 901.

The collision of the cab car-led passenger train with the standing freight train and the resultant sideswipe of the conventional locomotive-led passenger train were simulated with a two-dimensional lumped-parameter computer model. This model was also used to evaluate the influence of having a conventional locomotive in the lead of train 100. For this analysis, it has been assumed that the locomotive would derail in the same fashion as the actual cab car did. This assumption was made based on the accident history, which indicates that cab cars and conventional locomotives are equally likely to derail during a highway-rail grade crossing collision as shown in Appendix C.

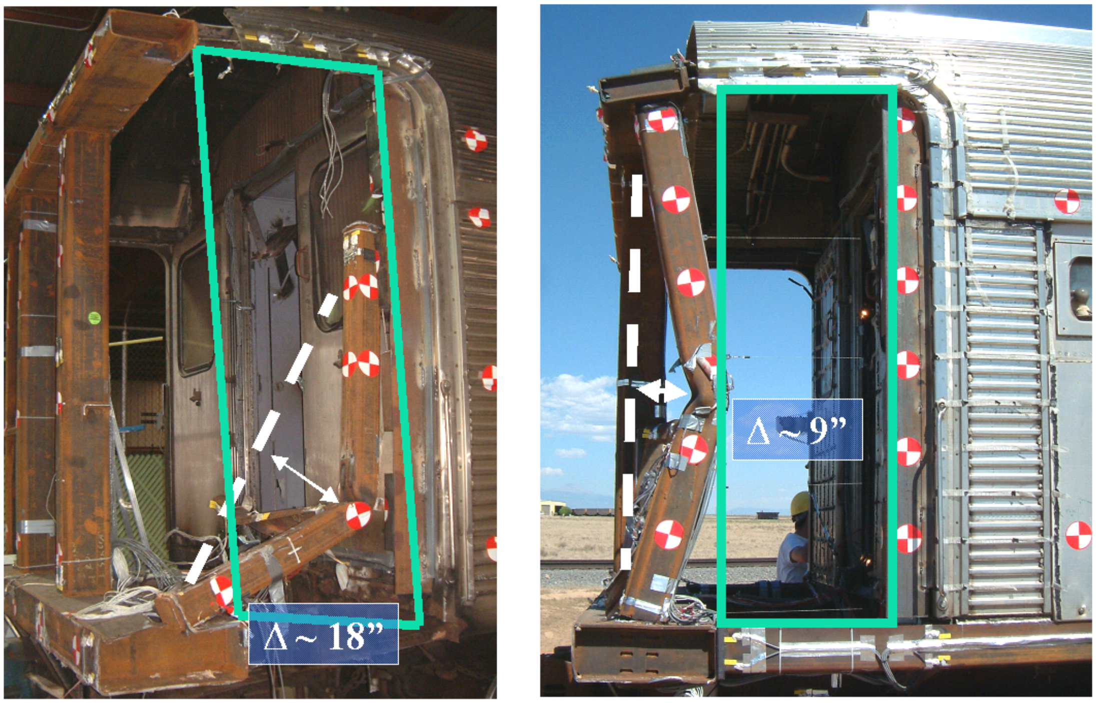
The simulation results show that in a conventional locomotive leading scenario there would be crush of the occupant volume of the first coach car behind the conventional locomotive, although this crush is predicted to be less than the crush sustained by the cab car in the incident. A conventional locomotive is predicted to yaw to a greater angle than the cab car, owing to the shorter length of the conventional locomotive. The sideswipe between the rear of the conventional locomotive and the side of train 901 is expected to be more severe due to the increased yaw of the conventional locomotive, the increased structural strength of the conventional locomotive, and the increased height of the conventional locomotive underframe. The increased height of the conventional locomotive underframe essentially puts the strongest portion of the conventional locomotive structure in contact with the weakest portion of the sidewalls of the passenger equipment of train 901. With a conventional locomotive in the lead of train 100, it is estimated that fewer fatalities would occur on train 100 and more fatalities on train 901, with the total number of fatalities due to the collisions remaining approximately the same. The increased potential for fire with a fossil-fueled locomotive in the lead of train 100 has not been evaluated.

3.3 Grade Crossing Collisions

Train collisions involving cab cars and MU locomotives have occurred with objects other than trains in which their end frame structures were engaged above the underframe, and a subsequent loss of operator survivable volume occurred [35, 36]. The Portage, IN grade crossing collision in 1998 between an MU commuter train and a tractor-tandem trailer carrying coils of steel is an example of such a collision.

The purpose of the cab car and MU locomotive end frame structure is to provide protection for the operator and passengers of the cab car and MU locomotive in the event that a collision occurs where the superstructure of the vehicle is engaged. This structure is composed of several structural elements that act to resist inward deformations under load. The four major vertical members are two collision posts located at roughly one-third points along the width of the car and two corner posts located at the outermost width of the car. The underframe and vehicle body structural elements support these vertical members.

Two full-scale oblique grade crossing impact tests were conducted in June 2002 to compare the crashworthiness performance of alternative corner post designs on cab cars. On June 4, 2002, a cab car fitted with an end structure built to pre-1999 static load requirements impacted a steel coil at approximately 14 mph. Following on June 7, 2002, a cab car fitted with an end structure built to large-deformation requirements—the state-of-the-art (SOA) design—underwent the same test. The corner and collision posts of the SOA design were engineered to collapse in a graceful manner. During the test of the 1990s design, the corner post failed, eliminating the survival space for the operator. During the test of the SOA design cab car, the corner post remained attached and deformed less than 9 inches, preserving space for the operator [16, 18]. Figure 9 shows the results from the two tests.



1990s Design **SOA Design**

Figure 9. Post-Test Photographs: 1990s and SOA End Frames

APTA recently adopted an industry standard for large deformation of cab car and MU locomotive end frame members, with compliance shown with quasi-static tests [37]. Based on an RSAC consensus recommendation, FRA is currently drafting large-deformation regulations for cab car and MU locomotive end frame members utilizing quasi-static tests to show compliance. An alternative for use of dynamic tests may be added as research results are finalized. As part of its crashworthiness research, FRA is currently planning two quasi-static tests and one more dynamic test to confirm these analyses' results.

Publication of these end frame large-deformation criteria will be accompanied by proposed adoption of APTA's standard for corner posts, which doubles the strength incorporated in earlier designs and will complement FRA's increase in collision post strength mandated in the Passenger Equipment Safety Standards in 1999. Taken together, these end structure requirements will contribute to operator and passenger safety in train-to-train collisions, as well as highway-rail grade crossing collisions and impacts with other obstacles.

3.4 Safety Implications of Interior Configurations

In FRA's crashworthiness research, SIV, along with the engineering parameters of the interior, have been used to calculate injuries caused by an occupant impacting an interior part of the train. SIV refers to the velocity at which an occupant strikes some part of the interior, such as the forward seat back. To estimate occupant injury, test data have been used to correlate SIV with head, chest, and neck injuries for specific interior arrangements. Figure 10 shows a representative SIV plot for a cab car in a 35 mph train-to-train collision. The figure shows various seating configurations in relation to allowable travel distances. Typically, a shorter travel distance correlates to a lower SIV, as less time is allowed to build up relative velocity.

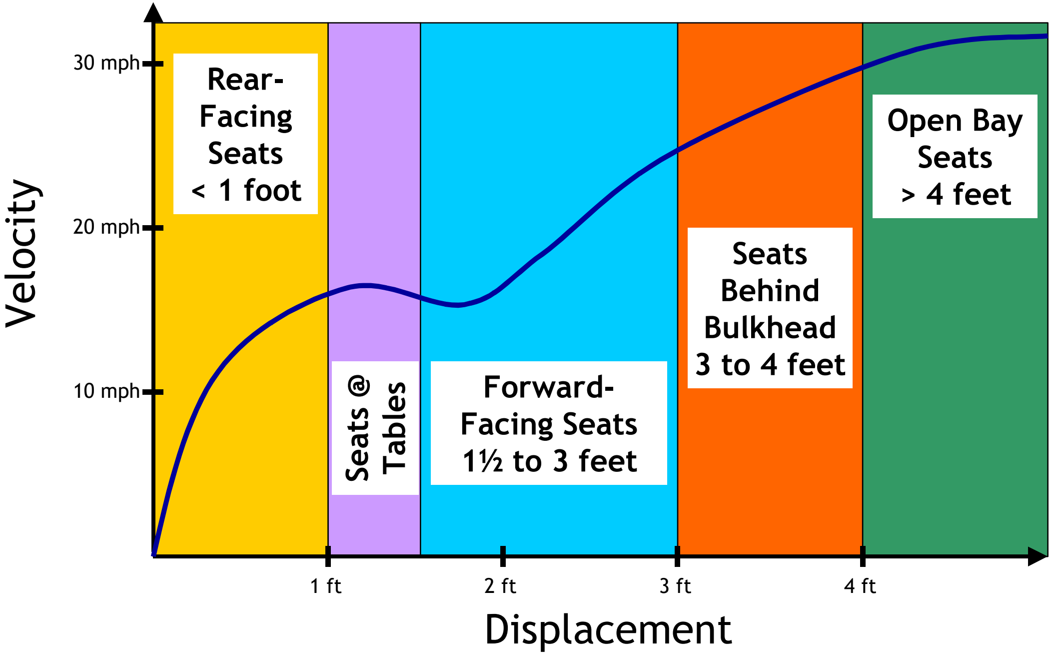


Figure 10. Representative SIV Plot Corresponding to Various Seating Configurations

The plot in Figure 11 shows the severity of SIVs and the possible measures for mitigating the likelihood for injury. A secondary collision environment of less than 18 mph SIV is survivable with conventional interior equipment for all interior configurations that have been evaluated. Between 18-25 mph, the interior environment is deemed survivable if compartmentalization is ensured and if passive safety modifications are provided in the seat and table designs. Above 25 mph, active protection features (i.e., air bags, inflatable structures, seatbelts, etc.) are necessary to reduce the risk of injury.

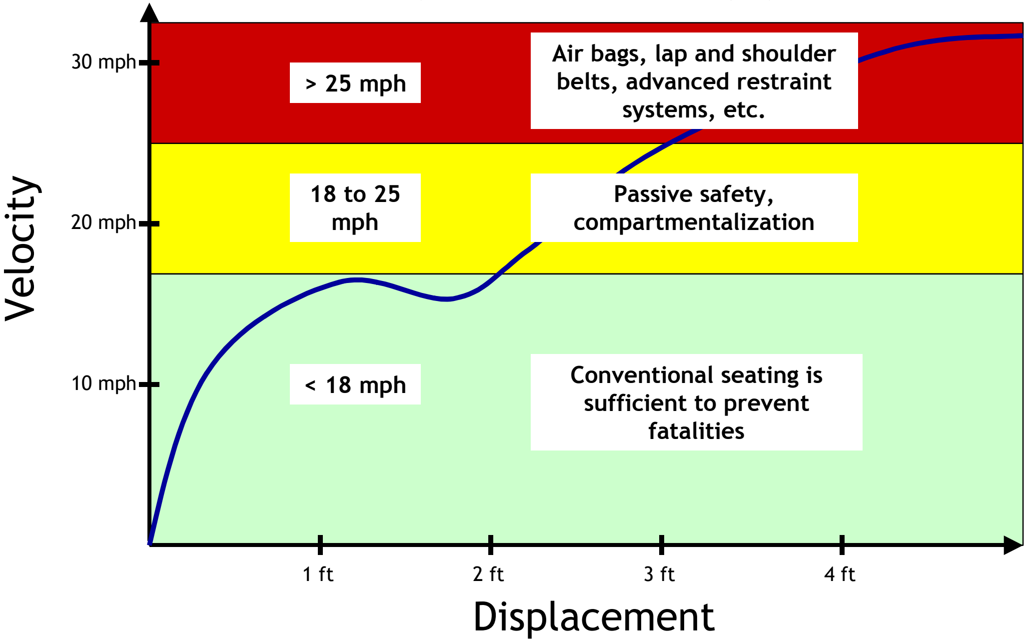


Figure 11. SIV Plot with Injury Interpretation

Trains with CEM cab cars leading are expected to have SIVs in the 18 to 25 mph range in the cab car for train-to-train collisions at primary collision speeds greater than 25 mph. Trains with cab cars not utilizing CEM designs are expected to have SIVs of less than 18 mph in the cab car. (The SIV is typically lower than the primary collision speed because the occupant generally impacts the interior before the primary collision is finished.) Trailing equipment is expected to have SIVs below 18 mph, regardless of the leading equipment (CEM cab car, existing cab car, or conventional locomotive). Occupant protection measures greater than those provided by common interior fixtures are required in CEM cab cars to mitigate the potential for occupant injury in train-to-train collisions with closing speeds above 25 mph.

The probability of injury in CEM cab cars can be mitigated by incorporating better interior designs, such as rear-facing seats with high enough head rests that protect against neck injury. Referring to Figure 7, rear-facing seats allow for a travel distance of between zero and 1 foot, consequently resulting in a low SIV. Optimized commuter seats, which provide more energy absorption capacity than conventional seats [14], and improved workstation tables [13], which limit the load into the occupant’s abdomen, have been developed to reduce injury due to secondary impacts for unrestrained passengers.

3.5 Recent Application of Research Results and Ongoing Passenger Equipment Crashworthiness Research

As part of its response to the Glendale incident, Metrolink decided to apply recent results of FRA's research into passenger train crashworthiness in its latest procurement. In coordination with APTA, Metrolink approached FRA and the Federal Transit Administration (FTA). FRA, FTA, and APTA decided to form the ad hoc CEM Working Group in May 2005, which included participants from the rail industry, such as passenger railroads, suppliers, unions, and industry consultants [38]. Many of the participants in this working group also participate in RSAC's [4] Crashworthiness/Glazing Task Force and in APTA's Construction/Structural Subcommittee. The CEM Working Group developed recommendations for crush zones in passenger rail cars for Metrolink to include in its procurement specification. Metrolink released its specification [39], including the recommendations from the CEM Working Group in September 2005, as part of an invitation for bid. Metrolink received three responses to its solicitation and awarded a contract to Rotem in February 2006.

FRA has committed to work with Metrolink to develop specifications for workstation tables that incorporate the key features of the prototype developed by FRA. Metrolink is planning to procure such tables and retrofit them onto their equipment. Injury criteria for passenger equipment and cab car passenger secondary impact protection are on the RSAC Passenger Safety Working Group Consolidated List of Issues, and these are expected to be addressed in the near future.

The optimized commuter seat, both forward facing and rear facing, and the improved workstation table have been tested as part of the train-to-train test of CEM equipment [19]. FRA is also planning to develop means of improved occupant protection for passengers in side-facing seats, passengers in bulkhead seats at the end of an aisle, and standing passengers. In addition, FRA is pursuing seat belts with airbags as a strategy for improving locomotive operator protection [40] and is planning to pursue inflatable structures as a means of improving cab car and MU locomotive operator protection [41].

4. Accident Avoidance and Mitigation

Train-to-train collisions and other impacts with heavy objects result from precursor events that, in and of themselves, seldom result in a subsequent, serious collision. These precursor events, which in actual operations rarely lead to a subsequent collision, include:

- Train derailment (track and/or vehicle caused)[16]
- Train collision with an object on, or within the fouling distance of, the track (but not related to a grade crossing) and with a subsequent derailment
- Train collision with a vehicle or object at a highway-rail grade crossing and with a subsequent derailment
- Operation of the train in contravention or signal indications, written authorities, or permanent or temporary speed restrictions
- Dispatch-related error
- Very rarely, a failure of a signal or train control system

To avoid train-to-train collisions, railroads and other operationally responsible entities focus on reducing the likelihood of these accident precursors by designing them out of the system, reducing them to negligible levels where it is not feasible (technically or economically) to remove them completely from the system, and finally, where necessary, designing systems to mitigate the consequences of a precursor event if its occurrence cannot be designed out of the system or its likelihood be reduced to essentially zero.

FRA also focuses much of its effort on the prevention of such occurrences, including the following:

- Develops and enforces regulations governing railroad operating rules, including requirements for programs of operational tests, requires certification of locomotive engineers, prohibits use of alcohol and other drugs, and requires random and other alcohol and drug testing—*all designed to ensure that employees are fit, qualified, and properly supervised.*
- Enforces the hours of service law, and promotes partnership efforts to encourage training in good sleep hygiene and adoption of progressive scheduling practices—*intended to prevent fatigue among train crews.*
- Promotes the use of close call reporting systems—*designed to identify the causes of employee errors before they result in serious harm*.
- Requires adherence to track safety standards commensurate with the speed over which train operations are conducted and qualification of new equipment to operate over that track—*designed to prevent derailments*.
- Maintains requirements for railroad signal and train control systems—*ensuring, to the extent possible, that they are reliable and fail in a safe mode.*

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[16] Extremely rare events, such as earthquakes and wind-related derailments, are not specifically mentioned here but clearly related to signal system design requirements where significant earthquakes and winds can be expected.

- Requires periodic inspection, testing, and maintenance of highway-rail grade crossing warning devices, use of locomotive horns to warn persons approaching crossings, and installation and use of auxiliary alerting lights—*protecting train occupants as well as highway users.*

Beginning with issuance of E.O. 20 in 1996, FRA has developed an extensive set of regulations directed specifically at preventing and mitigating events involving rail passenger service.

4.1 Emergency Order No. 20

Background

In 1996, following two very serious passenger train accidents, FRA issued E.O. 20, "Emergency Order Requiring Enhanced Operating Rules and Plans for Ensuring the Safety of Passengers Occupying the Leading Car of a Train." The order required prompt action to immediately enhance passenger train operating rules and emergency egress and the development of interim system safety plans addressing cab car forward and MU operations that did not have either cab signal, automatic train stop, or automatic train control systems.

Human Factors

E.O. 20 required two signal-related operating rules over territory lacking at least cab signals to enhance safety by adding a layer of redundancy in safety procedures where none existed. First, the engineer must call out signal indications, for an approach or less favorable than approach, as they are seen. A designated crewmember will acknowledge the communication and, in the absence of an appropriate response to a restrictive indication that has been communicated, take action to ensure an appropriate response takes place.

Second, if a passenger train enters a block immediately preceding a signal location capable of displaying a stop indication or an indication limiting the train to restricted speed, and the train stops for any reason, including a station stop, or its speed is reduced below 10 mph, the train shall proceed under speed limitations set forth in existing applicable operating rules, but in no case greater than 40 mph, and, in addition, must be prepared to stop before passing the next signal. The train must maintain the prescribed speed until the next wayside signal is clearly visible, that signal displays a proceed indication, and the track to that signal is clear. Appropriate signs must be placed at each affected signal and at the departure end of stations. This particular enhancement to the operating rules is intended to make it less likely that a locomotive engineer will act as if the prior signal indication was more favorable than displayed.

These operating rule elements of the order appear to be successful in addressing the issues they were designed to address, but they do not address the full range of circumstances that can lead to a collision.[17]

Emergency Exits/Emergency Responder Training (Familiarization with Rolling Stock)

E.O. 20 addressed passenger train emergency egress, requiring that each commuter and intercity passenger railroad ensure that each emergency exit location on every passenger car is clearly marked on the inside and that operational instructions are posted; that each rescue access window be marked on the exterior; that, at least twice a year, a representative sample of both has been inspected and tested to ensure that they are operable; and that each railroad discuss in an Interim System Safety Plan its programs and plans for liaison with and training of emergency responders with respect to emergency access to passengers, as well as the methods used to inform passengers of the location and method of operation of emergency exits (e.g., flyers, announcements, messages on tickets).

4.2 Passenger Train Emergency Preparedness Rule

Several requirements of E.O. 20 were incorporated into, and superseded by, 49 C.F.R. Parts 223 and 239, the Passenger Train Emergency Preparedness final rule, which was issued in 1998. The final rule emphasized development of emergency preparedness programs, improved onboard emergency systems, training of personnel, and conducting drills and debriefings so that both the railroad and emergency responders progressively improve their readiness to deal with an emergency.

Section 223.9 requires that (1) each emergency window be conspicuously and legibly marked with luminescent material on the inside of each car to facilitate passenger egress and that clear and legible operating instructions be posted at or near such exit; and (2) each window intended for emergency access by emergency responders for extrication of passengers be marked with a retroreflective, unique, and easily recognizable symbol or other clear marking; and (3) that clear and understandable window-access instructions be placed either at each window or at each end of the car.

Section 239.107 requires that (1) all door exits intended for emergency egress be lighted or conspicuously and legibly marked with luminescent material on the inside of the car and that clear and understandable instructions be posted at or near such exits; (2) all door exits intended for emergency access by emergency responders for extrication of passengers be marked with retroreflective material and that clear and understandable instructions be posted at each such door; and (3) railroads test a representative sample of emergency window exits at least once every 180 days to verify that they are operating properly.

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[17] Two derailment events have occurred on Metra (Chicago region) where this provision of E.O. 20 did not apply because the signal in question required a reduction in speed, but not traversing of the turnout at restricted speed. One of these events involved a train in the pull mode and the other in the push mode. The RSAC Passenger Safety Working Group will evaluate this limitation of the order.

Section 239.101 requires that each railroad establish and maintain a working relationship with the on-line emergency responders by, at a minimum, (1) developing and making available a training program for those that could reasonably be expected to respond during an emergency situation; (2) inviting emergency responders to participate in emergency simulations, which are required to be held on a regular basis; and (3) distribute applicable portions of its current emergency preparedness plan at least once every 3 years. It also requires that each railroad's required emergency preparedness plan provide for passenger awareness of emergency procedures to enable passengers to respond properly during an emergency, and each railroad must post emergency instructions inside all passenger cars and utilize one or more additional methods to provide safety awareness information.

4.3 Passenger Equipment Safety Standards Rule

In 1999, FRA issued the Passenger Equipment Safety Standards, which further enhanced emergency systems requirements and addressed an extensive number of additional safety requirements for the safety of passenger equipment.

In the area of emergency systems, the Standards require that (1) each main level of a passenger car have a minimum of four emergency window exits either in a staggered configuration where practical or with one exit located in each end of each side on each level, (2) each sleeping car and any similarly designed car having a number of separate compartments intended to be occupied by passengers or train crewmembers have at least one emergency window exit in each compartment, (3) each emergency window exit be designed to permit rapid and easy removal without the use of a tool or other implement, and (4) each powered exterior side door in a vestibule that is partitioned from the passenger compartment of a passenger car have a manual override device located adjacent to the door and that can be operated without the use of a tool or other implement. These rules apply to all passenger cars, new and existing.

The Standards also require that new passenger cars have (1) a minimum of two exterior side doors and that each powered exterior side door have a manual override capable of releasing the door from the inside and outside of the car, that is located adjacent to the door, and that can be operated without the use of a tool or other implement, and (2) emergency window exits with an unobstructed opening with minimum dimensions of 26 inches horizontally by 24 inches vertically. In addition, the Standards include other emergency system requirements, such as requirements for emergency lighting.

Additional criteria of the APTA Standards and Recommended Practices supplement these requirements. Through RSAC, FRA and the industry are currently developing enhanced emergency systems requirements.

In addition to emergency system requirements, the Passenger Equipment Safety Standards set forth an extensive number of requirements for safety analysis, inspections, structural characteristics, training of personnel, and other topics.

As noted in the introduction to this report, the Standards included more stringent requirements for cab car and MU locomotive collision posts and material protecting the nose of the car. The standards were supplemented by an APTA requirement for strengthened corner posts, and FRA is presently preparing an NPRM, recommended by RSAC, that would make mandatory compliance with the APTA corner post standard and require that new cab car and MU designs be qualified against static load requirements for graceful deformation of the end structure.

The Standards also included new fire safety requirements that address materials characteristics and fire safety hazard analysis. The Standards include mandatory requirements for passenger locomotive fuel tank safety, with the objective of mitigating derailment events.

Subject to consideration within RSAC and economic analysis, future enhancements to the Passenger Equipment Safety Standards may:

- Require that all seating in cab cars be rear facing and that seats incorporate high backs with neck supports
- Provide specifications for tables based on research now ongoing
- Establish requirements for CEM, carrying forward the concepts already incorporated into Metrolink's current procurement

4.4 Positive Train Control

FRA is supporting national deployment of advanced signal and train control technology to improve the safety, security, and efficiency of freight, intercity passenger, and commuter rail service through regulation, technology development, infrastructure implementation, and financial assistance. PTC refers to technology that is capable of preventing train-to-train collisions, overspeed derailments, and casualties or injuries to roadway workers (e.g., maintenance-of-way workers, bridge workers, signal maintainers) operating within their limits of authority. PTC systems vary widely in complexity and sophistication based on the functions performed and the extent to which an unsafe failure within the system can be detected and acted upon. While PTC systems can be designed to operate independently, most of these developments focus on the enhancement of previously existing methods of rail operations, sometimes as an overlay. This technology has the potential to limit the consequences of the aforementioned precursor events that sometimes lead to serious accidents.

Communications-based PTC systems use onboard position determination systems in concert with data radio links to draw information from the wayside and provide information in turn to the wayside and central office. In some versions of the technology, the locomotive engineer is provided an integrated display showing route conditions ahead of the train. The great safety benefit of PTC is its ability to intervene should the locomotive engineer make a mental error, be unable to maintain alertness, or be incapacitated.

FRA is aggressively pressing development and deployment of PTC technologies, which have the potential to provide collision avoidance benefits as powerful as automatic cab signals and automatic train control and to provide the platform for other safety systems.

Over the past several years, PTC has been deployed on the high-speed portions of the Northeast Corridor in the form of Amtrak's Advanced Civil Speed Enforcement system (supporting speeds to 150 miles per hour) and on Amtrak's Michigan line in the form of the Incremental Train Control System (currently supporting speeds to 95 miles per hour, with increases anticipated to 110 miles per hour). FRA funding continues in support of the ARR's Collision Avoidance System (CAS). The installation of the first phase and detailed design of the second phase of CAS is in progress.

Since 1997, FRA has worked through RSAC to describe technology-neutral performance standards intended to facilitate the introduction of PTC systems. The final rule, entitled "Standards for Development and Use of Processor-Based Signal and Train Control Systems," was published March 7, 2005, and became effective June 6, 2005. This rule revised the existing Rules, Standards, and Instructions Governing Signal and Train Control Systems (49 C.F.R. Part 236) and implemented the necessary technology-neutral, performance-based criterion for supporting the development and determining the safety of processor- and communication-based signal and train control operating architectures.

Work continues in several venues for what will need to be a highly interoperable PTC technology that can serve the needs of the freight rail network and commuter and intercity railroads providing service over that network. FRA Signal and Train Control staff is closely monitoring the process and progress of these systems, as well as providing direct support where appropriate. FRA's Office of Railroad Development has provided further technical and financial support to many of these projects.

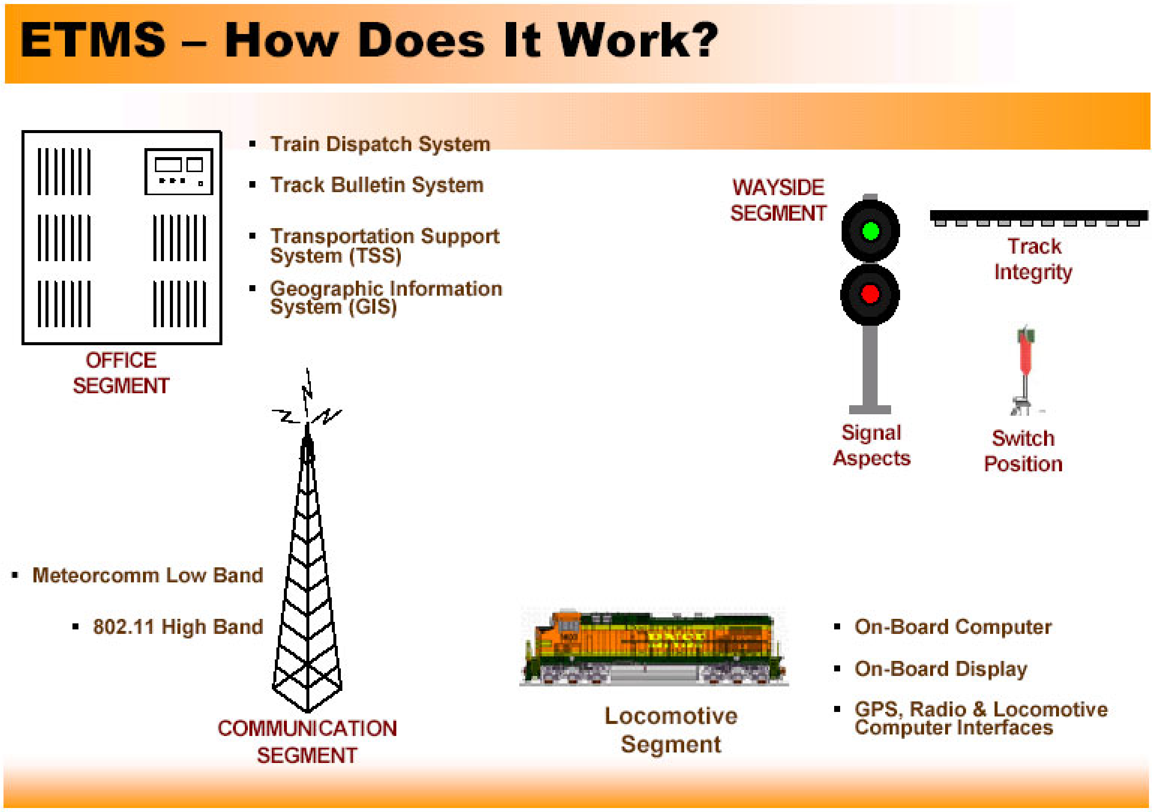

Figure 12. BNSF Railway Company's (BNSF) Electronic Train Management System (ETMS) Architecture

The most significant recent developments clearly involve the major Class I freight railroads. BNSF's ETMS (Figure 12) is in the final stage of its first pilot in Illinois; as this report was prepared, FRA had a request pending for a second pilot on the rail line from Fort Worth to Arkansas City, KS. Further, BNSF had submitted a Product Safety Plan for ETMS and had informally indicated a strong commitment to proceeding with the system. CSX Transportation, Inc. (CSXT), continues with development of its Communications-Based Train Management System, and the Union Pacific Railroad Company (UP) has briefed FRA on its commitment to a Communications-Based Train Control pilot project that will include significant installations in dark, wayside signal, and cab signal territory. For the first time, BNSF, CSXT, and UP are apparently working to ensure that their systems now under development will be interoperable. Meanwhile, the Norfolk Southern Railway Company has advised FRA that it has initiated work on an optimized train control system (with an initial application in South Carolina).

4.5 Other Intelligent Railroad Systems

FRA is working along with other Department of Transportation organizations, such as the Federal Highway Administration, to ensure close integration of their respective Intelligent Transportation Systems (ITS), so that converging operations are more efficient and safer. One example of this convergence is at grade crossings, known in ITS nomenclature as highway-rail intersections (HRI), where use of ITS-like technologies can improve the safety of such crossings.

Initial field implementations have already shown success on the rail side. Amtrak's Integrated Train Control System, for instance, not only pre-starts highway-rail grade crossing warning devices, it also warns the train if the devices are not functioning properly (remote health monitoring). In cooperation with the State of Minnesota, FRA has provided waiver authority for successful testing and demonstration of a Global Positioning System-based system for activating grade crossing warning systems on light density railroads. In connection with installation of four-quadrant gates,[18] FRA and Amtrak have successfully implemented a technology for detection of obstructions at highway-rail grade crossings equipped with four-quadrant gates that warns trains through the cab signal system.

As ITS platforms in commercial and private motor vehicles become more capable and as sector communication systems are provided to advise motor vehicle operators of dangers on the route ahead (e.g., obstructed roadways or major accidents in heavy fog, rain, or snow), information regarding the position, direction, and velocity of trains can be provided by PTC systems to facilitate in-vehicle warning of approaching trains. Such a capability could reinforce warning provided by crossing signals, where present, and provide active warning at other grade crossings where active warning devices are not present.

Over time advanced sensor technologies will be integrated into PTC systems to provide more timely warning of developing problems on the route ahead, such as displacement of bridges and fouling of the ROW at critical locations.

Intelligent Railroad Systems could also assist with the need to improve security in the railroad industry. With advanced communications equipment, sensitive areas of railroad property can be remotely monitored, and situational awareness can be increased. Notification to the proper authorities can be managed more effectively and may help to avoid a disastrous event. Achieving maximum synergies in application of these technologies over time will require close coordination between public and private entities responsible for safety and security.

4.6 Grade Crossing Safety and Trespass Prevention

General Trends and Successes

Significant progress has been made in improving the safety of public highway-rail grade crossings. Even though motor vehicle and train traffic have increased, for the years between 1993-2003, the data has shown that the number of collisions at grade crossings has decreased by 41 percent, from 4,892 to 2,909 collisions. More importantly, the

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[18] Four-quadrant gates are gates that block both the entrance and exit to a crossing for all lanes of traffic, discouraging risk-taking motorists who go around entrance gates and into the path of the oncoming train.

number of fatalities has declined from 626 to 325, a reduction of 48 percent. Trespass fatalities have been holding steady at an average of just over 500 per year over the past several years. The trespass problem actually surpassed the highway-rail grade crossing problem in 1996. Despite the positive trends, the challenge is continuing to improve the safety of grade crossings since they represent a significant portion of the overall risk from the integration of highway and railroad operations.

Three active research areas being conducted by FRA have been identified to limit or reduce the occurrence and severity of push-pull incidents and specifically include: (1) identification of attempted suicide/suicide and the implications and impacts on train operations; (2) identification of a framework and field operational testing of technologies in the area of intrusion/obstacle detection at and nearby HRI; and (3) identification of aggravating risk factors that may impact the severity of the incident on railroads rights-of-way.

FRA currently has two research initiatives active in the area of trespass/suicide prevention. The first initiative is a collaborative effort under a memorandum of understanding with Transport Canada and FRA's Office of Research and Development addressing human factors issues. This initiative will try to scope the problem of suicide on the rails. The second initiative is being conducted by FRA's Office of Safety and entails identifying the demographics of trespassers. This study may provide indicators for suicides as well. Further research could be conducted to provide indicators for incident reports identifying the probability of suicide occurrences, and guidance on the appropriateness of fencing in high suicide identified areas could be developed.

Intrusion Detection Research

FRA has, in the recent past, conducted research activities in two categories of obstacle and intrusion detection. These categories include HRI and infrastructure applications. The following summarizes these two activities.

1. <u>Obstacle/Intrusion Detection Workshop and Technology Evaluations</u>. A national workshop entitled, *"Intruder and Obstacle Detection Systems (IODS) for Railroads Requirements,"* was held at the Volpe Center in 1998 under sponsorship of FRA. Its main objective was to assemble a representative set of researchers and rail industry representatives and brainstorm possible IODS requirements and constraints. One of the central findings was that efforts should be concentrated on highway-rail grade crossing safety over ROW safety, since most high severity incidents occur at crossing locations.[19] Another result from the workshop was the creation of the IODS operation process flow, as shown in Figure 13.

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[19] The Glendale incident clearly constitutes a striking counterweight to this assessment.

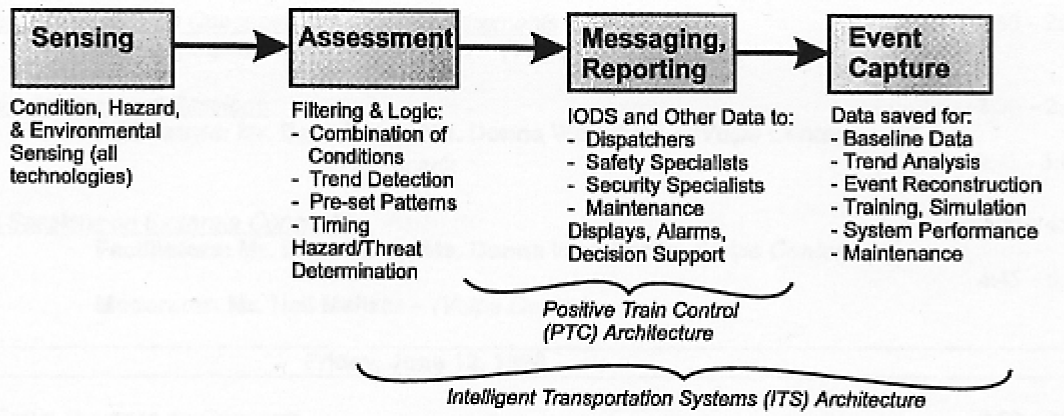


Figure 13. IODS Data Flow

The functional requirements developed during the workshop for sensors, processing, communication, and decision support were later used to test a limited set of detection systems at the Transportation Technology Center, Inc. by the Volpe Center. Five technologies were evaluated for their ability to detect trains and/or highway vehicles approaching and occupying HRI. Results suggest that, although promising performance was observed, most of the prototype systems using these alternative detection technologies did not always interpret train and highway vehicle presence indicators within prescribed limits. Features of some of the prototype detection systems tested were encouraging, and future evaluations could be planned. Since the events of September 11, 2001, and the more recent attacks on railroad infrastructure as in Madrid, Spain, more research is necessary to develop a set of guidelines and standards for use by the railroad industry and the private sector to build upon the existing research.

4.7 Infrastructure Safety Research

This research project has demonstrated and evaluated a stand-alone video-based trespass monitoring and deterrent system for railroad infrastructure applications using commercial off-the-shelf technology. The system was installed at a pilot location in August 2001, just before the terrorist attacks on the United States. Significantly less security component options were available before this time. The objective of the research was to demonstrate a video-based monitoring system that has the capability of detecting trespass events when they intrude onto the railroad ROW or a bridge. The video system monitored the apertures of the trestle bridge entrances that correspond to the railroad ROW. The system had the capability to alert the staff at the security company, which then analyzed the nature of the situation and took the appropriate action(s). During the demonstration period, two events occurred where trespassers were removed from the area just before a train's arrival. As personal safety and security concerns continue to grow over the coming years and advanced technology becomes more affordable, solutions may be available to reduce the possibility that persons and vehicles fouling the ROW will adversely affect the safety of passenger service.

Aggravating Risk Factors

Over the past few years, adoption of more crashworthy fuel tanks on passenger and freight locomotives has reduced the likelihood that fire will aggravate a derailment or collision. To enhance fire safety, FRA has been pursuing further research on locomotive fuel tanks. FRA has developed computer simulation models of baseline underslung and integral locomotive fuel tanks. These models have been exercised to evaluate the influence of various design parameters (material type, thickness, etc.) in simplified loading conditions. FRA is planning to evaluate the likelihood of locomotive fuel spillage and fire per train-mile for each type of locomotive fuel tank from the accident data and, based on the accident data, develop scenarios that bound the range of accidents. The influence of modifications to current designs will be re-evaluated in these scenarios, and the performance of conventional and modified fuel tanks will be compared. In a parallel manner to the development of CEM as a crashworthiness strategy, improved strategies for minimizing the potential for locomotive fuel tank spillage and fire will be sought.

4.8 Vehicle/Track Interaction: Minimizing Derailment Potential

Derailments may occur when train dynamics (vehicle motions and forces within the suspension and on the rails) produce undesirable excursion of a wheel from its intended path on the rails or produce loads exceeding the restraint capacity of the track structure. Several distinct derailment scenarios, including wheel climb, wheel lift, rail rollover, gauge spreading, track panel shift, track buckling, and component failure, such as broken rail, can occur that are largely dependent upon the vertical and lateral forces present at the wheel-rail interface. In order to prevent derailment, different wheel force criteria have been established that are based on the various forces existing between the wheel and the rail. Current work in support of the RSAC Passenger Safety Working Group’s Vehicle/Track Interaction Task Force focuses on revised criteria for track geometry and appropriately conservative track/vehicle interaction limits associated with various levels of curving unbalance (cant deficiency). Although this effort focuses on high-speed operations, much of the learning will also transfer to conventional speed operations.

4.9 Corridor Improvements

Protecting rail traffic from highway traffic and obstructions that can encroach on the rail ROW can significantly reduce collision risk. Strategies under this heading include increasing law enforcement efforts, improvements to highway-rail grade crossing warning devices, channelization of roadways, fencing of ROWs, and grade separations.

In the wake of the 2005 Glendale incident, a State legislative committee in California suggested that Metrolink consider barriers parallel to the roadway at highway-rail grade crossings that would bar access along the rail line. Coupled with selective use of fencing, other physical barriers, or incursion detection systems, this type of concept is consistent with the idea of an urban sealed corridor intended to reduce both the possibility of accidental occurrences and the possibility that the railroad’s ROW will be used as a site for criminal acts against its trains. Metrolink and FRA are working together to develop a sealed corridor plan for one of Metrolink's major routes.

The system safety planning effort described below is an effective means of identifying needed infrastructure improvements.

4.10 System Safety Planning

Among the provisions of E.O. 20, FRA required railroads operating push-pull or MU locomotive passenger service, both diesel and electric, to prepare interim system safety plans evaluating and addressing the safety of these operations. FRA intended these plans to serve as a temporary measure in the light of the passenger safety standards then under development. In a letter to FRA dated June 24, 1996, the chairman of APTA's Commuter Railroad Committee announced that APTA commuter railroads were in compliance with the requirements of E.O. 20 and had agreed to adopt additional safety measures, including comprehensive system safety plans. FRA had reviewed the interim safety plans required by E.O. 20 and met with representatives of commuter railroads, Amtrak, and APTA to develop and implement more comprehensive system safety plans. These plans are broader in scope than the interim plans, are modeled after transit system safety plans, which were being successfully used by rapid transit authorities, and include a triennial audit process. In 1997, after adoption of the Guide to Establishing Commuter Rail System Safety Plans, the existing commuter railroads completed system safety plans, and the audit process began in early 1998. FRA has codified certain discrete aspects of system safety planning in the Passenger Train Emergency Preparedness Regulations, issued in May 1998, and the Passenger Equipment Safety Standards, issued in May 1999, but comprehensive system safety planning remains the province of the individual passenger railroads.

Following the Glendale incident in 2005, FRA developed a draft guide for the conduct of collision hazard assessments. FRA cannot identify hazards specific to a particular operation as well as the operator can; therefore, FRA has requested that all commuter railroads and Amtrak perform such assessments to identify potential hazards and take necessary actions to eliminate, control, or mitigate any hazards that have not already been adequately addressed. FRA has asked passenger railroads to focus their analyses on the potential for derailment and to include secondary collisions in addition to primary ones.

A pilot program for conduct of a collision analysis using the FRA guide is currently concluding at Tri-Rail with participation of APTA, Volpe Center, and FRA staff. FRA will update the guide to reflect insights gained from this effort, and other commuter railroads will be provided with toolkit materials to make the collision hazard analysis process as cost effective and useful as possible. Results of the hazard analysis should provide insights to be incorporated into existing operating and mechanical practices and long-term plans for enhancement to train control systems, training programs, infrastructure, emergency planning, and other aspects of system safety.

FRA intends that this collision hazard analysis framework will address any short-term actions needed to address cab car-forward concerns.   For instance, as a result of its unusually adverse experience over the past several years, Metrolink has elected to bar passengers from seating in the forward mezzanine level of its cab cars. Metrolink has also elected to order equipment that will replace all of its cab cars with newer, more crashworthy cars incorporating all of the newer FRA structural requirements as well as CEM features developed by an *ad hoc* government/industry working group sponsored by FRA and FTA, utilizing the results of FRA research. Metrolink has also elected to work on the sealed corridor concept described above.

Although other commuter systems have generally had a more favorable accident experience in recent years, those systems will benefit by re-examining the state of their current operations and determining what further actions may be appropriate in their individual service environments.

5. Implications of Prohibiting or Restricting Push-Pull and MU Service

FRA is aware that concerns arising in relation to push-pull service could in theory be addressed by strategies such as turning trains; operating with cabbage cars in the lead using de-powered locomotives; or operating with the cab car empty when in the lead. Needless to say, commuter railroads are permitted to employ these approaches as they may wish, consistent with available resources. State and local agencies funding these services may direct that they do so. Since public resources available for capital and operating support for passenger railroads are limited, however, service levels would likely be adversely affected. See estimates in Appendix D.

Turning trains takes time that may affect schedules and equipment requirements, and, in many parts of the country, acquisition of additional property needed to build loops or wyes would be extremely costly. In some cases, using a conventional locomotive forward is undesirable because downtown stations have long sheds and stub tracks, and placing the locomotive deep under the shed exposes passengers and workers to undesirable concentrations of diesel exhaust and noise.

Using heavy de-powered locomotives may be a solution for some applications, but the supply of suitable units is limited. In addition, they are heavy and negatively affect acceleration. Further, adding weight on the back of the train in the pull mode will adversely affect stopping distance and unnecessarily increase the chances that the train will buckle in the event of a collision or derailment, resulting in greater equipment damage and potentially contributing to fouling adjacent tracks.

Leaving a cab car empty when in the lead is feasible in the case of light passenger loadings, and some commuter railroads follow this practice. Others, including Metrolink and Altamont Commuter Express (ACE), may elect to leave the forward mezzanine empty because of load factors or heightened concern over exposure at highway-rail grade crossings (particularly in the case of older cab cars). During rush hour periods in the morning when trains are full, however, significantly under-utilizing the cab car can result either in increasing the number of standees or driving passengers to alternative forms of transportation. In general, neither result would be a positive contribution to transportation safety. This issue is best resolved on the merits of individual operating environments and in the context of system safety planning, including the conduct of a suitable collision hazard analysis.

MU locomotive service would be even more adversely affected, as each vehicle in an MU commuter train is intended to transport and be occupied by passengers—regardless of the direction of travel. Turning an MU train would be meaningless, and operating with a cabbage car in the lead would not be a realistic option.

There is no reason to believe that eliminating use of cab car-led trains would prevent events such as occurred at Glendale, CA, in January 2005. Whether accidental or deliberately caused (as in the case of Glendale), an event involving very high amounts of energy that is resolved through rapidly unfolding impacts with other rail equipment is unlikely to be materially affected by placement of the locomotive in the consist.

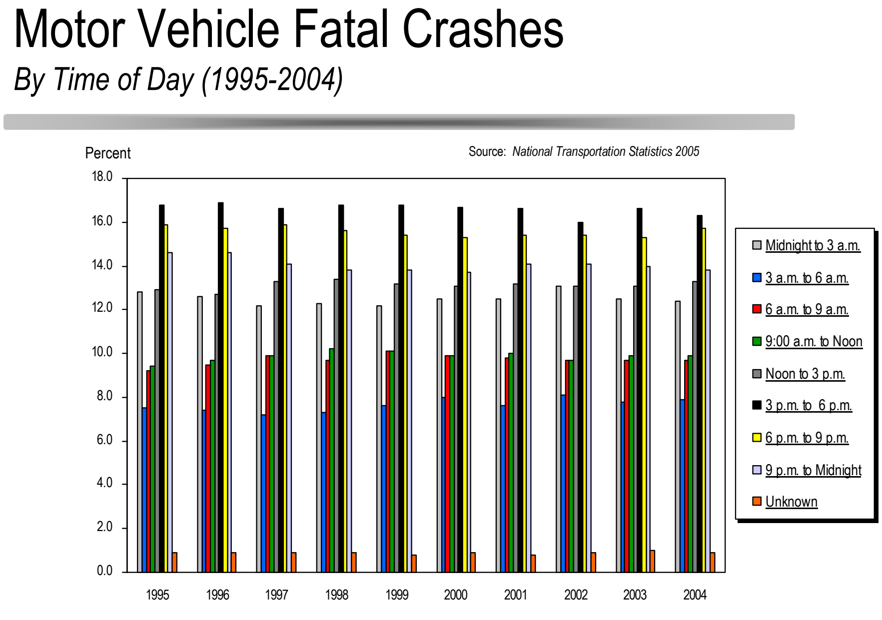
APPENDIX A. STATISTICAL DATA

A.1 Influences on Grade Crossing Accident Rates

Time of Day

Commuter railroads typically operate in the push mode into downtown areas and in the pull mode as they leave. FRA noted that more grade crossing collisions occur in the pull mode than in the push mode. Commuter railroads generally park trains at outlying points overnight so that trains can initiate operations into urban areas in the morning. They may run some of the trains during the midday non-rush but have most of the trains return downtown in time to serve the evening rush. Thus, generally, push-mode operations are more prevalent during the morning rush, and pull-mode operations are more prevalent during the evening rush. Time of day may influence the relative levels of highway-rail grade crossing incidents that occur during the morning and evening rush hours.

This theory is supported by motor vehicle accident statistics. The following two charts show the number of fatal crashes that occur throughout the day and during the morning rush and evening rush.

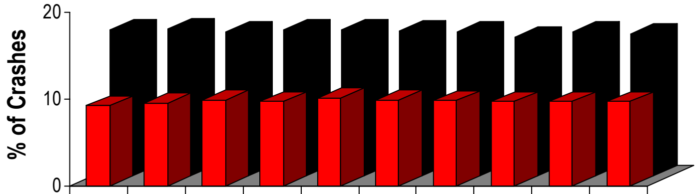


A-1. Motor Vehicle Fatal Crashes

Motor Vehicle Fatal Crashes

Peak Time Comparisons (1995-2004)

Source: *National Transportation Statistics 2005*



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
🟥 6 a.m. to 9 a.m.	9.2	9.5	9.9	9.7	10.1	9.9	9.8	9.7	9.7	9.7
■ 3 p.m. to 6 p.m.	16.8	16.9	16.6	16.8	16.8	16.7	16.6	16	16.6	16.3

A-2. Motor Vehicle Fatal Crashes

Other Influences

Data available indicate that about the same proportion of push-mode and pull-mode operation highway-rail grade crossing incidents involving the lead vehicle result in motorist fatality. The proportion for MU locomotive grade crossing incidents resulting in motorist fatality, however, is much lower. This may be due to various reasons, which may include the more favorable braking characteristics of MU equipment and the closer proximity of rail stations to grade crossing in MU territory resulting in lower MU operating speeds in the vicinity of grade crossings.

Highway vehicles struck by trains often suffer extensive structural damage. Such incidents frequently result in fatality to the occupants of the motor vehicle. Although it may seem that the snow plow on a conventional locomotive would make for a less severe outcome for a highway vehicle struck by a train than a cab car because, to some extent, the snow plow may deflect the highway vehicle, Department of Transportation technical experts cannot identify any engineering rationale that would indicate train makeup has any influence on motorist survivability. In more serious collisions, potential for fire from breach of the locomotive fuel tank can certainly also affect the outcome. Most existing MU operations, however, are electric.

A.2 Methodology and Assumptions

Highway-rail grade crossing incidents are reported to FRA on Form 6180.57. Train accidents resulting in railroad property damage in excess of a monetary threshold (currently $7,700) are reportable on a Form 6180.54. Grade crossing incidents that result in property damage exceeding the threshold must be reported on both forms.

1. The following railroads were included (identified by reporting code for passenger railroads from the FRA Guide for Preparing Accident/Incident Reports):

   ACEX
   ARR
   ATK
   CDOT
   LI
   MACZ
   MBTA
   MNCW
   NICD
   NIRC
   NJTR
   PATH
   PCMZ
   SCAX
   SCR
   SDNX
   SEPA
   TCCX
   TRE
   TREX
   VREX

2. The grade crossing collision data analysis was limited to the following types of incidents:

   - Only incidents involving the first unit of the train (Form 6180.57, block 18).
   - Only incidents involving motor vehicles (Form 6180.57, block 13).
   - Passenger and commuter trains only–excluded freight trains (Form 6180.57, block 24) work trains, single cars, cut of cars, yard/switching, light locomotive(s), maintenance/inspection cars, and special maintenance-of-way equipment.

   The following SAS code was used:

```
If rrequip in ('1','2'); /* limit to equipment identified as either pushing or pulling in
block 17 */
If typeq in ('2','3'); /* limit to passenger trains as identified in block 24 */
If typveh < 'K';        /* drop non mv */
If typacc = '2' and wherehit > 1 then delete; /* if highway user struck train beyond
1st unit/car then exclude */
```

3. The grade crossing accident/incident report (Form 6180.57, block 17) classifies rail equipment involved as:

   Train (units pulling)
   Train (units pulling)
   Train (standing)
   Cars (moving)
   Cars (standing)
   Light Locos (moving)
   Light Locos (standing)
   Other
   Remote Control Movements

   Train (units pushing) and train (units pulling) were used to make an initial classification as to whether the train was in push or pull mode. The number of locomotive units and cars are reported in fields 28 and 29. If the ratio (locomotive units/number of cars) was greater than or equal to (2/3), the train was reclassified as an MU train. This would account for married pairs and triplets while not capturing push-pull trains that were deadheading other locomotives.

The following SAS code was used:

```
conleng = nbrlocos + nbrcars; /* calculate consist length */
  rati = nbrlocos/conleng; /* ratio of locos to total consist length */

If railroad in ('ATK','ARR') THEN GRP = 4
ELSE IF rati >= .666666666 then grp = 3
Else if rrequip = '2' then grp = 2
Else if rrequip = '1' then grp = 1
```

Some railroads report MU married pairs as having an equal number of locomotives and cars. FRA analysts further examined individual reports for trains classified as either push or pull with more than one locomotive.

4. Whether a derailment occurred following a train accident was determined using Form 6180.54, blocks 34 and 35, which identify the location of the cars and locomotive unit(s) and whether any derailed.

   Whether a train involved in a reportable accident was in push or pull mode was also determined using Form 6180.54, block 34. If a locomotive was in the head end, the train was initially classified as being in pull mode. Otherwise the train was classified as being in push mode. As with the grade crossing incidents, if the ratio (locomotive units/number of cars) was greater than or equal to (2/3), the train was reclassified as an MU train. This would account for married pairs and triplets while not capturing push/pull trains that were deadheading other locomotives.

5. Analysis then reconciled mode of operation classification resulting from information on Forms 6180.57 and 6180.54. Where there was conflicting information regarding the type of car in the lead position (i.e., cab car or locomotive), the information from the grade crossing incident report was used. In certain cases, non-database information was used to reclassify the type of car in the lead position. For instance, where one could determine the type of car in the lead by the direction of travel, by the lead unit car number, or the train number.

6. Finally, FRA asked railroads to clarify/correct inconsistent information regarding the type of vehicle in the lead contained in the 6180.54 and 6180.57 reports. Corrections were made to data for use in statistical analysis.

Note that probably not all derailments were reported as train accidents. It is likely that many low-speed derailments that occurred in the Northeast in the mid- to late- 1990s did not result in sufficient damage to trigger such a report.

APPENDIX B. ACCIDENT REVIEW 1986–1995

From 1986 through 1995, a total of 14 passenger train accidents and grade crossing incidents occurred, resulting in one or more train occupant fatalities. Ten of these involved Amtrak intercity pull-mode operations; the remaining four involved commuter MU trains.

B.1 Amtrak Pull-Mode Train Accidents

On October 9, 1986, near Columbus, WI, an Amtrak train traveling at excessive speed through a crossover derailed two locomotives and 10 passenger cars. The train fireman died.

On April 1, 1987, an Amtrak train collided with the rear of a Conrail train that unexpectedly entered the track ahead of the Amtrak train, which had been traveling between 120 and 125 mph only a few seconds earlier, near Baltimore, MD. The Amtrak train's two locomotives and three front passenger cars were destroyed in the collision. The engineer and 15 passengers aboard the Amtrak train were fatally injured, and 174 other persons aboard the train were injured.

On May 19, 1989, in Rochester, NY, an Amtrak train was struck by pieces of lumber that shifted from a passing Conrail train. Pieces of lumber came through the window of the Amtrak engine, resulting in a fatality to the Amtrak fireman.

On December 19, 1989, an Amtrak train, consisting of one locomotive unit and five passenger cars, struck a tractor semi-trailer in a dense fog at a highway-rail grade crossing near Stockton, CA. As a result of the collision, the locomotive and all five passenger cars derailed. A fire followed the train impact with the truck. The engineer, fireman, and truck driver were killed in the collision and fire. Three of the seven train crewmembers and 49 of the 150 passengers were injured.

On October 10, 1990, in Houston, TX, a flatbed truck made a left turn at a crossing and was struck by an Amtrak train. The train struck the trailer portion of the rig. One crewmember died.

On July 31, 1991, in Lugoff, SC, eight passengers were killed following incursion of a freight car into the side of two Amtrak coaches beginning at the corner of each car.

On January 19, 1992, an Amtrak train struck a truck at a private highway-rail grade crossing in Solano County, CA. One railroad employee was killed.

On September 22, 1993, barges that were being pushed by a towboat in dense fog struck and displaced a railroad bridge near Mobile, AL. An Amtrak train, with 220 persons on board, struck the displaced bridge and derailed. The three locomotive units, the baggage and dormitory cars, and two of the six passenger cars fell into the water. The fuel tanks on the locomotive units ruptured, and the locomotive units and the baggage and dormitory cars caught fire. Forty-two passengers and five crewmembers were killed; 103 passengers were injured. All passengers died from asphyxia due to drowning. The train's three locomotive engineers died from asphyxia and blunt force trauma while inside the lead locomotive that became filled with mud. Two other employees died from smoke inhalation inside the dormitory coach car that had caught on fire.

On May 16, 1994, an Amtrak train derailed after striking an intermodal trailer that had fallen or was falling from a freight train traveling northbound on an adjacent track at Selma, NC. The lead locomotive of the Amtrak train rolled over, and the assistant engineer was killed. The engineer sustained serious injuries, and 120 other occupants of the Amtrak train reported injuries.

On September 21, 1995, an Amtrak train traveling at 81 mph struck a loaded tractor-trailer at a private highway-rail grade crossing near Indiantown, FL. The assistant engineer was killed, and five other persons on board the train were injured.

On October 9, 1995, an Amtrak train derailed near Hyder, AZ, while operating at 50 mph, because the railroad track structure had been sabotaged. The derailment killed an Amtrak employee who occupied a passenger car, which had rolled over onto its side. Seventy-eight passengers were also injured.

B.2 MU Train Accidents

Two of the accidents were collisions involving NICTD trains. One was a head-on collision with freight cars that were fouling the main track in 1987. It resulted in one crewmember fatality and two passenger injuries.

The other was a corner-to-corner collision between two NICTD trains in Gary, IN, in 1993. When the left front corners and adjacent car body sidewall structures were destroyed on both of the lead cars in each train, occupied space was lost. Four passengers died in the lead unit of one train and three passengers in the lead unit of the other. Ninety-five people sustained injuries. In 1999, FRA issued structural corner post and collision post standards for passenger cars to help prevent the type of intrusion that occurred in this incident. FRA intends to adopt enhanced corner and collision post standards for new passenger cars to strengthen the end structure and better absorb collision energy.

Two accidents involved Metro North MU trains. One occurred in 1991 when a tree fell, and a limb smashed through the end door, killing the engineer and injuring three people on board. The other occurred in 1988, when an MU train rear-ended another that had stopped along the ROW so that crewmembers could inspect the pantograph. The engineer of the rear-ending train died.

B.3 Commuter Push- and Pull-Mode Train Accidents

No fatal commuter rail accidents involving push or pull operations occurred during the 10-year period from 1986 through 1995.

APPENDIX C. ACCIDENT REVIEW DATA TABLES 1996-2005

The following tables summarize the data collected from an evaluation of passenger injuries and fatalities resulting from passenger rail accidents that occurred in the period from January 1996 through December 2005. The FRA's RAIRS was queried for incidents resulting in five or more combined employee and passenger injuries. These incidents were then correlated with FRA Incident Reports, NTSB reports, and accident investigation data collected by the Volpe Center. The incidents that were supported by sufficient information to determine the configuration of the train, as well as the number, location, and probable cause for the injuries and fatalities, were included in this dataset. A total of 30 incidents (a collision between two trains is listed as two incidents) is included; 14 of which resulted in one or more fatalities.

NOTE: Nine fatalities are not included in this dataset. On February 16, 1996, in Silver Spring, MD, a locomotive-led train sideswiped a cab car-led train at a crossover switch. The fuel tank of the colliding locomotive was punctured and caused a fire, which spread to the impacted cab car. This collision resulted in 11 fatalities, all occupants of the cab car. Two of these fatalities resulted from loss of occupied volume of the cab car (and are included in this dataset), while nine of the fatalities occurred due to smoke inhalation. Shortly after this incident, FRA issued E.O. 20, which remains in effect and was followed by issuance of the Passenger Train Emergency Preparedness and Passenger Equipment Safety Standards final rules. Had E.O. 20 and these final rules been in place at the time of the incident, it is likely that the fatalities due to smoke inhalation would not have occurred.

Table C-1 summarizes the causal mechanisms for fatalities that occurred in the 30 incidents surveyed.

Table C-1. Summary

		Number of Fatalities					
Train Makeup	**Incident Type**	**Loss of Survival Space**	**Secondary Impact**	**Fire (Burns, Smoke Inhalation)**	**Ejection**	**Unknown**	**Total**
Cab-Led N = 9	Train-to-Train Collision	12	2	0	0	0	**14**
	Derailment	2	1	0	0	0	**3**
	Grade Crossing	3	0	0	0	0	**3**
	Subtotal	17	3	0	0	0	**20**
Locomotive-Led N = 21	Train-to-Train Collision	10	0	5	0	0	**15**
	Derailment	1	1	0	4	0	**6**
	Grade Crossing	0	0	0	0	1	**1**
	Subtotal	11	1	5	4	1	**22**
Total, 30 Incidents		**28**	**4**	**5**	**4**	**1**	**42**

Table C-2 lists each of the 30 incidents. The total number and severity of the injuries sustained during each incident is listed in the shaded column in the center of the table. Each injury was then categorized based on (a) the location of the car in the train on which the injury occurred and (b) the probable cause of the injury. Other information is included on the right-hand side of the table to facilitate classification of the incidents.

Table C-2. List of All Incidents[20]

Location of Incident Date of Incident Mode of Service	Injury Severity	Injuries						Probable Cause						Other				
		Cab Car/Locomotive	2nd Car	3rd Car	4th Car and Beyond	Unknown	Total	Loss of Survival Space	Secondary Impact	Burns	Smoke Inhalation	Ejection	Other/Unknown	Cab- or Locomotive-Led	Intercity/Commuter	Lead Car Derailed?	Pos. of First Derailed Car	Type
Chicago, IL	Fatal				2	0	2	2						C	C	Y		Derailment
September 17, 2005	Serious			5	10		15	3	12									
Cab-Led	Minor						?											
Glendale, CA	Fatal	8					8	8						C	C	Y		Collision
January 26, 2005	Serious	15	6	3			24	9	15									
Cab-Led	Minor	27	19	7			53	3	50									
Glendale, CA	Fatal			2	1		3	3						L	C	N	2	Collision
January 26, 2005	Serious			1	3		4	3	1									
Locomotive-Led	Minor		1	9	6		16	4	12									
Flora, MS	Fatal				1		1	1						L	I	Y		Derailment
April 6, 2004	Serious				10		10		10									
Locomotive-Led	Minor				41		41		41									
Chicago, IL	Fatal					0	0							L	C	Y		Derailment
October 12, 2003	Serious					3	3		3									
Locomotive-Led	Minor					44	44		44									
Macintosh, GA	Fatal					1	1						1	L	I	Y		Grade Crossing
May 6, 2003	Serious						0											
Locomotive-Led	Minor					25	25						25					
Burbank, CA	Fatal	1					1		1					C	C	Y		Derailment
January 6, 2003	Serious	2					2		2									
Cab-Led	Minor	5	3	4		8	20		20									
Kensington, MD	Fatal						0							L	I	N	3	Derailment
July 29, 2002	Serious				16		16		16									
Locomotive-Led	Minor				86		86		86									
Baltimore, MD	Fatal						0							C	C	N	5	Collision
June 17, 2002	Serious						0											
Cab-Led	Minor	1			6		7		7									
Baltimore, MD	Fatal						0							L	I	Y		Collision
June 17, 2002	Serious						0											
Locomotive-Led	Minor	1	1				2		2									
Aurora, IL	Fatal						0							C	C	Y		Collision
June 12, 2002	Serious						0											
Cab-Led	Minor					5	5						5					
Aurora, IL	Fatal						0							L	C	Y		Collision
June 12, 2002	Serious						0											
Locomotive-Led	Minor	2	11	10	19		42						42					
Coosawatchie, SC	Fatal						0							L	I	Y		Derailment
May 14, 2002	Serious						0											
Locomotive-Led	Minor	2			7		9						9					
Placentia, CA	Fatal	2					2		2					C	C	Y		Collision
April 23, 2002	Serious	15	11	11			37		37									
Cab-Led	Minor	42	24	34			100		100									
Crescent City, FL	Fatal				4		4					4		L	I	N	5	Derailment
April 18, 2002	Serious				36		36						36					
Locomotive-Led	Minor				105		105						105					
Nodaway, IA	Fatal				1		1	1						L	I	Y		Derailment
March 17, 2001	Serious				9		9		9									
Locomotive-Led	Minor				20		20		20									

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[20] For purposes of this table and Tables C-3 and C-4, “Cab-Led” refers to a passenger train led by a cab car or an MU locomotive, and “Cab Car” refers to both a cab car and an MU locomotive.

Syracuse, NY	Fatal						0							L	I	Y		Collision
February 5, 2001	Serious			2	4		6		6									
Locomotive-Led	Minor			10	42		52		52									

Location of Incident Date of Incident Mode of Service	Injury Severity	Injuries						Probable Cause						Other				
		Cab Car/Locomotive	2nd Car	3rd Car	4th Car and Beyond	Unknown	Total	Loss of Survival Space	Secondary Impact	Burns	Smoke Inhalation	Ejection	Other/Unknown	Cab- or Locomotive-Led	Intercity/Commuter	Lead Car Derailed?	Pos. of First Derailed Car	Type
Carbondale, KS	Fatal						0							L	I	N	4	Derailment
March 15, 2000	Serious				1		1		1									
Locomotive-Led	Minor				31		31		31									
Cumberland, MD	Fatal						0							L	I			Collision
September 20, 1999	Serious					3	3						3					
Locomotive-Led	Minor					37	37						37					
Bourbonnais, IL	Fatal				11		11	6		4	1			L	I	Y		Collision
March 15, 1999	Serious	2			32		34						34					
Locomotive-Led	Minor			15	40		55						55					
Portage, IN	Fatal	3					3	3						C	C			Grade Crossing
June 18, 1998	Serious						0							MU				
Cab-Led	Minor	6					6						6					
Garden City, GA	Fatal						0							L	I	Y		Derailment
October 9, 1997	Serious	1					1						1					
Locomotive-Led	Minor	1	1	1	7		10						10					
Kingman, AZ	Fatal						0							L	I	N	3	Derailment
August 9, 1997	Serious				24		24		24									
Locomotive-Led	Minor				149		149		149									
Jacksonville, FL	Fatal						0							L	I	Y		Derailment
February 5, 1997	Serious						0											
Locomotive-Led	Minor	2	3	3	4	3	15						15					
Granite, WY	Fatal						0							L	I	N	1	Derailment
January 13, 1997	Serious						0											
Locomotive-Led	Minor					24	24						24					
Silver Spring, MD	Fatal	2					2	2			9*			C	C	Y		Collision
February 16, 1996	Serious	3					3						3					
Cab-Led	Minor	8					8						8					
Silver Spring, MD	Fatal						0							L	I	Y		Collision
February 16, 1996	Serious	2	1				3		3									
Locomotive-Led	Minor		12				12		12									
Secaucus, NJ	Fatal	2					2	2						C	C	Y		Collision
February 9, 1996	Serious					4	4						4					
Cab-Led	Minor					74	74						74					
Secaucus, NJ	Fatal	1					1	1						L	C	Y		Collision
February 9, 1996	Serious					4	4						4					
Locomotive-Led	Minor					74	74						74					
Wakefield, MA	Fatal						0							L	C	Y		Grade Crossing
January 16, 1996	Serious					15	15						15					
Locomotive-Led	Minor					21	21						21					

Table C-3 examines the dataset with respect to the cause of the incident. Three causes exist: collision between two trains, derailment, and highway-rail grade crossing collision. The incidents are classified based on the cause of the injuries and/or fatalities. For instance, in Bourbonnais, IL, the locomotive-led train impacted a highway vehicle at a grade crossing, which in turn caused the train to derail, which subsequently caused the train to impact a standing freight train on an adjacent track. Since the impact with the freight train resulted in the loss of survival space and fire that injured the occupants, the Bourbonnais incident is classified as a collision.

Table C-3. Comparison of Incident Cause

Type of Incident	Injury Severity	Injuries					Total	Probable Cause of Injury					
		Cab Car/Locomotive	2nd Car	3rd Car	4th Car and Beyond	Unknown		Loss of Survival Space	Secondary Impact	Burns	Smoke Inhalation	Ejection	Other/Unknown
COLLISION	Fatal	15	0	2	12	0	29	22	2	4	1	0	0
	Serious	37	18	17	39	11	122	12	62	0	0	0	48
	Minor	81	68	85	113	190	537	7	235	0	0	0	295
Locomotive-Led N = 7	Fatal	1	0	2	12	0	15	10	0	4	1	0	0
	Serious	4	1	3	39	7	54	3	10	0	0	0	41
	Minor	3	25	44	107	111	290	4	78	0	0	0	208
Cab-Led N = 6	Fatal	14	0	0	0	0	14	12	2	0	0	0	0
	Serious	33	17	14	0	4	68	9	52	0	0	0	7
	Minor	78	43	41	6	79	247	3	157	0	0	0	87
DERAILMENT	Fatal	1	0	0	7	1	9	3	2	0	0	4	0
	Serious	3	0	5	106	3	117	3	77	0	0	0	37
	Minor	10	7	8	450	79	554	0	391	0	0	0	163
Locomotive-Led N = 12	Fatal	0	0	0	6	0	6	1	1	0	0	4	0
	Serious	1	0	0	96	3	100	0	63	0	0	0	37
	Minor	5	4	4	450	71	534	0	371	0	0	0	163
Cab-Led N = 2	Fatal	1	0	0	1	1	3	2	1	0	0	0	0
	Serious	2	0	5	10	0	17	3	14	0	0	0	0
	Minor	5	3	4	0	8	20	0	20	0	0	0	0
GRADE CROSSING	Fatal	3	0	0	0	1	4	3	0	0	0	0	1
	Serious	0	0	0	0	15	15	0	0	0	0	0	15
	Minor	6	0	0	0	46	52	0	0	0	0	0	52
Locomotive-Led N = 2	Fatal	0	0	0	0	1	1	0	0	0	0	0	1
	Serious	0	0	0	0	15	15	0	0	0	0	0	15
	Minor	0	0	0	0	46	46	0	0	0	0	0	46
Cab-Led N = 1	Fatal	3	0	0	0	0	3	3	0	0	0	0	0
	Serious	0	0	0	0	0	0	0	0	0	0	0	0
	Minor	6	0	0	0	0	6	0	0	0	0	0	6
TOTAL		19	0	2	19	1	42	28	4	4	1	4	1
		40	18	22	145	29	254	15	139	0	0	0	100
		97	75	93	563	315	1143	7	626	0	0	0	510

Table C-4 examines the same dataset but arranged by the mode of service, intercity versus commuter.

Table C-4. Comparison of Mode of Service

Type of Incident	Injury Severity	Injuries					Total	Probable Cause of Injury					
		Cab Car/Locomotive	2nd Car	3rd Car	4th Car and Beyond	Unknown		Loss of Survival Space	Secondary Impact	Burns	Smoke Inhalation	Ejection	Other/Unknown
INTERCITY	Fatal	0	0	0	17	1	18	7	1	4	1	4	1
	Serious	5	1	2	132	3	143	0	69	0	0	0	74
	Minor	6	17	29	532	89	673	0	393	0	0	0	280
Locomotive-Led N = 16	Fatal	0	0	0	17	1	18	7	1	4	1	4	1
	Serious	5	1	2	132	3	143	0	69	0	0	0	74
	Minor	6	17	29	532	89	673	0	393	0	0	0	280
Cab-Led N = 0	Fatal	0	0	0	0	0	0	0	0	0	0	0	0
	Serious	0	0	0	0	0	0	0	0	0	0	0	0
	Minor	0	0	0	0	0	0	0	0	0	0	0	0
COMMUTER	Fatal	19	0	2	2	1	24	21	3	0	0	0	0
	Serious	35	17	20	13	26	111	15	70	0	0	0	26
	Minor	91	58	64	31	226	470	7	233	0	0	0	230
Locomotive-Led N = 5	Fatal	1	0	2	1	0	4	4	0	0	0	0	0
	Serious	0	0	1	3	22	26	3	4	0	0	0	19
	Minor	2	12	19	25	139	197	4	56	0	0	0	137
Cab-Led N = 9	Fatal	18	0	0	1	1	20	17	3	0	0	0	0
	Serious	35	17	19	10	4	85	12	66	0	0	0	7
	Minor	89	46	45	6	87	273	3	177	0	0	0	93
TOTAL		19	0	2	19	2	42	28	4	4	1	4	1
		40	18	22	145	29	254	15	139	0	0	0	100
		97	75	93	563	315	1143	7	626	0	0	0	510

APPENDIX D. COST CONSIDERATIONS OF PROHIBITING OR RESTRICTING PUSH-PULL AND MU SERVICE

Of the approximately 8.3 billion commuter rail passenger miles traveled annually, about 35.4 percent is in MU service and 64.5 percent is in push-pull service (32.5 percent in push mode and 32.1 percent in pull mode). The following discussion describes the impacts of two options for further reducing risk associated with push-pull and MU service: prohibiting these modes of operation outright or restricting passenger occupancy of lead vehicles. These are, to some extent, worst-case portrayals, but they do clearly illustrate the point that the public has substantial investments in these forms of rail service.

Option 1: Prohibit Push-Mode and MU Operations

If all passenger trains were required to operate with a conventional locomotive in the lead, MU operations would cease altogether as they do not have conventional locomotives with which to operate. Push-mode operations would, of course, cease as well, thereby significantly curtailing existing push-pull service.

MU Service: NICTD, which operates MU locomotives exclusively, would have to discontinue service altogether. Commuter service in the Northeast would also be significantly affected. Other railroads that have some extent of MU operations include the Southeastern Pennsylvania Transportation Authority (SEPTA), LIRR, Metro North (MNCW), NJT, Metra, and the Trinity Railway Express (TRE).

Table D-1 presents the number of cars that would lie idle, as well as the percentage of service that would be discontinued at each commuter railroad with MU service.

Table D-1. Affected MU Locomotives and Service

Railroad	Number of MU Locomotives	Percentage (%) of Passenger Miles in MU Service
NICTD	58	100
SEPTA	304	94
LIRR	954	80
Metro North	628	72
NJT	230	33
Metra	165	12
TRE	13	10
TOTAL	**2,352**	**--**

The capacity of MU locomotives ranges between 96 and 156 seats (some are multi-level). The norm is between 115 and 120 seats. Standee counts are not readily available but would add substantially to capacity levels. Multiplying the number of MU locomotives (2,352) by the number of passenger seats in each MU locomotive (115 to 120) results in a range of 270,480 to 282,240 seats. That means that between 270,000 and 282,000 revenue seats would not be available to riders on any given weekday. MU trains are run several times each day. Assuming MU locomotives are operated an average of 2.5 times each day at capacity and that non-peak travelers may round the number of total capacity trains to three per day, this means that, on any given weekday, between 800,000 and 850,000 passengers would have to find an alternate, and probably less safe, means of transportation.

Push-Mode Operations: Push operations would cease, thereby significantly curtailing push-pull operations as a conventional locomotive would have to be transferred from one end of the train to the other at every turn. Wye track and loops, both of which could be used for this purpose, are very rare on commuter lines at outlying terminals. Moreover, in many cases, the land is not available to install these features. Aside from Amtrak, which operates between major downtown stations and on a less rigorous schedule, both of which simplify the logistics of transferring locomotives between train ends, pull-only operations are rare. The one instance that FRA is aware of in commuter service is on LIRR where fewer than 10 daily trains operate with dual-mode (diesel and electric) locomotives on each end for the purpose of alternating between diesel and electric power along a route. (A locomotive is required at each end for this service for the electric portion of the route.) A significant amount of resources would have to be spent to purchase land, if it is available, to lay track and incorporate any other required enhancements or mitigations.

Commuter rail schedules would be impacted due to the extra time needed for locomotives to be transferred from one end of the train to the other. Riders would have to adjust their schedules accordingly. The number of trains that could be operated along a route during the rush hour windows would be reduced to allow time for the transfer of locomotives (or the turning of trains if either wyes or loops are employed). In some instances, longer trains could be run to compensate somewhat for the diminished overall number of trains resulting from the delays associated with transferring locomotives. In many instances, and particularly during peak travel times, however, station platform length would not easily accommodate longer trains. To avoid creating a safety hazard for passengers boarding and de-boarding cars that were not properly aligned with the platform, passenger access to, and egress from, the train would have to be restricted to certain cars in the train and, therefore, add to station dwell time. Another concern would be any reduction of the engineer's visibility of the ROW from operating the locomotive long-nose forward if a facility does not exist to turn the locomotive at turn points.

Nationwide, 16 railroads rely on push-pull operations. Table D-2 lists the breakdown of the number of cab cars operated by each railroad in push service.

Table D-2. Affected Cab Cars

Railroad	Number of Cab Cars
Metrolink	35
SEPTA	10
LIRR	23
Sounder	10
ACE	9

Caltrain–JPB	29
MBTA	110
Conn.DOT	8
VRE	22
MARC Train	27
Metro North	42
NJT	171
Metra	234
Tri-Rail	23
San Diego Northern	10
TRE	7
TOTAL	**760**

FRA estimates that, on any given weekday, approximately 146,000 to 153,000 passengers would have to seek alternate, and probably less safe, forms of transportation. This estimate was developed on the following assumptions: (1) all 760 cab cars operate in the lead on any given weekday; (2) an average train consists of five passenger cars and one locomotive; (3) half of the trips with cab cars in the lead are not possible due to insufficient time to turn the locomotive around to meet the peak-time demands; (4) 67 percent of seated passengers that would normally ride on the trains that no longer operate find an alternate means of transportation, and the remainder transfer to trains that remain in service, filling those trains to capacity; and (5) cab cars have the same average number of passenger seats as MU locomotives. The ratio of emergency exits to passengers on trains that remain in service would also be negatively impacted.

If, on the other hand, commuter railroads providing push-pull service decide to purchase locomotives to place on both ends of the train, they would incur costs in excess of $3 million per locomotive[21] for a total industry cost (even assuming that fewer locomotives than cab cars would be required) in excess of $1.5 billion. Facilities would also have to be modified to permit servicing of the locomotives and to allow for longer train lengths. Since all commuter railroads are publicly funded and do not recover their full costs from the fare box, either additional public funding would be required or new commuter rail starts would be significantly constrained (as scarce Federal capital dollars were exhausted for this purpose). Furthermore, hauling an additional diesel locomotive would result in increased fuel consumption and pollution emissions.

Option 2: Restrict First Car Occupancy in Push-Mode and MU Operations

Push-Mode and MU Operations with No Passengers in Lead Vehicle

If passengers were restricted from riding in cab cars in cab car-led trains, and also restricting from riding in the leading MU locomotive in MU trains, the number of standees in the trains would increase, particularly during the morning rush hours when

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[21] This is the approximate cost of a new passenger locomotive. Very few serviceable older locomotives are available for this purpose. An unoccupied cab car built on a locomotive frame could be used as an alternative at lower cost for lighter trains, but train performance would be adversely affected.

most commuter trains operate in push mode. Standees are generally more at risk of sustaining an injury during an accident or incident than are seated passengers. The impact during off-peak hours would be less significant as passenger loads are reduced.

MU Service: Given that MU service is comprised of semi-permanently coupled locomotives, which in many cases cannot be readily reconfigured to operate independently of their mate(s), the two concerns associated with adding capacity to MU trains are the lack of equipment available to add capacity given that doing so would generally mean adding an MU pair or triplet to an existing trainset[22] and the ability to accommodate longer trains along a route where maximum train length is determined by station length and platform curvature. Even where practicable, the only way to increase consist length would be by adding more MU locomotives or operating fewer trains. Commuter railroads maintain low, spare MU locomotive ratios. The spare MU locomotive fleet is mainly composed of MU locomotives that are undergoing required periodic servicing, which can take several days. To the extent that railroads would choose to add MU locomotives to trains so that MU locomotives in the lead would not operate with passengers on board, railroads would have to purchase additional MU locomotives, which cost approximately $1.5 million for single-level equipment and $2 million for multi-level equipment. Although some riders could adjust their schedules to take less crowded trains and some could find standing room in other MU locomotives, it is still possible that many passengers would switch to alternate means of transportation, again probably on a less safe mode of travel.

The impact during off-peak hours would be less as passenger loads are significantly reduced and shorter trains could be increased more readily in length without increasing existing fleet size. Mechanical inspections, which normally occur during the off-peak hours, would be impacted due to the reduced time frame in which to perform these inspections.

Push-Mode Operations: These operations would be impacted in much the same way as MU operations, but to a somewhat lower extent given that capacity could be added on a single-unit basis.

Push Mode and MU Operations with Seating Restrictions in the Lead Vehicle

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[22] A few railroads have single cars that could be used to vary car length by single units.

If passengers were restricted from occupying portions of cab cars and MU locomotives when operated as the lead vehicles in passenger trains, the effects during peak travel times and particularly the morning rush hours would remain significant but would be considerably less disruptive than any of the options previously discussed. Again, the number of standees would increase, particularly during the morning rush hours. The level of increase in standees would depend on what portion of the lead vehicle is blocked off to passengers. Assuming that railroads restrict passengers from riding in intermediate (mezzanine) levels of multi-level equipment with such levels, the number of standees on these trains could increase between 4 and 18 per train (based on the number of seats that would be in the restricted area). In single-level vehicles with quarter-point doors, seating would likely be restricted to the part of the vehicle behind such doors. It is less obvious where the restrictions would be in vehicles with vestibules in the middle or the far ends of the equipment. Assuming that railroads restrict passengers from riding in the front seven or eight rows of such vehicles, as many as 28–40 seats would be in the restricted area, adding between 28 and 40 standees to such trains. For trains already operating at capacity during the peak hours, this could present significant challenges.

In its Interim System Safety Plan, Metrolink noted that crewmembers routinely cordon off the four seats in the forward-most part of cab cars with half-width cab compartments, when such cars are in the lead, to avoid passenger distraction of the engineers. Conductors ensure that this policy is complied with. The lost revenue seating area is normally used as a workstation for the conductor. This policy was not applied to cab cars with full-width cab compartments since no passenger distraction concern exists. The effect in terms of passengers restricted from riding in the front-most locations in cab cars when they are in the lead is virtually the same for both full-width and half-width cab compartment cars. Tri-Rail has had a policy of cordoning off the entire mezzanine area to minimize engineer distraction. ACE also has a long-standing policy of restricting passengers from occupying the forward mezzanine level of lead cab cars.

If, as a result of an evaluation of the risks associated with cab car forward and MU locomotive operations, railroads prohibit passengers from occupying the forward part of the equipment, between 4 and 40 passengers may be affected on a five-car train. Realistically, passengers affected would be those boarding at stations nearest to downtown and therefore those with the shortest commute. These passengers may become standees for the duration of their commute, they may elect to ride an earlier or later train with seating space available, or they may switch to an alternative form of transportation. Approximately 760 cab cars are in service. Assuming that (1) all 760 cab cars operate in the lead on any given weekday; (2) an average train consists of five passenger cars and one locomotive; (3) only peak rush-hour train service or one cab car trip per day would be notably affected, due to the greater ridership levels during the peak; and (4) one-fourth of the affected passengers find seats elsewhere on the train (middle seats in cars with the three-seat configuration usually go unfilled), one-fourth of these passenger would become standees, one-fourth would change their commuting schedules, and one-fourth would find alternative means of transportation (some by other means of public transportation modes and some by private highway vehicle). Overall, on any given weekday, between 3,040 and 30,400 passengers would be impacted.

Most standee injuries occur near the downtown stations as passengers stand up while the train is moving and move towards door exits in anticipation of the arrival at their destination. Assuming that between 760 and 7,600 additional passengers become standees and 1 percent of them suffer a minor injury annually as a result, between 1,900 and 19,000 minor injuries would result. The value of preventing these injuries would total between $11,400 and $114,000 annually. It is possible that, if ridership increases, more of the impacted passengers would not be able to find seats in other parts of the train.

APPENDIX E. REFERENCES

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