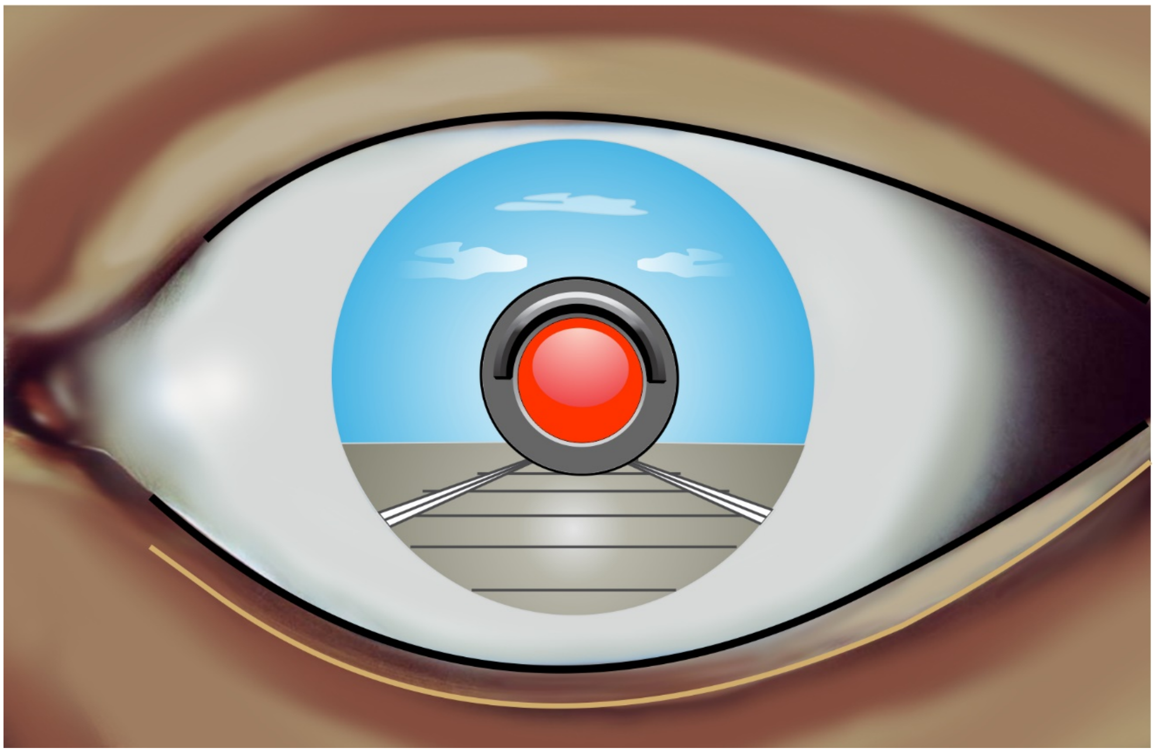
U.S. Department of Transportation

Federal Railroad Administration

Why do Passenger Trains Pass Stop Signals? A Systems View

Office of Research, Development
and Technology
Washington, DC 20590



DOT/FRA/ORD-19/19

Final Report
June 2019

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 2019	3. REPORT TYPE AND DATES COVERED Technical Report March 2015 – April 2016	
4. TITLE AND SUBTITLE Why do Passenger Trains Pass Stop Signals? A Systems View			5. FUNDING NUMBERS RR04A9/QA046
6. AUTHOR(S) Jordan Multer, Hadar Safar, Emilie Roth, Megan France			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Volpe National Transportation Systems Center 55 Broadway Cambridge, MA 02142			8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-FRA-17-04
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Railroad Policy and Development Office of Research, Development and Technology Washington, DC 20590			10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FRA/ORD-19/19
11. SUPPLEMENTARY NOTES COR: Rachel Grice			
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the FRA website.			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) This report documents the findings and recommendations from an investigation into stop signal violations at several passenger railroads. The study collected data on accidents related to stop signal overruns (SSO) from the National Transportation Safety Board (NTSB) reports and from the Federal Railroad Administration's (FRA) accident database to identify the common factors and provide a descriptive summary of the frequency and severity with which these events take place. Stop signal overrun data for six passenger railroads was collected and analyzed to identify their frequency over time. Qualitative data in the form of documents describing stop signal overruns and interviews with employees were conducted to identify how the railroad system produces stop signal overruns. The study identified a wide variety of factors that contributed to stop signal overruns and offered recommendations for mitigating these events.			
14. SUBJECT TERMS Stop signal overrun, SSO, passing a stop signal, PASS, stop signal violation, SSV, signal passed at danger, SPAD, passenger rail, human factors			15. NUMBER OF PAGES 150 16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC / METRIC TO ENGLISH

LENGTH (APPROXIMATE)

English to Metric			Metric to English		
1 inch (in)	=	2.5 centimeters (cm)	1 millimeter (mm)	=	0.04 inch (in)
1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

English to Metric			Metric to English		
1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)	1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)	1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			

MASS - WEIGHT (APPROXIMATE)

English to Metric			Metric to English		
1 ounce (oz)	=	28 grams (gm)	1 gram (gm)	=	0.036 ounce (oz)
1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kilograms (kg)
				=	1.1 short tons

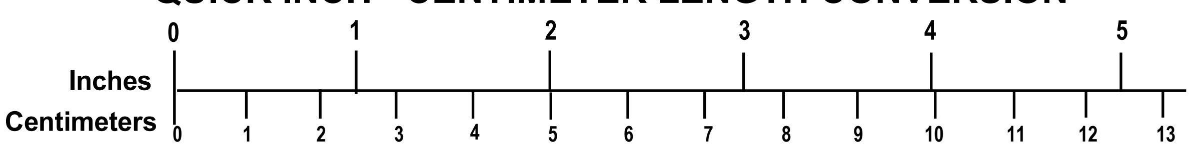
VOLUME (APPROXIMATE)

English to Metric			Metric to English		
1 teaspoon (tsp)	=	5 milliliters (ml)	1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

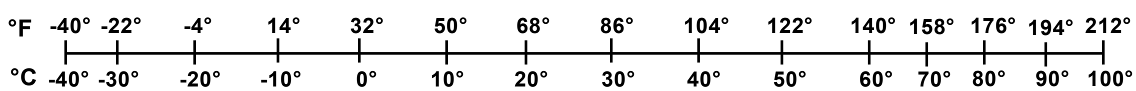
TEMPERATURE (EXACT)

English to Metric			Metric to English		
[(x-32)(5/9)] °F	=	y °C	[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

Acknowledgements

We would like to thank the passenger railroads who shared their data with us on this sensitive topic and enabled us to speak with employees across a diverse set of crafts and operating departments. The information you provided to us was invaluable in learning how the system elements interact to contribute to pass stop signals.

We would also like to thank our colleague Dr. Kim Davies-Schrils for her expertise supporting the coding of our interview data. She streamlined this task and made our job interpreting this information immeasurably easier.

Contents

Illustrations

Tables

Executive Summary

This report is the second in a series of studies completed by the Volpe National Transportation Systems Center and sponsored by the Federal Railroad Administration (FRA) to identify the factors that contribute to trains passing stop signals. The first study focused on factors that contribute to passing stop signals in the terminal at a single railroad (Safar, Multer and Roth, 2015). The current study began in March 2015 and completed in April 2016, conducted across multiple passenger railroads, identifies factors that contribute to passenger service train crews passing stop signals in the terminal and on the mainline, as well as offers recommendations to reduce their occurrence.

We used a sociotechnical systems framework to identify multiple factors that interact to contribute to stop signal overruns (SSO). The design of the system, including the design of the physical infrastructure, technology, railroad organizational practices, and interactions between multiple stakeholders contribute to passing stop signals.

We collected and analyzed SSO data from three sources: the National Transportation Safety Board's (NTSB) accident reports, FRA's accident database, and six passenger railroads. We also interviewed employees from five railroads to understand how railroad practices enable train crews to pass stop signals, observed signals from the head end of the locomotive at three railroads, and observed dispatchers at two railroads.

Frequency and interview data show that SSOs and resulting accidents are infrequent events that can rarely be attributable to a single cause. Rather, they occur due to a confluence of multiple interacting factors at different levels that combine to create breakdowns in overall system safety. These factors include

- The physical environment and available technology
- Individual and team behavior
- Railroad organizational processes
- Regulatory activities
- External factors

As a consequence, approaches to mitigating SSOs need to address these multiple factors. Addressing these multiple factors will not only result in reduced SSOs, but will also contribute to overall system safety. We discuss our findings and recommendations as they relate to these factors in detail throughout the report.

An additional finding of this study is that there is a need for more effective stop signal overrun data collection, investigation, and analysis systems. Data collection was inconsistent across railroads as well as within railroads, across different SSO events. The investigation process tends to focus on the train crew's behavior and assigning responsibility for the failure rather than understanding the factors that contributed to the event and how to prevent the failure from recurring. Collecting additional qualitative and quantitative data will allow FRA and railroads to better understand why SSOs occur and identify effective corrective actions to address them.

1. Introduction

This report is the second in a series of studies sponsored by the Federal Railroad Administration (FRA) to identify the factors that contribute to trains passing stop signals. Stop signal overruns (SSO), also known as passing a stop signal (PASS) without proper authority,[1] can lead to collisions, derailments, and injury to employees working on or near the track. The first study in this series focused on the factors that contributed to passing stop signals in the terminal station at a single railroad (Safar et al., 2015). The current study examined factors across the entire railroad system for multiple passenger railroads.

1.1 Background

Railroad signals convey information to the operators of trains and moving equipment for safe operations. Signals serve several safety functions, such as providing train crews with information about the speed and route ahead of the signal. Signals protect their associated switches so that trains only move in the direction of travel supported by the switch. In combination with the track circuits that protect a section of track called a block, signals can indicate conditions such as broken rail, a train in the block ahead, a protected zone where employees are working, interrupted track circuits from track washouts or failure of a bridge to be properly aligned (National Transportation Safety Board, 1971). Failure to comply with a stop signal can result in collisions, derailments, and broken switches. Accidents attributed to passing stop signals have resulted in significant loss of life and property damage.

After two accidents resulted in a significant loss of life, Congress passed laws requiring FRA to create regulations that contribute to reducing passing stop signals (National Transportation Safety Board, 1988; National Transportation Safety Board 2008). In 1988, Congress passed the Rail Safety Improvement Act of 1988 requiring the certification of locomotive engineers, the prohibition of tampering with a safety appliance and prohibitions on the use of illegal drugs and alcohol. In 2008, Congress passed the Rail Safety Improvement Act of 2008 requiring railroads to install Positive Train Control (PTC) technology to prevent trains from passing stop signals and requiring the certification of locomotive conductors. The estimated cost to the railroad industry for the installation of PTC is $10 billion (Association of American Railroads, 2018).

The railroad industry adopted signals after moving from a time based system for separating trains to a distance based system. Across the world, railroads separate trains by dividing the track into segments, called blocks. Signals protect each block and when a train encounters a stop signal, it may mean that a train occupies the block ahead. The length of a block may vary from several feet to several miles.

Signals may be displayed on the right of way and/or in the cab. The design of wayside signals evolved from semaphores to position based lights using a single color, to the use of colored lights. Some wayside signals use both position and color to convey information to the train crew. In the semaphore system, a semaphore in the vertical position indicated that the train could proceed at the maximum authorized speed. A semaphore in the horizontal position meant the train must stop before entering the next block. A semaphore in an intermediate position between vertical and horizontal indicates an intermediate speed between zero and the maximum

[1] We use the phrases “passing a stop signal” (PASS) and “stop signal overrun” (SSO) interchangeably in this report.

authorized speed. Position based signals using lights adopted the same approach as the use of semaphores. So, two lights in the vertical position represent maximum authorized speed and two lights in the horizontal position represent a stop signal. Colored lights offer a more complicated way to present direction to the train crew based on the number of the signal heads, the colors used and the rules assigned for how to interpret these different configurations. Cab signals display the signal indication shown on the wayside signal for the current block in which the train is located.

Signal systems have grown increasingly complex which enables railroads to better manage the movement of trains and equipment. This complexity is manifested by using multi-head signals and adding interlockings that create additional flexibility to manage the movement of trains. The larger number of signal heads enable the railroad to create a larger number of discrete speed limits at the cost of increasing the burden on the operator to learn and remember this information. Over time, passenger railroads added signals as they added stations, interlockings and crossovers to meet the demands for more service. The additional signals create new opportunities for passing stop signals. This increasing complexity creates challenges for the people who have to understand what each signal represents. The information that a given signal conveys depends upon meaning that is assigned by the railroad. This meaning is assigned through the development of railroad rules that indicate their meaning. Even this knowledge is not sufficient by itself to understand what the maximum authorized speed is for a given block. The operator must acquire knowledge about the physical characteristics of each track section to properly interpret the signal. The track characteristics, type of switches and cross-overs support different speeds. Trains vary in their braking characteristics that depend on the type of locomotive, installed braking systems, type of rail cars (passenger or freight), the order in which the rail cars are arranged, the amount of cargo, etc. The operator must learn and retain all this information to properly interpret the signal and safely control the train. The expanding complexity of signal systems combined with the mergers of many railroads over time has increased the challenge for train crews in responding safely to the information conveyed by the signal system. Multiple, ambiguously worded rules (National Transportation Safety Board, 1971) for interpreting signals make the operator’s job more difficult and increases the opportunity for passing stop signals. In the United States, standards for the interpretation of signals do not exist in the same way that signals in the highway traffic control system are standardized across the country. While two commonly used sets of rules guide many railroads (NORAC and GCOR), railroads may diverge from the use of these rules for interpreting signals.

The installation of PTC in the next few years offers to reduce the frequency and severity of train accidents associated with stop signal overruns. However, it will only impact the territory where it is installed. The FRA regulation requiring PTC excludes territory in yards and terminals where the speeds tend to be less than 15 mph. Therefore, PTC will not impact SSOs in yards and terminals. Where PTC is in place, this technology may mask the underlying conditions that contribute to these events while increasing the overall complexity of railroad systems. When there are no adverse consequences, in situations where PTC protects the train from passing the stop signal, the railroad may not detect a problem that contributes to an unsafe condition. When the problem is detected the railroad may feel less urgency to address the contributing factors because PTC, as the last line of defense, will protect the system from harm. These contributing factors may manifest themselves in other ways that may create new accident types or increase the number of other accidents that do not depend on PTC, but have some of the same contributing factors in common. So if a locomotive engineer is fatigued or inattentive and would have passed a stop signal if not for the use of PTC, the conditions that created the fatigue or inattention will still be in place. Investigating the factors that contribute to SSOs can suggest corrective actions to address these factors.

An earlier study sponsored by FRA examined the factors that contributed to passing stop signals in the terminal environment (Safar et al., 2015). While the terminal environment is a complex network with many signals and many trains, it represents only a portion of an entire passenger railroad's network. Do the same factors identified in the terminal environment also contribute in other parts of the railroad network? To what extent do common factors across passenger railroads contribute to passing stop signals? Exploring contributing factors to stop signal overruns across multiple railroads will give the railroad industry a better sense of the factors involved and what different stakeholders can do to make the likelihood of passing a stop signal smaller.

1.2 Objectives

This study asked the following questions:

- Does the railroad system contribute to trains and other railroad equipment passing stop signals?
- How does the structure of the railroad as defined by the physical design and the processes as defined by organization practices and individual behavior and the interactions between the structures and processes contribute to passing stop signals?

We offer recommendations based on our findings that stakeholders can use to prevent or reduce the likelihood of these events occurring in the future.

1.3 Overall Approach

To understand contributing factors at all levels of the system, we conducted interviews with railroad employees at different organizational levels, including locomotive engineers, conductors, trainers, road foremen, dispatchers, communications and signaling department employees, as well as supervisory personnel. We also observed dispatchers managing trains in and out of the terminal, and rode in a locomotive cab throughout the terminal to observe locations where SSOs occurred. We also reviewed NTSB's accident reports involving trains that passed stop signals. Finally, we analyzed data collected by FRA and passenger railroads documenting the reported cases in which a train or piece of equipment passed a stop signal.

1.4 Scope

Except for an analysis of NTSB and FRA's accident reports involving passed stop signals, our study focused on passenger operations. Operations for most passenger railroads are more geographically confined compared to the large Class I freight railroads which made it less expensive to collect data. While passenger and freight railroads may share many of the same factors that contribute to SSOs, we believe that differences in physical design and operating practices between the two types of operations result in these factors combining in different ways to create the conditions by which trains pass stop signals. For example, passenger operations run on a set schedule and signals are more densely packed within a given geographic area. Freight operations do not typically operate on a set schedule and the signals tend to be dispersed more widely. In passenger service, the locomotive engineer and conductor are separated physically with the engineer working in the cab and the conductor spending most of their time in the body of passenger cars and interacting with passengers. In freight operations, the locomotive engineer and conductor are collocated in the locomotive cab for most of the trip. Freight operations encounter fewer passenger stations and are less likely to encounter stop signals associated with stations. These operational differences may result in different distributions in terms of where stop signals occur and how contributing factors combine to produce these unwanted events.

1.5 Organization of the Report

Section 2 describes the study methodology. Section 3 presents our analysis of NTSB and FRA accident data. Section 4 presents our analysis of the data provided by the six passenger railroads and our recommendations to railroads and FRA for future investigation, data collection methods, analysis and documentation. Section 5 discusses our qualitative findings and recommendations from observations and interviews. Section 6 provides a synthesis of findings and key recommendations that will improve the risk management of SSO through the following topics:

- Improving FRA data collection and analysis of SSO
- Changing FRA compliance and enforcement practices
- Performing additional research to strengthen the empirical foundation for understanding and mitigating SSO risk

In Section 7 we present our conclusions. The appendices are provided at the end of the report: Appendix A describes the types of information contained in each of the spreadsheets we received, Appendix B presents the questionnaire, Appendix C compares the frequency and percentage in which the contributing factors were identified, and Appendix D shows the type of data to collect as part of this effort.

2. Method

We used a sociotechnical systems framework to understand the multiple factors that combine to collectively increase the probability of human errors that result in passing stop signals. A sociotechnical system integrates social systems and technology to create successful or unsuccessful performance. Our framework, based on the work of Rasmussen (1997), encompassed the physical environment, individual and team behavior, task and technology, and railroad organizational processes. We also looked at how regulatory activities and external factors may impact SSOs. We reviewed the literature on SSOs, NTSB's accident reports, and SSO frequency data from FRA, as well as six passenger railroads. We also interviewed railroad employees at five of those railroads, observed signals at three railroads, and observed the conditions under which dispatchers worked at two railroads.

2.1 Literature Review

There is extensive literature on stop signal overrun, commonly referred to internationally as signals passed at danger and referred to as a SPAD. We reviewed much of the stop signal overrun literature as part of our first task (Safar, et al., 2015). Most of the SSO research has been conducted in the United Kingdom, after two major accidents resulting from stop signal overruns resulted in multiple fatalities (Gibson et al., 2015; Lowe, Li & Lock, 2004). SSO research is also steadily increasing in Australia, Canada, the Netherlands, and New Zealand (Banbury et al, 2015; Independent Transport Safety Regulator, 2011; Naweed 2013; Naweed 2014; Van der Flier and Schoonman, 1988). Our literature review pointed to systemic factors that served as a starting point for our investigation and helped to shape the sociotechnical systems framework.

We also reviewed the regulatory language that created the requirement for monitoring and documenting when an individual passed a stop signal (Federal Register, 1991).

2.2 Analysis of NTSB's Accident Data and Stop Signal Overrun Events

We collected and reviewed accident data from NTSB reports from 1986 to 2016. From each report we identified 37 accidents attributed to an SSO. Each report was reviewed and coded using a coding framework we developed based on our sociotechnical systems framework. NTSB's accident analysis is discussed in Section 4.3, below.

2.3 Analysis of FRA and Railroad Stop Signal Overrun Data

We obtained data from the FRA accident database to analyze for SSO frequency and severity; reviewed railroad historical SSO data to understand SSO frequency and to uncover potential contributing factors; and sent questionnaires out to six railroads to obtain information about their investigation methods and implemented mitigations to SSOs. We discuss these analyses below.

2.3.1 FRA Accident Database

We reviewed data from FRA's accident database from 2003 to 2015. The year 2003 was the first year FRA began using the cause code for accidents involving stop signal overruns. We analyzed for SSO frequency and severity (which we correlated with train speed) according to service type (passenger vs. freight), FRA's accident analysis will be discussed in Section 4.3.

2.3.2 Railroad Historical Data

We also reviewed historical stop signal overrun frequency data compiled by six passenger railroads. Four railroads provided data they collected on each event. The data fields collected by each railroad varied and included things like crew experience level, whether the engineer had a previous SSO, weather and lighting conditions, type of equipment, etc. Data included SSO reports and spreadsheets from 2005 through early 2015 and included stop signal violation report documents and investigation reports. Analysis of the railroad historical data will be discussed in Section 5.

Appendix A describes the types of information contained in each of the spreadsheets we received. Each data set was reviewed, such as for typographical errors, duplicate records, different descriptions for the same term, and other sources of error. This information allowed us to discover potential factors that need to be explored in more depth and locate the knowledge that was needed to identify the factors that contribute to SSO across multiple passenger railroads.

For the three railroads we visited, we also reviewed railroad track charts, signal system design, and stop signal overrun briefings, if available, put out by the railroad documenting contributing factors, trends, and mitigation strategies. These documents all helped us to identify factors to be explored in more depth and provided site specific background knowledge that helped us to assess factors that contribute to SSO at these locations.

2.3.3 Railroad Questionnaire

We also sent out a questionnaire to the six railroads to understand how SSO investigations are conducted, including what types of information railroads collect during SSO investigations, who conducts the investigations, how the data is aggregated and stored, and whether or not the data gathered is analyzed for trends. We also asked questions pertaining to engineer qualification and certification, and what changes in rules, policies, training, or physical infrastructure have been put in place to mitigate SSOs within the past 5 years. We received responses from four of the railroads. See Appendix B for the questionnaire.

2.4 Passenger Railroad Interviews

Of the six railroads that provided SSO data, we conducted interviews at five railroads and observations at three of the railroads. At two of the railroads, these interviews and observations spanned two separate site visits. We conducted only one site visit at the third railroad. The amount of interviews and site visits we conducted varied by railroad due to time and budget constraints. Some interviews were conducted by phone. Interview questions and topics varied by railroad as well as by interview. Group interviews lasted between one and a half to 2 hours, while interviews with supervisors and department heads generally lasted 1 hour. A list of interviews by railroad is shown in Table 1.

At railroads in which we interviewed craft employees we worked with labor union officials to assist in soliciting volunteers. In some instances, a union representative sat in on a group interview.

Data from these interviews was then coded by five separate coders using a coding scheme we created which included the level 1 and level 2 themes discussed in Section 5.1. Each coder coded a different subset of interviews, so that each interview was coded by a single coder.

Table 1. List of Interviews by Railroad

	Railroad					
Interview	**1**	**2**	**3**	**4**	**5**	**6**
3-5 Engineers with SSO			✓		✓	✓
3-5 Engineers with >5 years' experience					✓	✓
3-5 Engineers with <5 years' experience					✓	✓
3-5 Engineers with mixed experience			✓		✓	✓
Conductors			✓		✓	✓
Yardmaster						✓
Road foreman			✓		✓	✓
Training department					✓	✓
Safety department		✓			✓	✓
C&S department					✓	✓
Rules department					✓	✓
Operations department					✓	
Crew scheduling					✓	
Equipment scheduling department					✓	✓
Transportation department					✓	✓
Expert Dispatcher			✓		✓	✓
Dispatching department	✓		✓		✓	✓

We also rode with road foremen in the head end of the locomotive cab at three railroads. The purpose of the head end ride was to see the signal system and examine signals that have been described as particularly susceptible to SSO. In addition, at two of the three railroads, we physically walked areas of the yard to view signals.

Finally, at two railroads we observed dispatchers managing trains in the dispatch center and spoke, informally during periods of low workload, with them to understand strategies they employ to route trains.

3. Analysis of Accident Data

This section presents a discussion of our analysis of accidents attributed to passing stop signals from NTSB's accident reports and the FRA accident database.[2] Although FRA began enforcing the regulation that would decertify locomotive engineers starting in 1992, FRA did not have a field in their accident/incident database for this accident type until 2003. The current analysis covers data from 2003 to 2015 and includes accidents for both freight and passenger service. While the report focuses on passenger service, this section examines passenger and freight service.

3.1 NTSB Reports of Accidents Resulting from Stop Signal Overruns

We searched 30 years of NTSB accident reports (1986–2016) and identified 37 accidents in which a train passed a stop signal. Twenty-eight accidents (76%) involved a freight train passing the stop signal and 9 accidents (24%) involved a passenger train passing a stop signal. The proportion of SSO related accidents investigated by the NTSB is not representative of the actual percentage of accidents that occurred during that time period. The NTSB decides which accidents to investigate based on issues of importance to public safety or which have generated particular public interest. A more accurate count of accidents in which trains passed stop signals is captured in the FRA accident and incident database, discussed in Section 3.2.

Figure 1 shows the distribution of locations where accidents took place by service type. All the accidents involving freight operations took place in main line operations. One accident took place at a grade crossing and two accidents took place at or near a siding. The remaining 25 accidents took place on the main line, but not at locations impacted by either the siding or grade crossing.

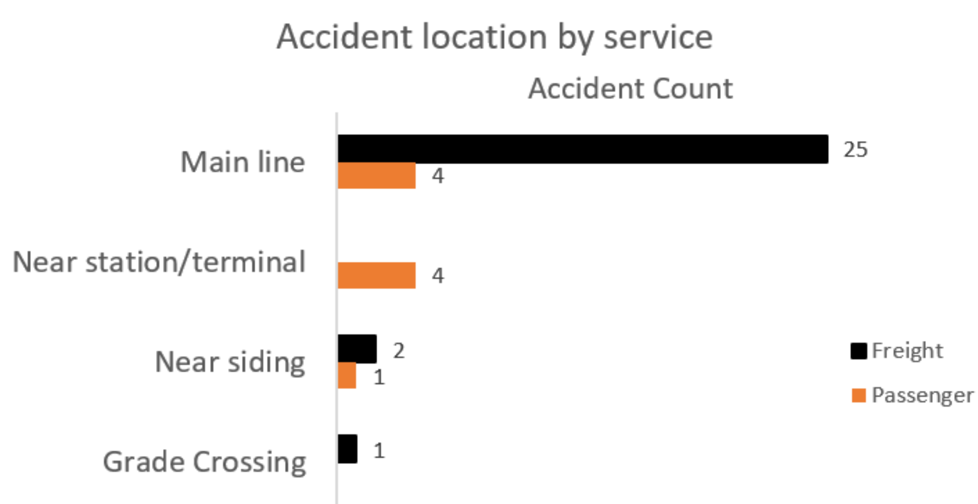


Figure 1. Distribution of NTSB Accidents by Location and Service

[2] Report and Accident Database

For passenger service, the accidents were distributed more broadly. Four accidents took place entering or exiting the station or terminal area and one accident took place near a siding. The remaining four accidents took place on the main line where stations or sidings did not play a role.

We also identified whether the collision involved equipment from the same railroads or from different railroads. **Error! Reference source not found.** shows the distribution of accidents by whether the collision involved equipment from the same railroad or a different railroad. For both freight and passenger service, the majority of the accidents involved equipment from the same railroad. To the extent that railroads tend to operate more of their own equipment on their railroad compared to another railroad's equipment, this finding is unsurprising. The accidents involving mixed service, meaning a collision between a passenger train and freight train, have exerted an outsized impact on safety because of the loss of life and media attention paid to these accidents following their occurrence. For two of the mixed service accidents, Congress passed legislation requiring FRA to create multiple regulations to more closely oversee the industry safety.

Table 2. Collision Involving Equipment from Railroads

Service	Same	Different
Freight	19	7
Passenger	5	1
Mixed	0	5

For each of the 37 NTSB accident reports, we coded the reports to document the identified factors. We used the same coding categories used for coding the interview data discussed in Section 4.6. Using Rasmussen's Accimap approach (Rasmussen, 1997), we identified the following categories shown in **Error! Reference source not found.**. **Error! Reference source not found.** shows the count and percentage of times each of the contributing factor categories was used in the NTSB reports. The factors documented most frequently involved individual behavior and characteristics followed by railroad organizational processes, physical environment and technology.

Table 3. Contributing Factors Categories for NTSB Reports

Contributing factor category	%	Count
Individual and Team Behavior	46%	42
Railroad Organizational Processes	26%	24
Technology and Environment	25%	23
Regulatory Activities	3%	3

Error! Reference source not found. shows in greater detail the contribution of each category of contributing factors. Within individual behavior and characteristics, distraction, fatigue and expectations were identified most frequently followed by expectations. Within railroad organizational processes and supervisory practices were the most frequently mentioned factor followed by crew assignment and scheduling, policies and practices and training.

Table 4. Contributing Factors Within Categories for NTSB Reports

Contributing Factors within categories	Percent	Count
Individual Behavior and Characteristics		
Distractions	31%	13
Fatigue	29%	12
Expectations	14%	6
Experience Level	7%	3
Teamwork	7%	3
Communication	7%	3
Visual Scanning	2%	1
Paperwork Requirements	2%	1
Railroad Organizational Processes		
Supervisory Practices	29%	7
Crew Assignment and Schedule	13%	3
Policies and Practices	13%	3
Employee Training	13%	3
Incident Investigation	13%	3
Dispatcher Train Management	8%	2
Workforce Management	4%	1
Data Collection and Analysis	4%	1
Resource Constraints and Management	4%	1
Technology & Environment		
Displays and Alerts	26%	6
Environmental Issues	26%	6
Signal Maintenance	17%	4
Infrastructure Layout	9%	2
Equipment Malfunction	4%	1
Technology in Dispatch Center	4%	1
Signal Design	4%	1
Cab Signals	4%	1
Locomotive Type	4%	1
Regulatory Activities		
Engineer and Conductor Certification	67%	2
Regulatory Mandated Testing	33%	1

3.2 Review of FRA Accident Data

In this section we discuss our analysis of the FRA accident data with regard to SSO frequency and severity and present limitations to the FRA accident database.

3.2.1 Frequency

Figure 2 and Figure 3 show the annual number of accidents and the accident rate involving trains that passed a stop signal from 2003–2015, for accidents that surpassed the FRA monetary reporting threshold. The upper and lower gray lines represent the 99 percent confidence intervals. The center gray line shows the mean across this time period. In 2015, the reporting threshold was $10,500. If an accident involved damage that was below the threshold, the accident would not be included in the database. The reporting threshold varies from year to year as the agency revises the threshold to reflect changes in inflation.

Over this 13-year period, accidents averaged 10 per year. During this period, the accident range has varied between 6 and 14 annually. During the last 5 years, the range has narrowed to between seven and eight accidents per year. This reduction can be explained by separating accidents attributed to freight trains passing stop signals compared to passenger trains. The accident rate shows the same trend.

Figure 4 and Figure 5 show the annual number of accidents and accident rates separately for freight and passenger service involving trains that passed a stop signal from 2003–2015. The yearly freight accident frequency is higher than for passenger railroads, but shows a steady decline over time. The last 5 years stay consistently below the average of eight accidents. Yearly accidents are lower for passenger railroads, but remain close to the average of two accidents per year over the entire time period. Figure 5 shows the accident rate normalized by the number of train miles indicating that the accident rate has declined over time for freight service. Over the 12-year period, freight service shows a steady decline in the accident rate. By contrast, passenger service shows no decline across the 12-year period and much larger year to year variability than freight operations. The passenger service accident rate fluctuated within a range of 0–0.42 accidents per million train miles (0–6 per year). The overall decline in the accident rate is due to the reduction in accidents associated with freight service.

The observed behavior suggests that freight operations have better control over their operations than does passenger operations. Understanding why freight accidents declined requires investigating what changed in freight operations, which was beyond the scope of this study.

Figure 2. SSO Accident Frequency: 2003–2015

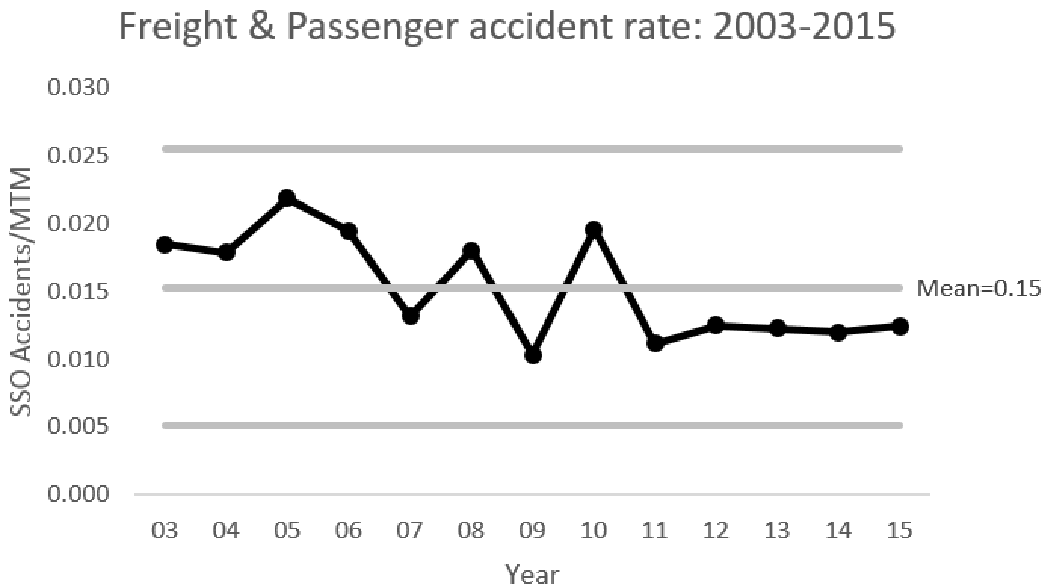


Figure 3. SSO Accident Rate 2003–2015

A challenge in interpreting this data is that we lack the appropriate denominator to evaluate the impact of exposure on accidents. Traditionally, FRA and the industry use train miles as shown in Figure 3 and Figure 5 as a measure of exposure in calculating rate measures. However, the number of train miles over which a railroad operates is a poor measure of exposure to passing stop signals. Signals vary in density between tracks owned by freight service compared to passenger service. Signal density per mile tends to be greater on passenger owned track due to the need to cross trains onto different tracks, and to address bottlenecks that occur at stations and terminals where multiple tracks converge or diverge. The number of signals or the number of stop signals that a train encounters is a better metric for assessing exposure to these events. Figure 6 compares two measures of accidents for freight and passenger service: percentage of accidents and accident rate as measured by train miles.

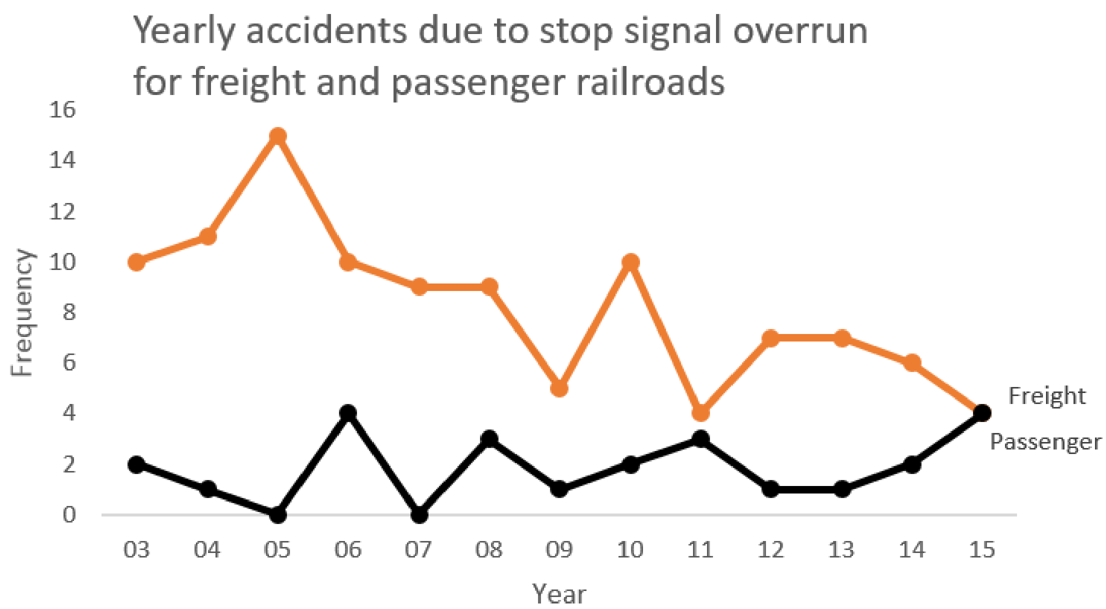


Figure 4. SSO Yearly Accident Frequency by Freight and Passenger Service

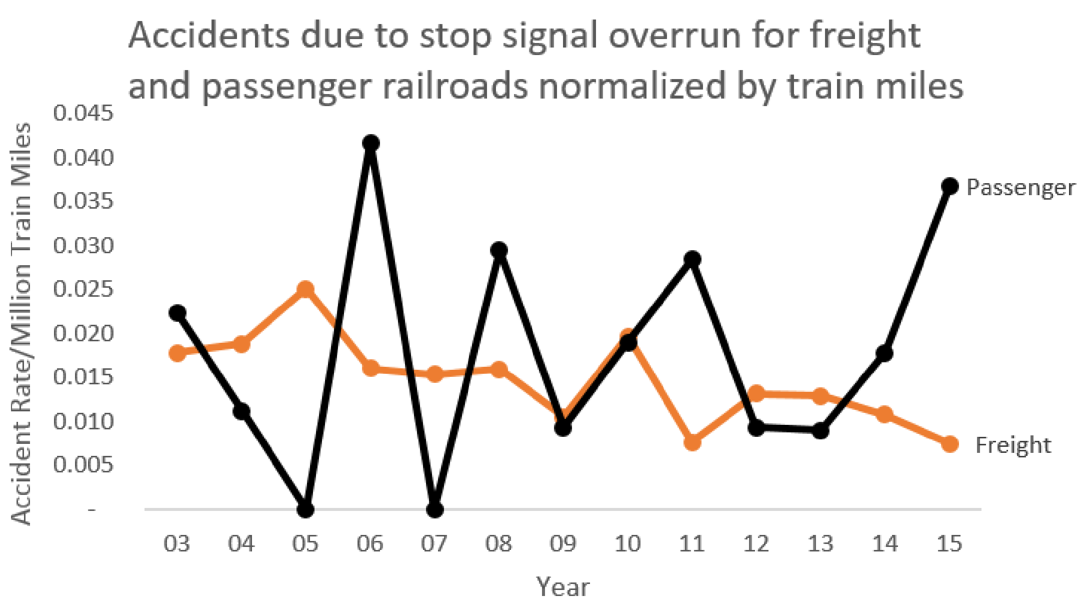


Figure 5. SSO Yearly Accident Rate by Freight and Passenger Service

Depending upon the measure used, a different picture emerges. In the case of percentage of stop signal related accidents, freight service exhibits 82 percent of the accidents and passenger service exhibits 18 percent of the accidents. The greater percentage of accidents by freight operations is not surprising when you consider that freight service operates more frequently as measured by train miles. When normalized for the number of train miles as shown in the right chart in Figure 5, passenger service exhibits a greater accident rate. However, using train miles is misleading since it does not provide an understanding of how many stop signals occur within a given train mile. The number of stop signals in particular represents a better measure of exposure

(Nickandros and Tombs, 2007; Safar et al, 2015; Zhao, 2016). Zhao (2016) developed a method to detect different approaches to a stop signal, such as when the train is stopped or when the train is approaching a red signal which changes to a permissive signal.

The railroads do not record data on the number of signals encountered for the purpose of measuring exposure to stop signals.

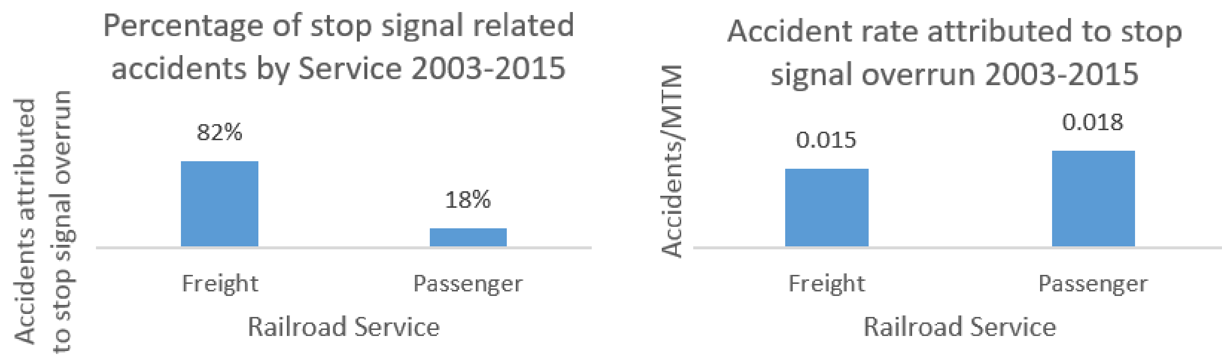


Figure 6. Comparison Between Accident Percentage and Rate for Freight and Passenger Service

When we examined the railroads that experienced SSO accidents, we discovered that the number of railroads that experienced these accidents is tiny relative to the total number of railroads. Figure 7 shows the number of railroads that experienced at least one SSO accident over the 12-year period for which we collected data. Out of 537 freight railroads, only 15 (3%) experienced a SSO accident. For passenger railroads, 9 out of 29 (31%) railroads experience a SSO accident.

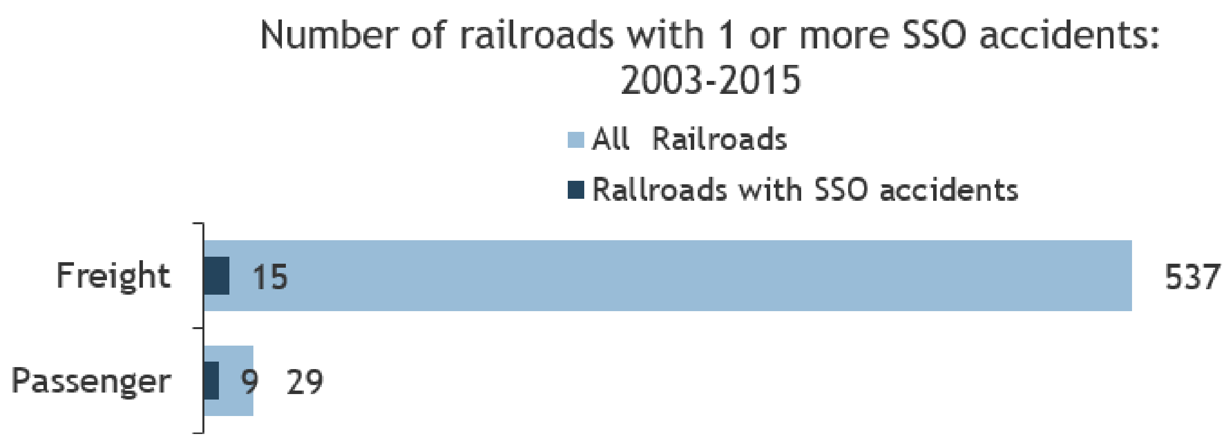


Figure 7. Number of Railroads with One or More SSO Accidents

Figure 8 shows the number of SSO accidents by railroad for freight and passenger service. For freight operations, four railroad accounts for approximately 80 percent of SSO accidents. The railroads with the largest number of accidents are among the railroads with the largest operations as measured by the number of train miles and number of employee hours worked. For passenger operations, three passenger railroad account for 80 percent of the SSO accidents and are also among the passenger railroads with the largest operations by train miles. The remaining passenger railroads experienced only one SSO accident in the 12-year period. If past experience is predictive of future behavior, focusing interventions on these seven railroads with the largest number of accidents, if successful would significantly reduce the frequency of SSO accidents.

This data indicates that most railroads never experienced an accident where a train passes a stop signal. For the majority of those railroads that do experience such an accident, these accidents are rare events. For a tiny fraction of railroads in freight and passenger operations that experience multiple accidents, they are the busiest railroads in their category.

The data displayed in Figure 8 suggests one possible explanation for the greater variability in SSO accidents in passenger operations compared to freight operations. The greater variability in passenger operations may be a statistical artifact of the lower exposure to SSO accidents.

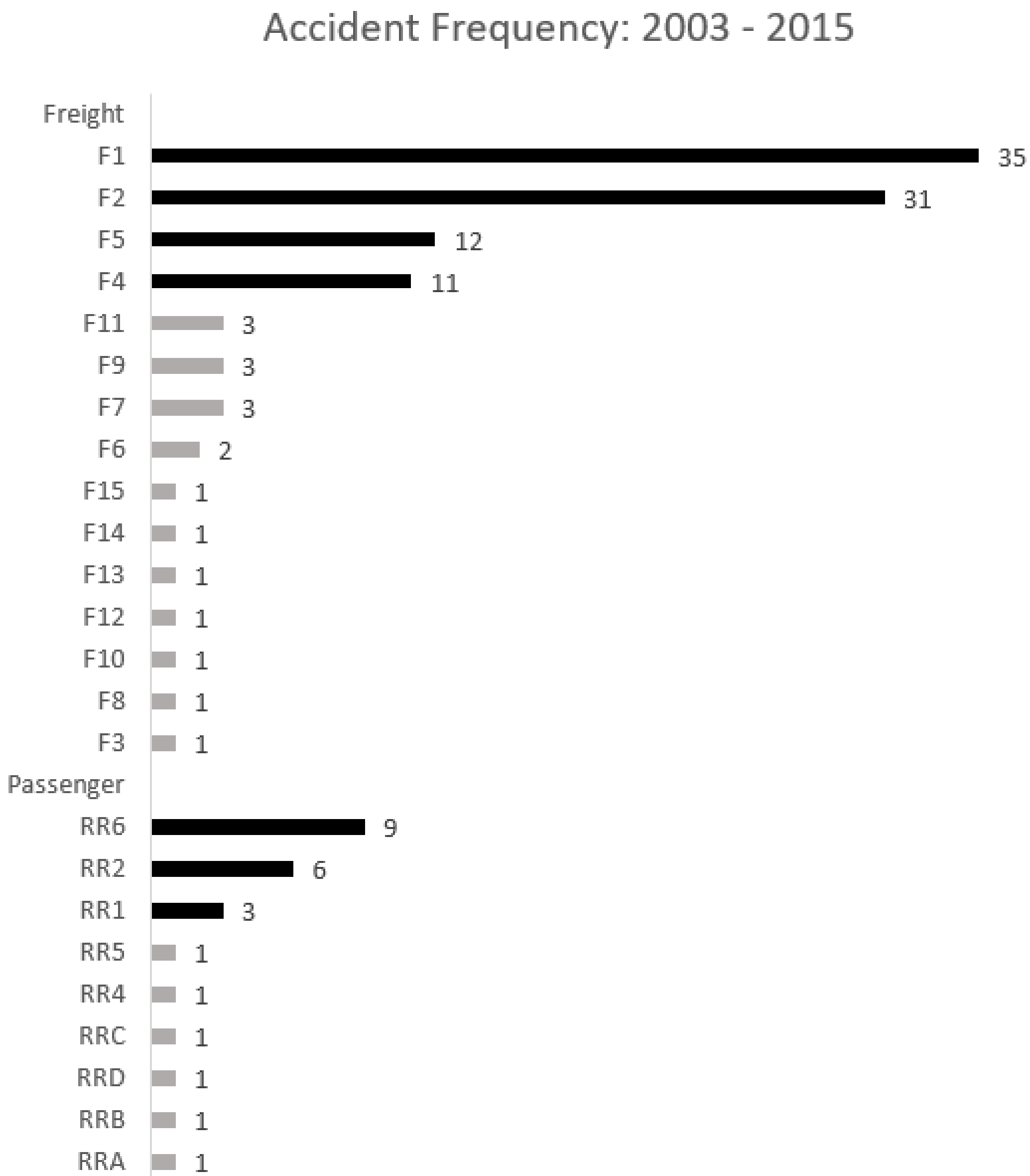


Figure 8. Frequency of SSO Accident by Railroad for Freight and Passenger Operations

3.2.2 Severity

A key concern when a SSO accident occurs is the level of harm that may occur. While rare, these accidents make for dramatic photographs and video and draw significant attention from the media. The harm to people, equipment, and the environment can have significant consequences that go beyond the railroads involved. Figure 9 shows the relationship between accident cost and train speed. For the 131 accidents in our sample, cost varies between approximately $10,000[3] and $10 million. There is a moderate positive correlation of 0.53 ($t_{(105)} = 6.91$, p, <0.0001) between accident cost and train speed for freight operations. The correlation of 0.33 between accident cost and train speed for passenger operations was not significant. For freight operations, higher trains speeds are associated with greater accident cost.

Figure 9. Relationship between Accident Cost and Train Speed

Overall, the frequency of SSO accidents declined as train speed increased. Figure 10 shows the relationship between accident frequency by train speed at the time of the accident. For freight operations accident frequency peaked at the interval between 10–19 mph and declined as train speed increased. For passenger operations, accident frequency peaked between 0–9 mph and declined as train speed increased. This data suggests that PTC technology will positively impact freight operations more than passenger operations. The FRA regulation does not require railroads to implement PTC in yards and terminals and where the train is traveling at restricted speed, where the speeds are lower than 20 mph. Since all but 3 of the 24 (12.5%) passenger accidents took place below 20, mph, this data suggests that positive train control may have a more limited impact on preventing SSO accidents in passenger operations. In freight operation, 48 out 107 (45%) accidents were at 20 mph or above. In this case, PTC should prevent a greater number of SSO accidents in freight operations compared to passenger operations. Nevertheless, 55 percent of freight accidents would not be addressed by PTC.

---

[3] FRA requires railroads to report accidents when they rise above a reporting threshold. The reporting threshold rises periodically with the rate of inflation.

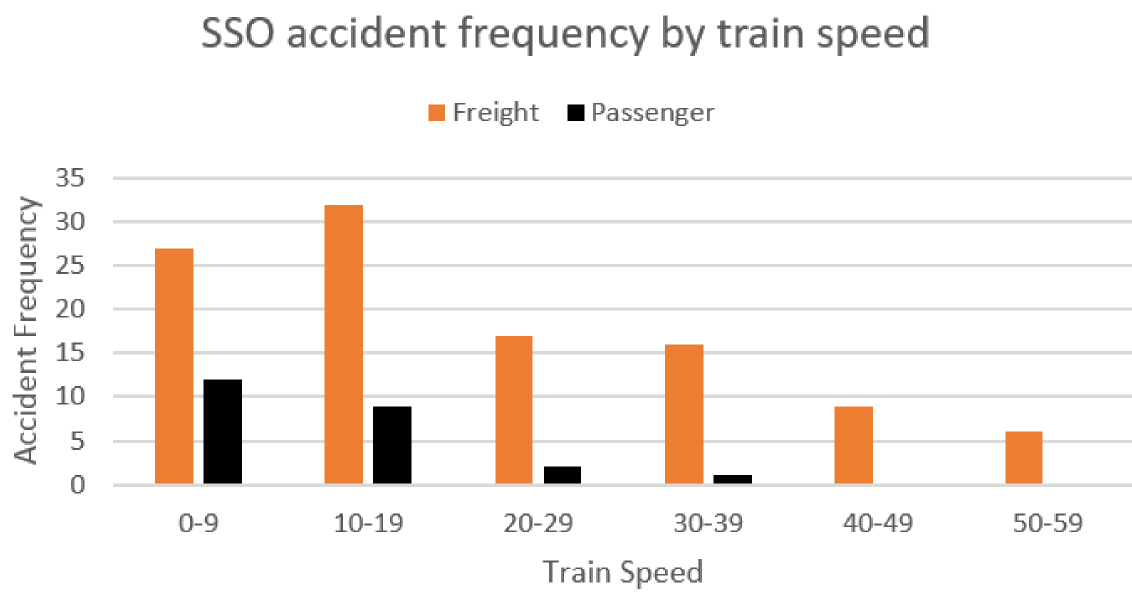


Figure 10. SSO Accident Distribution by Train Speed for Freight and Passenger Operations

3.2.3 Limitations of the FRA Accident/Incident Database

The FRA accident and incident database contains significant limitations for learning why trains pass stop signals. Although FRA began requiring the railroads to report when their trains pass stop signals in 1992, it did not begin to code when these accidents involving a passed stop signal until 2003.[4]

The database contains data fields that identify the contributing factors in a limited way. Many of the fields address: date, time, location, environmental conditions at the time of the event (e.g., weather, visibility), and equipment conditions (e.g., loaded, unloaded), accident cost. The database allows for only a primary cause and a secondary cause. The information in the cause code fields explain what happened (e.g., past a stop signal), but not why the events occurred. The narrative data tends to be a single sentence describing the event (e.g., train A struck train B on the mainline). The accident form provides a supplementary form for the railroad to complete when an accident is identified as a "human factors" accident. This form enables the railroad to enter data describing the behavior of each employee involved in the event. The form does not request any other narrative information about the status of other elements of the railroad systems, such as the operation of the signal system, dispatcher control system or any of the other elements that could have contributed to the accident. We could find no fields in the database that contained this type of narrative data. The problems with collecting, coding, and analyzing accident databases are well documented (Mayer and Ellingstad, 1992) and the problems that we encountered with the FRA accident/incident database share many of these attributes. This data is useful for understanding the frequency of SSO events over time as well as who experiences these types of events. We provide additional information about why these accidents occur in Section 6.

[4] The FRA accident code for trains passing stop signals is H221.

4. Analysis of Passenger Railroad SSO Data

This section reviews the data collected by six passenger railroads. The type of data and level of detail we received varied by railroad. The railroads provided data on each event that addressed fields like date, time, type of employee (locomotive engineer or conductor), equipment, and location. Table 5 shows the kinds of data we received from each of the six railroads. Within fields, the level of detail varied by railroad. Many fields had missing data, misspellings, and ambiguously worded data. The railroads shared this data in different ways that made showing relationships between railroads challenging.

Table 5. SSO Information Provided by Railroads

SSO Information	Railroad					
Data	1	2	3	4	5	6
Annual SSO frequency	√	√	√	√	√	√
Period of time covered	2012-2014[5]	1978-2015	2005-2015	2005-2015	2005-2015	2000-2015
Date	√		√	√	√	√
Time			√	√	√	√
Craft		√	√	√	√	√
Employee		√	√	√	√	√
Location	√	√	√	√		
Equipment (locomotive, control car)			√		√	
Signal name	√	√	√		√	√
Age					√	
Years of experience in craft			√		√	
Time on duty					√	
Direction of travel					√	
Narrative description			√		√	√

Our analysis begins with an overview covering all six railroads to describe system behavior. This overview consists of two ways of showing the trends in SSO behavior. The remainder of the analysis describes our findings across either a subset of railroads where the same type of data was provided or an analysis of individual railroads.

[5] We obtained additional data on annual SSO frequencies from another source (FRA) so we could compare annual SSO frequencies and rates for the period 2005–2015.

4.1 Comparisons Across Six Passenger Railroads

Figure 11 shows the mean SSO rate with 95 percent confidence intervals for six railroads in our sample. The mean SSO rate for five of the railroads cluster between 0.4 and 0.67 accident/million train miles (MTM). Except for Railroad 6, all the railroads show similar average rates. The railroads differ in variability around these mean SSO rates. Railroads 1 and 2 have lower variability around their means. Railroad 6 has a mean SSO rate of 1 accident/MTM. The difference between Railroad 6 and Railroads 1 and 5 are statistically significant. The annual variability in system SSO performance is displayed more clearly in Figure 12.

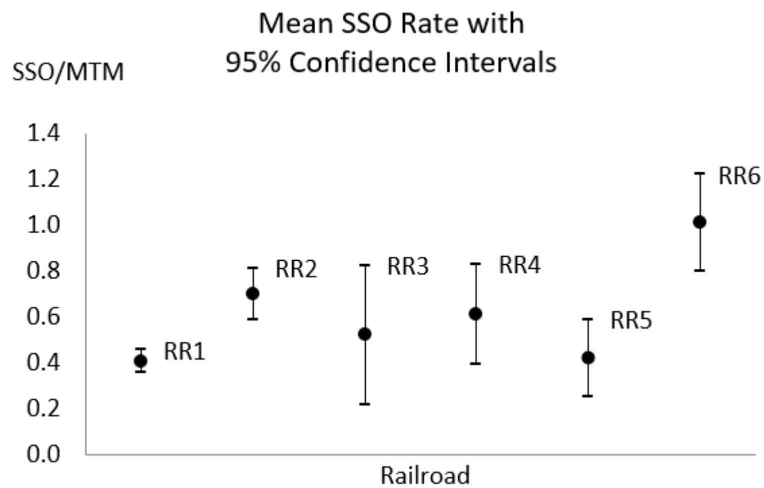


Figure 11. SSO Rate with 95% Confidence Intervals

Figure 12 shows the trend in annual SSO events for the 10-year period from 2005–2015. Each railroad displays a different pattern from each other. These patterns reflect routine variation. From a process behavior perspective the trends for all six railroads were the result of common cause variation, which means that SSOs were the product of normal system behavior (Wheeler, and Chambers, 2010). Railroads 1 and 2 show the lowest variability across the 10-year period. The other four railroads show greater year-to-year variability.

In talking with managers at several of the railroads, it was clear that spikes in SSO rates would grab their attention and create concern about the potential for a serious accident. This concern occurred when multiple SSO events were spaced close in time (e.g., 30–40 days between events). In these situations railroads took a variety of actions, including conducting special investigations on why stop signals were occurring or exhorting their train crews to pay closer attention to the signals. We observed no sustained reduction in the SSO rate as a result of any railroad's action, as illustrated in Figure 12.

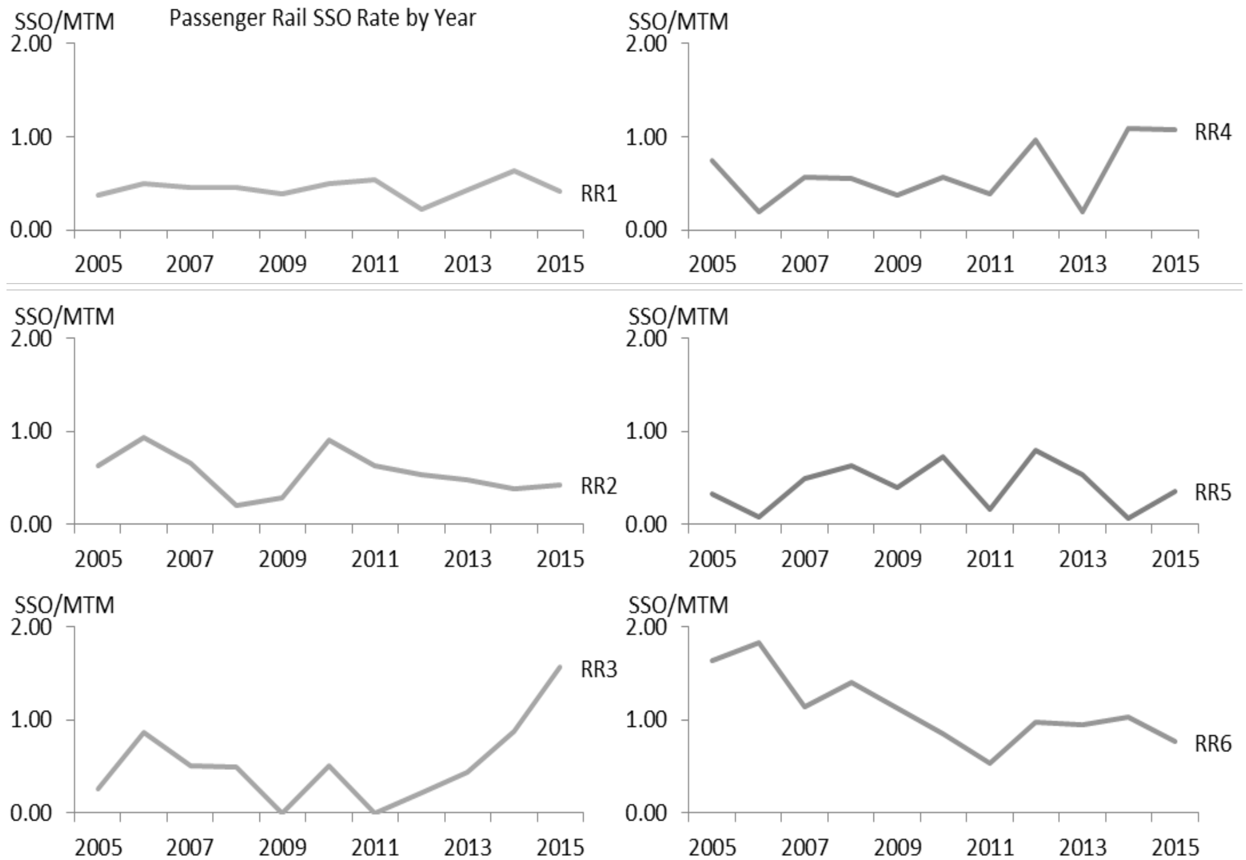


Figure 12. SSO Rate for Six Passenger Railroads: 2005–2015

4.2 How Big is the Problem of Employees who Experience Multiple SSO Events?

When a railroad encounters employees who experience multiple SSO events, managers may express concern that they have a problem with bad actors. Because the investigation of SSO events takes place in the context that anticipates a disciplinary process, the focal point is the employee as the source of the SSO problem. When an employee experiences multiple SSO events, managers' concern about the employee's behavior is amplified. This concern begs the question of how often an employee is involved in SSO events over time. For two of the six railroads for which we received data that included which employees were involved, we analyzed data to answer this question. Figure 13 shows the percentage of employees involved in SSO events according to the number of events. The majority of employees (between 97–98 percent) never experienced a SSO. Between 1–2 percent of employees experienced a single SSO event.

The percentage of employees who experienced multiple SSO events was less than 1 percent.

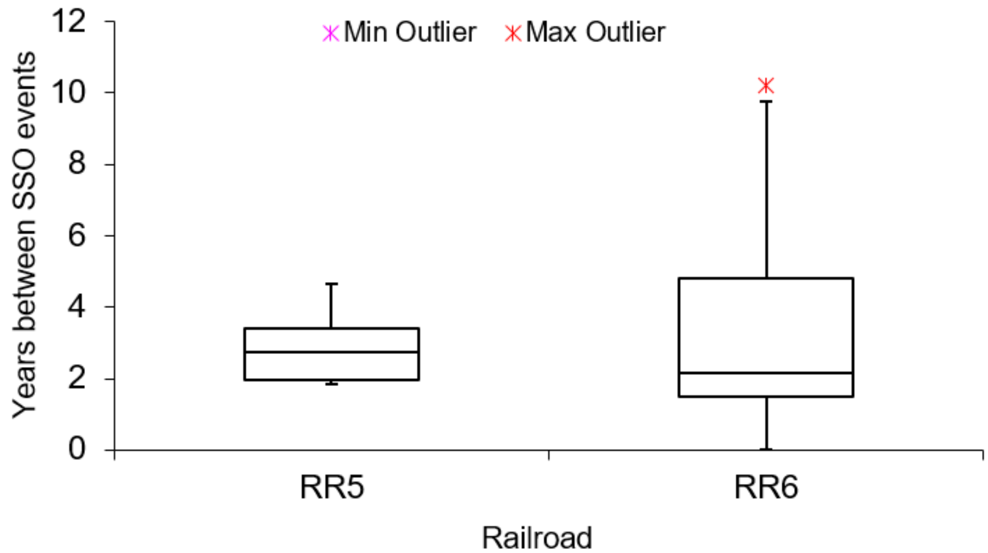


Figure 14 shows the time lapse between events for employees at the two railroads. The median time between events is between 2.1 and 2.7 years. The range varies between the two railroads. Railroad 5 has a narrower range with the 25–75 percent distribution staying between 1.9 and 3.4 years between events. For Railroad 6, the 25–75 percent distribution is between 1.5 and 4.8 years between events. The ends of the distribution are also more extreme for Railroad 6 compared to Railroad 5. In both railroads, multiple SSO events by a single employee tend to be distant in time. The events in every case took place at different locations and under different conditions (e.g., location, time, visibility).

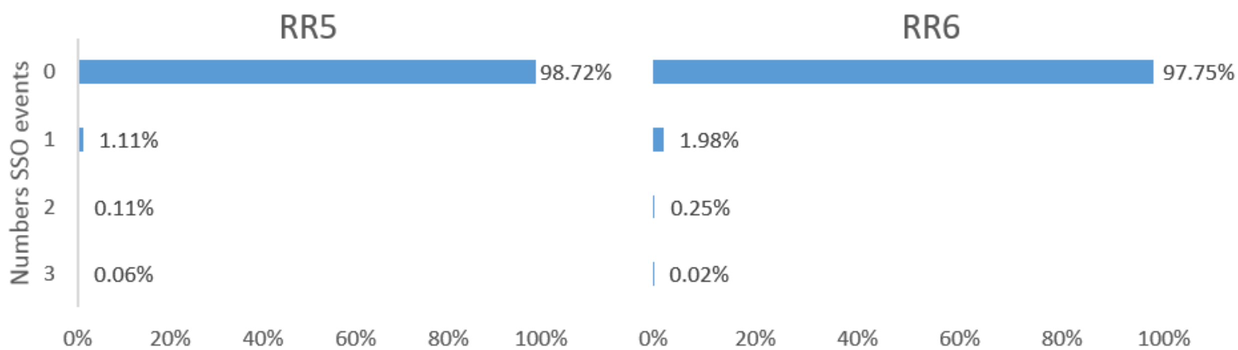


Figure 13. Percent of Employees Experiencing Multiple SSO Events for Two Railroads

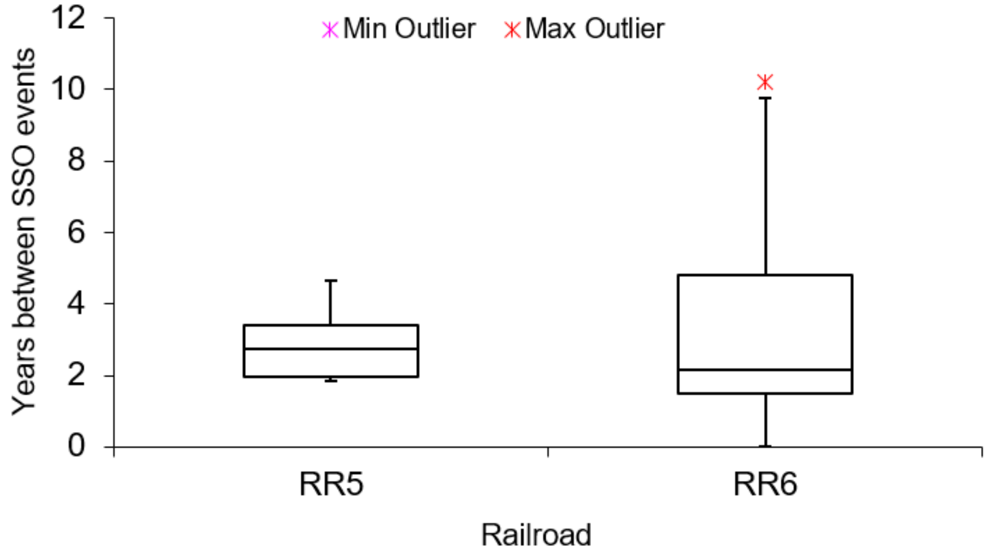


Figure 14. Time Between SSO Events for Employees with Multiple SSO Events

4.3 Putting SSO Events in Context of the System as a Whole

Although stop signal overruns are of particular concern to the railroads and FRA, they are not the only signal related events that contribute to unsafe events. Signal system failures on the wayside or in the cab also occur, as do failures to detect problems with grade crossing warning devices. Figure 15 shows the annual frequency with which different kinds of signal failures occur at one railroad for 1 year. SSO events represent the smallest percentage (0.04%) of signal related problems. Grade crossing related signal failures represent the biggest problem (33%) followed by a category referred to as "other" (33%) and track circuit failures which represent 26 percent of the total. Wayside signal failures represent 3.4 percent of the failures followed by cab signal failures which represent 2 percent of the failures. So, SSO events represent a tiny fraction of the failures that take place involving the signal system. Data from more railroads is needed to determine if this finding applies across the industry.

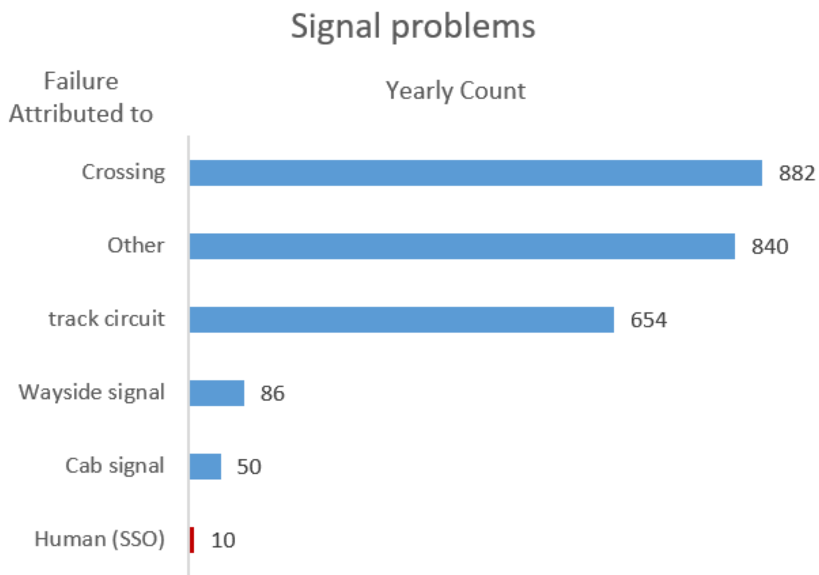


Figure 15. Frequency of Signal Problems by Type

In our first study that consisted of examining why trains pass stop signals, we identified the number of stop signals that occurred on one railroad (Safar et al., 2015). Based on their data we estimated that the probability of a SSO varied between 1/10,000 (10^{-5}) and 1/100,000 (10^{-6}). Since this study was published, Gibson et al. (2015) reported that the probability of SSO in the United Kingdom is 1/25,000 (Mills et al., 2016). This data is consistent with our findings and suggest that SSOs are rare events. Mills et al. (2016) uses the method suggested by Nickandros and Toombs (2007) in which the number of SSO events is divided by the number of approaches to a stop signal. Their data collected from across the United Kingdom rail network indicated that 5 percent of signal approaches were at stop (Zhao, Y., 2016).

4.4 What Was the Impact of the FRA Regulation Requiring Certification of Locomotive Engineers?

Following the 1988 Chase Maryland accident, Congress required FRA to create a regulation certifying the locomotive engineer to perform their duties (National Transportation Safety Board, 1988). FRA put this regulation into effect at the beginning of 1992. What was the impact of this certification process on the occurrence of passing stop signals? How did this regulation change behavior? Figure 16 shows the SSO rate for one railroad before and after Title 49 Code of Regulations (CFR) Part 240 went into effect impacting how locomotive engineers are treated after a SSO. The data shows that the average annual SSO rate increased from 0.7 to 0.8. The differences between these two periods are not statistically significant. While this only includes data from a single railroad, we hypothesize that the regulation contributed to an increase in reporting for this railroad, compared to reporting prior to the regulation. More importantly, the impact of the regulation has not contributed to a decrease in trains passing stop signals for passenger railroads. Figure 12 also suggests that there has been no significant change in SSO occurrence for our sample of passenger railroads.

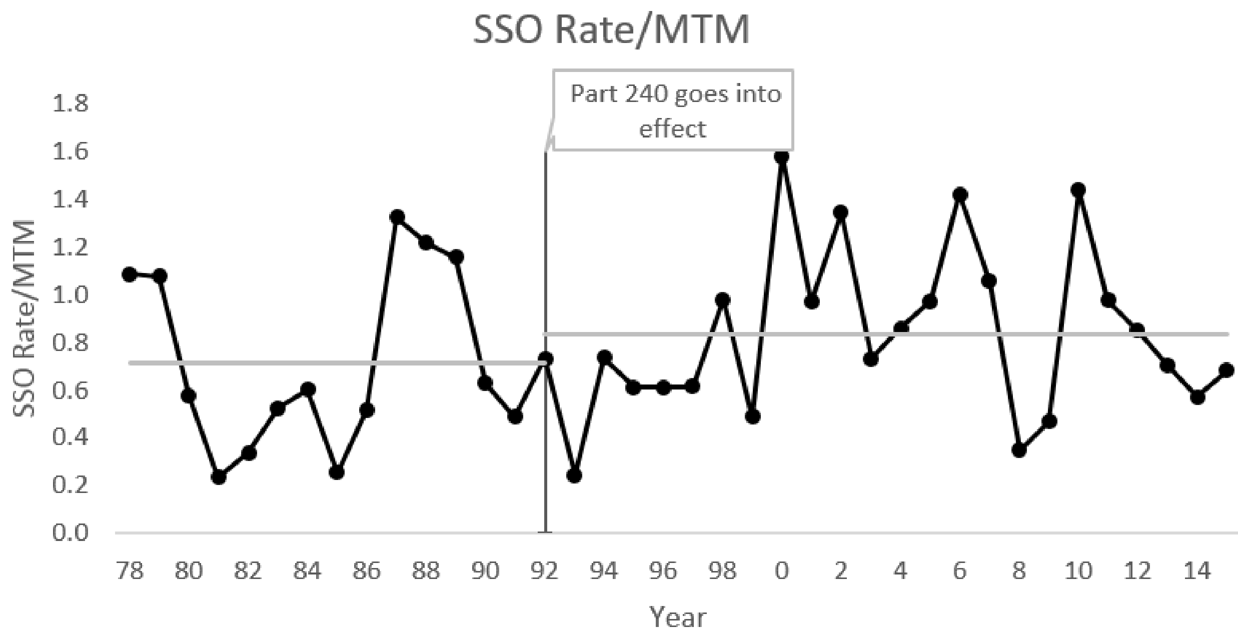


Figure 16. Comparison of SSO Rate Before and After Stop Signal Regulation Went Into Effect

4.5 What Does an Analysis of Where SSOs Occur Say About Contributing Factors?

Examining the SSO data from multiple passenger railroads suggests that the SSO events are distributed non-randomly across the system. Figure 17 and Figure 18 show the distribution of SSO events by location. Figure 17 shows the number of frequency of SSO events by their location for two railroads. Figure 18 shows a fictitious track chart illustrating the locations where SSO events typically occur.

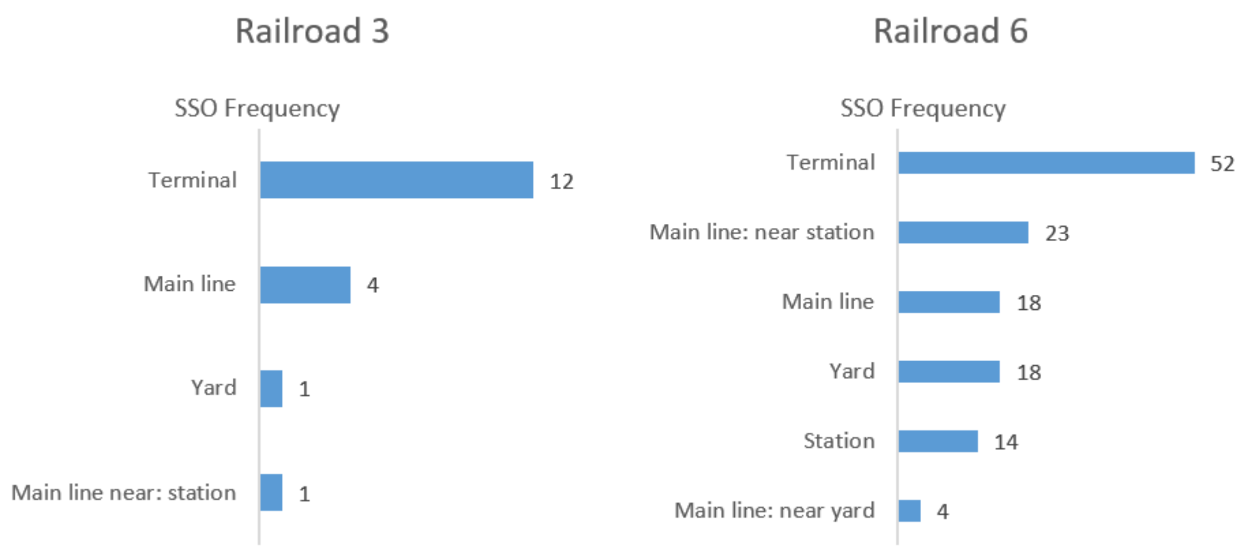


Figure 17. Distribution of SSO Events by Location

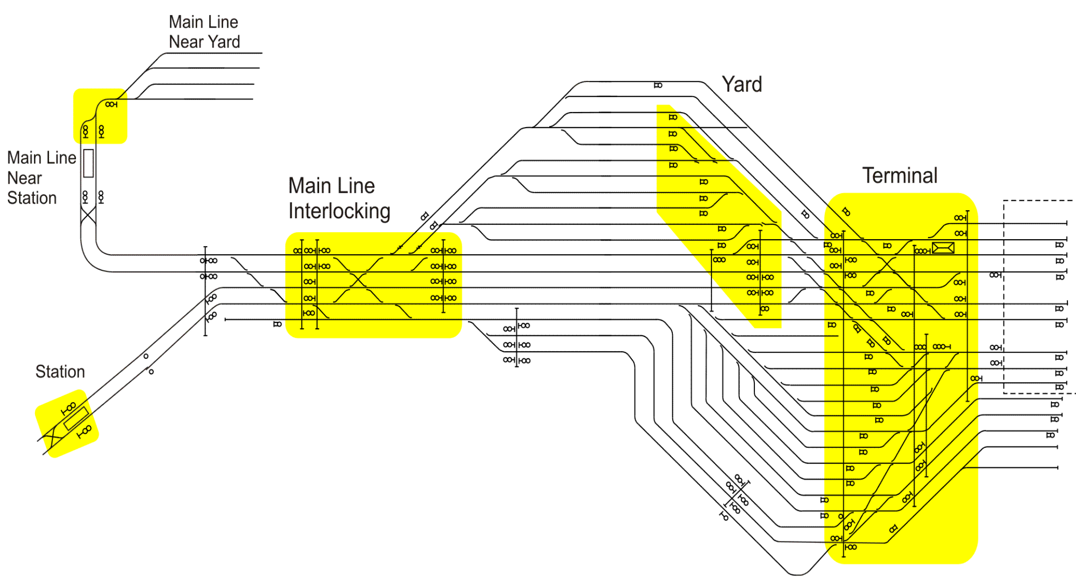


Figure 18. Track Chart Showing Distribution of SSO Events by Location

For the two railroads where we could identify the location of the event on a track chart, the highest number of events took place in the terminal environment. This location was followed by either locations on the main line near stations or entering or exiting an interlocking. The common element is a set of signals located in close proximity to each other. The locations may represent a bottleneck where many tracks converge as in the terminal environment or where multiple tracks converge along the main line. These locations provide a complex visual background that can make it challenging for the locomotive engineer to detect which signal controls their train movement. These challenges are consistent with eye tracking studies that find locomotive engineers glance more frequently at locations with six signals on gantry than locations with only two signals and verbal reports that multi-signal gantries or large numbers of signals close together increase the difficulty of identifying the correct signal (Luke et al., 2006). In this environment, locomotive engineers reported being more likely to look past the current signal to the next signal.

4.6 Relationship Between SSO Events and SSO Related Accidents

Given that a small but important class of accidents involve passing stop signals, what can we say about the relationship between passing stop signals as a precursor to these accidents? Figure 19 shows the relationship between the SSO rate and accident rate for the six passenger railroads in our sample. In examining the relationship between the SSO rate and accident rate, we observed no relationship between the SSO rate and accident rate attributed to passing stop signals. The correlation between the yearly SSO rate and yearly accidents was 0.09. So SSO events may be a precursor to SSO related accidents, but we cannot predict a SSO related accident on the basis of how many SSO events a railroad experiences.

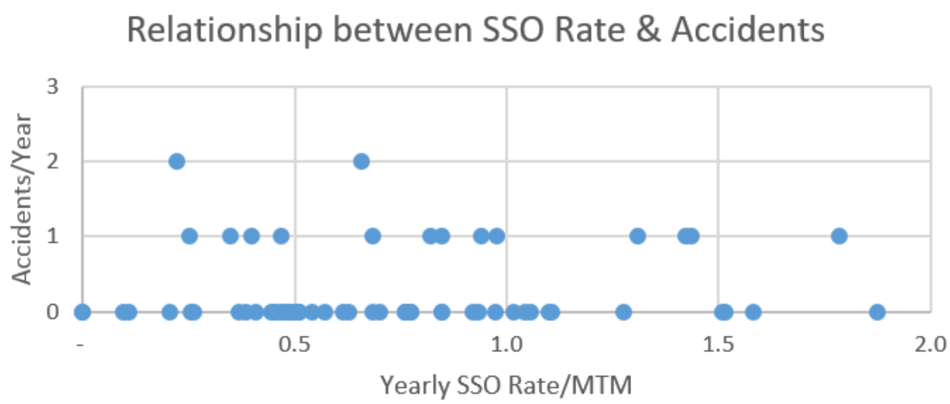


Figure 19. Relationship Between Yearly SSO Rate and SSO Related Accidents

While the data we collected suggested that SSO rate does not predict accident rates, three of the railroads (Railroad 6, 2, and 1 as shown in Figure 20) in the group we studied account for 75 percent of SSO related accidents over the 10-year period for 2006–2015. From a risk perspective, assisting these three railroads in reducing stop signal overruns would significantly reduce the overall risk of these accidents.

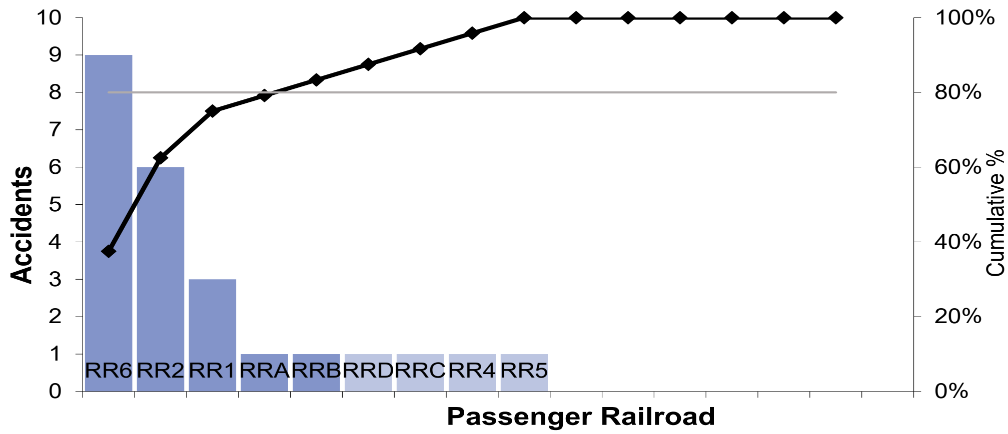


Figure 20. Three Railroads in Sample Account for 75 Percent of Accidents Over 10-Year Period

5. Qualitative Findings: Factors Contributing to Stop Signal Overrun

In investigating why trains pass stop signals, we examined how the railroad system produced this unwanted behavior. The work of Rasmussen (1997) and Leveson (2011) informed our thinking in exploring the contributing factors. Rasmussen and Leveson propose that we understand how stop signal related accidents occur by taking a systems view. In a systems view, safety is an emergent property of the system. Safety arises from the multitude of interactions of the system. Likewise, unsafe conditions and behavior also emerge from the interdependencies and interactions between different components within the system. One of the implications of systems thinking is that an unsafe event, like a stop signal overrun, may not always be explained by the chain of events. Conditions and interactions can combine in unexpected ways to produce stop signal overruns or can emerge from normal behavior. The coupling or interdependency between different factors that combine in unexpected ways to create stop signal overruns is frequently hidden from view when explaining unsafe events through the lens of looking at the chain of events. When examining how a train passed a stop signal, it is essential to identify the context in which the event took place.

This context is shaped by the activity of railroad personnel at different levels inside and outside the organization, the technology used and the environment in which the system operates.

Figure **21** shows the layers within the system that have a role in controlling safety. The left column identifies five layers. The right-hand column represents factors within each layer that we identified. Stop signal overruns result from one or more interactions of different factors within and between the different layers. This section describes how each of the factors can contribute to stop signal overruns and how they interact with other factors to produce stop signal overruns.

Figure 22 shows a different view of the railroad system involved in producing stop signal overruns. The figure shows a portion of the safety control structure for the elements directly involved with the movement of trains. The solid black arrows show what is being controlled (Leveson, 2011). The solid light green arrows show the feedback between elements. A bi-directional arrow indicates that the control or feedback goes in both directions. In analyzing the safety control structure, the goal is to identify where the safety controls or feedback were inadequately enforced (e.g., no hazard was identified), controls were inadequately executed (e.g., a time lag in execution), or inadequate or missing feedback (e.g., a communication failure) (Leveson, 2004).

In the current study, we focus on identifying the contributing factors at each of the five levels. The remainder of this section discusses what we learned from our interviews, observations and responses to the questionnaire. In a future study we can identify the flaws in the existing safety control structure associated with passing stop signals.

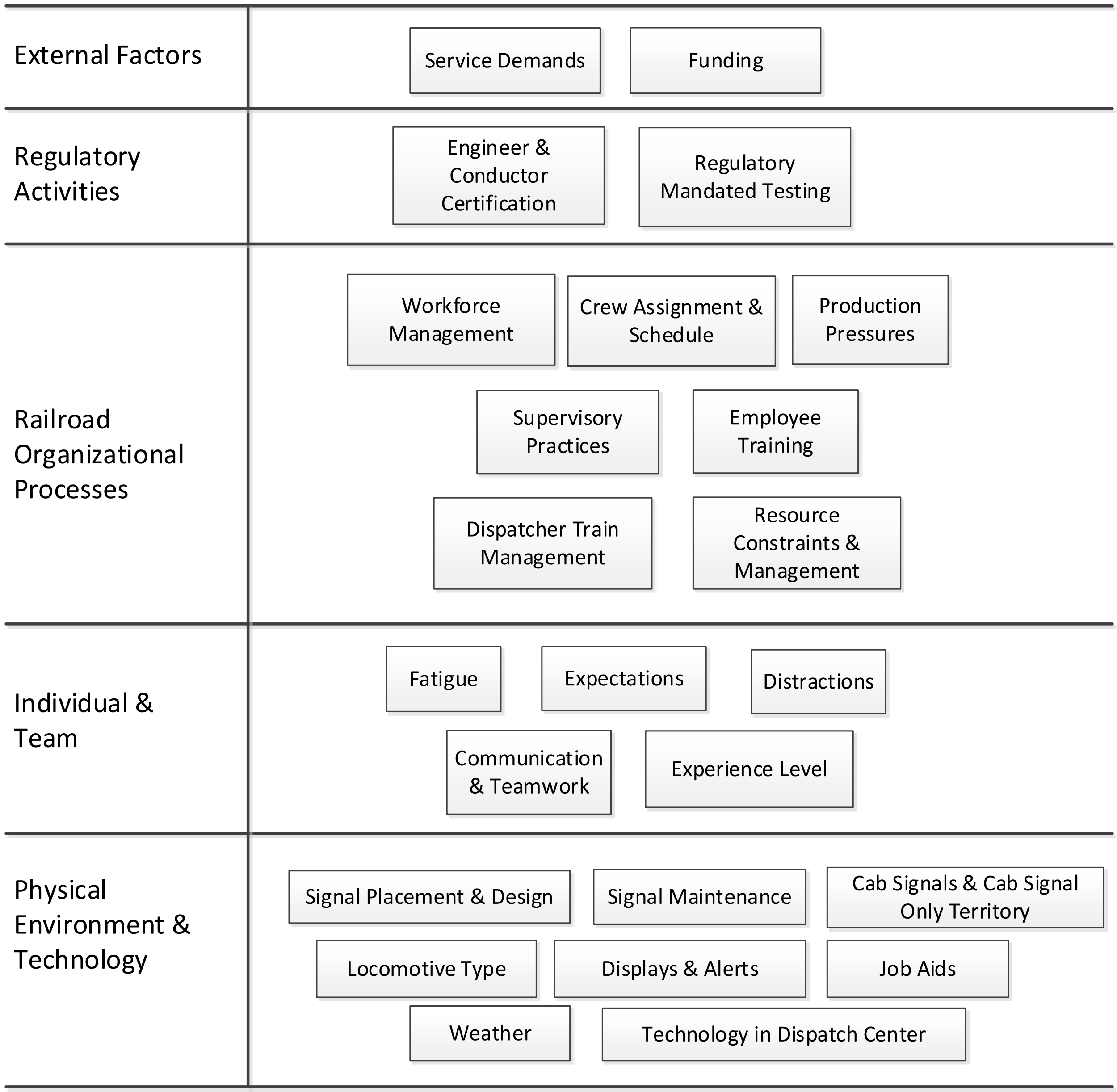


Figure 21. Contributing Factors to Stop Signal Overruns

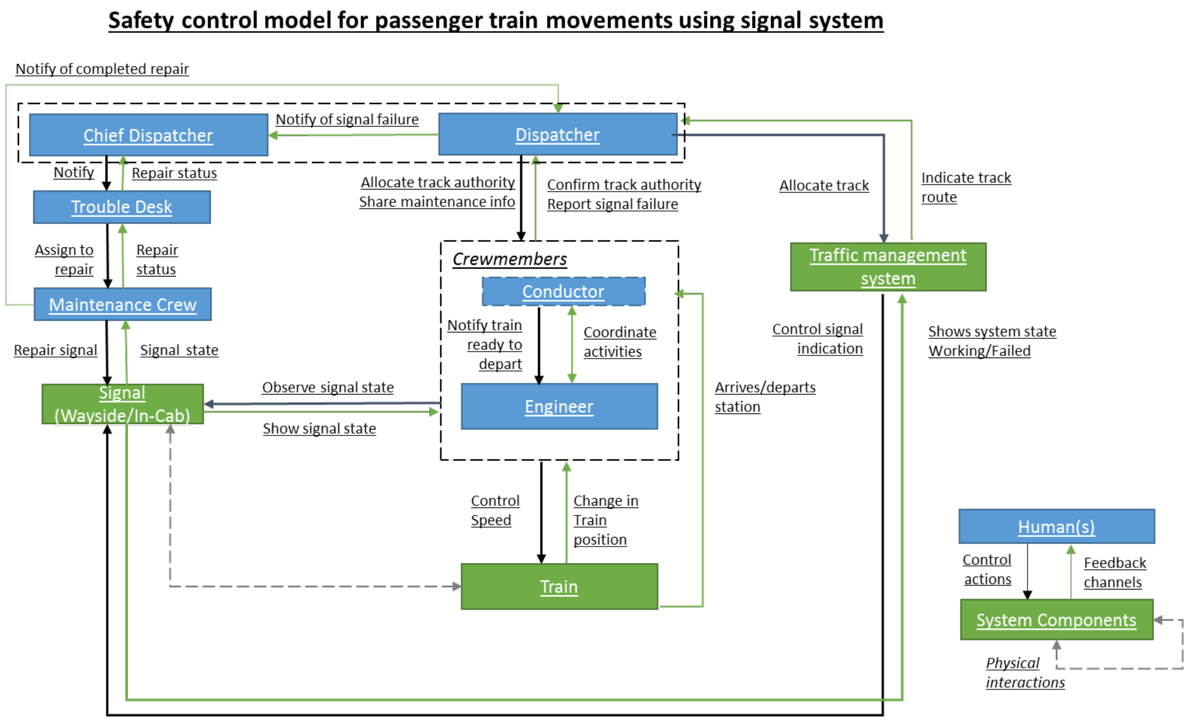


Figure 22. Safety Control Model for Passenger Trains Using a Signal System

Table 6 shows the distribution of the contributing factors that came up in the interviews when talking about problems that contribute to passing stop signals. One column shows the percentage of times a comment addressed one of the five categories of contributing factors. The other column shows the frequency counts of the observation by category. The contributing factors were evenly spread among three categories: technology and environment, individual and team factors, and railroad organizational processes accounting for 96 percent of the comments. Regulator and external factors accounted for only four percent of the comments we received. Appendix C compares the frequency and percentage in which the contributing factors were identified.

Table 6. Contributing Factors Associated with SSOs

Contributing Factors	Percent	Count	
Technology & Environment	33%	272	
Individual and Team Behavior	33%	271	
Railroad Organizational Processes	30%	245	
Regulatory Activities	2%	14	
External Factors	2%	14	
Total	100%	816	

5.1 Environment and Technology

In this section, we discuss attributes of the physical environment and technology used by the crew that can impair the train crew's ability to locate the signal or identifying its aspect.

The physical environment can challenge the crew in different ways. In the terminal, the train crew is challenged by the complexity of the environment, inconsistent and ambiguously placed signals, and platforms that are too short for today's increasingly longer trains. On the mainline, snow, ice and leaves make train handling, and the ability to stop the train in time, difficult. Snow and glare can also inhibit the ability of the engineer to correctly locate and identify the signal aspect. Signal maintenance also plays an important factor in the terminal and the mainline.

Technology, including the locomotive or control cab and cab configuration, may interact with signal placement to create conditions that can lead to stop signal overruns. Cab signals add to complexity and may create conditions for SSOs when they fail or where cab signals are inactive. Conversely, we must also consider how cab signal only territory (territory where wayside home signals are not in use and engineers operate based on in-cab signal indication only) may create conditions that might lead to stop signal overruns.

The following sections describe our findings and suggest mitigations to reduce SSOs.

5.1.1 Signal Placement and Design

Poor signal placement, particularly in the terminal, was one of the most discussed contributors to stop signal overruns during interviews with engineers. This is in large part due to complexity and evolving nature of the terminal environments we visited. Service demands continue to grow, however, available real estate to accommodate these demands is not always readily available. Over time, these constraints create a complex web of tracks within the terminal that can create routes that cross several different tracks. As the number of tracks and crossovers increase, the need for additional signals do as well. Signal placement to accommodate intersecting tracks is dictated by the track layout, safety concerns, and the need to maximize throughput. As a result, signals may be placed in non-optimal locations including around curves and behind retaining walls. Additionally, because tracks (and, therefore, signals) may be in close proximity, signals may be ambiguous as to which track they govern. Signals in close proximity to tracks also create opportunities for maintenance vehicles carrying equipment or supplies to knock the signals out of position. Finally, as service demands grow, train car lengths increase as well resulting in trains exceeding platform size in some locations.

In speaking with employees and observing signals located in the terminal and on the mainline, we observed multiple examples of poorly placed signals which create traps for the train crew. Some signal placement issues were unique to a specific territory while others were common to terminal stations at multiple railroads. A railroad's reliance on the engineer's memorizing signal locations works well most of the time, but is subject to cognitive limitations discussed in Section 5.3.2. Optimizing signal placement is a much more effective way to mitigate stop signal overruns than relying on human memory. Signal placement contributes to stop signal overruns in the following ways.

Contributors to SSO

Signal Placement at Platforms—Platforms are too Short

Signals at platforms in the terminal present two challenges that interact to create additional complexity. Signals at platforms in the terminal may be placed in inconsistent and problematic locations. In one terminal we observed signals located too close to the end of the platform, given the length of the train. Train lengths that were too long for the platform to accommodate was a common problem across several of the railroads in this study. When the train arrived at the station platform the signal was located behind the cab and out of the engineer's line of sight. In the same terminal we observed other signals at platforms located too far out from the platform (and again out of the engineer's immediate line of sight). These types of inconsistencies increase the complexity of operating within the terminal because the engineer must remember whether the signal is behind the locomotive cab (which is out of view when looking forward) or several car lengths ahead (and therefore out of view).

Some platforms lacked markings to help the locomotive engineers decide where to stop their train at the platform according to their train length. This is significant because the stopping location of an incoming train determines if the signal is visible to the engineer. Some engineers use adjacent trains as a cue for where to stop the train, or have even created their own signal markings with chalk or inanimate objects. Placing signs (according to train lengths) at station platforms would enable the engineer to quickly determine where to stop the train given different car lengths. If the previous engineer stops his train too short at a platform, the incoming engineer is at greater risk for a stop signal overrun because the signal may not be clearly visible. Especially given the inconsistency of signal placement at stations, an engineer might 'look through' to the next signal, thinking it was the first signal.

Engineers pointed out that stop signal overruns are more likely to occur when a secondary task arises that can distract them from remembering that the signal is behind them. One engineer described his stop signal overrun as such:

> "Was a 10 car train on track 5, which is very tight. There's a sign that says the train must stop here. If the engineer that brings that train in doesn't pull it in far enough, to the sign, then the signal is behind the cab going the other direction. The engineer who brought the train in didn't bring it in far enough, so the signal was behind me. The train also shouldn't have been routed to this platform, there are other tracks that can hold a 10 car train easily. I had to open my window and stick my head down to look at the signal. I see a terminal proceed. I look forward and see my switches are lined for me. Now, trainmen shows up and has a problem with the doors. Being a mechanical foreman, I get out of the seat and help her… fix everything. Now we're running late. When you leave late, it's a big deal. So I get two to go from the conductor and left. Forgot to stick my head out the window again to check the signal, to see if it had turned. In those couple of minutes it had turned from terminal proceed to stop."

This example illustrates how stop signal overruns are caused due to the interaction of multiple factors. In this case, in addition to time pressure and poor dispatcher train management (discussed in Section 5.4), the factors that created the condition for the stop signal overrun was a train being routed to a platform that was too short, as well as a secondary task (fixing the doors) distracting the engineer from remembering that the signal was behind the cab. If the signal had been clearly visible from within the cab he may have seen that the signal had dropped from terminal proceed to stop.

Signals Located Around Curves

Signals that are placed around curves shorten the advanced viewing time required by engineers to respond to the signal. We observed signals around curves most frequently in the terminal, where operating rules require the engineer to be able to stop with half the visual range of the signal. When a signal is placed directly after a curve the engineer may need to travel at speeds lower than the maximum allowable speed to safely stop the train when the signal is located around a curve. However, engineers are often under time pressure (discussed in Section 5.4.1) and may be weary to reduce the locomotive speed especially if they expect the signal to be permissive (we will discuss the impact of expectations in depth in Section 5.3.3). If the signal is unexpectedly at stop the engineer may overrun the stop signal.

We also observed and heard from engineers about signals around curves on the mainline, where maximum allowable speeds are greater than within the terminal. In these cases, signals around curves can be especially dangerous because at greater speeds the train will take longer to stop than at the restricted speeds found in the terminal. Time pressure, engineer expectations, and/or lapses in memory can all interact to create a higher probability for a stop signal overrun.

Signals Imbedded in Walls

Similar to signals located around curves, signals imbedded in walls shorten the advance view of the signal required by engineers to respond to the signal. This is an issue inside the terminal. From our observations, we found that many of the signals imbedded in walls also tended to be located around curves, which can make the engineer's task of viewing, interpreting and responding to the signal within the allotted time even harder.

Closely Spaced, Inconsistently, or Ambiguously Placed Signals

Closely spaced signals create a challenge to the engineer because they can result in the engineer looking past the first signal towards the second signal. The likelihood of 'looking through' to the next signal is greater when the closer signal is obscured (such as imbedded in a wall) or placed in a non-standard (inconsistent) location so that it is difficult to quickly detect when scanning out the window. This close proximity between signals can result in a stop signal overrun when the first signal is red and the second signal is green.

Signals that are inconsistently placed also add complexity. For example, some signals along the route were located on the left of the locomotive despite the rest of the signals being located on the right. We also saw an instance of a signal in a terminal located after the switch it protects. In that situation, the engineer could run through a switch, but stop prior to the signal. At one railroad, a particularly problematic signal was located equidistant between two closely spaced tracks, causing engineers to become confused as to which signal governed the track over which they were operating. In large complex terminals with many tracks, these types of inconsistent and ambiguously placed signals make the engineer's job of deciding which signal belongs to their track harder. Relying on engineer knowledge of where each and every signal on their route is located is one of the least effective strategies for preventing stop signal overruns. Particularly in the case of engineers on the extra list who operate over different territory each day. Placing signals in consistent locations next to the track helps engineers to better anticipate where to look for signals as they operate. Inconsistent and ambiguously placed signals are more liable to be "looked through" to the next signal, which increases the potential for a stop signal overrun.

Signal Design

Signal design was also cited as a contributor to stop signal overruns. Single aspect signals (signals with only one bulb) are more difficult to locate than signals with multiple aspects because lit bulbs stand out in conditions of low light and visibility. Dwarf signals (particularly single aspect) may also be difficult for locomotive engineers to locate in the terminal, yard and on the mainline because of how low to the ground they are. Dwarf signals may not be as visible to the locomotive engineer for various reasons, including cab design (long hood forward) and weather (snow accumulation and glare). Curves, walls, and other factors mentioned above that make signal detection difficult are exacerbated for dwarf signals. Dwarf signals may also be more liable to be "looked through" when other signals on the route are high mast because the engineer may be looking for a high mast signal (we discuss expectations in depth in Section 5.3.3).

Recommended Mitigations

Generally, the best way to reduce signal sighting hazards due to signal placement is to design the signal system in a way that takes into account human performance considerations. Placing signals so that engineers can easily locate their intended signals and have ample viewing time prior to approaching the signal while operating at track speed will minimize the potential for SSOs. Australia's standard setting body recommends that designers provide engineers with 6 seconds to read the signal (Naweed and Aitken, 2014; Australian Rail Track Corporation, Ltd, 2006). This time can be interrupted by 20 percent of the sighting distance except in the last 50 meters. The American Railway Engineering and Maintenance-of-Way Association (AREMA) has no standard that addresses visibility and FRA regulations (49 CFR Part 236) address how fast the train can move as it approaches a stop signal, but not whether the signal is actually visible. When traveling under a restricting signal, the engineer must be able to stop with half the range of vision, but not exceed 20 mph.

However, railroads are often unable to make significant changes to the physical layout of their territory or are reluctant to make changes due to the high cost associated with moving signals. While not all recommendations may be feasible due to cost and/or physical infrastructure limitations, we believe that implementing them to the fullest extent possible will mitigate stop signal overruns resulting from poor signal placement. Recommended mitigations include:

- Placing signals at train platforms in consistent locations, within sight distance in front of the longest train that the platform can accommodate. (Related: Dispatchers should avoid routing trains on platforms that cannot accommodate them. Also, discussed in Section 5.3.3). Positioning signals in front of the train. A signal located behind the cab is not visible to the engineer and may be missed.
- When changing crews, the departing train crew should verify that the signal is visible in front of the train for the next crew to depart the platform. If the signal is not visible, the

departing crew should communicate to the new crew that the signal position is located behind the engineer.

- When possible, extend the length of the platform to accommodate the longest train lengths expected. Where this is not possible, recognize that when the signal is located behind the engineer it can contribute to a stop signal overrun.
- Placing clearly visible signs at every station platform showing where to stop the train for different train lengths. This will minimize the situation, described above, where the train has not been pulled up far enough resulting in the signal being behind the engineer at the other end of the train. Establish a schedule to clean and maintain these signs.
- Re-examining signals that are known to be problematic and provide visual cues in a prominently visible location ahead of the signal to indicate that there is a signal ahead—analogous to road signs indicating that there is a stop light or stop sign ahead.
- Placing retroreflective signal markers on dwarf signals to make them more visible to train crews and maintenance workers. Place retroreflective signal borders on signal mast and bridge to make signals easier to locate. (See Figure 23, below).
- Replacing signal bulbs with LED bulbs (where appropriate) to make them easier to see. Before implementing LEDs, measure the luminance values of the LEDs and other non-LEDs to determine whether they will be too bright or attract attention to the wrong signal.
- For signals imbedded in walls or located around curves, or for closely spaced signals:
  - Provide visual cues in a prominently visible location ahead of the signal to indicate that there is a signal ahead—analogous to road signs indicating that there is a stop light or stop sign ahead
  - Consider coupling the signals electronically so that the signal prior as well as the problematic signal are always both red or are always more favorable than red. (This is something experienced dispatchers typically do on their own, but automating it within the system is better)
- When designing or re-designing terminals, yard, or tracks on the mainline conduct signal sighting tests and invite all stakeholders, particularly engineers and conductors into the design process to facilitate optimal signal placement.
- Provide guidance for signal designers that specifies adequate time for engineer to see and respond to the signal and the level of signal obstruction that is tolerable.

For signal mast & bridges: Retroreflective signal border

For dwarf signals: Retroreflective signal marker

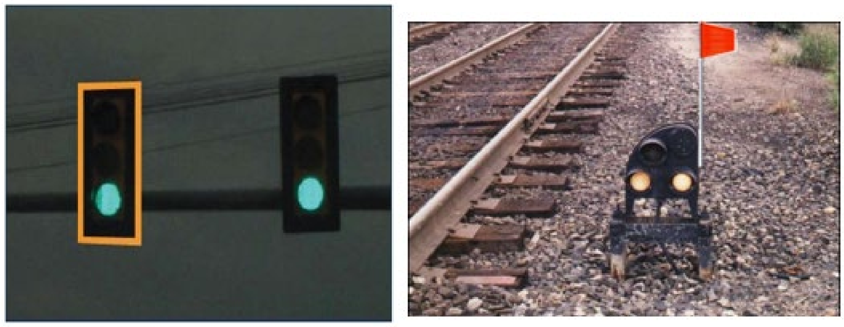


Figure 23. Retroreflective Border and Marker on Signals

5.1.2 Weather

Contributors to SSO

Weather and seasonal occurrences, including sun, snow, ice and leaves, contribute to stop signal overruns. When the sun is behind the signal it can be difficult to make out the signal aspect because sunlight can blind the train crew. In the other direction, when the sun is behind the engineer, the sun can "wash out" the signal aspect and even make it appear as though it is something other than stop. One engineer gave the following example:

> "On our territory, the sun might make it appear as though a yellow bulb is illuminated, despite it not being illuminated. So you might see restricting. On [other territory I've operated over] the sun could illuminate the signal to make it look like stop."

In these situations, engineers told us they would slowly creep up to the signal so that they could make out the signal aspect when the signal was in the train's shadow. Engineers might also call the dispatcher to ask if the signal was permissive. Both these strategies have implications on the train schedule, as in each case the train would have to come to a near, or complete, stop.

During the fall, engineers cited fallen leaves as a contributor to stop signal overruns when leaves on the track cause the train wheels to slip and reduce braking effectiveness. If the engineer comes up on a signal and was not prepared for leaves on the track, this may make the train more prone to slipping along the tracks and make it difficult to come to a stop in time.

In the winter months, heavy snow and ice create conditions where signal sighting and proper train handling becomes difficult. Snow and ice can accumulate on the wheels and in the brakes and make it difficult for the engineer to stop the train. Large amounts of snow can also cover the tracks and make it difficult for engineers to make out switch position as well as accumulate over dwarf signals and make it difficult to locate them. Engineers at one railroad mentioned an example of a particularly snowy winter where there was so much snow that the track department had a difficult time finding the dwarf signals in order to shovel them out. At one railroad, the track department put flags on dwarf signals to make them easy to locate despite heavy snow accumulation.

In the case of ice and leaves on tracks, engineers told us proper and cautious train handling was extremely important. One experienced engineer said their strategy is to “ride with the brake on” in snow conditions, otherwise brakes start to stick. That same engineer said that in extreme conditions they will operate at 40 mph, rather than the normal speed of 70 mph. Another engineer said that operating the train slowly in cold weather (for example into the terminal) made it even more difficult to stop because it did not allow for the brakes to heat up. An experienced engineer responded that in cases like those he would not use brakes, but would put the train into emergency and slide into the terminal. This, they mentioned, was an expert strategy and not necessarily something an inexperienced engineer would know to do.

At one railroad, engineers brought up equipment type as a factor when it comes to ice and snow conditions. Passenger trains with single level coaches were the most challenging in icy conditions whereas bi-level coaches braked better. Equipment maintenance was also a factor. Specifically, brake shoes may not always be replaced as often as necessary to stay functioning in the snow and ice. We heard several firsthand accounts of instances where engineers operated their trains during snow and ice conditions despite knowing that the brakes were not in good working condition.

Recommended Mitigations

Stop signal overruns due to wheel slip from ice and leaves on the track are not always avoidable (and therefore not always de-certifiable events). One manager of rules and training told us that at their railroad they will obtain the event recorder downloads and look at the engineer’s train handling. If the engineer ‘did everything right’ they will not be decertified. As much as weather is out of the railroad’s control, there are things the railroad can do to mitigate stop signal overruns due to inclement weather. These include ensuring good signal visibility, proper and functioning equipment, adequate training for sub-optimal weather conditions, and allowing extra time in the schedule for engineers to operate at slower than normal speeds. Specifically, we offer the following recommendations:

- Provide adequate training on safe train handling in inclement weather.
- As discussed in Section 5.1.1 (above), place retroreflective signal markers (flags) on dwarf signals so they can be easily located in heavy snow and place retroreflective signal borders on the signal mast and bridge to make them easier to see in glare. (See figures above).
- FRA regulations provide minimum standards for equipment maintenance, railroads should seek to exceed these standards when possible.

5.1.3 Signal Maintenance

Contributors to SSO

Fallen and Dark Signals

Fallen signals are rare events. When a signal falls (e.g., because it was hit by moving equipment), the onus is on the engineer to know that a signal was there, treat it as a stop signal and call the dispatcher for instructions and to report the signal as down. Fallen signals may not always be obvious to the engineer. We believe fallen signals present a greater risk for SSOs in the terminal than on the mainline. This is because the terminal environment has many routes with dwarf signals that can be damaged by moving equipment, with many signals along each route. Engineers may see some routes frequently and some infrequently. Consider the following scenario. A locomotive engineer who operates over the same route each day in the terminal. Due to track maintenance, the dispatcher routes this engineer on a track that they have not seen in a long time and exposes the engineer to a set of signals with which they are no longer familiar. In this situation, a fallen signal may go undetected and could result in a SSO.

Dark Signals

Similarly difficult to detect are dark signals. Dark signals are signals in which the bulbs have burned out. In this instance, the engineer must proceed similarly to a fallen signal: treat it as a stop signal, call the dispatcher and await instructions. In the case of single aspect signals inside the (typically dark) terminal, if the only bulb is burned out, detecting the dark signal may be difficult, for similar reasons as described above. Putting the onus on the engineer to remember the location of every signal, even when they are not visible, may not be reasonable.

Dirty Signals

We also heard multiple instances of signals being extremely dirty, particularly in the terminal. One engineer mentioned a bee's nest inside the signal. Anything that inhibits the engineer from clearly viewing the signal or signal aspect can contribute to SSOs.

Recommended Mitigations

Signal maintenance is often completed on a pre-assigned schedule. In addition to ensuring that signals are maintained often, we recommend the following to mitigate SSOs due to fallen, dark and dirty signals:

- Identify conditions that cause signals to come out of position (e.g., fallen signal) and find ways to prevent these conditions from occurring. If moving equipment knocks signals out of position, provide training or methods of moving equipment that minimize the opportunity for these opportunities.
- Notify the dispatcher and signal department that a signal has fallen or gone dark. Dispatchers should immediately communicate to train crews when a signal is down, malfunctioning, or where a bulb burnt out.
    - One option is to place sensors on the signals to alert dispatchers and the signal department that a signal has been moved out of position (e.g., knocked down).
- Consider replacing signal bulbs with LEDs where appropriate, as LED bulbs last longer. This will reduce the likelihood of bulb burnouts.
    - LEDs allow for color-changing bulbs. Use of color changing bulbs should be further studied as possible mitigation strategies for missing signals. For example, consider the use of redundant color lights on signals with multiple aspects (e.g., use a redundant red signal such that the stop signal would show two red lights). This will mitigate the concern for SSOs resulting from burnt out incandescent bulbs.

- Place a visual warning in the terminal for engineers to indicate when signals have fallen or been knocked over so train crews can see where signals should be. Given the complex nature of many terminals and the difficulty of detecting the absence of a signal, providing information of where signals should be can alert train crews to a missing signal.
    - One relatively inexpensive option could be to use a mercury switch in the signal post to indicate it has fallen or is out of position.
    - Another option may be to paint the signal post a color that will ensure its visibility on the ground if it is knocked down.
- Some signal locations may require more frequent maintenance than others. Modify the maintenance schedule to reflect this need. For example, signals need to be cleaned more often in terminals where diesel locomotives operate compared electrically operated trains. Signals may need to be maintained more frequently in locations where heavy equipment traverses frequently, as these can knock signals out of place.

5.1.4 Cab Signals and Cab Signal Only Territory

Cab signals are an important source of information for engineers operating on the mainline. While wayside signals provide information about the state of the upcoming block (e.g., the track section the train will enter), cab signals can update in real time to give the engineer information about the state of track ahead of him, even within the same block and communicate speed restrictions to the engineer through a visual component (display) and an auditory component (alert). Cab signals, often in conjunction with speed enforcement technology like Automatic Train Control, act as a safety net for engineers on the mainline because they can apply a penalty brake application (up to the restricted speed limit) to prevent speeding if the engineer does not comply with the speed restriction.

Most engineers we spoke with said cab signals are useful for avoiding SSOs and many said they feel more at ease operating over territory with cab signals. Some engineers said that they rely on cab signals especially during periods of inclement weather (when it may be difficult to locate or identify the signal).

However, while cab signals generally help the engineer by providing additional information, experienced engineers said they prefer operating over territory without cab signals because they feel more in control of their train. Cab signals also create complexity when they fail or during transitional periods when engineers go from operating with cab signals to no cab signals.

Contributors to SSO

Cab Signal Failure and Mode Transitions

When engineers do rely on cab signals, cab signal failure is a cause for concern. We heard varying reports of cab signal failure across railroads and employees. According to the C&S Department at one of the railroads we spoke with, in 1 year cab signals failed approximately 50 times. Engineers we spoke with stated that cab signal failures happen “a couple times per year, per engineer.” Another railroad employee said cab signal failure happens twice a day out of approximately 120 sets of equipment. When cab signals fail while enroute, it may not be immediately obvious to the engineer. The common way to know cab signals have failed is when wayside and cab signals are in conflict. In this case, engineers operate on the more restrictive indication and call the dispatcher to notify them of the failure. However, in situations where wayside signals are difficult to locate and/or identify (i.e., in bad weather, glare, and signals around curves) engineers told us that they often rely on cab signals. At one railroad, we heard of instances where engineers operated according to cab signals when wayside signals were dark. By operating rule, engineers treat dark signals as a stop signal. As dispatchers at this railroad rely on engineers to inform them of dark wayside signals, the dispatcher was unaware that the signals were dark until another train crew reported it.) In this case, cab signals were in working condition. However, if cab signals had also failed, a SSO, or worse, could have occurred.

Additionally, since cab signals are not always in use, engineers must be keenly aware of times of mode transitions, or times when cab signals shift from being in use to not being in use. These transitions occur when entering a terminal or yard, as well as along certain points in the territory. A SSO can occur if an engineer forgets he is operating within territory with no cab signals and expects to hear auditory alerts to know when he is being downgraded.

Another type of transition is from wayside and cab signal territory to cab signal only territory (no wayside signals). In cab signal only territory, engineers must rely on cab signals and do not have the added redundancy of wayside signals. This creates complexity particularly because, as engineers noted, it is not immediately evident when cab signals fail. Engineers told us that it can take up to two blocks to notice that cab signals have failed while operating in cab signal only territory. Employees we spoke with hypothesized that railroads will seek to remove wayside signals as they implement PTC and upgrade cab signal systems in order to reduce costs and increase throughput. This will result in increased cab signal only territory.

Recommended Mitigations

Cab signals are an important job aid for engineers on the mainline. Engineers rely on cab signals particularly when factors such as weather or signal placement make locating and identifying wayside signals difficult. We anticipate that the implementation of PTC and upgrades to signaling systems will lead to removal of wayside signals and, therefore, more cab signal only territory. Therefore, it is especially important for railroads to continue to invest in these systems. We offer the following recommendations for cab signals and cab signal only territory below and discuss implications of introducing PTC in Section 6.4:

- As technologies improve and become more cost effective there may be value in extending cab signals (and PTC) to both the terminal and yard, particularly because the majority of SSOs in passenger operations occur at speeds below 20 mph.
- Engineers are especially vulnerable to SSOs in sections of track without cab signals, such as the terminal, or in areas where cab signals have failed. Mode transitions from cab signal territory to non-cab signal territory, as well as cab signal failure should be clearly and immediately indicated to the locomotive engineer. Some railroads have mandated that the conductor must ride with the engineer in the cab if cab signals fail—railroads should track the impact this has to ensure no unintended consequences.

5.1.5 Displays and Alerts

Contributors to SSO

Displays As A Source of Distraction

Interviews with engineers indicated that displays and alerts (not associated with cab signals) in the cab contribute to distraction and SSOs. Engineers told us that some locomotive cab displays present non-safety critical alerts that can be disruptive. When triggered, these alerts may sound continuously despite being acknowledged by the engineer which can annoy and distract the engineer. Engineers reported that many of these non-safety critical alerts were intended for maintenance employees rather than for the train crew. Most engineers expressed a desire to permanently silence these non-safety critical alerts. When engineers were exposed to frequent non-safety critical alerts they attempted to tune them out, which can lead to missing safety critical alarms, if the alarms are similar.

Radio Volume and Static Inhibit Communication

Engineers described problems with static on radios that made it difficult to communicate with dispatchers or the conductor. At one railroad, in addition to the static engineers complained of radio volume being too high. Several engineers told us they would put stickers over the speaker to muffle the sound. One engineer said he used ear plugs because the high volume of the radio combined with the static was so distracting.

Recommended Mitigations

- Give the engineer the ability to control the display of non-safety critical alerts
- Allow engineers to acknowledge and silence alerts
- During times of high workload (e.g., in the terminal), show safety-critical alerts
- Display non-safety critical alerts during periods of low or moderate workload
- Minimize the number of non-safety related alerts displayed

5.1.6 Locomotive Type

Contributors to SSO

Historical frequency data for SSOs provided by the railroads did not specify equipment type. Therefore, we do not have quantitative data on relative frequency of SSOs based on locomotive type. However, discussions with railroad employees suggest that SSOs occur more frequently on electric locomotives, rather than diesel-electric locomotives, and in particular on newer models of electric locomotives. Because we lack quantitative data, we do not know whether these verbal reports by engineers are because more of these locomotive models exist within the fleet or because the locomotive design creates conditions for SSOs to occur. Interviews and observations at one railroad indicate that design differences may create conditions for different locomotive behavior to occur that may contribute to SSOs. We discuss these findings below.

Electric Locomotives

We have no quantitative data on how often SSOs occur with diesel-electric locomotives versus electric locomotives. However, according to discussions with employees at one railroad, none of the signal violations dating back 10 years occurred on diesel-electric locomotives. This is likely due to a combination of the following factors:

1. Engineers operate more cautiously with diesel-electric locomotives, particularly inside the terminal, because of concern of gapping and losing power.
2. Dispatchers were more likely to give diesel-electric locomotives clear routes in the terminal to avoid the risk of stopping at a location with no electrical contact and thus less likely to encounter a stop signal. Due to diesel-locomotives encountering fewer stop signals (in the terminal), the probability of a SSO was less likely.
3. The railroad operated more electric locomotives than diesel-electrics. Therefore, the exposure to stop signals was lower for diesel-electric locomotives.

Cab Configuration

In-cab configuration and train operation may also contribute to SSOs. At one railroad, the ergonomic design of certain models of new electric motive units (EMU) contributed to the potential for SSOs. In these cabs, the design of the workstations encourages engineers to sit back lower in their seat to see and operate the in-cab displays more easily. In this position, the engineer has a different view out the window than if he was sitting upright. When sitting back, it was more difficult to look out the window, since their displays partially blocked the view out the window. This design reduced their ability to see signals, especially the dwarf signals. Depending on how and where the PTC displays will be installed, these displays may also make it difficult for engineers in these cabs to see out the window. Engineers also said that display interfaces as well as the design of the controls in the EMUs were easier to operate than the diesel-electric locomotive. Some employees speculated that because operating the EMU was easier, engineers may be less vigilant or may take longer to respond to unexpected conditions.

Engineers mentioned that the spring-loaded throttles on older EMUs acted as a deterrent to SSOs. The spring-loaded throttle resulted in the engineer applying continuous pressure to the throttle. As one employee said, spring loaded throttles force engineers to "sit up straight and use both hands" while operating the locomotive." The need to sit up straight may make it easier to see out the window to locate signals (in contrast to the more reclined position in the newer EMUs) and the need to place continuous pressure on the throttle meant the engineer must remain at the control stand and cannot move around the cab or do other tasks (e.g., look through paperwork, etc.). Another advantage of the spring loaded throttle, according to railroad employees, was that the engineer can stop the train more quickly. With the spring loaded throttle the engineer only has to lift his hand from the throttle. In contrast, newer EMUs require the engineer to take the extra step of physically putting the train into emergency.

Recommended Mitigations

- Include locomotive type as a factor to be recorded and tracked when SSOs occur to understand the role that the cab type contributes to SSOs.

- Perform ergonomic analysis on cab configurations to assess the engineer's ability to look outside the window and at in-cab displays from a seated position. (A good time to do this is prior to purchasing new locomotives.)

5.1.7 Job Aids

Contributors to SSO

Railroads expect their train crews to be knowledgeable on the physical characteristics of the territory over which they operate. However, the ability for train crews to stay current is made difficult due to the dynamic nature of their work and environment. To keep engineers and conductors current, railroads provide them with job aids such as bulletin orders, track charts, and other paper based job aids that provide information on the state of the system. These job aides may be poorly designed to support the operators' needs for information.

Crew members are provided track charts that show the layout of the tracks, signals and switches, grade crossings and other relevant information. Many engineers we spoke with said the track charts that the railroads provide are out of date and lack important relevant information. These track charts are often not drawn to a scale, do not show curves in the rail, and may have incorrect signal information (i.e., placement of signal could be incorrect; could show a three signal aspect instead of a two signal aspect). Many engineers rely on hand drawn track charts rather than railroad issued track charts. The railroad issued track charts were created by the Communications and Signaling department for their use and were not intended to support the train crews. Engineers we spoke with either drew their own track charts, or used copies of hand drawn track charts, provided by the training department. These track charts are often updated over time and re-copied over. One engineer showed us a railroad issued copy he had been using, which was created 15 years earlier, which he updated by hand. The kind of information added to this chart included landmarks, speed limit changes, operating rule transition points, interlocking boundaries and compass location (e.g., north, south).

The track charts used by the engineers were not updated regularly to keep up with the changing physical characteristics of the territory. Of the four railroads for which we received information about the frequency with which they updated their track charts, two railroads said they updated their track charts annually while the other two railroads updated their track charts every 2 and 5 years respectively. Railroads do provide engineers with daily bulletin orders stating changes to the physical environment, but an engineer at one railroad lamented that the bulletin orders often contain the same information day after day, and it can be difficult to easily locate new information. For example, when a signal is moved, this information is included in the bulletin order that engineers receive. That information is included in every bulletin order until the track chart is updated to reflect the change. Since it can take months, if not years, for track charts to be updated, bulletin orders can become long and cumbersome to sift through for new information. At one railroad an engineer suggested highlighting any new information is included in the bulletin, so it would stand out as new. This information in the bulletin orders may be organized in a way that makes it difficult to find new information.

Recommended Mitigations

Railroads expect the train crew to be knowledgeable on the physical characteristics of the territory over which they operate. However, the ability for train crews to stay knowledgeable is compromised by the dynamic nature of the work and environment that take place regularly and the way that information is presented to the engineer. To help engineers stay current, we recommend the following mitigations:

- Provide an “engineer-centered” track chart to train crews that are updated regularly.
- Consider providing track charts and other paperwork to the crews in an electronic format.
    - This would reduce the amount of paperwork employees need to carry around with them and would enable them to quickly and easily download the latest (most up-to-date) track charts and bulletin orders.
    - Consider creating a customizable electronic version that allows the user to select or de-select the physical characteristics (e.g., signal type, milepost number, electrified track locations, etc.) they want to see according to preference.
    - Provide an ability for the user to annotate the electronically provided materials.
- Review the format of bulletin orders so that new information is easily identified and accessed.

5.2 Individual and Team Factors

In this section, we examine the cognitive processes that underlie individual and team performance in train operations. A primary aim is to summarize some of the fundamental characteristics and limitations of human cognition that create vulnerabilities for SSOs.

We begin by presenting a model of cognitive performance that provides a framework for understanding fundamental characteristics and limitations of human cognition that contribute to how train crews perceive and respond to signals. Next, we discuss how factors drawn from this model combine with other systemic factors associated with railroad operations to create conditions for SSOs to occur. This is followed by a discussion of team factors, including communication between conductors and locomotive engineers as well as communication between train crews and dispatchers, and how they contribute to SSOs. In each case, we present recommendations for possible mitigations that could be implemented to reduce SSOs.

5.2.1 Cognitive Factors Influencing Individual Performance

Figure **24** presents a simplified model of human cognitive processes adapted from a classic human engineering textbook (Wickens, Hollands, Banbury & Parasuraman, 2013). The model illustrates how information from the environment is processed to come up with assessments, make decisions and take actions. We use a simple automobile driving task to illustrate the model. We assume an experienced U.S. driver who possesses knowledge of driving, the rules of the road, and familiar routes based on training and experience (e.g., what the different signal light colors mean; the rules of traffic at four-way stop signs; the streets, signals and traffic patterns on the way from home to work.).

While the elements of the model are iterative and mutually interacting, in the simplest case one can start with cues in the environment (e.g., a traffic light) that trigger perception. Perception entails detecting and recognizing information in the environment. For example, detecting a green traffic signal and recognizing that it means you can go. Perception can sometimes trigger a direct and automatic response such as immediately applying a brake when seeing a traffic signal turn red in front of you. Other times the information may go into working memory where it is temporarily stored and combined with other information to generate a more general understanding of the situation. For example, when drivers come to an intersection with a four way stop, as they approach the intersection they will scan to determine whether there are cars approaching the intersection from other directions. They will assess the order in which the cars are reaching the stop in order to determine when it will be their turn to go. All this information is held and processed in working memory to assess the situation and select a response.

Past experience is stored in our long-term memory, which contains facts, memories of past events, and general knowledge of the world. In the current example, knowledge of rules of the road gained through training would be stored in long-term memory. Knowledge of traffic patterns and behavior of signals along familiar routes that is learned through experience is also stored in long-term memory. Knowledge from long term memory is used to generate expectations that can guide perception and action. For example, a driver might know from past experience that a particular traffic light stays yellow for a long period. When they see the light turn yellow they might decide to continue through the intersection rather than stop based on their expectations that they will have time to get through before the light turns red. Similarly, through experience they may learn the timing across a series of traffic lights and anticipate that the traffic light up ahead that is now red will turn green as they come to it.

Cognitive processing requires attention. Attention is a limited capacity resource that can act as a filter. One can direct attention toward one aspect of the environment, but this may be at the cost of attenuating other sources of input. For example, a driver might focus on reading highway exit signs and thus 'tune out' passenger conversations. The same cognitive processes can demand more or less attentional resources depending on the conditions. For example, straining to read highway signs through fog might require more attentional effort for perception than on a clear day, making it even more likely that the driver will 'tune out' passenger talk.

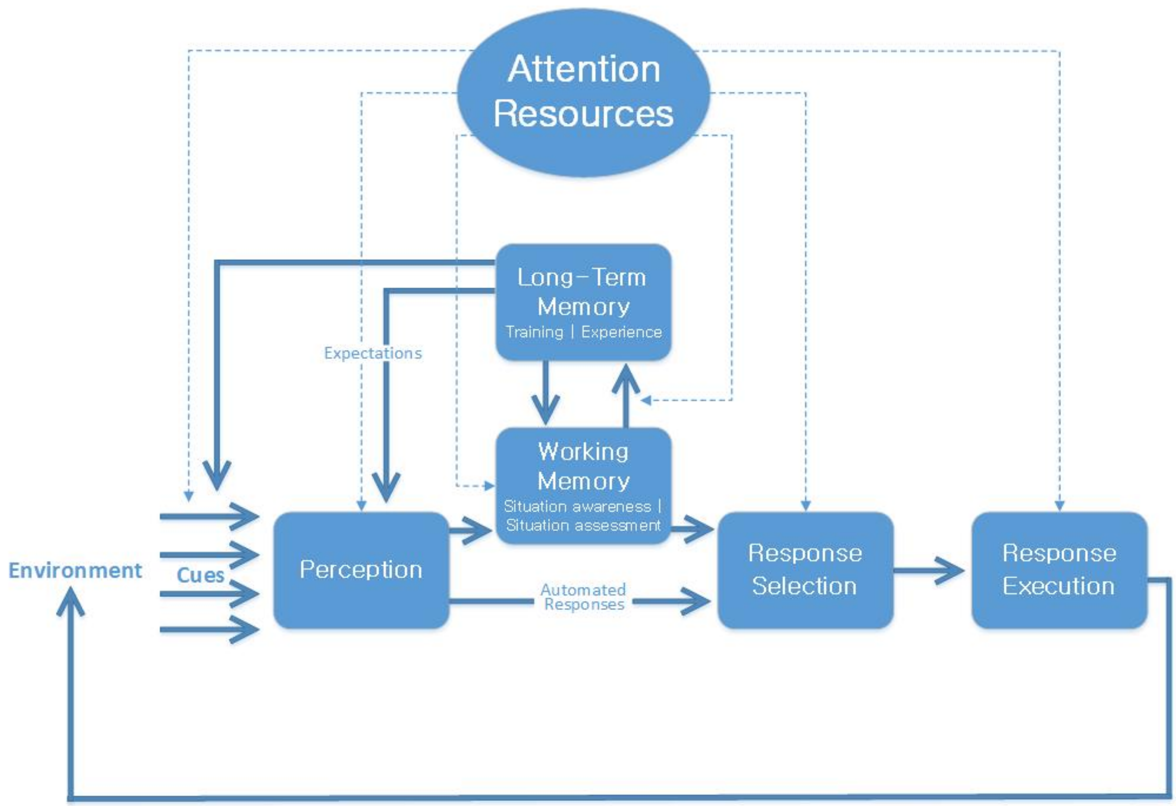


Figure 24 **A Simplified Model of Human Cognitive Processes**
(Adapted from Wickens, Hollands, Banbary & Parasuraman [2013]).

The model described in Figure **24** reflects some fundamental characteristics of human cognition that can contribute to SSOs. Most particularly:

- Information in long term memory is subject to *forgetting* over time
- Perception and understanding are driven by *expectations* resulting in potential for error if expectations are violated
- Cognitive processes are vulnerable to *distractions,* both from external events and ‘internal’ mind wandering.
- Information in working memory is subject to short-term memory lapses
- Frequent repetition can lead to *automated responses*

Information Learned in Training Will be Forgotten Over Time

People are subject to forgetting information in *long term memory*. While people store large amounts of knowledge and experiences in long term memory, facts and events are gradually forgotten if they are not constantly re-experienced. Figure 25 shows a prototypical forgetting curve. The figure shows that forgetting decays rapidly with the absence of practice. The greatest amount of forgetting occurs just after learning, and declines gradually over time (Hoffman et al., 2014).

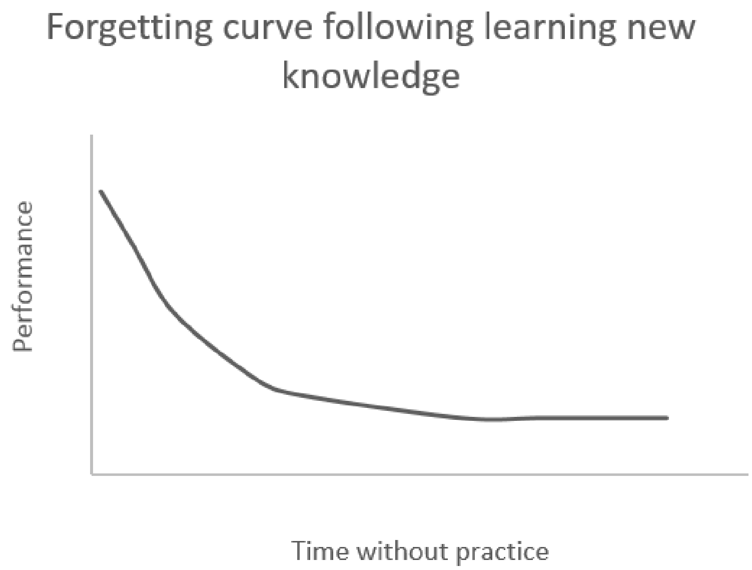


Figure 25. Prototypical Forgetting Curve

In the context of railroad operations, the fact that information in long-term memory gradually decays is important when considering how long one can expect information that train crews learn during training to be remembered. In particular, one can expect knowledge of physical characteristics of a territory to be gradually forgotten if it is not regularly re-experienced.

Violated Expectations Can Result in Delays and Failures of Perception

People's behavior is strongly driven by *expectations*. People's expectations guide where they look, how quickly they perceive information, how they interpret information, and what errors they make. For example, it will be easier and quicker for a person to 'find the pet in the scene' if the pet is a dog being walked by a person, then if it is a snake in a corner of the image because when they hear 'pet' people are more likely to expect, and therefore look for, a dog then a snake.

A striking example of the role of expectations in driving perception is the well documented phenomena of 'inattention blindness' (Mack and Rock, 1998). This is where someone fails to notice something even when they are directly looking in that direction. A well-known example is an experiment where participants looked at a video of a group of people passing a basketball, some in white shirts and some in black (Simons and Chabris, 1999). They were asked to count how many times white-shirted players passed the ball. In the video a man in a gorilla suit walks right through the scene of people passing the ball. Half of the viewers failed to notice the gorilla. This is because they were focusing their attention on the task at hand and were thus 'blind' to noticing something they were not expecting. This example highlights the inability of people to notice fully-visible, unexpected events when they are engaged in an attention demanding task.

In the railroad context SSOs can arise when locomotive engineers lack expectations to guide monitoring due to lack of training or experience. It can also arise when locomotive engineers have strong expectations, formed from repeated past experience, that turn out to be wrong. Multiple cases were described to us where engineers formed expectations as to how they would be routed or what the signal aspect was likely to be based on prior experience. When their expectations were violated they failed to detect the stop signal in time to stop.

It should be stressed that operating on expectations is a fundamental characteristic of human cognition. Consequently, attempts to reduce SSOs by admonishing train crews to avoid operating on expectations is not likely to be very effective. Railroads commonly tell train crews to operate as if each signal they come to could be a stop, but if their experience suggests differently the automated tendency will be to operate based on expectations built up from experience.

External Distractions and Mind Wandering Can Divert Attention from Primary Tasks

Attention is a limited resource that can be diverted from a primary task, either as a result of external distractions or as a result of mind wandering. Strong external signals can divert attention from a primary task. For example, hearing a siren will cause a driver to scan the side and rear mirrors for the source of the siren, momentarily diverting attention from looking out the front windshield. Attention can also be diverted by internal thoughts. This is referred to as 'mind wandering.'

Mind wandering entails shifting attention towards thoughts unrelated to the current demands of the external environment. These internal thoughts can be work related, such as planning for upcoming tasks, or personal in nature, such as thinking about a recent argument they had with their boss. Mind wandering is a default brain state that naturally arises when external demands are low. It is estimated that mind wandering occurs between 25 and 50 percent of the time during waking hours (Smallwood & Schooler, 2015; Killingsworth and Gilbert, 2010).

External distractions and mind wandering can have detrimental effects on visual attention and performance. Studies of automobile driving have shown that both external distractions and mind wandering cause drivers to narrow their attentional focus (He, Becic, Lee and McCarley, 2011). Visual scanning is more narrowly focused in front of the vehicle, with fewer gazes at side mirrors. External distractions and mind wandering can hinder visual detection and recognition and lengthen reaction time to external events requiring a quick response (He et al., 2011).

In the railroad context, external distractions and mind wandering repeatedly were mentioned as contributing factors to SSOs. In a review of SSOs, attentional problems associated with the engineer represented the most significant contributing factor (Edkins and Pollack, 1997). External distractions range from competing work demands such as radio communication, to unique events such as a rock being thrown at a windshield that divert attention away from monitoring for signals. Mind wandering was also mentioned as a potential contributor to SSOs. Mind wandering is most likely to arise during low demand periods, such as long stretches of rail with few signals.

It is important to note that distraction and mind-wandering are natural consequences of how the attentional system works. Attention is automatically directed to salient cues in the environment and mind-wandering is a common phenomenon that will naturally occur in low external stimulation conditions. These are automatic processes that are difficult to control through will-power alone. Consequently, attempts to reduce SSOs by admonishing train crews to avoid distraction and pay closer attention are not likely to have a substantial impact on SSOs. Edkins and Pollack (1997) suggest that lack of vigilance among locomotive engineers is a symptom of latent failures within the organization.

Information in Working Memory is Subject to Memory Lapses

Human working memory is subject to *memory lapses*, where information held in short term working memory is forgotten. Memory lapses are particularly prone to occur under high workload conditions where other events intervene to ‘knock out’ the information from working memory. In the railroad context, we were told of cases where locomotive engineers were at one point aware of the status of a signal but simply forgot because of other intervening mental demands. For example, they may have ‘known’ that a signal is behind them but the information slipped their mind when it was time to depart the station; or they might at some point have been aware that the prior signal was an approach and so the next signal could be a stop, but it was not at the top of their mind as they came to the next signal because of intervening events.

In the following sections, we discuss the impact of these cognitive factors on SSOs in the railroad context. In each case we present some recommendations for mitigations that can be implemented to reduce the impact of cognitive factors on SSOs.

Frequent Repetition Can Lead to Automated Responses

One of the hallmarks of skill acquisition is that behavior that initially takes explicit attention and effort to perform (e.g., riding a bicycle, driving a car) eventually becomes automatic, requiring little conscious effort. This is shown in Figure **24** as a direct link from perception to response selection. Examples of automated responses in driving is pressing the brake when the car in front suddenly stops or a light immediately up ahead turns red. Automated processes require little conscious effort, which is advantageous because it means the response can happen more quickly than if it required conscious processing and decision making. At the same time, because the response is automated, it is not under conscious control. As a consequence it cannot be easily stopped, even in cases where the response is inappropriate.

Locomotive engineers across multiple railroads described situations where they responded in an automated fashion resulting in potential for SSO. In particular, they reported a tendency to automatically depart upon receiving a ‘two to go’ indication from the conductor. The phrase ‘two to go’ refers to the conductor pressing an audible buzzer twice to inform the engineer that the passenger doors are closed. This means the engineer might depart when a permissive signal aspect is displayed. Locomotive engineers we interviewed indicated that sometimes they would automatically depart upon hearing ‘two to go’ without first checking to make sure they had a permissive signal aspect. This could lead to an SSO if the signal indicated stop.

Haga (1984) conducted laboratory experiments that illustrate how this automated response can develop. The study simulated a train departure task and showed that erroneous automated response to a cue (e.g., a ‘two to go’ indication) occurred most often when this cue was generally followed by the primary indicator for action (e.g., a permissive signal aspect). An erroneous automated response was particularly likely to occur where there were distracting factors in the environment.

5.2.2 Experience and Route Knowledge

Training and experience clearly play an important role in the ability for train crews to operate trains safely and efficiently. As one locomotive engineer we spoke with put it:

> "The first 5 years you still feel new... I used to tell students, after you get promoted, you'll feel confident, think you know what you're doing. But there will be some doubt. You need to be cautious. Eventually it clicks."

Locomotive engineers and conductors are taught signal aspects, their meaning, and the progression of signal aspects that are used to manage train movement. A clear signal indicates that a train can proceed at normal speed. A stop signal indicates that a train is to stop prior to reaching the signal. There are also additional signal aspects that are intended to reduce train speed.

Railroad signals typically operate in an ordered progression intended to control train speed and slow a train down gradually prior to reaching a stop signal. Figure 26 provides a simplified four signal progression intended as illustration. Under normal circumstances a clear signal would be followed by either another clear signal or an approach signal. The approach signal would be followed by either another approach signal or a restricting signal. In turn, the restricting signal would be followed by either another restricting signal or a stop.

Signal progressions allow train crews to anticipate what the next signal could be and adjust their train speed accordingly (Luke et al., 2006). For example, if the prior signal is clear the locomotive engineer can operate at a normal speed knowing that the next signal will not be at stop. If the prior signal is restricting they know to be alert to the possibility that the next signal will be stop.

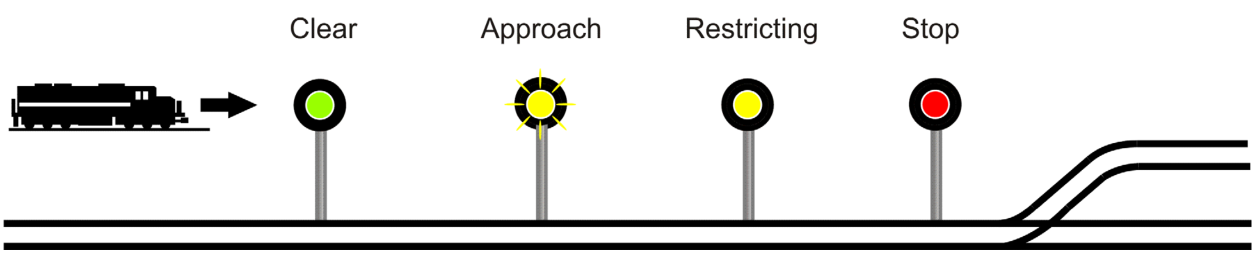


Figure 26. Illustrative Example of a Signal Progression Along a Line of Track

Locomotive engineers and conductors also gain knowledge and perceptual skills that enable them to better estimate distances (e.g., how many car lengths to a stop signal) and identify where they need to stop at a station to accommodate different train lengths. Locomotive engineers also develop sensory motor skills that enable them to know when they need to slow down and start to brake to avoid passing a stop signal in different environmental conditions (e.g., dry conditions, vs. rain, snow or leaves on the track that create slippage).

Locomotive engineers, and more recently conductors as well, are required to become qualified on the territory over which they operate. With increasing experience train crews develop route knowledge (mental models) of the physical layout of the track, the type and location of signals and the pattern of other rail traffic. This knowledge enables train crews to rapidly locate, read, and respond to signals.

With increased experience locomotive engineers also develop attention management and goal prioritization skills (Naweed, Rainbird, and Chapman, 2015). More experienced engineers ignore competing demands for attention during safety critical periods to focus on safe driving. For example, they will delay responding to radio requests if they are approaching a complex portion of track or signal. They may also be better able to prioritize safety over on-time performance in the face of time pressure.

Experienced engineers also develop strategies to help them guard against mind wandering and memory lapses, and unwanted automated responses. Naweed and colleagues (2015) report that more experienced engineers develop a variety of behavioral strategies, including use of train-related interactions, physical and verbal actions, and use of physical objects as memory aids. A common strategy is to put the throttle in neutral when stopped at a station as a reminder of the need to check the signal aspect before taking off, particularly when the signal is behind them. Train crews we interviewed across several railroads mentioned similar strategies. The need to take an explicit action, taking the throttle out of neutral helps to mitigate against the potential of an automated response to start the train upon hearing ‘two to go’ from the conductor. Other similar strategies we were told about was to ‘pull the shade down’ or put a glove on the controller of the locomotive when at a stop to block automatic action and serve as a reminder to check the signal. These strategies are not explicitly taught, but rather informally developed and disseminated by train crews.

Locomotive engineers also develop strategies for maintaining awareness that the prior signal was an approach. One example reported by Naweed and colleagues (2015) is to whistle “Mellow Yellow” when having passed an approach signal, or to place keys or coins on the control stand as a reminder that you are operating with an approach signal.

Locomotive engineers also divulged strategies to avoid mind-wandering. One locomotive engineer said to us:

> “For me, if I do something different keeps my mind on what I’m doing. I’ll stand up. Move position of my seat. Put it forward. Little things to keep you focused. Keep paper work in front of you. Circle what’s relevant to you.”

Locomotive engineers also told of strategies to minimize distraction. One locomotive engineer indicated:

> “I do things, so I don’t get distracted. For example in the terminal. I call out signals, no matter who is on the head end. And then they’ll call out the signal too. Or at least stop talking.”

These strategies, which are typically not part of the formal training curricula, helped the engineers avoid missing signals in situations they deemed as having a higher likelihood of a SSO. Experienced engineers we spoke with also emphasized the importance of only thinking ahead to the next signal, noting that less experienced engineers may be thinking too far ahead (i.e., to the next platform, to turn-time activities, to their next train) because of their inexperience, thereby missing signals in front of them.

Contributors to SSOs

While our findings suggest that route knowledge, and strategies for preventing SSOs, grow with experience, there is no clear quantitative evidence showing a relationship between number of years of experience and SSO rate. Most of the railroads who made data available us did not include number of years of experience in the SSO events data they provided. One railroad did collect and report on years of experience of the engineers who had SSOs. This railroad was the focus of our first report on SSOs (Safar et al., 2015). As described in that report the railroad provided data on SSOs that occurred at their railroad between 2005 and 2013. When the data was normalized to take into account relative frequency of locomotive engineers working for the railroad at each of the experience levels, the data indicated that engineers with 36–40 years of experience had the highest risk for SSOs. Engineers with 5 or less years of experience, came in a distant second, in terms of risk of an SSO. Thus, *years of experience working as a locomotive engineer*, in itself is not necessarily a good predictor of likelihood of SSO.

A more relevant factor may be level of recent training and experience on a particular territory. Train crews undergo extensive training and testing to ensure that they are qualified over the territories they operate. Typically, they are required to operate over a territory at least once a year to maintain their qualification on that territory. Due to these territory qualification requirements there is a general expectation within the railroad industry that train crews, particularly locomotive engineers, should possess detailed knowledge of the locations and characteristics of the signals in the territories for which they are qualified. However, while all engineers are qualified on the territory they travel over, it cannot be assumed that the engineers will be able to retain detailed recall of the location and characteristics of signals and other aspects of routes of every portion of the territory, particularly if they rarely, if ever are routed along a particular branch. The assumption underlying the 1-year qualification criteria is that a locomotive engineer will be able to maintain detailed recollection of the physical characteristics of a territory even if they have not operated on a particular portion of track for up to a year. This assumption may need to be re-examined. One year may be longer than is reasonable to expect people to remember the exact location and characteristics of a signal, particularly if the signal is difficult to see or distinguish from other signals in the environment. This point was made several times by locomotive engineers and conductors that we interviewed.

Moray, Groeger and Stanton (2017) provide a quote from Wilkins (Atkins 99817B) that emphasizes the danger of relying primarily on train crew route knowledge to prevent SSO:

> "Perfect signaling design and perfect sighting arrangements would demand little or no route knowledge on the part of the train driver. Conversely, the ideal in respect of SPAD risk minimization would require drivers to possess perfect photographic knowledge of the many hundreds of signals along the routes over which they drive. Neither ideal is capable of achievement in the practical world.... It would be wholly unreasonable to expect drivers to learn in photographic detail all the complexities of signal viewing in a complex layout…."

Recommended Mitigations

An important factor in reducing the possibility of SSOs is to strengthen the train crew's knowledge of routes so that they will be able to form accurate predictions of the location and characteristics of signals they will be encountering to guide perception. It is also important to strengthen the crew's perceptual, sensory-motor and communication skills.

Mitigations to support this include:

- Providing simulator based training to accelerate and preserve train crew experience and knowledge of all branches of territories they will be expected to operate over
- Providing scenario-based training to address particular challenges that come up with respect to SSOs

- Allowing and encouraging train crews to take additional refresher train rides on company time when they feel a need beyond the annual requalification criteria
- Providing accurate, up-to-date track charts tailored to the needs of train crews, that crews can consult prior to or during a train run to reinforce their knowledge of territory characteristics. This can be particularly important in the case of railroad yards and complex terminals that a train crew may be asked to enter that they may not have been to for a long time.
- Providing systematic on the job training to build the perceptual, sensory motor, and communication skills required to perform challenging tasks, such as shoving moves. Utilize objective performance criteria to establish mastery of those skills.
- Re-evaluating the 1-year requalification criteria for maintaining currency on territory characteristics. Objective performance-based criteria should be used to evaluate whether a year is a reasonable length of time to expect locomotive engineers and conductors to be able to recall the characteristics of portions of track that they have not had an opportunity to ride over.

5.2.3 Expectations

People form expectations based on prior experience of the likelihood of different events. People will respond faster and more accurately when those expectations are met. Conversely, they will be slower and more likely to make errors in cases where those expectations are violated (McCarley and Benjamin, 2013).

Train crews form expectations regarding the next signal aspect based on the prior signal, their knowledge of signal progression, and their past experience on a given route (Luke et al., 2006) (Phillips and Sagberg, 2014) (McLeod, et al., 2005). This includes expectations about how dispatchers are likely to route them, what signal aspects they are likely to experience, and their relation to other trains operating on the same territory (e.g., time and location of meets and passes). These expectations guide their visual scanning pattern and train handling (Luke et al., 2006) (McLeod et al., 2005). Expectations can have both positive and negative impacts on SSOs.

Expectations generated based on knowledge and experience can reduce the likelihood of a SSO. Knowledge of signal progression allows train crews to operate more efficiently. If the prior signal is clear they can confidently operate at track speed knowing the next signal will not be a stop. If the prior signal is restricting they know to be on the alert for the possibility that the next signal is stop. The train crews we interviewed stressed the importance of learning signal progression and operating based on expectations formed from signal progression.

Expectations are also formed based on route knowledge. Expectations based on route knowledge can reduce the possibility of a SSO by helping direct engineer attention. For example, knowing where to expect signals and the type of signals to expect (e.g., a high signal vs. a dwarf signal) enable engineers to locate the signal and perceive the signal aspect more quickly. For example, knowing that a particular signal is located under a platform enables the engineer to know where to direct attention.

Contributors to SSOs

Lack of well-formed expectations can contribute to SSOs. One way this can happen is when a locomotive engineer lacks sufficient route knowledge to develop accurate expectations. They may not know where a signal is, they may not know the type of signal to expect and so they may not know where to direct their attention resulting in delays and failures to perceive the signal. When the governing signal type is non-standard, positioned a non-standard location, or surrounded by other signals lack of well-formed expectation is more likely to contribute to SSOs.

People may miss a signal, even if they are looking in that direction, if it is different from what they expect, especially if their mind is on other aspects of the work. For example, if a locomotive engineer is expecting a high signal and comes across a low dwarf signal he may miss it. A locomotive engineer described to us an SSO he experienced that provides an example of this type of inattention blindness. The locomotive engineer explained:

> "I kept looking for the signal…I wasn't familiar with the area…I had never [operated the train] in that direction… I knew the signal was coming up, but I didn't know where it was. It was as a pot signal [low signal, also called a dwarf signal]. I wasn't looking for it that low. I didn't know it was a pot signal. It was on the curve. I had a limited amount of time to see it. I would have needed to know exactly where it is to see it."

In the above example, the locomotive engineer did not know to expect a dwarf signal (which he called a pot signal) and so was unable to efficiently direct his attention. As the signal was on a curve the locomotive engineer was unable to detect the dwarf signal in the short time window that was available. The example illustrates the role of experience and expectations in guiding perception, and how lack of territory familiarity can cause individuals to fail to detect a signal.

Lack of expectations based on signal progression can also contribute to SSO. We were told that some conductors do not have sufficient understanding of signal progression to anticipate when the next signal is likely to be stop. This can contribute to SSOs when performing shoving moves that require the conductor at the front to call out the signal to the locomotive engineer who is shoving the train from the locomotive in the back. As one conductor put it:

> "Often times conductors aren't taught signal progressions, engineers are… Approach, restricting stop. More experienced conductors get it best, from experience. But I didn't even know it existed when I first started. They could concentrate on that in training. So you know when you're likely to have a stop ahead of you."

Expectations can negatively impact operation when those expectations are disconfirmed. Train crews we interviewed expressed particular concern of situations where the order of signal progression was violated. We were given examples of portions of track where multiple interlockings came together where signals were not linked. As a result, the standard order of signal progression did not apply making it more challenging for locomotive engineers to anticipate the next signal.

Of even greater concern were cases where signals were dropped. A dropped signal is a stop signal that comes up suddenly, in violation of signal progression. This can occur either due to a signal malfunction or a dispatcher action. In those cases locomotive engineers could not anticipate the stop signal and were thus not always able to stop the train in time.

SSOs also occur when expectations based on prior experience on a route are violated. Many of the cases of SSOs we were told about by train crews involved this type of situation. Engineers formed expectations as to how they would be routed or what the signal aspect was likely to be based on repeated prior experience. When their expectations were violated they failed to detect the stop signal in time to stop. One locomotive engineer described an example of an SSO that occurred to someone else where violated expectations led to a delay in detecting a stop signal resulting in an SSO:

> "He was coming down the front ladder. Typically you go straight but the dispatcher crossed him over. He was looking at signal up ahead instead of the signal right in front of him, because they're so close together. We don't ever really use that short crossover. When you do, once in a while, it catches you off guard. You'll typically always have a slow approach. It was kind of a set up."

This example illustrates several ways that expectations guide perceptions and how violated expectations can combine with other factors to create conditions for an SSO. First the locomotive engineer was expecting to go straight so his gaze was likely in that direction and not toward the cross-over. Second, they looked past the signal immediately in front of them to the one ahead because the two signals were close together. Finally, he was expecting a slow approach rather than a stop.

Operating based on expectations is particularly likely in high workload situations where there are competing demands for visual attention or when there are distractions exacerbating the potential for SSO (McLeod et al., 2005).

Recommended Mitigations

Generating and operating on expectations based on prior experience is a fundamental aspect of human cognition that cannot be changed through counseling or admonition. A better strategy is to provide countermeasures to foster more accurate expectations with respect to routing and signal aspects.

Mitigations to support this include:

- Strengthen and reinforce training on signal progression, particularly for conductors.
- Have dispatchers contact train crews before or during train runs of any route deviations that are foreseen to counter incorrect expectations (Phillips and Sagberg, 2014).
- Explore the possibility of in-cab displays that show the anticipated routing. This would eliminate the need to add workload (radio communication) to the dispatcher and train crew, because during periods of high workload the dispatcher may not have time to communicate with the train crews. Cab signals serve some of this role by providing signal aspect information, but they do not extend to yard or terminal operations where speeds are below 20 miles an hour. Similarly, some PTC systems provide routing look ahead, but those too only apply in territory with speeds above 20 miles an hour. There is a need for FRA to conduct research into visual route indicators, particularly for high workload the terminal environments, so as to establish safe implementation of these types of displays before this is a viable option.
- Combat engineer's reliance on incorrect expectations through simulator training. Simulators can be used to provide train crews with broader experiences of alternative

routing and different signal aspects when reaching particular interlockings. The simulator can thus provide virtual experiences to help combat incorrect expectations.

- Instead of giving train crews the same route every day, 'mix it up' when possible to provide opportunity to experience more of the territory, and counter strong expectancies regarding likely routing and expected signal aspects. This recommendation was suggested to us by multiple individuals we interviewed.
- Link track signals to insure they conform to order of signal progression.
- Improve track maintenance to reduce potential for dropped signals due to signal failure.
- Improve dispatcher training and procedures to avoid dropping signals without first informing the train crew unless it is an emergency.

5.2.4 Distractions and Memory Lapses

Distractions and memory lapses were often mentioned as contributors to SSOs.

External distractors and mind wandering can divert attention from the primary task of operating the train. It can delay detecting a stop signal or cause the signal to be entirely missed. Distraction was frequently mentioned as a primary reason for SSOs. People at all levels within the railroad organization, ranging from the locomotive engineers and conductors themselves all the way up to the highest levels of management used phrases such as 'complacency' and 'distraction' as the reason in their opinion that SSOs occur.

Memory lapses, where real-time information stored in working memory is forgotten due to other events impinging, also came up when discussing contributors to SSOs.

Contributors to SSOs

The train crews we spoke with described multiple sources of external distraction:

- Radio communication, particularly calls from dispatchers directed at them
- Consulting job related 'paper-work,' such as reviewing time schedule and speed restrictions
- Conversations with conductors in the head end that are unrelated to the immediate situation
- In cab displays and alerts, particularly non-immediately-actionable alerts that go off at high workload times
- Unique events (e.g., a malfunctioning side door unexpectedly opening)

Under the dynamic conditions of operating a train external distractions do not need to take long to cause a locomotive engineer to miss a signal. Two examples make this point clearly. The first example, as told by the locomotive engineer, involves a conversation he had with a conductor:

> "The conductor was on head end. He commented on how late we were. In the time it took for me to look at my watch I looked up and saw we weren't lined. I put train in emergency. We were past stop signal. From my conductor, the last signal I had should have been my last signal. I took it for granted that it was my last signal. I'm extra—

> different job every day. Was expecting that to be my last signal into the depot. But that day they routed us differently. So, there was a second signal. The signals were really close."

This example illustrates a couple of factors that occur repeatedly in SSOs. The first is the occurrence of a *distraction*. In this case, momentarily looking down at the locomotive engineer's watch. However, there were several equally important contributors. The engineer was on the extra list and was not familiar with the territory (*lack of familiarity with territory*). They were not expecting another signal because the conductor indicated they had passed the last signal, so might have felt it was safe to momentarily shift attention away (*violated expectations*). The signals were physically very close together leaving little margin for momentary lapse in attention (*signal placement*). As was typically the case, there was no single factor that caused the SSO, but rather the interaction of multiple concurrent factors.

The second example illustrates that distractions can be unique, unexpected events that automatically draw attention:

> "I had a slow approach. I had a meet on the bridge with another train on track X. that's regular. That's my only meet. Seeing a slow approach I should've known I could see a red signal at the next signal, about half or 3/4 mile away but, routine. Pass a train on the bridge. We wave. Forget I'm slow approach (which was normal, they always give me that). Around the bend I turn around because the cab door opened. This engine had been written up for over a year…. I was distracted because the door came open. I know the history of this locomotive, so I'm already annoyed by it. I turn around to pull it shut, when I sit back down, straight ahead is a red signal. I put it into emergency, came to a stop half an engine length by the signal. The signal was red because dispatchers forgot to put it in. That signal shouldn't have been red. I already had the meet with that train. The signal I went by, you'll never see it red."

This second example provides another illustration that SSOs involve the interaction of multiple factors. In this case, the malfunctioning door was a compelling factor that drew the locomotive engineers' attention away (*external distraction*). The event also involved *violated expectations.* The locomotive engineer was not expecting a red signal both because that signal is not normally red, and because he had already encountered the train that was the only meet he was expecting. While in principle, he was aware that the last signal was a slow approach and so the next signal could be a stop, the distance to the next signal (more than a half mile) and intervening events caused the prior approach signal to drop out of his awareness (*memory lapse*). Had the locomotive engineer expected a stop signal, he might have better resisted the impulse to turn away to close the door.

Train crews also mentioned mind wandering, which they sometimes refer to as 'mental vacations' as another source distraction. The locomotive engineers we interviewed provided no examples of SSOs due to mind-wandering.

Railroad personnel we interviewed also spoke of the impact of memory lapses on SSOs. We learned of cases where train engineers were at one point aware of the status of a signal, but simply forgot because of intervening work demands. Locomotive engineers mentioned two prominent examples. The first involved forgetting to look at a signal that was located behind the cab. This occurred at terminals and stations where the train length is longer than the station was designed so the locomotive engineer cannot see the signal from their position in the cab. In those cases, when the conductor tells the engineer ‘two to go’ the locomotive engineer may depart without checking the signal that is behind them.

One locomotive engineer alluded to the phenomenon saying:

> “Then you get the perfect storm where doors don’t close, then you get the GO and you forget the signal is behind you.”

This example reflects a combination of ‘automated responses’ where the locomotive engineer automatically starts to go upon getting the ‘two to go’ signal due to repeated experiences, and a memory lapse, due to external distractions, that results in forgetting to check the signal that is behind him.

A second example that was mentioned to us, is forgetting that the immediately prior signal was an approach. This is most prone to happen when there is an intervening event that displaces information in working memory about the prior signal with new competing information. For example, if there is a station between the last approach signal and the subsequent stop signal, the locomotive engineer may forget that they had an approach signal prior to entering the station when they start up again. This type of working memory lapse has been observed by others as well. Naweed and colleagues have coined the phrase ‘station dwell’ to refer to this type of memory lapse (Naweed, Rainbird and Chapman, 2015).

Recommended Mitigations

We came across a general belief across the railroads we visited that lack of attention on the part of the individual(s) in the cab was the primary cause of SSOs. For railroads, this led to the natural conclusion that SSOs can be reduced by simply urging individuals to focus more attention on signals. During interviews and focus groups, locomotive engineers and conductors often mentioned paying closer attention as a way to reduce SSOs. Based on a similar belief, a common mitigation strategy to reduce SSOs implemented by railroads was to initiate campaigns designed to alert train crews to the dangers of SSOs and urge them to ‘keep the focus’ on monitoring signals. However, as we explain earlier, urging individuals to ‘pay closer attention’ is an ineffective strategy for preventing SSOs.

While distractions and memory lapses are often factors in SSOs, attention management is an automated process that is challenging to counter. Salient signals tend to capture attention and long periods of low stimulation will tend to result in mind wandering. New incoming information can displace prior information in working memory resulting in memory lapses. Thus, urging people to ‘pay closer attention’ is unlikely to be effective in and of itself because it counters how human attentional and memory processes fundamentally operate. Further, as we have shown through multiple examples, SSOs generally involve several interacting factors including physical layout characteristics that create perceptual challenges and expectations based on prior experience that may lead crew members to (erroneously) believe that it is safe to divert attention. Progress on reducing SSOs is more likely to be made by improving physical infrastructure to facilitate perception of signals and fostering more accurate expectations regarding signal location and aspect.

The automotive industry is actively working on research programs to prevent and mitigate the consequences of distraction (Victor, 2011). One approach focuses on real-time distraction prevention. Mechanisms include filtering, prioritizing, and scheduling information so that drivers receive information at the time needed and when he or she can safely process it. For example, there is research to manage workload by prioritizing among incoming system messages, as well as postponing system initiated information depending on driving conditions. There are also systems that 'lock out' certain non-driving tasks during demanding driving situations. Examples of locked out tasks are entering addresses into a route navigation system or receiving incoming phone calls. Demanding driving situations are assessed based on multiple sensor signals such as speed, acceleration, and steering wheel angle.

There is also ongoing research on ways to automatically detect when people's attention is distracted or their mind wanders based on eye and head-tracking as well as driving characteristics, such as lane-keeping ability. Real-time distraction mitigation strategies include providing visual or auditory alerts when driver distraction is sensed to exceed a limit value (e.g., total off-road glance time exceeds a threshold value). There are also systems that adjust the behavior of crash avoidance systems based on the estimated level of driver distraction. These systems operate as interaction managers and serve the goal of preventing high workload and/or distraction from occurring (Engstrom and Victor, 2008; Victor, 2011). For example, forward collision warnings may come on sooner to compensate for possible delays in reaction time due to distraction.

While the technologies being developed in the automotive industry may not be sufficiently mature for current application in the railroad industry, some of the basic principles of identifying ways to reduce sources of distraction, as well as ways to mitigate the effects of distraction can be applied to the railroad industry

Recommended mitigations include:

- Reviewing in-cab alerts to make sure that non-critical alerts that do not require an immediate response do not occur while the train is operating
- Instituting a 'sterile cab' policy in the cab during high workload conditions (e.g., as the train enters a terminal). 'Sterile cab' is a term that borrows from a similar term used in the airline industry called 'sterile cockpit.' It specifies that only immediately task-relevant communication is allowed between individuals in the cab. The objective is to eliminate what engineers indicated was a major source of external distraction.
- Providing sufficient time to review paper-work prior to departure, to reduce the need to review paper-work during train operation as a source of distraction
- Considering providing audio alerts as the train approaches a signal with a stop aspect to redirect attention toward the signal. This would also serve to counter wrong expectations that the upcoming signal will be permissive
- Communicating effective strategies for attention management and task prioritization and provide opportunities to practice them. Many examples were covered in the section on experience and route knowledge. For example, experienced locomotive engineers are able to prioritize focusing on upcoming signals over other potentially distracting tasks (e.g., responding to a radio communication). The skill that can be developed with appropriate practice.
- Assigning a second person, such as the conductor, to independently perform the task to mitigate against locomotive engineer memory lapses. An example is to require the

conductor to personally confirm a clear signal before giving the engineer ‘2 to go’ indicating that it is OK to start the train as a way to guard against station dwell memory lapses. This policy was put in place by one railroad to mitigate against locomotive engineers starting the train upon hearing ‘2 to go’ without first checking the signal in cases where the signal was behind the engineer. A study by Phillips and Sagberg (2014) provides some support for the efficacy of this strategy. In a survey of SSOs and near misses they report 21 cases where the locomotive engineer missed the signal, but the conductor caught it, and only 2 cases where they both missed the signal.

- Explicitly teach effective behavior strategies that have been developed by experienced engineers for guarding against mental lapses. Many of these techniques are listed in the section on experience and route knowledge and encompass train-related interactions, physical and verbal actions, and use of physical objects as aids to memory.

5.2.5 Role of Communication and Teamwork: Locomotive Engineer and Conductor Interaction

Railroad operations involves interaction among multiple individuals requiring effective communication and teamwork. While the locomotive engineer operates the train, the actions of others, particularly conductors also impact the likelihood of an SSO both positively and negatively.

In passenger operations conductors juggle multiple responsibilities. They are responsible for interacting with customers and insuring their safety. They are also responsible for supporting the locomotive engineer. This includes alerting locomotive engineers to upcoming speed restrictions, reminding them to check signals, communicating with dispatchers, and in certain cases going into the cab to help the engineer identify signals.

Specific activities in support of locomotive engineers that we were told about include:

- Providing a ‘two to go’ indication when all passengers are on board and the train doors are closed to let the locomotive engineer know it is OK to go provided a permissive signal
- Saying “ok to proceed on signal indication” as a reminder that the locomotive engineer should check signal indication
- In certain stations, where the engineer may not be able to see the starter signal (e.g., because the position of the locomotive engineer is in front of the signal because of train length), the conductor is required to confirm a permissive signal indication before giving the ‘two to go’ indication
- If an engineer has not been on a territory for six or more months the conductor is required to be in the head end, calling out the signals
- If engineer loses cab signals, the conductor is required to be in the head end, calling out the signals
- In selected busy terminals, the conductor may be required to be in the head end, calling out the signals

- Calling out signals during shoving moves when the locomotive engineer is pushing the train from a locomotive in the back and cannot see the signals up ahead

Interviews and observations indicated that these support activities were generally viewed positively. This is consistent with research conducted in Australia on the positive contribution of conductors in two-person train crews (Naweed, A., Every, D., Balakrishnan, G. and Dorrian, J., 2014). Naweed et al. found that a second person in the cab was perceived as helpful "if they talked in a timely or on-task way, the driver was new and still needed guidance, the difficulty in the task was very high (i.e., from fatigue, visibility issues, and/or track complexity) or if the main driver was more extroverted and liked company."

At the same time, our interviews and focus groups suggested that conductors could negatively impact SSOs, when they served as the source of distraction or made errors in calling out signals due to lack of familiarity with signals, signal progression and the route.

Contributors to SSOs

One example where teamwork can contribute and detract from safety occurs when conductors join the engineer in the cab to identify and call out signals. This practice is intended to provide a second set of eyes in the cab to better avoid missing, or misinterpreting, signals. However, discussions with engineers and conductors indicated that conductors in the cab could be a source of distraction when they engaged in non-work related discussions. Conductors also pointed out that calling out signals can be difficult as they do not receive the same training as engineers and lacked the level of knowledge about the territory that the engineers had. As a result, they risked missing or misinterpreting signals.

Similarly, locomotive engineers expressed concern in conducting shoving moves with conductors who were unfamiliar with the territory and/or were not well-practiced in reading signals and understanding signal progression. We were told of multiple examples where conductors misread signals or called out signals too late. Several locomotive engineers indicated that they would change ends because they did not trust the conductor to accurately call signals.

Recommended Mitigations

- Institute a "sterile cab" during high attention demand conditions, such as operating in a terminal. This is a communication policy in which train crew members discuss only safety-related issues related to train operations. Non-work related conversations are prohibited as they can distract the crew from attending to safety-critical tasks. Discussion in the cab should only involve conversation around railroad operations related to the task at hand or anticipating the next move.
- Strengthen the training of conductors with respect to reading signals and understanding signal progression. Conduct performance-based testing to establish mastery of these concepts.
- Provide more extensive training on conducting shoving moves, paying particular attention to communication and coordination requirements between conductors and locomotive engineers. Conduct performance-based testing to establish mastery of shoving operations.

- Providing Crew Resource Management (CRM) training to train crews (locomotive engineers and conductors). CRM training is meant to educate crews regarding the roles and responsibilities of each member and how team members will communicate with each other. This should be helpful in getting locomotive engineers to speak up as needed (to institute a "sterile cab") as well as provide guidance for constructive communication among team members.

5.2.6 Role of Communication and Teamwork: Dispatcher and Train Crew Interaction

The actions of dispatchers also can play an important role in both avoiding and contributing to SSOs.

We were told of several strategies that dispatchers can use to reduce the potential for SSOs. Specifically, dispatchers indicated that if they have the time they will try to let locomotive engineers know when they are going to move them in a different routing than usual. This helps to reduce the possibility of SSOs resulting from locomotive engineers having inaccurate expectations.

Dispatchers can also reduce the possibility of SSOs by their selection of routing. Examples we were given include:

- Giving the best route during rush hour for late trains. Best route is a route where the engineer can see the next signal (and can therefore see that he is "lit up" to go straight in).
- Routing to avoid SSO traps, such as for example, when the dispatcher knows two signals are close together, they will make sure they are both permissive, so that the locomotive engineer does not come to a stop signal with little time to react.

Contributors to SSOs

We were also told of ways dispatcher behavior can negatively impact SSOs. These included instances where dispatchers dropped signals, without first informing the locomotive engineer. This caused locomotive engineers to suddenly see an unexpected stop signal, increasing the possibility of running through it.

Another way dispatchers contributed to potential SSOs was via radio communication that served as a source of distraction. Locomotive engineers mentioned that dispatchers sometimes called at inopportune times to ask why a train was delayed contributing to distraction.

Locomotive engineers have developed informal communication strategies to support dispatchers in routing decisions and shift communication to lower workload periods. For example, engineers described situations where they proactively called the dispatcher when their train car count was changed and they believed they were being routed to a platform that was too short to enable the passengers to disembark from all the cars. Engineers also described situations where they pre-emptively call the dispatcher to explain why they may be late. These are not formally prescribed or taught communication strategies, but rather additional tasks engineers take on proactively in order to avoid perceived complications in the future. They enable the dispatcher to better manage routing trains on his or her territory. These are important communications that should not be discouraged. However, these communications may distract the engineer from the signal monitoring task when done during high workload periods.

We also identified opportunities for more effective communication between train crews and the dispatcher that could facilitate movement within the terminal as well as to help avoid SSOs. One example that engineers and dispatchers both described is in a situation where the dispatcher may have forgotten about a train at a signal. Dispatchers described these situations as times of high workload for the dispatcher and expressed a desire for engineers to call and remind them that they have been sitting at a signal for several minutes and were late as a result. As one dispatcher put it:

> "A lot of our desks have multiple lines. You get so focused on making sure all trains have form Ds, all signals are in. Then you look up and realize you forgot to line a train. It definitely happens."

Another dispatcher said:

> "Sometimes the job gets really busy during rush hour, and it could happen that I might lose track of a train. One time, I forgot to give a train a green light at the platform and he stood there for 15 minutes past his due out time. Why didn't he call me and ask what's up? The engineers never call me for stuff like that, but they should."

Recommended Mitigations

- Provide explicit training for communication between dispatchers and train crews (shown in Table 7). Note that while these strategies may better facilitate movement in the terminal, they also run the risk of distracting the engineer. For this reason, we recommend the engineer initiating these communications (denoted with an asterisk) only during times of low workload.

Table 7. Recommended Communication Between Dispatcher and Train Crews

Railroad Personnel	Communication Between Dispatchers and Train Crew
Dispatcher → Locomotive Engineer	Dispatcher is holding the train at a signal; routing the train differently than normal; or 'dropping' a signal
Locomotive Engineer → Dispatcher *	Dispatcher left train at signal for prolonged duration
Locomotive Engineer → Dispatcher *	Train will be late and why
Locomotive Engineer → Dispatcher *	Operating a different size train than expected

**Engineer initiates these communications only during times of low workload*

5.2.7 Role of Fatigue

Fatigue is a function of the amount of sleep and circadian rhythm (Gertler, DiFiore and Raslear, 2013). The amount of time and time of day when sleep occurs strongly impacts fatigue. In the railroad industry work schedule affects the timing and duration of when sleep can occur resulting in potential for fatigue.

Because passenger railroads operate 24/7 the scheduling of train crews necessarily involves multiple shifts with different start times. In some cases, there are regular job assignments with predictable start times. These regular jobs may nevertheless involve different start times on different days potentially impacting circadian rhythms. In additional to regular job assignments there are also ‘extra board’ jobs where personnel are ‘on call’ to replace others who may be out due to personal leave (e.g., vacation, sick time) or other assignments. Unlike the regularly scheduled positions there is greater uncertainty about when individuals on the extra-board will be called to work and the job assignments will vary from day to day in terms of what trips they will make. As a consequence, employees on the extra board are at greater risk of coming into work fatigued.

Evaluating and managing fatigue has been a major concern of FRA and the railroad industry (Gertler et al., 2013). There are Federal hours of service laws in place that date back to 1907 that specify the maximum hours train employees may work, as well as minimum off-duty hours. New regulations on hours of service for commuter and passenger trains went into effect in 2011. If an employee works less than 12 hours in a 24-hour period, then the required off duty period is 8 hours. If the employee works more than 12 hours in a 24-hour period, then they must have at least 12 hours off duty before returning to work. In addition, the new regulations add a requirement to analyze employee work schedules with fatigue modeling tools and paces limits on the number of days of consecutive work that takes into account differences between work during daylight hours and work during nighttime hours.

While regulatory limits on hours of service are helpful there is an indication that these regulations may not be sufficient to prevent railroad worker fatigue. According to Gertler et al. (2013):

- The risk of a human factors accident is increased 11 to 65 percent above chance by exposure to fatigue.
- The economic costs of an accident where an employee is very fatigued is approximately $1,600,000 compared to $400,000 in the absence of fatigue.
- Railroad workers are more likely to get less than 7 hours of total sleep on workdays than U.S. working adults more generally, putting them at greater risk for fatigue. On average, however, they have more total hours of sleep than U.S. working adults as a whole, when total sleep on workdays and rest days are combined.
- Railroad workers report sleep disorders that exceed U.S. norms for working adults.

Contributors to SSOs

Fatigue is likely to be a contributor to SSO (Fitness and Naweed, 2017). Fatigue has been shown to impact susceptibility to distraction (Anderson and Horne, 2006). It has also been shown to impact judgment and decision-making (Harrison and Horne, 2000).

Analysis of the NTSB reports of SSOs indicated that fatigue was mentioned 29 percent of the time. In our own focus groups and interviews it was mentioned less (5%) but nevertheless was brought up as a contributor to SSOs. Individuals we interviewed reinforced the point that difficult schedules, and particularly for engineers and conductors on the extra board, contribute to fatigue which in turn can create vulnerability for SSOs. For example, one individual brought up the fact that even in the case of regular schedule jobs, the fact that the start time can vary by day can contribute to fatigue: “Certain jobs that we have – work nights 4 days in a row, but then start at 8am the next day. You can’t get proper rest.”

Fatigue was mentioned as a particular problem for individuals working the extra-board. Individuals on the extra board have unpredictable schedules and are most impacted by the hours of service regulation. They emphasized that meeting the ‘letter of the law’ with respect to minimal legal requirements for hours of rest (8 hours of rest if the prior work period was less than 12 hours) often left workers with insufficient time off to get an adequate amount of sleep. One individual described it as follows:

> “Fatigue is definitely an issue... What looks on paper [hours of service regulation], is not what actually happens in real life. Especially since I’m on the list... This year was very busy on the list. Not sure if it’s because people retired but seems like every 8 hours you were getting off an 11 hour 59 minute job and then commuting home 2 hours. Say I’m done at 10 at night, the clock starts then. I don’t get home until midnight. Since [the work period] was just under 12 hours, I only get 8 hours instead of 10 hours. So you get home at midnight. By the time you get home, they can call you after you’ve barely had 3 hours sleep.”

Train crews also mentioned that work schedules that left little turn-time between trips also contributed to fatigue. One locomotive engineer explained:

> “Job scheduling needs to be looked at. Quick turns. Top contributing factors to fatigue. When you have 10 minutes between round trips, you’re shot out.”

While train crews did not mention fatigue as a primary cause of any SSO, they often mentioned it as one of several contributing factors. For example, someone mentioned an SSO where violated expectation played a major role, but fatigue was also a contributing factor:

> “The locomotive engineer got a terminal restricting signal. He was expecting to be switched to his normal route (to the left) where he was not expecting to see another signal for a while, but in fact he was moved straight and the next signal was red and he failed to stop. Fatigue also played a role.”

The example highlights how multiple factors converge to create vulnerability to SSOs. In this case, fatigue may have contributed to the locomotive engineer operating on expectations and degraded his ability to detect the stop signal and stop the train in time.

There is also some evidence that the role of fatigue on SSOs may be underreported. Individuals we interviewed indicated that there may be some reluctance for train crews who experience an SSO to bring up fatigue as a contributing factor. They raised the concern that they would be held legally liable for accepting the assignment when they were fatigued. At the same time, they mentioned that train crew members can be penalized for refusing too many assignments, placing them in a ‘double-bind’ situation.

Filtness and Naweed (2017) also found evidence of reluctance to bring up fatigue in investigations of SSOs in a study they conducted on SSOs across Australia and New Zealand. They indicated that locomotive engineers told them they would be reluctant to tell an investigator that they had had little sleep. They point out that the culture of not wanting to be seen as fatigued because of fear of its personal implications, can lead to underreporting of fatigue as a problem contributing to SSOs.

Recommended Mitigations

- Examine scheduling practices to evaluate the impact on fatigue and the potential for scheduling practices to contribute to SSOs

Encourage train personnel to talk about their fatigue, what causes it, and ways to mitigate it, both with each other and with management. This is consistent with guidelines in the UK rail industry that highlight the need for an open culture on the issue of fatigue to facilitate early identification before it becomes a safety critical issue (Rail Safety and Standards Board, 2014).

5.3 Railroad Organizational Processes

SSO investigations focus primarily on the train crew in understanding why the train passed a stop signal. Very rarely are the railroads' policies and practices examined in this context. However, from interviews with employees it became clear that railroad policies and practices are important contributors to the overall safety of the railroad system, and specifically have implications for SSOs.

Production pressures, for example, may cause train crews to prioritize on-time arrivals and departures sometimes at the cost of safety activities. The emphasis on adhering to schedule also causes dispatchers, particularly inexperienced ones, to send trains out right away, even though this may mean less clear routes. Crew assignment and scheduling also creates circumstances that can exacerbate the potential for safety related incidents because new, inexperienced employees are often given extra list jobs that challenge them due to the vast territory they may be expected to operate over and the hours and shifts they may be expected to work. Understanding the impact of employee training and employee supervision is also important in understanding safety breakdowns. The type of training and supervision employees receive directly impacts their performance.

In this section we discuss how various railroad organizational processes can contribute to SSOs and in each case recommend possible mitigations that could be implemented to reduce SSOs.

5.3.1 Production Pressures

On-time performance is an important aspect of passenger railroad operations. Keeping trains on schedule, however, is becoming more difficult in part due to longer and more frequent trains operating in physical infrastructure that was not built to support them. The increase in train density reduces the amount of slack in the system and causes train crews to experience shorter turn times as a result of tight schedules that cannot support the train density. The lack of spare capacity means the system as a whole is more brittle and has difficulty adjusting to unexpected conditions. As a result, the humans operating the system (train crews, dispatchers, consist coordinators, planning department) are more likely to make mistakes. Incentives for meeting production requirements cause train crews and dispatchers, in particular, to be susceptible to production pressures which may compromise safety and contribute to SSOs. We discuss our findings related to production pressures and recommendations to mitigate their consequences below.

Contributors to SSO

Train Density

As revenue service continues to increase and track capacity remains the same, train density is at an all-time high as longer and more trains are operated in the same amount of space. In the terminal in particular, during peak periods when nearly all platforms and tracks are occupied, trains are constantly moved in and out of the system with little slack. As a result, engineers are subject to more "stop and go" traffic and see more stop signals in the terminal because there are fewer opportunities for dispatchers to give clear routes, especially as they seek to maintain on-time performance. Statistically speaking, when train crews encounter more stop signals there are more opportunities for SSOs.

Short Turn Times

When trains run according to schedule, the railroads we visited built in approximately 15–20 minutes between trains for train crews to complete the necessary personal and safety-related tasks. For some railroads, this turn time duration may be too short to complete all the required tasks without taking shortcuts. Trains may arrive late at their destination, giving crews even less time to perform their post-arrival and pre-departure tasks. One engineer told us his train, which already had a short turn time built into schedule, routinely arrived late which caused him to only have 9 minutes in between trains. The Operations Department at one railroad estimated that meeting the schedule over the course of a 24-hour period occurs 2 percent of the time and the other 98 percent of the time disruptions occur, requiring the Operations Department to make adjustments to the operation. Operating with so little slack in the system creates pressure to take short cuts to address the production pressures. An analysis of the time it takes to perform all the duties required of both the engineer and conductor at one of the railroads in our study indicated that the allotted time for performing all their duties was inadequate for 64 percentage of the trains scheduled at their terminal stations. The implication is that this railroad's system design creates pressure for train crews to take shortcuts to meet scheduled departures 64 percent of scheduled trains that could compromise safety.

In some cases, often when the train is available but the crew is arriving late, a new crew is assigned to take the outgoing train out of the terminal. In other instances, an emergency engineer is sent to complete the turn-time activities in place of the engineer in order to save time. This saves some time for the outgoing engineer, however some engineers opposed this practice, as they felt uneasy not testing the brakes themselves.

In other cases, the train crew arriving late remains assigned to the outgoing train and have less than the allotted time in between trains. In these cases, the crew may not have sufficient time to complete the required turn-time activities. The engineers we spoke with said when this happens they may skip some turn-time activities, use time on their current trip to prepare for their next trip, or shift pre-departure activities they would normally be expected to perform prior to leaving the station to during their trip. These actions all have important safety implications. Skipping a brake test, for example, can have dangerous consequences if brakes need maintenance. Similarly, diverting attention from train operation and scanning of surroundings to attend to paperwork is a distraction that can lead to a missed signal sighting. The need to respond to dispatcher inquiries about why the train is late is an added task that can also lead to distraction and stress.

Employees told us of two stop signal overruns that were a result of engineers looking down at paperwork while operating in the terminal because of too short turn times. Telling engineers to avoid these types of behaviors is not an effective mitigation strategy for dealing with production pressures, particularly when the railroads seemingly emphasize production requirements over safety. Finding ways to reduce production pressures is a more effective approach to eliminate the resulting distractions and unsafe behaviors that can lead to stop signal overruns.

Production Requirement Incentives

Railroads (understandably) provide incentives for meeting production requirements. Dispatch centers, for example, keep tally of how many on-time trains they have, and road foreman keep track of how often engineers are late. Production requirement incentives result in unsafe practices that can contribute to stop signal overruns. For example, many engineers expressed frustration at the practice of dispatchers calling them while enroute to ask why they are late. Particularly, they noted, because it was often due to circumstances beyond their control like malfunctioning equipment, weather, or passenger related issues. This practice, they said, causes congested communication channels and is a source of distraction to engineers, often causing them to take shortcuts or operate at faster speeds than they would have otherwise.

We also heard of expressly unsafe behaviors resulting from production requirement incentives. A manager level employee at one railroad told us he often employed “out of the box” methods to keep trains moving, admitting they sometimes have implications for safety. We heard multiple instances from engineers at all three railroads of locomotives being put into service despite maintenance needs in order to keep trains moving.

While it is not clear how widespread these varying practices are among all railroads, it is evident that employees feel pressure to meet production requirements at the expense of safety.

Recommended Mitigations

We understand railroads are under pressure to provide frequent, on schedule trains for passengers. However, providing too-tight schedules with little slack creates conditions for errors. It is important to identify ways to reduce the demands across the system to enable employees to operate safely and recover from mistakes without compromising safety. Providing incentives for safe practices, in addition to on-time performance, will also reduce stop signal overruns related to production pressure. We offer the following recommendations:

- Understand that increased train density is a significant contributor to stop signal overruns because it results in more stop signals for the engineer. Consider adjusting the schedule to space out trains so that fewer trains are in the terminal at once.
- Adjust train schedules to be more representative of train distribution and crew turn-time needs.
    - Identify all the activities (safety and personal) that train crews need to perform and determine the time range needed for each activity.
        - Consider employees who are required to dead head into the terminal—particularly those dead-heading on empty equipment, who state that they often have short turn times because empty trains are given low priority to get into the terminal when

tracks are congested. These jobs may require extra turn-time built into their schedules.

  - Compare the total time needed to perform all these activities with the turn-time available for the train crews.
  - Make adjustments in either the procedures train crews need to follow and/or the amount of time available between trains.
  - Allow for some slack in the system based on historical data on late trains.
- Modify work flow requirements to offload tasks and reduce non-essential activities where possible.
- Use technology to facilitate information flow (e.g., rather than having to go up to office to get bulletins, receive them electronically).
- Provide similar incentives for safety as for on-time performance for all railroad employees.

5.3.2 Crew Assignment and Schedule

One organizational factor that can impact SSO is the process by which locomotive engineers and conductors are assigned jobs. Job selection occurs twice a year, in the spring and fall. New schedules are posted and employees are given the opportunity to select which job they want in the order of seniority, provided they are qualified for that assignment. This seniority-based process is governed by collective bargaining agreements.

A result of the seniority based job assignment system is that more senior engineers and conductors get the more desirable assignments. There are a variety of factors that impact job desirability, including how much the job pays, job location, time of day, etc. More desirable jobs are typically ones that conform to a regular work schedule (e.g., the territory over which they operate and the time schedule is the same each day, preferably during daylight hours). Less senior engineers and conductors are left to choose from jobs that have more variability in schedule (i.e., non-routine work schedules) as well as 'extra-list' jobs. Individuals who are assigned to the extra-list are 'on call' to fill in jobs for other personnel who may be taking leave days, sick time, or vacation. Because they are 'on call,' these assignments tend to be highly variable with respect to when you might be called (subject to the legally mandated hours of crew rest), what particular equipment (type of locomotive) you might be asked to operate and on what territory.

Contributors to SSO

One of the unintended consequences of this seniority-based assignment process is that less experienced conductors and engineers, because of their lower seniority, may end up with the more cognitively challenging jobs, with the result of increased risk of SSO. Jobs with less regular schedules (schedules that include non-routine start and stop times, particularly when they include both daytime and nighttime shifts) makes engineers more susceptible to fatigue (Raslear, 2014). Fatigue in turn contributes to SSO, particularly when coupled with inexperience.

Extra list assignments are especially challenging. As was discussed in Section 5.2.7, the unpredictable nature of when someone on the extra board will be called, as well as the fact that they can be called back to work as soon as the minimum legal hours of rest are satisfied, increases the risk of fatigue and thus SSOs.

An additional cognitive challenge of extra list jobs is that they have more route variability. Engineers on the extra list are less likely to traverse the same route each day. Thus, they have less opportunity to develop the kind of route knowledge that engineers who have a regular route gain that allows them to form and act on expectations of signal location, type and aspect. As discussed in Sections 5.2.2 and 5.2.3, experienced based expectations are important for rapid and accurate identification and response to stop signals. Train crews on the extra-board are less likely to have developed experience-based expectations, and are thus more vulnerable to SSOs.

At the same time, employees with high seniority are likely to have regular routes that cover only a portion of the territory on which they are qualified to operate. As a consequence individuals with high seniority are at greater risk of forgetting the physical characteristics for the portions of territory over which they no longer operate, as well as not learning the changes on those portions of territory that are likely to have occurred since the last time they traversed them.

Recommended Mitigations

- Understand that less experienced engineers are often assigned jobs with greater schedule and route variability, which may contribute to SSO.
- Provide additional support for individuals that are operating on a portion of territory that they have not traversed in the recent past. This includes providing job aids, such as accurate track charts that are tailored to the needs of locomotive engineers and conductors, as well as providing the opportunity to be accompanied by an experienced locomotive engineer or road foreman on a familiarization run on the territory prior to taking on the assignment.
- Discuss strategies with labor crafts for managing the bi-annual job selection process to mitigate the opportunity for the least experienced employees to work the most challenging jobs, for which they may not be as well equipped to handle. If adjustments to the job selection process cannot be negotiated, provide additional support in the form of job aids and training to the employees assigned to these jobs to minimize their potential to make mistakes on the job.

5.3.3 Dispatcher Train Management

The routes that dispatchers set can increase or decrease the probability an engineer will overrun a stop signal. If everything goes according to schedule, dispatchers told us, the routes they give each train could be scripted, and therefore, optimized to provide each train with the most efficient route out of the terminal. However unexpected conditions, such as train delays and breakdowns, occur often, which creates the need for train dispatchers to dynamically change the routing of trains. Experienced dispatchers say it can take several years to learn effective routing strategies that minimize disruptions and keep trains moving when delays and breakdowns occur. The routes that dispatchers set are important because they impact the amount and location of stop signals that an engineer will encounter. Effective dispatching include proper communication with train crews when necessary and giving clear routes when possible. Conversely, less optimal train routing can result in awkward routes, more “stop and go” within the terminal, and dropped signals—which all contribute to stop signal overruns. We discuss examples of poor train management and recommended mitigations to consider, below.

Contributors to SSO

Production Pressure

Conversations with dispatchers showed that dispatchers also feel production pressure. Dispatchers who work in the terminal told us that emphasis is placed on 'on-time' departures and arrivals. "On-time" may vary according to the railroad, but is often defined as being within 5:59 minutes (after the scheduled time of arrival or departure). In order to avoid a late departure in the terminal, for example, many dispatchers will send trains out from the platform as soon as possible—even if they are unable to give them the next signal—rather than wait and delay the train's departure in order to give the train a better route with less stop signals. Conversely, experienced dispatchers said they prefer to delay the train initially, even causing it to leave a little late, in order to give it a better route. Doing this often results in a faster route out of the terminal. Dispatchers would rather send trains out of the platform right away because they are evaluated based on their ability to move trains according to schedule rather than on providing engineers with optimal routes.

Dispatcher Inexperience

Dispatchers may also give trains more "stop and go" routing (i.e., advance trains one block at a time) in the terminal in order to keep the trains moving. This type of routing results in engineers seeing more stop signals, which increases the probability of stop signal overruns. This is in part due to pressure to keep trains moving, but also because of inexperienced dispatchers may not know effective routing strategies. Whereas, expert dispatchers are able to anticipate consequences of train movement and, therefore, move trains efficiently (even when unexpected situations like delays and breakdowns occur) inexperienced dispatchers often do not. This is in part due to inexperience and in part due to inadequate, non-uniform dispatcher training (we discuss dispatcher training below.) This type of efficient routing allows for quicker entrances and exits into/out of the terminal and at crowded interlockings. These strategies should be taught to less experienced dispatcher staff.

Related to dispatcher inexperience, engineers also mentioned scenarios in which the dispatchers forget a train at the station (and expect the train crew to remind them that they have been forgotten, which results in a delay) or forget to give a full route (resulting in stop signals where a more permissive signal would typically be). Engineers also brought up situations where dispatchers adjust routes at the last minute, which results in a dropped signal (changing the signal from permissive to stop after the train had passed a prior signal suggesting that the following signal would not be a stop). Forgetting to route and dropping signals both contribute to signal overruns. Stop signal overruns due to dropped signals are not considered stop signal violations and engineers are not found to be at fault. Nonetheless, we believe this is an important finding that may have safety consequences. The railroads we worked with do not store frequency data on dropped signals that result in stop signal overruns, therefore we do not know the extent to which this is a problem at the railroads. However, qualitative data suggested that many, if not all, engineers have experienced a dropped signal at one point during their career, though the dropped signal did not result in a stop signal overrun.

Discussions with dispatchers and engineers also suggest that dispatchers (particularly less experienced dispatchers) may not be aware of the challenges that engineers face, and are not familiar with the territory characteristics they are routing engineers through (particularly in the terminal). Dispatchers may unknowingly assign trains difficult routes, i.e., to platforms that are too tight given the length of the train, routes that cross many tracks, routes with signals around curves and/or signals that are very close together. These are all contributors to stop signal overruns. Conversely expert dispatchers told us, for example, they would only give engineers a permissive signal at certain locations if the following signal, which is closely spaced to the first, was also permissive so as not to create a trap for the engineer. These types of expert strategies help to mitigate stop signal overruns.

Dispatching Systems

The types of errors, or inefficient dispatching, that we discuss above could be mitigated if the dispatching systems were able to act as real-time decision aids to dispatchers to generate optimal routing based on the entire system. However, dispatching systems at the railroads we worked with do not currently have these capabilities. Dispatchers typically use the system to view train location and manually input train routes. Systems do not provide feedback to the dispatcher on their routing, though they do prevent egregious errors (e.g., trains routed to the same track). Dispatch systems also provide alerts for stop signal violations and power failures as well as some maintenance-related information, but generally do not include other information that would aid the engineer is providing better routes—like train length or signal aspect shown (dispatchers can only see if the signal is at stop, or is permissive).

We also heard instances of the dispatch systems portraying "phantom track occupancy lights" that might give dispatchers incorrect information about the state of the track, though at one railroad the dispatch manager said these are often known locations and dispatchers are able to quickly understand what occurred. During one stop signal overrun, however, the dispatch system failed to register it as a SSO and instead alarms indicated it was a "power and code failure." As a result, the train (that went through the stop signal) kept operating for upwards of 10 minutes. This could be because, as one road foreman told us, engineers may sometimes be unsure as to whether or not they went through a stop signal. Engineers may stop at the location and wait for a call from the dispatcher informing them that they passed a signal, if they do not receive a call they assume they did not go by the signal and proceed with their route. In this instance, because the dispatch system did not alert the dispatcher to the SSV (but did, incorrectly, alert the dispatcher to other failures) the engineer was not told he passed a signal. We also heard from one employee at one of the railroads we visited that the alert for a stop signal overrun is not easily noticeable and "does not really stand out." Important alerts, such a SSO alerts, should be obviously and quickly brought to the attention of the dispatcher.

Better, more advanced dispatching systems could provide dispatchers with more information about the state of the tracks and system as a whole, as well as provide optimal routes based on historical and current information of the system to avoid the pitfalls of inefficient routing discussed above. (We are aware that some railroads are in the process of developing new dispatching systems, though we do not know if any of these systems will have rapid re-planning capabilities. We hope the above mentioned issues will be resolved and suggested capabilities will be implemented.)

Dispatcher Communication

Finally, there is a need for better communication between dispatchers and train crews. Engineers gave examples of dispatcher communication as a source of distraction—for example, when dispatchers call to ask why the train is running late. However, engineers also expressed a desire for additional communication with dispatchers in other instances. For example, when giving a different route than usual, engineers said it would be helpful for dispatchers to call them and let them know to anticipate a different route. Locomotive engineers that we spoke with told us that experienced dispatchers often do this, but not all.

Dispatcher Training

Many of the issues described above are a result of lack of training and experience. Because dispatchers are not certified in the same way that engineers and conductors are, the dispatcher training programs have in the past been more informal. One of the railroads we visited had only in the past 2 years hired a Dispatcher Trainer, and the other railroad was in the process of re-vamping their dispatcher training program. These railroads are seeing a shift in dispatcher experience level, as many experienced dispatchers have begun to retire and railroads are hiring off the street. In part because employees are increasingly hired off the street, expert dispatchers at both railroads suggested more could be done to improve the training. In contrast to train crews who undergo both formal classroom and field-based training much of dispatcher training, they said, was apprentice based. In this model, a newly hired dispatcher would "post" with an experienced dispatcher and observe how they work. As a result, dispatcher training can be inconsistent. Similarly, because training was at the discretion of the dispatcher 'trainer' some apprentice dispatchers could "graduate" to full dispatcher status before they were fully ready, since they were not required to meet objective performance criteria as part of training.

Recommended Mitigations

More formal dispatcher training should result in more efficient dispatcher train management which will help to mitigate stop signal overruns. Expert strategies should be passed on to new hires through better training programs and more value should be placed on providing efficient routes to engineers.

There is also an opportunity for research and development efforts to develop more advanced displays, real-time decision-aids systems, and training aids to enable dispatchers and others involved in rapid re-planning to generate plans that are able to take the whole system into account and are able to prioritize movement of trains in such a way as to minimize overall delays, while also minimizing the number of stop signals trains experience.

- Dispatcher training should become formalized, with trainers receiving formal guidance on teaching expert strategies. The duration of dispatcher training should be determined by objective performance criteria such that trainees only graduate to "full dispatcher" after displaying competence.
    - Training should emphasize:
        - Efficient and safe train routing
        - Effective communication strategies
        - Workload management strategies

        - Strategies for rapidly identifying and responding to stop signal overruns
    - Training should include field observations to make dispatchers aware of the complexity of the territory they work over.
- Emphasizing efficient and safe train routing, rather than emphasizing on-time departure and arrival rates, could help to minimize potential for stop signal overruns.
    - Emphasis should not be on strictly adhering to time-table. This may cause dispatchers to prematurely route a train out of the platform only to then sit at a stop signal all the while blocking other tracks.
    - Based on discussions with expert dispatchers, efficient routing helps move trains in and out of the terminal more quickly.
- Railroads should consider procuring and/or developing software that would support more efficient real-time rerouting of trains to optimize the ability to maintain the schedule while simultaneously reducing the need to stop trains within the terminal.
- Dispatch systems should clearly and immediately notify dispatchers when a stop signal overrun occurs so that dispatchers can quickly stop the trains from proceeding.

5.3.4 Employee Training

Section 5.3 presented findings on the role of individual and team factors in SSOs. It emphasized the importance of individual knowledge and skill of locomotive engineers and conductors and how knowledge and skills can degrade over time. The section also emphasized the importance of developing teamwork skills. Teamwork skills include the ability to communicate and coordinate work within the train crew, skills in communicating with the broader distributed team (e.g., with dispatchers and yard masters), radio communication skills, and skills associated with conducting good job briefs. These individual and team skills depend on the foundation provided by initial training as well as the quality of ongoing refresher training.

Locomotive engineers undergo extensive initial training before receiving certification. Training consists of a combination of classroom training and on the job (OJT) training. The training is typically broken out in different modules (operating rules, equipment, territory characteristics) and tests are conducted after each module. The length of training varied across the railroads we visited, and ranged from 13 to 22 months. Classroom training covers material, such as operating rules (e.g., NORAC rules) and mechanical characteristics of the equipment (e.g., the different types of locomotives, and their components, such as the brake system and the cab signal system). In some railroads classroom instruction is supplemented with training on a simulator. Locomotive engineers are also required to memorize the physical characteristics of the territory on which they will operate, including the type and location of every signal. OJT is conducted by experienced engineers who are selected to serve as mentors. OJT covers yard, terminal and mainline operations. Locomotive engineers are evaluated during OJT and are tested on train handling and physical characteristics by road foremen before receiving their locomotive engineer certification.

Once certified, locomotive engineers get additional refresher training. Current FRA regulations require that the locomotive engineer operate over the territory for which they want to maintain their qualification at least once a year and recertify every 3 years.

In 2012, FRA instituted 49 CFR Part 242 that requires conductors to be also certified to perform their duties. As a result of the certification requirement, conductor training has become more extensive. In the past conductor training was as little as 4 months. The railroads we visited had recently implemented more in-depth training programs of up to 13 months.

As with locomotive engineers, current conductor training includes a combination of classroom and OJT. It covers both passenger related activities (e.g., ticket taking) as well as activities associated with managing the train consist, switching operations, and activities in support of the locomotive engineer (e.g., calling out signals).

Contributors to SSO

While initial and recurrent training is extensive for both locomotive engineers and conductors, we identified and were told about limitations of current training programs that can contribute to SSOs. Most notably:

- Training department resources are strained. Some railroads are experiencing a shortage of qualified training staff and/or have training staff that are relatively new.
- Keeping training materials up to date is a challenge. Examples include using outdated track charts and multi-media materials resulting in discrepancies between training materials and actual physical characteristics.
- Use of training simulators is limited. Some railroads do not have in-house simulators. In other cases, we were informed that the simulator software was out of date and has not kept up with the changes to the physical infrastructure. We were told of plans to upgrade simulator software and obtain state-of-the-art simulators but those were not yet in place during our site visits.
- The railroads depend on OJT for imparting some of the most important skills of train operations. This includes how to work as a team and effective communication and coordination techniques, and how to handle different complex situations that can arise in yard and mainline operations. However, opportunities to learn these skills vary with the particular activities that happen to occur during the OJT period and the quality of the mentor.
- The process by which mentors are selected and trained results in considerable variability in the pedagogical skills of the OJT mentors. In the past OJT mentors were often selected based on recommendation of the unions or because they were familiar to the training instructors. This did not necessarily guarantee that they had the mentoring skills or motivation to serve as an effective mentor. Further the selected candidates did not get any training on how to be an effective mentor. Several of the railroads we visited indicated plans to upgrade the OJT mentoring selection and training process.
- Conductor training does not provide sufficient training and experience on signal progression nor on conducting complex tasks, such as shoving moves that depend on rapid recognition of signals, estimation of distances, and communication and coordination with locomotive engineers. Conductors and locomotive engineers across several railroads indicated that more training and experience on signal progression and conducting shoving movements was needed.

- The current formal requirements for being qualified on a territory may not be sufficient for locomotive engineers to maintain detailed knowledge of territory characteristics. Engineers are considered to be qualified on a territory for up to a year from the last time they operated on that territory. However, as discussed in Section 5.2 knowledge of territory characteristics may deteriorate more rapidly than that, and there can be significant changes in signals, switches and rules in effect over that period of time. Another concern is that a locomotive engineer can maintain his or her qualifications on a line by merely riding in the headend with an engineer on that line. However, in order to maintain technical skill in may be necessary to actually operate a train on that line. Finally, we noted that some railroads require locomotive engineers to requalify on a territory on their own time which can serve as a disincentive.

Recommended Mitigations

SSOs can be reduced through more effective training. Many recommendations relating to training have already been listed in prior sections of this report. We relist them here with some additional recommendations intended to strengthen training programs so as to reduce SSO.

Recommendations Already Provided in Prior Sections:

- Provide simulator based training to accelerate and preserve train crew experience and knowledge of all branches of territories they will be expected to operate over.
- Combat engineer's reliance on incorrect expectations through simulator training. Simulators can be used to provide train crews with broader experiences of alternative routing and different signal aspects when reaching particular interlockings. The simulator can thus provide virtual experiences to help combat incorrect expectations.
- Provide scenario-based training to address particular challenges that come up with respect to SSOs. 'Scenario-based' approaches refer to explicitly designing simulated situations (i.e., scenarios) that the train crews are expected to respond to. These scenarios are intended to expose the train crews to complex situations they are likely to confront in actual events and provide them the opportunity to practice how they would respond. The scenarios can be set up in a high fidelity train simulator and/or through 'role-play' situations where for example train crews might practice performing a job brief, or communicating with dispatchers or yard masters.
- Provide systematic on the job training to build the perceptual, sensory motor, and communication skills required to perform challenging tasks such as shoving moves. Utilize objective performance criteria to establish mastery of those skills.
- Strengthen and reinforce training on signal progression, particularly for conductors.
- Communicate effective strategies for attention management and task prioritization and provide opportunities to practice them. Many examples were covered in the section on experience and route knowledge. For example, experienced locomotive engineers are able to prioritize focusing on upcoming signals over other potentially distracting tasks (e.g., responding to a radio communication). The skill that can be developed with appropriate practice.
- Explicitly teach effective behavior strategies that have been developed by experienced engineers for guarding against mental lapses. Many of these techniques are listed in the

section on experience and route knowledge and encompass train-related interactions, physical and verbal actions, and use of physical objects as aids to memory.

- Strengthen the training of conductors with respect to reading signals and understanding signal progression. Conduct performance-based testing to establish mastery of these concepts.
- Provide more extensive training on conducting shoving moves, paying particular attention to communication and coordination requirements between conductors and locomotive engineers. Conduct performance-based testing to establish mastery of shoving operations.
- Providing Crew Resource Management (CRM) training to train crews (locomotive engineers and conductors). CRM training is meant to educate crews regarding the roles and responsibilities of each member and how team members will communicate with each other. This should be helpful in getting locomotive engineers to speak up as needed (to institute a "sterile cab") as well as provide guidance for constructive communication among team members.
- Provide explicit training for communication between dispatchers and train crews (shown in Table 1).
- Allow and encourage train crews to take additional refresher train rides on company time when they feel a need beyond the annual requalification criteria.
- Re-evaluate the 1-year requalification criteria for maintaining currency on territory characteristics. Objective performance-based criteria should be used to evaluate whether a year is a reasonable length of time to expect locomotive engineers and conductors to be able to recall the characteristics of portions of track that they have not had the opportunity to ride over.

Additional Recommendations for Strengthening Locomotive Engineer and Conductor Training:

- Improve the process of selecting, training and evaluating the performance of the individuals assigned to mentor students during OJT.
- Ensure that training materials, including track charts, multi-media training materials, and simulator modules are kept up to date.
- Use 'scenario-based' approaches to develop more effective team communication and coordination skills both between conductors and engineers and between the train crew and others (e.g., dispatchers and yardmasters).

5.3.5 Supervisory Practices

An important part of ensuring continued system safety past initial training for employees includes supervisory oversight and supervisory practices. Some of these practices are Federally mandated whereas some are railroad specific, so the tasks supervisors are assigned may vary by railroad. However, at the railroads we spoke with many employees reported too few supervisors to conduct these necessary oversight tasks and safety checks. Some employees also reported concern with supervisor qualifications.

Contributors to SSO

Several railroads reported that they had insufficient road foremen to complete their required safety checks and supervisory practices. The ratio of road foremen to engineers varied by railroad, as did the tasks required of road foremen. Some road foremen reported being responsible primarily for check rides and operational efficiency testing, whereas others were also responsible for training. The ratio of road foremen to engineers, however, did not decrease as road foreman responsibilities increased. (For an additional discussion on road foreman to engineer ratios, see Section 5.4.1).

Road foreman, particularly at railroads with high ratios of road foreman to engineers, reported difficulty completing the required operational efficiency testing and check rides. Similarly, supervisors in the dispatch center reported insufficient staffing of supervisor level dispatchers, which resulted in dispatchers being unable to fulfill certain qualification requirements in a timely manner. Often, employees reported complying with the minimum standards set forth by FRA though some admitted that more would be better, if they had the resources.

Employees also expressed concern regarding attracting talented staff for management level positions due to significant pay cuts managers must often take. (Resource constraints are discussed in detail in Section 5.3.7). At two of the railroads we visited some engineers expressed dissatisfaction with the qualifications of the trainers and road foreman, who in some cases had very little experience operating as locomotive engineers. Supervisors themselves reported little training for important supervisory practices, such as investigating why stop signal overruns occur. As a result, they are often expected to "learn as they go" and use their experience in the field as a guide when conducting stop signal investigations. This is problematic when they have very little experience in the field.

Recommended Mitigations

Railroads should determine acceptable supervisory staffing levels based on required tasks, with the understanding that complying with regulations does not necessarily make the system safe. FRA regulations provide minimum standards, railroads should seek to exceed these standards when possible.

Railroads should also determine what qualifications are required in order to become promoted to supervisor. For example, how many years of experience as a locomotive engineer should one have prior to being eligible for promotion to road foreman, or engineer trainer? How many years of experience as a conductor should one have prior to being eligible for promotion to train master or conductor trainer? Placing too rigid requirements may inhibit the available pool of applicants, especially given the pay structure most railroads have in place. When increases in pay are not possible, railroads might consider providing additional incentives to attract talented employees.

5.3.6 Workforce Management

Contributors to SSO

The process by which railroads acquire and retain institutional knowledge occurs through the processes by which railroads plan for workforce development, transition and retention policies. In the past, new employees may have begun work in non-safety sensitive positions or moved from less safety sensitive positions to more safety sensitive positions (e.g., from block operator to dispatcher). Some of these positions no longer exist and new employees are more likely to join the railroad without any previous knowledge about railroad operations. These changes increase the time it takes to train new employees to learn the duties of locomotive engineer, conductor, and dispatcher. As the current generation of railroad employees retires, the railroads we studied lacked transition plans to accommodate the predictable rate at which current employees retired. The employee retirements created shortages in positions needed to operate passenger trains and allocate track authority. This loss of institutional knowledge also contributed to shortages in supervisory staff (e.g., road foreman or train masters) or support staff (e.g., training) with less experience than employees in these positions had in the past.

This lack of workforce development plans contributes to a loss of institutional knowledge as employees in specialized crafts (scheduling, dispatching, crew assignment) no longer have mentors with the same level of experience to teach them the specialized skills that take years to acquire. Without planning ahead and developing workforce development plans to smooth the transition process with high levels of turnover, they also neglected to solicit the information from these domains experts so that their expertise could be passed on to the next generation of employees. This loss is a missed opportunity to retain the strategies that employees, like dispatchers, use to minimize the potential for stop signal overruns while making more efficient moves that keep trains on schedule during high workload periods. When railroad employees acquire specialized expertise they can benefit from learning how these employees use their knowledge to safely and efficiently manage railroad operations. This knowledge can serve to support new employees through the development of decision support systems and can also facilitate faster learning on the job.

Recommended Mitigations

We recommend that railroads develop workforce development plans to plan for these generational transitions. We also recommend conducting cognitive task analyses to capture the knowledge of experts in specialized crafts that can be used to develop decision support systems that can facilitate sharing this information more widely.

5.3.7 Resource Constraints

Each of the six railroads we studied for this report experienced increases in demand for service while facing significant challenges in finding revenue to support their operating budgets. Employees at all levels of the organization reported that lack of funding created resource constraints in performing their work. Since transporting passengers takes precedence, supervisory and maintenance activities experience the impact of resource limitations more acutely. We discuss these findings below.

Contributors to SSO

Some railroads reported difficulty finding and keeping railroad employees, in particular management level employees, due to pay practices. At one railroad, a management level employee told us promoting an employee from train crew to train master or road foreman, for example, was becoming more difficult due to the decrease in pay that comes with the promotion. As a result, attracting talented people to important supervisory positions is increasingly difficult.

Supervisors, for example, indicated they lacked sufficient road foreman to perform important safety activities, such as check rides. (See Section 5.4 for a more thorough discussion of insufficient staffing for road foremen). Lack of road foreman oversight, particularly in performing efficiency tests and ensuring up to date crew qualifications, but also with informal tasks of checking in with train crews, has safety related consequences.

Adequately maintaining equipment is also challenging due to insufficient maintenance employees coupled with aging equipment. Malfunctioning equipment or equipment breakdowns have far-reaching consequences as they impact the schedule, dispatcher train management, and can be a source of distraction to the crew. These all have implications on safety and stop signal overruns.

For some railroads funding limitations also impacted locomotive engineer retention rates. Too few locomotive engineers leads to more engineers being called in off the extra-list. Often, extra-list engineers are newly hired and/or have inexperience with the territory. Another consequence of working on the extra-list is fatigue due to erratic schedules. Both fatigue and inexperience are all contributors to stop signal overruns.

Over the last decade all the passenger railroads in the studies experienced increased ridership demands. The increased ridership demands created additional pressure on the railroads limited resources since the railroads may not have been in a position to add staff and/or purchase additional equipment to support the rising demand. A management level employee at one railroad told us that the railroad's budget is not related to the level of service they are expected to provide. He went on to say they are asked to "do more with less money." Therefore, railroads responded to increased service demands by using their existing resources more intensively. As railroads sought to move more trains with less funding, employees and equipment in good working order, production pressures and short turn times increased. Schedule pressure manifested itself when the dispatcher called train crews to ask why they were delayed enroute. Train crews also experienced shorter turn times, meaning that the time allowed to complete procedures after arrival and preparing for departure was inadequate. This placed train crews in the position of taking shortcuts and potentially creating opportunities for stop signal overruns to occur. Poorly designed timetables also increase risk by increasing exposure to stop signals (Kohls and Watson, 2010). Kohls and Watson found that by modelling changes to timetables they could assess the change in stop signal overrun risk.

Recommended Mitigations

Lack of resources at all levels impacts the safety margin. Railroads should promote the importance of additional funding by making a business case for safety. Collecting the right data can allow railroads to perform a risk assessment based on sound data.

5.4 Regulatory Oversight and External Factors

5.4.1 Regulatory Implications and Recommendations for FRA

Railroads take direction from the regulatory environment in which they operate. Under 49 CFR Part 240, which regulates the certification of locomotive engineers, grew out of the Rail Safety Improvement Act of 1988 and the Chase accident in eastern Baltimore, MD, involving a collision between a passenger railroad and a freight railroad (NTSB, 1988). Among the factors responsible for the accident, the NTSB identified the locomotive engineer's use of marijuana and the deactivation of a safety appliance prior to the accident. The purpose of the FRA regulation (49 CFR Part 240) was to prevent employees from operating trains who lack the proper regard for their safety or the safety of others (Federal Register, 1989). However, this regulation focused attention on human behavior and ignored many other factors that play a role in SSOs. By contrast, following the Ladbroke Grove accident investigation in 1998, which also involved passing a stop signal, the United Kingdom's Rail Safety and Standards Board embarked on a research program to identify the factors that contribute to stop signal overruns and supplied the industry with a variety of recommendations for mitigating them.

In complying with this FRA regulation, railroads focused their attention on locomotive engineer behavior as the regulation required. In complying with the regulation, the railroads have downplayed the role that these other factors play in interacting with human behavior to contribute to stop signal overruns. Without receiving information about how these other factors contribute to stop signal overruns, it is understandable that railroads would focus their efforts on regulatory compliance.

The focus on regulatory compliance by the railroads has contributed to several unintended consequences. Since the regulation focuses on compliance with the behavior of the locomotive engineer, when FRA inspectors engage with the railroads to investigate a stop signal overrun or audit compliance with the regulations, they focus on the behavior of the locomotive engineer, conductor or dispatcher. The many other factors that combine in different ways to contribute to stop signal overruns are outside the scope of FRA regulations. While nothing prohibits FRA inspectors from investigating these factors, because they are outside the scope of the regulation, they are less likely to be considered.

Some railroad managers treat the regulation not as a minimum requirement, but as a ceiling on what they need to do to prevent stop signal overruns. Railroads comply with the 3 year certification process and the annual testing requirements, but generally do not exceed those requirements. FRA did not offer an explanation for why they selected the time intervals for recertification and testing. For some of the mangers we interviewed, compliance with this requirement meant that the railroad was operating safely.

Railroads require locomotive engineers to be qualified on their territory, which entails operating on that territory at least once in a year or taking a requalification ride. However, knowledge about the physical characteristics and skills can decay long before the end of the 1 year or the annual testing period. Since these requirements are unrelated to the rate at which knowledge or skills may decay with lack of use, the railroads may not be operating at the proficiency level intended by the regulation. Figure 25 shows the rapid rate of forgetting that can take place when practice ends. The abscissa shows the time that transpires following new learning. The ordinate shows the level of performance following this learning. Retention decays rapidly following new learning and then decays more slowly over time. Conducting research to identify the rate of forgetting in physical characteristics and skills can inform the railroad industry when training is needed for knowledge and skills related to passing stop signals and when testing should be done to assess knowledge retention and skill retention. This approach would provide an evidence based approach to the current annual requalification requirement for testing and recertification intervals.

Resource constraints limit the amount of time that railroads can devote to testing and training. So, there is an incentive to conserve resources by complying with the minimum requirements established in the regulations. Figure 27 shows the range in the number of locomotive engineers that a road foreman supervised across the six railroads we studied. The ratio for supervisors' ranges between 10 and 80 per person.

What is a reasonable number of employees for a road foreman to supervise so that they can perform all their safety functions? The road foreman at railroad 5 with 80 people per road foreman has less than half the time to spend with each engineer than any of the road foremen at the other railroads. Likewise, Railroads 3 and 6 have almost twice the supervisory load as the three railroads with the lowest number of employees to supervise. Determining the appropriate supervisory load can help the railroads determine whether supervisors can perform their safety management role adequately. Planning the required annual testing and recertification activities can consume significant chunks of time. Therefore, railroads may be reluctant to additional testing to their workload given the demands already placed on these supervisors. Does the road foreman support the training process? Establishing the conditions when testing and recertification are needed can help in making effective use of scarce railroad resources.

One road foreman suggested that a ratio of 1 road foreman to 25 locomotive engineers was a reasonable workload. If the training department supports the road foreman in managing the training elements of the road foreman's job, the road foreman might be able to handle a higher supervisory ratio. Thus, the appropriate supervisory ratio depends on their specific job responsibilities. Determining through research what the minimum number of road foremen needed to perform their safety related duties can serve as a leading indicator of resource constraints that may be impacting railroad safety.

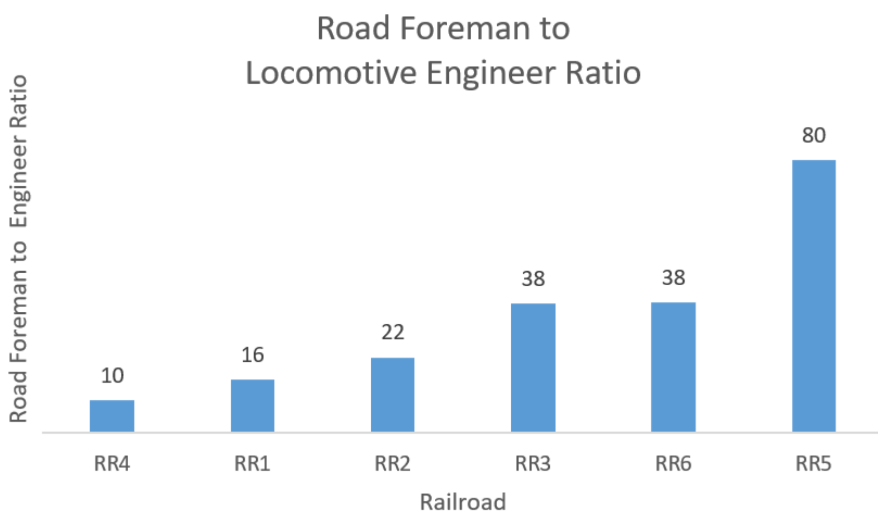


Figure 27. Ratio of Road Foreman to Locomotive Engineers by Railroad

Second, some people use the regulatory requirements as a justification to avoid going beyond the minimum safety requirements established in the regulations. For example when asked about the inability for locomotive engineers to see the signal in fog or snow, one railroad manager pointed out that it is the employee's responsibility to know where the signals are and comply. Because the regulation indicates that passing a stop signal is evidence that the employee has failed to attend to operational safety concerns, the railroad normally removes the locomotive engineer from service. Unless the railroad identifies a problem such as a signal system failure or the dispatcher took an action that changed the signal to stop without giving the engineer sufficient notice, the engineer is disciplined. Another manager stated that since the locomotive engineer was qualified based on passing the qualification test months or years earlier on the territory, they should be able to operate safely over the territory regardless of whether they have operated over that territory recently.

The Federal regulation for locomotive engineers discourages learning from stop signal overruns in its approach to asking the railroad to determine the employee's conduct that contributes to unsafe behavior and its focus on employee discipline (Federal Register, 1989). It says nothing about investigating how the railroad system contributes to these events. The regulation suggests the use of a point system in administering discipline, like those used in many railroad discipline systems. The administration of discipline contributes to the suppression of learning about the event as employees will minimize information disclosure to minimize the level of discipline applied.

The regulation (Part 240) has not been updated to reflect the safety research that has been published since the publication of the final rule in 1991. The current study suggests that the use of discipline as recommended in FRA regulations is ineffective in reducing stop signal overruns. The challenge is how to get beyond using discipline as the primary mechanism for addressing stop signal overruns. While it enables the railroad to deflect blame onto the frontline employees, it inhibits the opportunity to learn how the railroad system contributes to stop signal overruns. Looking beyond the simple explanation that the employee was at fault offers an opportunity to learn from these failures. The current study and the body of research that has accumulated since the Chase Maryland accident points to a multitude of factors that contribute to stop signal overruns (Safar et al., 2015). The United Kingdom regulator (Health and Safety Executive) has moved away from recommending blaming individuals and has developed investigation guidance that involves root cause analysis (Rail Safety and Standards Board, 2014).

The ability of FRA to analyze accident/incident data and data on stop signal overruns depends on the quality of the data it receives from the railroads. As FRA noted in the notice of public rulemaking for 49 CFR Part 240, it encountered difficulty analyzing its data because the data did not indicate causal factors. The problems we describe about the data collection and analysis of railroad data in Section 4 impact the data that FRA receives as well. Another part of the problem results from FRA reporting requirements in the accident/incident database. The data fields in the database allow railroads to enter a primary and secondary cause. The fixed fields that FRA provides do not allow railroads to enter the kind of contributing factors described in this report. For example, the causal code "Automatic block or interlocking signal displaying a stop indication - failure to comply" is an outcome, not a cause. With the opportunity to enter only one or two factors, the report lacks the information necessary to understand how or why these events occur. Additionally, the narrative data that accompanies the report varies from one or two sentences to a paragraph. This amount of detail in a narrative is insufficient to support a detailed understanding of the event. The database only requires railroads to submit reports that rise above an inflation adjusted reporting threshold which means that the database provides an incomplete picture of the frequency with which these events occur.

If FRA wants to support reductions in stop signal overruns, it needs to monitor the railroad system, not just behavior of the locomotive engineer and the conductor. To support this change, it will need to collect data on a much larger set of factors than it is currently collecting data.

Collecting data on the kinds of factors discussed in this report will contribute to better insights on how railroad systems contribute to stop signal overruns. Monitoring trends over time will enable to see if industry efforts to fix the identified problems and where the industry may need assistance.

6. Discussion and Recommendations

6.1 Considerations for Improving Data Collection and Analysis

The railroads we studied were generous in sharing their data for this study and providing employees to interview. This data provided a rich source of information to understand why trains pass stop signals in passenger service. In reviewing the data, we identified several opportunities to improve the data collection and analysis process that will enable the railroads and FRA to better identify the source of the risks associated with passing stop signals.

The process by which the railroads investigate stop signal overruns is biased in favor of collecting information to support the discipline process over learning from failure. FRA regulations 49 CFR Part 240 (applies to locomotive engineers) and 49 CFR Part 242 (applies to conductors) requires railroads to discipline locomotive engineers and conductors who are found to be at fault after a SSO. The regulation gives the railroad discretion to decide whether the employees are at fault and the level of discipline to apply. The investigation process tends to focus on the train crew's behavior and assigning responsibility for the failure rather than understanding the factors that contributed to the event and how to prevent the failure from recurring. After detection of a stop signal overrun, the railroad pulls the train crew out of service and replaces them with another crew. The investigators will test the crew for drugs and alcohol and ask the crew to give a statement to the explaining what happened. The Communications and Signal department checks the operation of the signal system. If the Communications and Signal department determine that the signal system operated properly, the railroad's transportation department proceeds to the disciplinary process. The regulations clearly state that the locomotive engineer and/or conductor are at fault after a train pass a stop signal. While the regulatory requirements do not preclude the railroad from continuing to investigate to learn why these events occur, in practice railroads do not take the opportunity to learn from these near miss events. The tracking of stop signal overruns takes place for the purpose of meeting regulatory record keeping requirements.

The potential to lose their certification and their opportunity to work as engineers and conductors inhibits the opportunity for railroads to learn from SSOs and prevent them from occurring in the future. Employees are reluctant to share information if they believe that information will harm them. While railroad managers in our study expressed sympathy for train crews and did not think they were purposely passing stop signals, they viewed explanations involving employee behavior as evidence of the employee's fault in the event. If the event involved inattention or distraction, no one recorded the source of the inattention or distraction. Was the distraction work related or non-work related? Whether this was the result of the reluctance of the employee to share more information or the failure of the investigator to probe more deeply is unknown. Both factors may play a role. Nevertheless, providing an environment in which this kind of information is pursued and documented would be useful in designing measures to minimize stop signal overruns.

The investigation process as it currently operates to support the regulatory requirements associated with certification conflicts with the goal of investigation for the purpose of learning from the event. Given the lack of improvement over time in the frequency of stop signal overruns, our study suggests that discipline is not an effective measure in reducing the frequency of these events. Using these events as learning opportunities for improving safety may be a more fruitful avenue for preventing future stop signal overruns.

The investigation process is not limited to talking with the train crew. Railroad managers will also interview the dispatcher and check the status of the traffic control system that the dispatcher uses to manage train movements and check the signal system to determine whether these technologies operated as designed. However, none of the railroads we studied integrated the different sources of information to enable a holistic analysis of the event and only one railroad examined trends across multiple events. Instead the investigation reports were stored in paper documents in one place. The documents were never digitized so that they can be easily accessed in the future. Data that was stored in digital form was typically stored in separate databases. The data that is collected from interviews and converted to digital form is often an abbreviated summary that leaves out important information for understanding the event. If reports are consolidated, they are stored in paper files and archived in a way that makes it difficult to retrieve. Once archived, the reports were rarely reexamined. As part of regulatory requirements, each railroad provides FRA with a summary of data from those stop signal overruns that meet the reporting requirements. Due to how the data was stored, senior managers could not access current information about the state of safety on their system or obtain a picture of how safety was changing across the system.

We encourage railroads to integrate the disparate sources of information so that they can easily access this information. Modernizing their information systems to accomplish this goal will also enable them to support a new regulation 49 CFR Part 270 requiring passenger railroads to develop and implement system safety plans (Federal Register, 2016). As part of developing system safety plans, they will need to identify and manage hazards within their system. Integration of multiple data sources will enable decision makers to better track in real time the state of safety on their railroad. The problems we identified related to the investigation process, inaccurate or incomplete data entry, data cleaning, and lack of integration with multiple sources of information suggest that decision makers possess an incomplete picture about the current state of safety on their railroad. In addition, providing the complete narratives from interviews in digital form provides a more complete picture for railroad analysts to evaluate.

Another opportunity to improve the data collection process involves introducing error checking to correct errors that take place during the data collection process. When documenting the results of their investigations, employees make two types of errors that if not corrected create an incomplete or inaccurate representation of the facts. First employees make errors that result in data being miscoded or coded in different ways. Numerical information like milepost locations or signal names may contain transpositions or typographic errors. While knowledgeable railroad employees may be able to adjust for these errors if they review the raw data, the information systems that an employee uses to analyze the data may not be able to make adjustments for these errors. Second, different investigators document the same type of information in multiple ways. So a station name may be referred to by its full name or an abbreviation. The result is an analysis that provides an inaccurate representation of the problem.

To solve erroneous and inaccurate data entry, the railroads can introduce error checking processes. Provide a uniform set of terms for common fields that investigators will use. Providing a standardized form, preferably in digital form can streamline the process and show all the fields that are available to use. Appendix D shows the type of data to collect as part of this effort. It uses both simple check boxes to facilitate selecting categorical information and a text box to provide a narrative of the event along with additional details learned from the interviews. Changing the data collection process from a paper-based process, in which investigators prepare handwritten documents, can be replaced with digital tools using speech recognition and computer based data entry will make it easier to share the data from an investigation with other employees quickly and easily along with reducing the potential for making data entry errors. Once the information is entered into the system, the railroad can assign an employee to complete the data validation and verification process by checking for consistency in the use of names. The use of computer based tools can support the modernization of their information systems. We recommend that the FRA pilot test use this template with one or more railroads. FRA can make the resulting template available for the railroads as a uniform method for collecting information during SSO investigations.

Another area where the railroads can better support their investigation process is by providing training in how to conduct an investigation for the purpose of understanding why the event occurred. Railroad employees who conduct the investigations generally receive no training in how to interview employees or how to collect information, (e.g., witness statements, interviews, photographs, event recordings), analysis and synthesis of the event data and how to document their findings. The narrative reports we reviewed varied widely in the information they provided. We could not determine how much variability was due to the reluctance of the employee to share information and how much was due to the skill of the interviewer to solicit information and document that information. We recommend that railroad managers with responsibility for event investigations receive training in all facets of the investigation process. Investigators who interview employees after a stop signal overrun can benefit from learning how to interview employees and collect evidence, such as photographs and event recordings, analyze event data, and document their findings to produce safety improvements. Learning how to frame questions and how to probe for additional information is a skill that can improve with training. Providing investigators with training in how to interview employees can improve the quality of the information that they collect. We also recommend that investigations involve at least two people. One person should focus on interviewing the employee while the second person focuses on recording the information (Willis, 2005).

In US passenger railroads, managers within each functional department investigates its own employees' role in the event. The road foreman interviews the locomotive engineer and the trainmaster interviews the conductors. The chief dispatcher interviews the dispatcher involved in the event and someone in the communications and signal department investigates the state of the signal system. Since the investigation process tends to focus on rule compliance, once railroad managers decide whether to proceed with discipline, the event investigation concludes. When the investigation is complete, information gathered from different sources is not always integrated to create a holistic picture of how the event unfolded and how systemic factors contributed to the event. Assigning the responsibility to a single entity, such as the safety department, can facilitate this process.

An important task in integrating the disparate sources of data involves aggregating the contributing factors identified to see how the factors change over time. One way to know if particular mitigation efforts are effective is to track how the contributing factors change over time along with tracking the number of trains that pass stop signals. Figure 28 illustrates how a railroad can track this data over time. The top left half of the illustration shows examples of contributing factors that a railroad might track. The right hand side of the figure displays the yearly frequency with which each factor was identified. The chart at the bottom of the figure shows the annual count of stop signal overruns. As the railroad implements actions to address one or more contributing factors, the railroad can monitor how their occurrence changes. As the railroads learn about how different constellations of contributing factors occur together or under particular circumstances, they can refine how they track these contributing factors.

CONTRIBUTING FACTOR TRACKING TEMPLATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Engineer & Conductor Certification					1			2		1						
Regulatory Mandated Testing		1					3			2	1		1	2		
Production Pressures	2		6	8	2	1	3	5		3		4	4	6	2	3
Employee training	1	2	4	3	4	5	2		2	3	4	5		2		1
Crew Assignment & Schedule			1		2		2	1		2	3	1		1	1	
Supervisory practices																
Cross-railroad processes	1		2		3		1	2		2		2	3		2	1
Communication	2	3	2	3	1	1		2	4	5	2	4	3	3		
Route knowledge			1		2		2		3		1		2		3	
Expectations		2	1			3	2			2	1		1			1
Distractions		1	1	4	3	2			1			2	2	1	1	
Signal placement				2				1		2		1				
Signal Maintenance	1		2				1						1			1
Job Aids					1			1						1		
Station Dwelling	2		3		2	1	2			1	1		2	1		
Locomotive Type				1				1								
Displays and Alerts		1					1			2					1	
Signal Design	3		2		2	1			2	1				1		

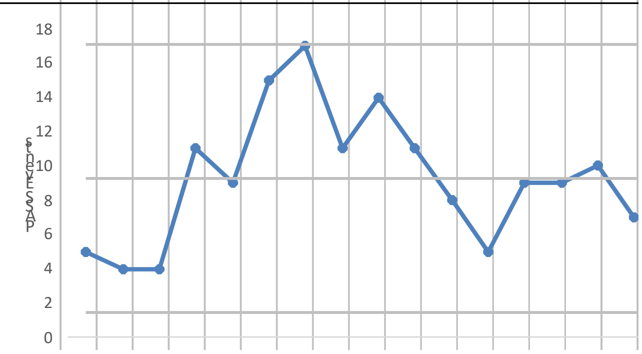


Figure 28. Tracking Contributing Factors Over Time

There is an opportunity for railroads to learn from each other by standardizing the terminology they use to talk about contributing factors to facilitate communication between railroads and with FRA. Benner (2013) discusses the value of standardizing the collection of incident data so that actionable information can be used to effect change. As part of its regulatory oversight, FRA convenes a meeting each year for the Class I railroads and large passenger railroads to share information on the number of trains that pass stop signs and the actions that they have taken to address these unwanted events. However, the kind of information that they collect and track vary by railroad as does the language they use to describe this information. Appendix A shows a list of data fields collected to monitor stop signals for five of the six railroads for which we received data. This data reflects the data they shared with us and may not reflect a complete list of the data that they track. Nevertheless, the variation in data collected from railroad makes inter-railroad communications more difficult. Since passenger and freight railroads do operate over each other's territory, using a common language and sharing data that can be understood without confusion would facilitate communication about problems between railroads.

Finally, to better approximate the risk of passing stop signals FRA and the railroad industry should obtain data on the total number of signals in the territory being evaluated (or, if possible, the total number of times a signal displayed stop when a train was approaching). Currently, the US railroad industry uses train miles as the denominator in calculating the SSO rate. However, passenger railroads often space their signals closer together whereas freight railroads often do not require the same number of signals within the same track mile. As a result, using train miles as a denominator can overestimate the risk for passenger railroads and underestimate the risk for freight railroads.

6.2 Train Crew Qualifications Impacted by the Job Assignment Process

In the United States, passenger railroads assign locomotive engineers and conductors to specific jobs based on a bidding process negotiated in their collective bargaining agreements. These agreements enable employees to select which job they work usually two times a year based on seniority. As a result of the way in which employees select jobs, employees with lower seniority were more likely to operate over more of the territory that they were certified to operate over. Employees with high seniority were more likely to operate over only a portion of the territory on which they were certified to operate. In this situation employees with high seniority are at greater risk of forgetting the physical characteristics for the portions of the territory over which they no longer operate as well as not learning the changes on the territory that occur.

Current FRA regulations require that the locomotive engineer operate over the territory for which they want to maintain their qualification at least once a year and recertify every 3 years. However, locomotive engineers and conductors we spoke to indicated that their knowledge of the physical characteristics degrades long before 1 year goes when they go without operating on the parts of territory for which they are certified.

This problem is more challenging for conductors, since they spend most of their time in the body of the train and cannot easily observe wayside signals. In 2012, FRA instituted 49 CFR Part 242 that requires conductors to be certified to perform their duties. This regulation can result in a conductor losing their certification if a train passes a stop signal when the conductor is in the locomotive cab or control car. In our study, some conductors expressed reluctance to enter the cab or control car to avoid the potential for losing their certification. However, they may be required by operating rule to support the engineer in reading signals.

As conductors spend most of their time in the body of the train, they have less opportunity to learn and maintain their knowledge of the physical characteristics when viewed from the cab or control car. Consequently, their knowledge of the signals as viewed from the front of the train degrades even on territory over which they regularly operate. When they need to confirm signals in the head end or support a reverse move, they may lack the experience to support these tasks. As a result, conductors may not serve as an effective barrier in preventing trains from passing stop signals without permission.

We recommend that FRA conduct research to better understand how the variety of factors that impact knowledge and skill retention. How much time can lapse when no longer operating over a territory before requalification is necessary, and what kind of performance demonstrates a satisfactory threshold for maintaining a qualification? This research could facilitate the railroads ability to design more effective training programs to maintain employee proficiency in train operations and help determine when railroads should test their employee’s knowledge of physical characteristics and skill retention. Recertification and training intervals should be based on an assessment of knowledge and skill retention that reflects actual practices not an arbitrary time for assessing qualification. As railroads introduce new technology into the locomotive, such as energy management systems and PTC, FRA should revisit how skills and knowledge degrade, as well as assess whether recertification and periodic testing needs adjustment.

6.3 Brittleness of Team Processes Contribute to SSO Vulnerabilities

Three railroad processes: crew scheduling, crew design, and training impact teamwork in ways that increase vulnerabilities to SSO. Together, the design of these processes create maladaptive interactions among train crews and dispatchers that increase the likelihood of SSO.

Crew scheduling takes place based on a system negotiated as part of collective bargaining agreements (CBAs) in which employees bid on job assignments based on seniority. Job assignments do not take into account the employee's experience, skill level and complexity of the job assignment in deciding how to allocate employees. Instead employees bid a job based on personal factors, such as the pay they may receive on a particular job, or the date and time based considerations. Safety considerations play a role in that employees can only bid for jobs on the territories for which they are qualified to operate on. If an employee is qualified to operate on a particular territory, then that employee is assumed to be capable of performing the work safely.

In practice, the least experienced employees start on the extra board where an employee takes the place of another employee who calls in sick or takes vacation. These jobs are on-call jobs which means unlike the scheduled positions there is greater uncertainty about when they will be called to work. These employees are at greater risk of coming into work fatigued and the job assignments vary from day to day in terms of what trips they will make. While the breadth of experience across territories benefits these employees in giving them opportunities to gain experience, it also means they are likely to experience very little stability in terms of the other employees they will work with. They have less opportunity to develop shared mental models with a given group of employees because they are constantly working with different employees.

Day-to-day job assignments occur independent of craft. So an individual locomotive engineer may find him or herself working with multiple conductors over the course of a day. Similarly, conductors find themselves working with multiple locomotive engineers. The lack of time working with the same group degrades teamwork performance since their time together is limited (Hackman, 2002). Each employee must adjust to working with different people over the course of the day. As time that a team spends together increases, the number of errors declines (Hackman, 2002). Working with the same team members on a regular basis gives them the opportunity to develop effective working relationships and develop shared mental models. Freight operations are more likely to experience these kinds of arrangements (referred to as married pools) where one locomotive engineer and one conductor make many trips together. We suggest experimenting with teams that work together on a regular basis to evaluate this process change on safety.

Employees aspiring to become conductors or locomotive engineers are trained separately. They first receive classroom training that focuses on learning the operating rules and how the equipment and track infrastructure operate. Then, employees receive on the job training. The training in both instances focuses on their individual duties. Each employee learns the job duties related to their craft. However, once in revenue service, locomotive engineers and conductors need to interact with each other. Most passenger railroads provide no formal team training in how to work with each other. Crew resource management training which focuses on interpersonal communications, leadership, and decision-making would support learning how to interact with each other (Morgan et al., 2007) (Roop et al., 2007). Joint training that provides the opportunity to practice addressing common problems that involve joint problem solving would also help. For instance when a train is dwelling at a station and the locomotive is in close proximity to the signal that controls its movement, it is imperative for the conductor to coordinate with the locomotive engineer in a way that the engineer does not automatically proceed after the passengers have completed the boarding/disembarking process and closed the train doors, if the signal is at stop. Providing joint training to address this scenario could reduce the likelihood of this pathway to passing a stop signal.

6.4 Implications of Introducing PTC for SSO Accidents

PTC improves safety by making the railroad system more error tolerant. PTC is designed to trap human errors and slow or stop the train if the locomotive engineer does not stay within the limits of their track authority. If an engineer misses a signal, PTC should stop the train before reaching the limits of its authority. It will also enforce the speed at which the train is traveling and prevent the train from overspeeding. Our analysis of accidents resulting from passing stop signals suggests that PTC will exert a more positive impact in freight operations where 45 percent of stop signal related accidents took place at speeds above 20 mph compared to 12.5 percent for passenger operations. PTC will contribute to a reduction in SSOs and stop signal related accidents. Where stop signal related accidents do occur, they are likely to take place at lower speeds reducing their potential severity.

PTC will also create new safety challenges for both passenger and freight railroads. First, PTC will increase system complexity that will make it more difficult to uncover safety problems. PTC implementation requires railroads to install new technology in the locomotive, in the track infrastructure and in the office environment. The technology includes hardware and software. The addition of this technology layered on top of the existing infrastructure will increase interdependency between different components and expand the number of paths by which an accident can occur. The increase in the number of paths by which an accident can occur will make it more difficult and time consuming to identify the causal factors after an accident occurs.

Adding PTC on top of the existing safety system may result in unintended consequences by masking the problems that contribute to stop signal overruns identified in this report. PTC will mitigate the failure modes that contribute to stop signal overruns. By mitigating the adverse consequences of system design and operation that contribute to stop signal overruns in the absence of PTC, the systemic problems remain hidden. There is also less incentive to address the underlying conditions that contribute to those adverse consequences since PTC will protect the system. For example, a maladaptive work schedule that contributes to fatigued employees or distractions from competing work demands may no longer be addressed if the train never passes a stop signal due to the PTC system. However, these conditions may manifest themselves in other ways that compromise system safety or occupational safety. When a train goes from territory protected by PTC to unprotected territory, these factors will still be in place. A fatigued employee who can operate the train safely due to PTC may be at risk when commuting to and from work. Many of the systemic factors we identified may apply to other unwanted safety outcomes such as operating through switches in the wrong direction or run through switch related derailments. The smaller number of stop signal overruns that are expected following the introduction of PTC will make the analysis of these close calls more important to learn how the system is contributing to these events.

The implementation will also change the behavior of locomotive engineers in ways that will impact safety. With the knowledge that PTC will stop the train prior to a SSO, how will locomotive engineers direct their attention? How will PTC change how they operate their trains? Will their skills atrophy? What challenges will train crews experience when transitioning between PTC and non-PTC territories? Research supported by FRA (Einhorn et al., 2005; Marinakos et al., 2005; Roth and Multer, 2009; Sheridan et al, 1994) suggests that some of the ways in which locomotive engineer's behavior may change. This research suggests that the locomotive engineer will allocate their attention differently with PTC and adopt different strategies for train control. It will be important for railroads to monitor the locomotive engineers' performance to identify how these behavioral changes manifest themselves in SSOs and address them where needed.

6.5 Countering Some Commonly Held Misconceptions

Our review of how individual and team factors influence performance counters some commonly held (but inaccurate) beliefs in the railroad industry about human cognition. These misconceptions lead to unrealistic expectations about what can be expected of train crews, the primary causes of SSOs, and what might be effective mitigations.

During interviews with railroad employees at all levels of the organization, we encountered the following commonly held misconceptions:

(1). Since train crews are qualified on the territories they operate, they retain knowledge of the location and characteristics of the signals on those territories regardless of how much time they spend on that territory.

(2). Train crews should not rely on past experience. They should operate on the information provided by signal progression and be prepared to stop.

(3). Some SSOs occur because train crews are not paying sufficient attention. We were commonly told that SSOs occur because of 'complacency' or distraction.

(4). An effective way to reduce SSOs is to initiate communication campaigns that highlight the dangers of SSOs and urge train crews to 'focus' more.

The results of our study points to why these commonly held beliefs are oversimplifications. While training is important, personnel cannot be expected to retain a photographic memory for the material covered. A fundamental characteristic of long term memory is that it degrades over time. One cannot assume that because someone is qualified on a territory they will retain knowledge of the location and characteristics of signals on that territory until the expiration of the 1-year qualification period. In addition, the railroad environment is dynamic. It changes over time. As operating conditions change their knowledge becomes out of date if they do not operate over it continuously.

Operating on expectations is another fundamental characteristic of human cognition. People will more readily perceive and act on information they expect and are more likely to make errors in situations where expectations are violated. Developing expectations is a component of the skill acquisition process. As a consequence, asking people to ignore past experiences is unlikely to be successful. Offering periodic training where locomotive engineers are exposed to unexpected conditions can mitigate this problem. Similarly, dispatchers can change a train's routing periodically so that engineers receive greater variation in their routing and signal progressions.

Similarly, a common explanation for why SSOs occur is due to lack of attention on the part of the individual(s) in the cab responsible for identifying stop signals. People at all levels within the railroad organization, ranging from the locomotive engineers and conductors themselves all the way up to the highest levels of management used phrases such as 'complacency' and 'distraction' as the reason in their opinion that SSOs occur. While inattention and distraction play a role in many SSOs, hindsight bias leads to the inference that they were not focusing on the stop signal when their attention was directed elsewhere. This view leads to the inference that SSOs can be reduced by simply urging individuals to

focus more attention on signals.

Figure 29 shows a coin that one railroad gave its locomotive engineers to direct their attention to the signal system. During interviews and focus groups locomotive engineers and conductors often mentioned paying closer attention as a way to reduce SSOs. Based on a similar belief, a common mitigation strategy to reduce SSOs implemented by railroads is to initiate campaigns designed to alert train crews to the dangers of SSOs and urge them to 'keep the focus' on monitoring signals.

Figure 29. Token to Focus Locomotive Engineer's Attention

As we tried to show through multiple railroad examples, while distractions and mind wandering contribute to SSOs by diverting attention from monitoring for signals, these internal processes are difficult to control, consciously. As a consequence, communication campaigns that highlight the dangers of SSO and admonish train crews to focus attention on signals are not likely to have a strong impact on reducing SSOs since attentional processes are not largely under conscious control.

Inattention and distraction come from multiple sources. Distraction from competing work demands calls for a different kind of response than when the engineer's mind may wander. Appropriate interventions will vary depending on the source of distraction.

This report aims to counter these types of common misconceptions in the railroad industry and offers recommendations for ways to mitigate SSOs that more fully take into account fundamental characteristics and limitations of human cognition.

6.6 Synthesis of Findings

Passing stop signals and the accidents that result from those events are rare events. Based on our small sample, 98 percent of locomotive engineers will never pass a stop signal in a given year. The likelihood that a passenger train will be involved in an accident that results from passing a stop signal is 1.8 per one hundred million train miles (1.8×10^{-8}). The rate for freight trains is similar (1.5×10^{-8}). When we examine which railroads experience stop signal related accidents, they tend to be the railroads with the highest exposure in terms of train miles traveled. Identifying railroad exposure as a function of how many stop signals trains encounter would give a more accurate characterization of risk and support improved decision making in deciding how to allocate limited resources to address stop signal overruns. In freight operations four railroads accounted for 80 percent of the accidents. Similarly, in passenger operations, three railroads accounted for 80 percent of the accidents. The majority of freight and passenger railroads never experienced a stop signal related accident. Thus, reducing stop signal related accidents at those seven railroads would have a major impact on reducing this accident type.

When these accidents do occur, the public views the harm that occurs as unacceptable. This perception creates pressure to act to prevent these events from occurring again, such as the Rail Safety Improvement Acts (RSIA) of 1988 and 2007. Our analysis of FRA accident data indicate that the rate of stop signal related accidents in the United States remains unchanged for the whole industry as of 2015. While the actions taken because of the RSIA of 1988 and 2007 may contribute to safety across the industry, they have not reduced the rate of stop signal overruns or accidents related to stop signal overruns. Based on the conditions where PTC will be implemented, we hypothesize that PTC will result in a small reduction in stop signal overruns of around 12 percent for passenger operations and a larger reduction of 45 percent for freight operations, assuming no other changes take place. Larger reductions will require changes to the processes by which railroads operate.

In reviewing the accident data from NTSB and FRA and in interviewing employees at multiple railroads, we identified multiple factors that combine in different ways to contribute to SSOs. Our finding that multiple factors play a role in stop signal overruns is consistent with the findings of researchers in multiple countries (Banbury et al., 2015; Independent Transport Safety Regulator, 2011; Naweed 2013; Naweed 2014; Van der Flier and Schoonman, 1988). Our findings describe how the context in which railroad operations take place influence the way stop signal overruns manifest themselves. We observed that accidents tend to take place in different locations that reflect differences between freight and passenger operations. As one might expect, the majority of freight accidents take place on the main line with a small number near sidings and grade crossings. For passenger operations, the highest frequency of accidents were evenly split between locations on the mainline and near terminals or stations. In urban, light rail (subway) systems, SSOs occur most frequently in stations when the operators are also attending to other duties (Rjabovs and Palacin, 2016). When we examined stop signal overruns, we also observed that these events clustered at particular locations.

Our findings suggest that the nature of the work that takes place at these locations and the context in which this work takes place contributes to how stop signal overruns occur. Terminal stations represent the most complex environment and experience the highest number of SSOs. Approaching a signal in a terminal environment frequently occurs in a high workload situation, where the engineer must identify the proper signal among a large potential set of signals. The complex layout and number of signals can result in the engineer obeying the incorrect signal. At other stations, SSOs tend to occur when the train is preparing to depart. In that situation, the locomotive engineer is operating in a low workload environment waiting for the conductor to indicate the train is ready to depart. The signal may be close to the cab and when the locomotive receives the signal from the conductor to depart, the engineer may depart without assessing the state of the signal. Although this scenario can also occur in the terminal environment, it occurs less frequently than the scenario involving the approach to the terminal.

An important implication of this finding is that if railroads collect information to document how the context contributes to stop signal overruns, they can use this information to influence these factors. Understanding the context in which these factors can suggest how the railroads can adapt their system to reduce stop signal overruns from occurring.

6.7 Using Stop Signal Overruns as Opportunities to Learn from Failure

A consequence of focusing on SSO investigations for the purpose of punishment instead of learning is revealed in the following account of a stop signal overrun that took place at a passenger railroad. Figure 30 shows the path that each train took. In this event, the dispatcher lined Train A to proceed (traveling east) from the station and wait at the next signal labeled 4E until the Train B (traveling west) in the opposing direction on track 1 crossed over the switch labeled 3B/3A to track 2. After Train B crossed over to track 2, Train A was lined to cross over to track 2 at switch 1A/1B.

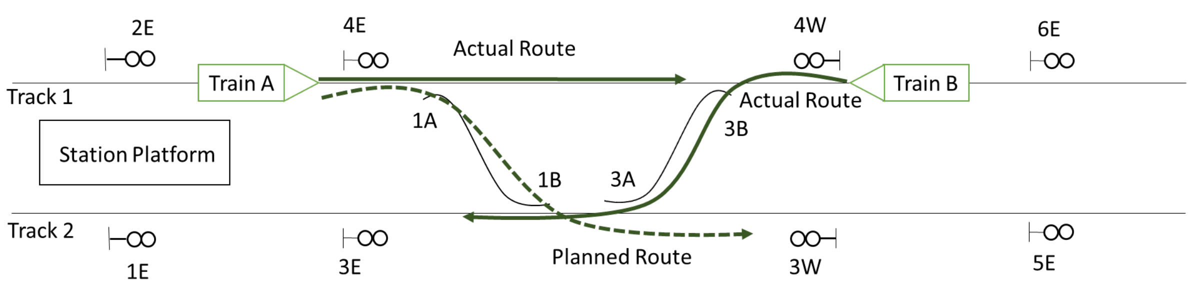


Figure 30. Track Layout Showing the Direction of Travel for Two Trains

Train A proceeded east from the station past signal 2E, which displayed a restricting signal. The restricting signal tells the locomotive engineer that the next signal may be a stop signal and should be prepared to stop. As Train A approached the stop signal 4E, Train B was passing the permissive signal 4W on track 1 preparing to cross over to track 2. Train A applied the emergency brake and stopped approximately two car lengths prior to the switch 3B. Meanwhile, Train B traveling west passed a crossed over switches 3B/3A onto track 2 toward the station. The Train A locomotive engineer mentioned to the conductor that he may have passed a stop signal. Normally, when a train passes a stop signal, the dispatcher's computer monitor immediately displays an alarm. If an alarm occurred, the dispatcher would notify the locomotive engineer of that train that the signal system indicated that the train passed a stop signal and the train should remain stopped at their current location. An investigation would take place and the train crew would be taken out of service and replaced with another train crew.

In this situation, the dispatcher's monitor did not display an alarm. Instead the indicator for Train A disappeared from the monitor and was replaced by an object with no identifier. The locomotive engineer received no communication from the dispatcher and after recharging the brake reservoir, resumed traveling on track 1. The train ran through the switch (3B) which was lined in the other direction and the locomotive engineer again applied the emergency brake. After recharging the brake reservoir a second time, the locomotive engineer again resumed traveling on track 1.

At the point when Train A passed the stop signal, the object representing Train A on the dispatcher's monitor disappeared from his monitor. A new unidentified object appeared on the dispatcher's monitor. While traveling on track 1, the dispatcher contacted Train A three times to determine the identity of the unknown object. The dispatcher asked the locomotive engineer for his location and the engineer responded each time that he was traveling east on track 2. The dispatcher's display continued to show an unknown object on track 1. While the dispatcher continued to call other trains on the territory to identify their location, Train A continued on track 1 until the train approached the next signal (6E) which displayed a stop signal. The locomotive engineer stopped before reaching the stop signal and contacted the dispatcher to indicate that they were stopped at the entrance to the next interlocking signal. The dispatcher contacted Train A again to ask for his location, the locomotive engineer responded that they were on track 1. At that point, the dispatcher indicated that the train should remain at its current location and a management team was on its way to investigate.

An investigation ensued to learn why the train continued past the stop signal. This investigation included interviews with the train crew and the dispatcher and checking the operation of the signal system and locomotive. The investigation indicated that the signal system and locomotive operated normally and the dispatcher followed the proper procedures in lining the trains and responding to the missing train object representing Train A on his computer monitor. The locomotive engineer was interviewed but could not explain why he continued past the stop signal, except to say that the headlights from Train B temporarily blinded him. He believed that he operated on the correct track and that the railroad was experiencing signaling problems. He could not explain why he believed that he was on track 2 when in fact his train was on track 1. Subsequent to his suspension from train operations as part of the discipline process, the locomotive engineer participated in a meeting with railroad managers and FRA inspectors to review a video recording of the event showing the out-the-window view. The locomotive engineer did not reveal any additional information to explain his actions. No information was available to understand the conductor's role in this event.

As the last line of defense in preventing train accidents, it was understandable that the investigation examined the behavior of the locomotive engineer. There was no indication that medical issues, drug or alcohol, or fatigue played a role in the event. Could the discipline process and concern for losing their FRA certification may have been a contributing factor to their behavior as well as their inability to explain their behavior? Could the concern for discipline have contributed to their behavior in saying they were on track 2 when they were on track 1? In interviews with other locomotive engineers, we learned that if a locomotive engineer believes they may have passed a stop signal, but is not contacted by the dispatcher shortly afterward, they may assume that they had not in fact passed the stop signal in the sense that they did not trigger the track circuit SSO indicator. In those situations, they will continue to operate their train normally. This situation can occur when the front of the train passes the signal, but the wheels have not passed the signal and track circuit that would indicate to the signal system that they entered an unauthorized track section. In the current situation, if the headlights blinded the locomotive engineer and obscured his ability to see the stop signal, while the locomotive engineer's expectation was that the dispatcher would have contacted them immediately if they passed the stop signal contribute to a belief that he had not passed a stop signal. Could this type of behavior sequence explain why the locomotive engineer chose to resume operation of his train?

In focusing on the locomotive engineer's behavior as the "cause" of the event, the railroad missed an opportunity to understand how the interaction of multiple system components contributed to the event. Consider the following questions:

- What was the role of the conductor in this event?
- The conductor indicated in a written statement that they heard the locomotive engineer say that the train may have passed a stop signal? Why didn't the conductor talk with the locomotive engineer about what they should do?
- Why didn't the conductor or the engineer contact the dispatcher to share their concerns?
- Did their mutual concern that they might be disciplined for passing a stop signal affect their decision not to contact the dispatcher and say they may have passed a stop signal?
- What was the role of the track circuitry and the dispatcher's computer system for monitoring train movements and track authority in contributing to this event?
- Is there a flaw in the design of the system for monitoring train movements that contributed to trains disappearing from the dispatcher's computer monitor?

It was not simply the failure of the locomotive engineer's behavior that contributed to this event. The locomotive engineer's behavior was influenced by the system, of which they are a part. The conductor's behavior and dispatcher's behavior were also influenced by the system design and operation. A combination of actions and behavior by multiple system elements contributed to this stop signal overrun. Paying attention to the weaknesses in the system may provide more fruitful opportunities to minimize the potential for this event sequence from occurring in the future. More generally, identifying how the whole system contributes to stop signal overruns provides an opportunity to learn from stop signal overruns and improve safety in a sustainable way.

Identifying how the system as a whole contributes to stop signal overruns requires conducting investigations that collect information about the railroad system and making effective use of this information to inform effective decision making around safety management. Our study revealed that the railroad investigation process, information storage, data processing and analysis of event investigations could benefit from process improvements. A study by the Federal Transit Administration (2016) looking at fixed guideway systems not regulated by FRA indicates that the problems also exist in operations beyond those regulated by FRA.

6.8 Implications for FRA Regulatory Oversight

In FRA's notice of public rulemaking for 49 CFR Part 240, FRA proposed that SSOs were indicators of unacceptable individual behavior, and constitutes evidence that the individual was inattentive to safety concerns (Federal Register, 1989). The research in this report and the amount of literature that has accumulated since FRA implemented this regulation paints a very different picture of why trains pass stop signals. This study suggests that the design and operation of the railroad system contributes to the occurrence of stop signal overruns. While the locomotive engineer and conductor play an important role in creating safe railroad systems, these individuals represent just two elements of a much larger system for creating safe railroad operations. Our data suggests that 98 percent of locomotive engineers will never experience a stop signal overrun. Since 1992, when 49 CFR Part 240 went into effect, the accident rate for stop signal related accidents has remained within the same range as before the regulation went into effect. For passenger railroads, the rate of SSO accidents fluctuates dramatically from year to year due to the very low frequency of these accidents. For freight railroads, the accident rate appears to be decreasing within a very narrow range. Does this decreasing trend represent normal variation or is there a systematic reason for this change? We do not know. For the six passenger railroads we studied, there was no significant reduction in the rate of stop signals overruns since 2003 when FRA began collecting data on this event.

In focusing their attention on the role of the locomotive engineer, the regulator and the industry have missed an opportunity to address the problems in the system that contribute to stop signal overruns. Our study along with the research of the international railroad community indicates that a multitude of factors interact with each other in complex ways to contribute to SSOs. Applying systematic investigation processes to understanding stop signal overruns can provide insight into how the design and operation of railroad systems contribute to these unwanted events. As a next step, studying the four freight railroads that experience the greatest number of SSO related accidents can contribute to an understanding of what processes are contributing to SSOs in the freight environment and lead to effective countermeasures that reduce the frequency of SSOs in the freight environment. Our research suggests that the context in which railroads contribute to the form in which SSOs manifest themselves. Understanding this context offers the opportunity to meaningfully reduce these events.

7. Conclusion

Accidents involving stop signal overruns are relatively rare events that may have severe consequences in terms of death and property damage. Despite the concern around this accident type, accidents attributed to SSOs and SSOs that have not resulted in accidents have remained relatively stable over the 30-year period reviewed. The use of train miles as a measure for establishing the rate of stop signal overruns and related accidents gives a distorted representation of the rate at which these events occur. Using the number of encountered stop signals would provide a more realistic representation for making decisions about how to allocate resources (e.g., between passenger and freight service) to address risk.

Our review and coding of NTSB data revealed that they identified very similar factors to ours (regulatory activities, organizational processes, individual and team behaviors, technology and physical environment), however in our study it was possible to perform our coding at a finer grain that identified more factors and interactions. In both, the accidents and stop signal overruns that did not lead to accidents identified in our study, multiple factors combined in different ways to play a role in these events. Our analysis of the stop signal overruns and interviews with multiple stakeholders at multiple passenger railroads suggest that the railroad system produces SSOs through a common set of processes. The systems processes (e.g., training, crew assignment, operating procedures, use of technology, etc.) create the opportunities for SSOs to occur and manifest themselves in different ways. We describe how the context in which the system operates and creates different ways for SSOs to occur. For example, in the terminal environment, the complexity of the environment along with the density of stop signals encountered creates high workload conditions where train crews may misread the signal. Waiting to depart a station may create a low workload environment where the locomotive engineer may operate reflexively when the conductor gives the signal that the doors are closed and the train can proceed. In this situation, the engineer may proceed without looking at the signal.

The investigation process as it currently operates, to support compliance with company policies and regulatory requirements associated with certification, conflicts with the goal of investigation for the purpose of learning from the event. Given the lack of improvement over time in the frequency of stop signal overruns, our study suggests that the current approach, focusing on the behavior of individual employees as the primary strategy for reducing SSOs, is ineffective. Using these events as learning opportunities for improving safety may be a more fruitful avenue for preventing future stop signal overruns. The focus on assigning blame on the individual(s) directly involved in an SSO inhibits the opportunity to learn how the railroad system contributes to stop signal overruns. Looking beyond the simple explanation that the employee was at fault offers an opportunity to learn from these failures.

Neither railroads nor FRA collect sufficiently rich data on the physical, individual, team and organizational factors associated with an SSO event to be able to understand how and why these events occur. There is a need to strengthen data collection, analyses, reporting processes for SSOs, and other human-performance related events. This includes use of more comprehensive investigation templates, improved training of those involved in the incident investigation, conversion of hand-written data to electronic form to support data aggregation and analysis, more in-depth statistical analysis, and trending to identify patterns and evaluate the impact of implemented mitigations.

Due to the limitations of available quantitative data our findings primarily relied on qualitative analyses of interviews and observations conducted at selected railroads. Study limitations include a limited sample of railroads and number of individuals sampled. In addition, while multiple potential contributors to SSOs were identified, our study methodology does permit establishing clear cause and effect relationship between the factors identified and SSOs. These limitations need to be kept in mind in viewing our recommendations.

While acknowledging study limitations, we also want to emphasize that other studies of SSOs, including studies in the United Kingdom and Australia have generated very similar findings and conclusions (Lowe et al., 204; Naweed, 2013, Naweed, 2014). The convergence of findings across such diverse studies strengthen confidence in our results and recommendations.

SSOs result not from a single cause, but a confluence of multiple interacting factors including physical characteristics, such as signal type and signal placement; individual factors, such as knowledge, skills and expectations and fatigue; and organizational factors, such as characteristics of training, supervision, dispatching practice and production pressure. As a consequence, approaches to mitigating SSOs need to address many system elements and their interactions. In turn addressing these elements and their interactions will not only result in reduced SSOs but will also improve other aspects of safety, such as passing misaligned switches and overspeeding.

We recommend that railroads review the list of mitigations suggested in this report for applicability to their operations, as prudent practice. Ideally the review of recommendations and selection of mitigations to implement would be conducted with input from multiple stakeholders, including front-line locomotive engineers, conductors, dispatchers and road foremen, and other railroad managers.

8. References

Anderson C., and Horne, J. A. (2006). Sleepiness Enhances Distraction During a Monotonous Task. *Sleep, Sleep, Restriction, and Performance*, *29*(4), 573–576.

Association of American Railroads (2018). Positive Train Control (PTC). Washington, DC: Association of American Railroads.

Australian Rail Track Corporation, Ltd. (2006). "Signals," in Engineering (Signalling) Standard SDS01, Version 2.0, ed.

Banbury, S. and Baker, K. (2015). Human Factors of Missed Signals in Railway Operations. Report: TP 15302E. Ottawa Ontario, CA: Transport Canada.

Benner, L. (2013). Standardizing Safety Investigation Inputs to Reduce Risks. 45th ESReDA Seminar on Dynamic Learning from Incidents and Accidents, Oportu, Portugal, October 2013.

Edkins, G. D., and Pollack, C. M. (1997). The influence of sustained attention on railway accidents. *Accident Analysis and Prevention*, *29*(4), 533–539.

Einhorn, J. Sheridan, T. B, and Multer, J. (2005). *Preview Information in Cab Displays for High-Speed Locomotives*. Technical Report No. DOT/FRA/ORD-04/12. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

Engstrom, J., and Victor, T. W. (2008). Real-time distraction countermeasures. In Michael A Regan, J. D. Lee and K. L. Young ( ) Driver distraction: Theory, effects and mitigation. Boca Raton: CRC Press.

Federal Register. (1989, December 11). Notice of Public Rule Making: Qualifications for Locomotive Operators. 49 CFR Part 240. Washington, DC: US. Department of Transportation, *54*(236), 50890–50939.

Federal Register. (1991, June 19). Final Rule: Qualifications for Locomotive Operators. 49 CFR Part 240. Washington, DC: US. Department of Transportation, *56*(118), 28228–22276.

Federal Register. (2016, August 12). Final Rule: System Safety Program. 49 CFR Part 270. Washington, DC: US. Department of Transportation, *81*(156), 53850–53905.

Federal Transit Administration. (2016). Stop Signal Overrun Investigation: Washington, DC: Federal Transit Administration.

Filtness, A. J. and Naweed, A. (2017). Causes, consequences and countermeasures to driver fatigue in the rail industry. *Applied Ergonomics*, *60*, 12–21.

Fisher, R. P. and Geiselman, R. E. (1992). Memory-Enhancing techniques for Investigative Interviewing. Springfield, IL: Charles C. Thomas.

Gertler, J., DiFiore, A., and Raslear, T. (2013). Fatigue Status of the U.S. Rail Industry. Technical Report No. DOT/FRA/ORD-13/06. Washington DC: US. Department of Transportation, Federal Railroad Administration.

Gibson, W. H., Mills, A., Basacik, D., and Harrison, C. (2015). The Incident Factor Classification System and Signals Passed at Danger. London: The Fifth International Rail Human Factors Conference.

Hackman, J. R. (2002). Leading teams: Setting the stage for great performances. Boston, MA: Harvard Business Review.

Haga, S. (1984). An experimental study of signal vigilance errors in train driving. *Ergonomics*, *27*(4), 755–765.

Harrison, Y. and Horne, J. A. (2000). The impact of sleep deprivation on decision making: A Review. *Journal of Experimental Psychology*, *6*(3), 236–249.

He, J., Becic, E., Lee, Y. -C., and McCarley, J. S. (2011) Mind wandering behind the wheel: performance and oculomotor correlates, *Human Factors*, *53*(1), 13–21.

Hoffman, R. R., Ward, P., Feltovich, P. J., DiBello, L., and Fiore, S. M. (2013). Accelerated expertise: Training for high proficiency in a complex world. New York: NY: Psychology Press.

Human Engineering Shore House. (2006). Who other than the driver has a role in reducing SPADs. London, UK: Rail Safety and Standards Board.

Independent Transport Safety Regulator. (2011). Managing signals passed at danger. Sydney, Australia: Independent Transport Safety Regulator.

Killingsworth, M. A. and Gilbert, D. T. (2010). A Wandering Mind Is an Unhappy Mind. *Science 330*, 932.

Kohls, H. H., and Watson, R. (2010). SPAD – reducing timetable related risk. WIT Transactions on State of the Art in Science and Engineering: *Safety and Security in Railway Engineering*, 45, 129–136.

Leveson, N. (2004). A New Accident Model for Engineering Safer Systems. *Safety Science*, *42*(4):237–270.

Leveson, N. (2011). Engineering a Safer World: Systems Thinking Applied to Safety. Aeronautics and Astronautics and Engineering Systems Division. Cambridge, MA: Massachusetts Institute of Technology.

Lowe, C., Li, G., and Lock, D. (2004). Human Factors Research Implications of Common Factors in SPADs Literature Database. London, UK: Rail Safety and Standards Board.

Luke, T., Brook-Carter, N., Parkes, A. M., Grimes, E., and Mills, A. (2006). An investigation of train driver visual strategies. *Cognition, Technology and Work*, *8*(1), 15–27.

Mack, A., and Rock, I. (1998). Inattentional Blindness. Cambridge, MA: MIT Press.

Marinakos, H., Sheridan, T. B., and Multer, J. (2005). *Effects of Supervisory Train Control Technology on Operator Attention*. Technical Report No. DOT/FRA/ORD-04/10. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

Mayer, D., and Ellingstad, V. S. (1992). Using transportation accident databases in human factors research. In Proceedings of the Human Factors Society 36th Annual Meeting, pp. 965–969.

McCarley, J. S., and Benjamin, A. S. (2013). Bayesian and signal detection models. In Lee, J. D., & Kirlik, A. (Eds.) The Oxford Handbook of Cognitive Engineering. New York, NY: Oxford University Press.

Mcleod, R. W., Walker, G. H., and Moray, N. (2005). Analysing and modelling train driver performance. *Applied Ergonomics*, *36*(6), 671–80.

Mills A., Gibson, H., Basacik, D., and Bowler, N. (2016, July 26). Human Factors Incident Classification System in the UK railways – recent analysis. Orlando, FL: Presentation given at 4th International Conference on Human Factors in Transportation.

Morgan, C., Olson, L., Kyte, T., Roop, S. (2007). *Rail Crew Resource Management (CRM): Pilot Rail CRM Training Development and Implementation*. Technical Report No. DOT/FRA/ORD-07/03. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

National Transportation Safety Board. (1971). Special study: Signals and operating rules as causal factors in Train Accidents. Report No NTSB-RSS-71-3. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board. (1988, January 4). Rear-End Collision of Amtrak Passenger Train 94, *The Colonial* and Consolidated Rail Corporation Freight Train ENS-121 on the Northeast Corridor, Chase, MD. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2008). Collision of Metrolink Train 111 With Union Pacific Train LOF65-12 Chatsworth, California September 12, 2008. Washington DC: National Transportation Safety Board.

National Transportation Safety Board (2016). Amtrak Train Collision with Maintenance-of-Way Equipment. Accident No. DCA16FR007.

Naweed, A. (2013). Psychological factors for driver distraction and inattention in the Australian and New Zealand rail industry. *Accident Analysis and Prevention*, 60, 193–294.

Naweed, A., and Aitken, J. (2014). Drive a mile in my seat: Signal design from a systems perspective. Institution of Railway Signal Engineers Technical Meeting, July 2014.

Naweed, A., Every, D., Balakrishnan, G., and Dorrian, J. (2014). One is the loneliest number: Exploring the role of the second driver in Australian rail operations. *Ergonomics Australia*, *1*, 1–8.

Naweed, A. (2014). Managing and Mitigating SPAD Risk in Rail Operations. Brisbane, Australia: Cooperative Research Center for Rail Operations.

Naweed, A., Rainbird, S., and Chapman, J. (2015). Investigating the formal countermeasures and informal strategies used to mitigate SPAD risk in train driving. *Ergonomics*, *58*(6), 883–896.

Nickandros, G., and Tombs, D. (2007). Measuring Railway Signals Passed At Danger. In. 12th Australian Conference on Safety Critical Systems and Software, Adelaide, Australia.

Phillips, R. O., and Sagberg, F. (2014). What did you expect? CREAM analysis of hazardous incidents occurring on approach to rail signals. *Safety Science*, *66*:92–100.

Rail Safety and Standards Board. (2014). Investigation Guidance: Part 3 Practical Support for Accident Investigators. London: Rail Safety and Standards Board.

Raslear, T. G. (2014). *Start Time Variability and Predictability in Railroad Train and Engine Freight and Passenger Service Employees*. Technical Report No. DOT/FRA/ORD-14/05. Washington, DC: U. S. Department of Transportation, Federal Railroad Administration.()

Rasmussen, J. (1997). Risk Management in a Dynamic Society: A Modelling Problem. *Safety Science*, *27*(2/3), 183–213.

Rjabovs, A., and Palacin, R. (2016). The influence of system design-related factors on the safety performance of metro drivers. Proceedings of the Institution of Mechanical Engineers, Part F: *Journal of Rail and Rapid Transit*, *231*(3), 317–328.

Roop, S. S., Morgan, C. A., Kyte, T. B., Arthur, Jr., W., Villado, A. J. and Beneigh, T. (2007). *Railroad Crew Resource Management (CRM): The Business Case for CRM Training in the Railroad Industry*. Technical Report No. DOT/FRA/ORD-07/21. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

Roth, E. M., and Multer, J. (2009). *Technology Implications of a Cognitive Task Analysis for Locomotive Engineers*. Technical Report No. DOT/FRA/ORD-09/03. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

Safar, H., Multer, J., & Roth, E. (2015). *An Investigation of Passing Stop Signals at a Passenger Railroad*. Technical Report No. DOT/FRA/ORD-15/25. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

Sheridan, T., Lanzilotta, E., and Askey, S. (1994). *Safety of High Speed Guided Ground Transportation Systems: Human Factors Phase 1: Function Analyses and Theoretical Considerations*. Technical Report No. DOT/FRA/ORD-94/24. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

Simons, D. J., and Chabris, C. (1999). Gorillas in our midst: sustained inattentional blindness for dynamic events. *Perception*, *28*, 1059–1074.

Smallwood, J. and Schooler, J. W. (2015). The Science of Mind Wandering: Empirically Navigating the Stream of Consciousness. *Annual Review of Psychology*, *66*(1), 487–518

Van der Flier, H., and Schoonman, W. (1988). Railway signals passed at danger. Situational and personal factors underlying stop signal abuse. *Applied Ergonomics*, *19*(2), 135–141.

Victor, T. (2011) Distraction and inattention countermeasure technologies. *Ergonomics in Design: The Quarterly of Human Factors Applications*, *19*(4), 20–22.

Wheeler, D.T., and Chambers, D.S. (2010). Understanding Statistical Process Control.(3rd ed). Knoxville, TN: SPC Press (Statistical Process Control).

Wickens, C. D., Hollands, J. G., Banbury, S., and Parasuraman, R. (2013). Engineering psychology and human performance. (Fourth edition). Boston, MA: Pearson Education.

Willis, G. B. (2005). Cognitive Interviewing: A Tool for Improving Questionnaire Design. Thousand Oaks, CA: Sage.

Wright, L., Dabekaussen, M., and Van der Schaaf, T. (2007). Predicting the causes of SPAD incidents. In: People and Rail Systems: Human Factors at the Heart of the Railway. Eds. Wilson, J., Norris, B., and Clarke, T. pp. 491–497.

Zhao, Y. (2016). Red Aspect Approaches to Signals (RAATS): Technical Report. London, UK: Rail Safety and Standards Board.

Appendix A.
Data Fields Provided by Individual Railroads

Railroad

RR1	RR2	RR3	RR5	RR6
Railroad	Craft	Craft	Age	Employee
Age	Date/Time	Date/Time	Contributing Factors	Date
Date	Employee number	Location	Damage	Department
Location	Location	Train/locomotive	Date	Violation
Revenue service	Name	Years of experience	Day of Week	Division
Signal name	Narrative		Days Worked	Location
Train number	Number of violations		Employee Number	Seniority Date
Experience			Engineer Markup Date	Time
			Engineer years of service	Train or Job
			Equip.	Type
			Hours On Duty Prior	
			Incident Number	
			Injuries	
			In-Out	
			Location	
			Name	
			Prior Craft	
			Prior signal	
			Probable Cause	
			Railroad years of service	
			Run	
			Seniority	
			Signal	

Appendix B:
Railroad Questionnaire

Railroad Name

SSV Investigation Methods & Data Collection

1. What kind of information do you collect about stop signal violations (SSV)? Check all boxes that apply.

- ☐ Date and Time of SSV
- ☐ Train crew demographic characteristics (e.g., age, years of experience in position)
- ☐ Other individuals in the cab besides the locomotive engineer (e.g., conductor, road foreman)
- ☐ Whether or not this is the locomotive engineer's regular assignment
- ☐ Date of engineer's last training course and/or qualification run on this territory
- ☐ When the locomotive engineer last operated a train on this territory and in this direction, prior to the SSV
- ☐ Time at which locomotive engineer came on duty
- ☐ How much time off the locomotive engineer had prior to coming on duty
- ☐ Location (line, proximity to a station, interlocking or milepost)
- ☐ The type of signal (e.g., dwarf signal) passed
- ☐ Equipment on which the SSV took place
- ☐ Prior signal indication
- ☐ Whether or not the signal was dropped (either by dispatcher or due to system malfunction)
- ☐ Train status: on schedule or delayed
- ☐ Conditions at the time of the SSV that differed from the usual for this route (e.g., cab signals out, unexpected routing, signal aspect different from past runs on this route, train consist length different than expected)
- ☐ Weather conditions at the time of the SSV
- ☐ Conditions that made the signal difficult to see (e.g., around a curve, snow, glare)
- ☐ Sources of distraction (e.g., radio communication, paperwork, personal concerns)
- ☐ If at a station, whether or not the locomotive engineer could see the signal (e.g., the signal was behind the locomotive engineer's position in the cab)

☐ Narrative description of SSV

- ☐ Statement from locomotive engineer
- ☐ Statement from conductor
- ☐ Statement from dispatcher
- ☐ Statement of road foreman

☐ Drug & Alcohol test results
☐ Other

2. Where do you store information from SSV investigations?

☐ All information is stored together in a centralized location
☐ Information from some departments is stored centrally. The rest is stored locally by each department

Please indicate which information is stored centrally

☐ Each department that collects information is responsible for storing it.

3. During SSV investigations:

a. Which departments participate?

b. Which department has the responsibility for coordinating or leading the SSV investigation?

4. When interviewing train crews after an SSV:

a. Who conducts the interview (e.g., road foreman)?

b. What kind of formal training does the interviewer receive on how to interview the train crew about the SSV?

c. Do they have a checklist or template for what information to ask about or collect during an SSV investigation?

○ Yes (please include a copy)
○ No

5. When interviewing dispatchers after an SSV:

a. Who conducts the interview (e.g., Dispatch Supervisor)?

b. What kind of formal training does the interviewer receive on how to interview the dispatcher about the SSV?

c. Do they have a checklist, or template for what information to ask about or collect during an SSV investigation?

○ Yes (please include a copy)
○ No

6. When new rules and policies are implemented in response to SSVs:

a. Who takes part in developing these new rules and policies?

b. Who has primary responsibility for monitoring the impact of these new rules/policies on SSV occurrence?

7. What role does the safety department play when a SSV occurs?

8. What department analyzes SSV data to look for trends?

Railroad Policies, Practices and SSV Mitigation Strategies

9. The FRA gives railroads discretion in terms of when an engineer should be de-certified for going through a stop signal. On your railroad, what are the criteria you use for deciding whether an engineer should or should not be de-certified?

10. For a locomotive engineer that is currently qualified to operate on your railroad:

a. What steps are required to maintain qualification on a particular territory (e.g., taking a paper test, taking a head-end ride on the territory, running a train on the territory)?

b. Do these steps take place on company time (i.e., paid) or employee's personal time. For example, if the locomotive engineer is required to take a head-end ride, is it done on company or personal time?

- ☐ Company time
- ☐ Employee personal time
- ☐ Varies with the situation (Describe)

11. For track charts:

a. What is the approximate date (year) of the latest printed version of your railroad's track charts that the train crew can access?

b. Do train crews have access to electronic version of the track charts?

- ◯ Yes
- ◯ No

c. How often are track charts updated?

Printed

Electronic

12. Approximately what percentage of track does 562 territory (cab signals only) cover on your railroad?

13. What new rules, policies, training, or changes to physical infrastructure have you implemented to mitigate SSVs in the last 5 years? Select all that apply. For each item checked please provide the approximate date(s) the change was made and briefly explain the change in the space provided.

Topic	Date(s)	Description
☐ Engineer training		
☐ Conductor training		
☐ Dispatcher training		
☐ Engineer and conductor qualification and recertification process (process e.g., more frequent head end rides to stay qualified on territory)		

☐ Conductor or second crew member in the cab calling signals with the engineer

☐ Conductor calls and/or concurs signals over the radio with the engineer

☐ Conductor gives 'two to go' only after observing a clear signal

☐ Dispatcher communicates with engineer when route changes occur

☐ Reduced maximum authorized speeds in certain locations

☐ Other rule changes

☐ Move signals

☐ Linked signals that are close together

☐ Added markings at platforms showing where to stop train for different car lengths		
☐ Other physical infrastructure changes		
☐ Changes to crew schedules		
☐ Changes to train schedules		
☐ Updated track charts for train crews		
☐ Other?		

14. Have you measured the impact of these changes on SSVs?

◯ Yes
◯ No

If so please briefly indicate which department is responsible for tracking the impact of the change on SSVs and how the impact is being measured

***Remember to include copies of investigation information checklists (if applicable)**

Appendix C.
Comparison of Contributing Factors: NTSB Reports vs. Interviews

Source: **NTSB reports**

Contributing Factors within categories	Percent	Count
Individual Behavior and Characteristics		
Distractions	31%	13
Fatigue	29%	12
Expectations	14%	6
Experience Level	7%	3
Teamwork	7%	3
Communication	7%	3
Visual Scanning	2%	1
Paperwork Requirements	2%	1
Railroad Organizational Processes		
Supervisory Practices	29%	7
Crew Assignment and Schedule	13%	3
Policies and Practices	13%	3
Employee Training	13%	3
Incident Investigation	13%	3
Dispatcher Train Management	8%	2
Workforce Management	4%	1
Data Collection and Analysis	4%	1
Resource Constraints and Managemen	4%	1
Technology & Environment		
Displays and Alerts	26%	6
Environmental Issues	26%	6
Signal Maintenance	17%	4
Infrastructure Layout	9%	2
Equipment Malfunction	4%	1
Technology in Dispatch Center	4%	1
Signal Design	4%	1
Cab Signals	4%	1
Locomotive Type	4%	1
Regulatory Activities		
Engineer and Conductor Certification	67%	2
Regulatory Mandated Testing	33%	1

Source: **Interview data**

Contributing Factors within categories	Percent	Count
Technology & Environment		
Signal Placement	34%	92
Equipment Malfunction	14%	37
Environmental Issues	11%	31
Signal Design	9%	24
Infrastructure Layout	8%	22
Cab Signals	7%	19
Signal Maintenance	5%	13
Job Aids	3%	9
Locomotive Type	3%	8
Displays and Alerts	2%	6
Technology in Dispatch Center	2%	5
Cab Signals w/o fixed block signals	1%	4
Signal type	0%	1
Phantom Signals	0%	1
Individual Behavior and Characteristics		
Distractions	18%	49
Communication	17%	45
Experience Level	14%	39
Route Knowledge	11%	29
Expectations	10%	26
Teamwork	7%	19
Station Dwelling	6%	17
Fatigue	5%	13
Communication Requirements	4%	10
Following Procedure	3%	9
Complacency	2%	5
Stress	1%	4
Paperwork Requirements	1%	4
Visual Scanning	1%	2
Railroad Organizational Processes		
Employee Training	16%	40
Production Pressure	15%	36
Dispatcher Train Management	14%	35
Crew Assignment and Schedule	13%	31
Train Schedule	7%	18
Policies and Practices	7%	18
Resource Constraints and Management	7%	16
Workforce Management	6%	15
Cross-Railroad Practices	5%	12
Discipline	4%	10
Incident Investigation	3%	7
Supervisory Practices	2%	6
Data Collection and Analysis	0%	1
Regulatory Activities		
Engineer and Conductor Certification	86%	12
Regulatory Mandated Testing	7%	1
Change operating practice	7%	1
External Factors		
Service Demands	64%	9
Funding	36%	5

Appendix D.
Stop Signal Overrun Investigation Template

PURPOSE OF THIS TEMPLATE

This investigation template represents a tool to identify contributing factors for SSO events and events which would have resulted in a SSO if not for Positive Train Control intervention. As the SSO database grows, railroads can use the aggregate data to analyze how contributing factors change over time and as a way to understand the efficacy of particular mitigation efforts.

HOW TO USE THIS TEMPLATE

- The template is comprised of separate sections to be completed by:
    - relevant departments within the railroad
    - individuals involved in the event (e.g., train crew, dispatcher)
    - the person(s) overseeing the investigation (principle investigator)
- For each investigation:
    - Sections A., E., F., G., and I. should be completed by the principle investigator, with the input of train crew members where applicable.
    - Sections B., C., and D. should be completed by the relevant departments.
    - Section H should be completed by each employee with knowledge of the incident (e.g., train crew, dispatcher).
- We assume that the investigation will be coordinated by one department (e.g., the safety department), and this department will be responsible for compiling, storing, and maintaining the investigation forms so that they are centrally located.
- For the investigation template to be most useful, data from each incident should be entered into a database.
- Since SSO events are rare events, data from multiple events should be analyzed over time to understand the multiple interacting factors that contribute to SSO events and how they change over time.

LONGER TERM VISION

This template serves to provide railroads with a starting point for the types of data to collect to understand why stop signal overrun events occur. We hope that the investigation process will change from a paper-based data entry process to computer-based data entry process that will simplify and streamline the data acquisition process. This will reduce the potential for making data entry errors, reduce the time it takes to collect the data, make it easier to share the data within the organization, and facilitate analysis that will enable railroads to identify important trends over time.

A: Stop Signal Overrun Cover Page

Incident date: ____/____/_______

Incident time: ______:_________

Railroad(s) involved	Train(s) / equipment involved	Incident number(s)[6]
1. ____________________________	__________________________	____________________
2. ____________________________	__________________________	____________________
3. ____________________________	__________________________	____________________

Railroad responsible for track maintenance: ____________________________

Location

City and state: __________________________

County: ________________________________

Division: _______________________________

Location type:

- ❑ Main
- ❑ Siding
- ❑ Passenger Station
- ❑ Crossing
- ❑ Yard
- ❑ Industry
- ❑ Terminal
- ❑ Other ___________________

Track number/name: _____________________

Milepost: _______________________________

Signal number: __________________________

Nearest interlocking: ______________________

Nearest station: __________________________

US DOT/AAR Crossing ID: __________________

Investigation Information

Railroad performing investigation: ________________________________

Investigator name and title: ______________________________________

Investigator phone number: ______________________________________

Investigator signature: _____________________________________

Date of investigation: _______________________________________

[6] If multiple railroads are involved (such as in a stop signal overrun event followed by an accident), they may each have a separate incident number. There may also be multiple train/equipment numbers.

B: Track Information and Environment

Track Information

Maximum allowable speed: _______________

Annual track density: ____________________

FRA track class:

- ❑ Excepted
- ❑ 1
- ❑ 2
- ❑ 3
- ❑ 4
- ❑ 5
- ❑ 6
- ❑ 7
- ❑ 8
- ❑ 9

Track curvature:

- ❑ Straight
- ❑ Curved

Track grade:

- ❑ Ascending
- ❑ Descending
- ❑ Level

Were track conditions (e.g. rail adhesion) compromised by factors such as wet leaves, ice, etc.?

- ❑ Yes
- ❑ No

If yes, please specify conditions:

____

____

Environment

Weather (check all applicable)

- ❑ Bright sun
- ❑ Clear
- ❑ Overcast
- ❑ Fog
- ❑ Haze/Smoke
- ❑ Wind/Rain
- ❑ Thunderstorm/Lightning
- ❑ Snow
- ❑ Hail
- ❑ Ice
- ❑ Other: _______________

Light Conditions

- ❑ Dawn
- ❑ Daylight
- ❑ Dusk
- ❑ Night

Was visibility reduced?

- ❑ Yes
- ❑ No

If yes, car lengths visible: _____________

C: Operation Information

Train Information

Railroad: ______________________

Train number: ___________________

Power type:

- ❑ Locomotive
- ❑ Cab control car
- ❑ EMU (Electric Multiple Unit)

Distributed power:

- ❑ Yes
- ❑ No

Remotely controlled:

- ❑ Yes
- ❑ No

Total train length: ___________________

Total train weight: ___________________

Number of locomotives: __________________

Head end locomotives: ____________

Helper locomotives: ______________

Number of cars in consist: _________________

Loaded cars: ________________

Unloaded cars: ______________

Number of cabooses: ________________

Other Equipment Involved

Please describe any other equipment below:

____

____

____

____

____

____

Schedule Information

Departure time: ______ : ________ am / pm

Origin: ________________________________

Destination: ____________________________

At the time of the incident, the train or job was:

- ❑ More than 5 minutes ahead of schedule
- ❑ On time or within 5 minutes of schedule
- ❑ 5-10 minutes behind schedule
- ❑ 10-15 minutes behind schedule
- ❑ More than 15 minutes behind schedule
- ❑ Other ___________________________

Reason for delay (if applicable):

____

____

Operation Type

Type of operation (check all applicable):

- ❑ Freight
- ❑ Passenger / Commuter
- ❑ Yard Assignment
- ❑ Maintenance
- ❑ Other: ______________________

Movement type:

- ❑ Shoving
- ❑ Pulling
- ❑ Push/pull
- ❑ Other: ______________________

Activity:

- ❑ Departure
- ❑ Enroute
- ❑ Arrival
- ❑ Switching in yard
- ❑ Other: ______________________

Direction of travel:

- ❑ North
- ❑ South
- ❑ East
- ❑ West
- ❑ Not applicable

Actual (recorded) speed: ___________________

Estimated speed (if actual speed unknown): ______________

Was the equipment unattended at the time of the incident?

- ❑ Yes
- ❑ No

Operating Rules

Rules in effect:

- ❑ GCOR
- ❑ NORAC
- ❑ Other: _______________

Was the crew operating on a foreign railroad (i.e. train not owned by the host railroad)?

- ❑ Yes
- ❑ No

Rules in effect / method of operation (check all applicable):

- ❑ Main block
- ❑ Timetable
- ❑ Radio
- ❑ Verbal permission
- ❑ Train order
- ❑ Centralized traffic control
- ❑ Interlocking
- ❑ Track warrant control
- ❑ Direct traffic control
- ❑ Yard limits
- ❑ Other than main track rules
- ❑ Positive train control
- ❑ Automatic train control
- ❑ Automatic block signal
- ❑ Automatic cab signal
- ❑ Automatic train stop
- ❑ None/dark
- ❑ Other: _____________________

Did the train start from a stationary position?

- ❑ Yes
- ❑ No

Was section (block) ahead occupied?

- ❑ Yes
- ❑ No

D: Signal and Train Control

Signal Type and Placement

Signal Type:

- ❑ Position
- ❑ Colored
- ❑ Semaphore
- ❑ Other: ___________________

Lighting Type:

- ❑ Incandescent
- ❑ LED
- ❑ Other: ___________________

Are there markers to indicate stop locations?

❑ Yes ❑ No ❑ N/A

Is the signal in a non-standard position?

❑ Yes ❑ No

If yes, describe how it is non-standard:

____

____

Are there other signals in close proximity (e.g., that might have resulted in a 'read through') or confusion as to which was the controlling signal)?

❑ Yes ❑ No

If yes, specify other signal and explain:

____

____

Have prior overruns happened at this signal?

❑ Yes ❑ No

If yes, give incident numbers or dates:

____

____

Signal Visibility and Maintenance

What is the furthest distance from which the signal could be seen by a crew? ___________

Was signal visibility impaired?

❑ Yes ❑ No

What factors limited signal visibility, if any?

- ❑ Weather (e.g., rain, snow, fog)
- ❑ Lighting (dawn, dusk, or nighttime)
- ❑ Glare – sunlight
- ❑ Glare – train headlights
- ❑ Track curvature
- ❑ Obstruction – structure
- ❑ Obstruction – vegetation
- ❑ Obstruction – other crewmember
- ❑ Obstruction – locomotive design
- ❑ Other: _______________________

Were there any maintenance issues with the signal?

- ❑ Bulb burned out – signal improperly displayed
- ❑ Bulb burned out – signal entirely dark
- ❑ Signal post down
- ❑ Signal obstructed by dirt / snow
- ❑ Signal malfunction
- ❑ Other: _______________________

Reason for Stop Signal

Why was the signal displaying a stop indication?

- ❑ Protecting a switch
- ❑ Meet or pass with another train
- ❑ Equipment in the block ahead
- ❑ Obstruction or broken rail detected
- ❑ Protected work zone
- ❑ Signal malfunction or circuit failure
- ❑ None—stop signal was unnecessary
- ❑ Other: ____________________

Preceding Signals and Unsignaled Stops

Preceding signal Identifier(s):	Milepost/control point(s):	Signal aspect(s):
______________________	______________________	______________________
______________________	______________________	______________________
______________________	______________________	______________________

Distance between immediate preceding signal and the signal that was overrun: ___________

Did the train make an unsignaled stop or unscheduled stop between the immediately preceding signal and the signal that was overrun?

- ❑ Yes, Unsignaled stop
- ❑ Yes, Unscheduled stop
- ❑ No

If yes, please give the reason for the stop (e.g., "unsignaled station stop" or "unscheduled stop due to a passenger incident").

____

Please describe any actions taken by the crew and events that took place during the stop(s) which may have contributed to the stop signal overrun:

____

Locomotive Technologies

Were any of the following technologies present in the locomotive? Check all that apply.

- ❑ Cab signal
- ❑ Positive train control
- ❑ Energy Management
- ❑ Other Locomotive Technology: _________________________

If cab signals were present:

Were cab signals operating at the time of the SSO?

❑ Yes ❑ No

If they were not operating, why were they not operating?

- ❑ Manually cut out
- ❑ Malfunctioning
- ❑ Other: ___________________

What was the cab signal at stop signal overrun location, if applicable?

____

What was cab signal in preceding block, if applicable?

____

If PTC was present:

Type of PTC system:

____

Was it operating at the time of the SSO?

- ❑ Yes ❑ No

If it was not operating, why was it not operating?

- ❑ Outside of PTC territory
- ❑ Manually cut out
- ❑ Malfunctioning
- ❑ Other: ___________________

If it was operating…

What state / mode was the system in?

____

Did the system provide any alerts or indications to the crew?

- ❑ Yes ❑ No

If yes, please describe any indications or alerts:

____
____
____

Did automatic braking activate?

- ❑ Yes ❑ No

If yes, when did automatic braking activate?

____
____
____

If energy management was present:

Type of energy management:

____

Was it operating at the time of the SSO?

- ❑ Yes ❑ No

If it was not operating, why was it not operating?

- ❑ Manually cut out
- ❑ Malfunctioning
- ❑ Other: ___________________

If it was operating…

What state / mode was the system in?

____

Did the system provide any alerts or indications to the crew?

- ❑ Yes ❑ No

If yes, please describe any indications or alerts:

____
____
____
____

Describe any other relevant information about the role of energy management in the stop signal overrun.

____
____
____
____

E: Train Crew Overview

This section provides an overview of the train crew's experience during the incident. Sections E, F, and G contain questions that pertain to the experience of individual employees.

Crew Composition

Please fill in the number of crew members in the table below:

	Regular crew members:	Extra board crew members:
Locomotive Engineers		
Conductors		
Assistant conductors (Rear brakemen)		
Ticket takers		

How long has this crew been working together, if applicable?

____

Which individuals were in the cab at the time of the stop signal overrun?

- ❑ Engineer
- ❑ Conductor
- ❑ Other (specify job title): ________________________

Total number of employees in the cab: ____________________

Crew Response to Stop Signal

When did the crew first recognize the stop signal?

- ❑ Before passing the signal (unable to stop in time)
- ❑ After passing the stop signal
- ❑ Unknown
- ❑ Other __________________________

Did the crew attempt to brake before passing the stop signal? ❑ Yes ❑ No

If yes, at what distance from the stop signal was braking initiated ? _______ ft.

How much time elapsed between the brakes being applied and passing the stop signal? _______ mins

How far past the stop signal did the train go before stopping? _______ft.

Did the train pass the point of danger (e.g. switch, broken rail)? ❑ Yes ❑ No

If no, how close did the train come to the point of danger, if applicable? ______ft.

Did the train strike another train or piece of equipment before stopping? ❑ Yes ❑ No

If no, how close did the train come to other equipment, if applicable? ______ft.

Who initiated communication between the dispatcher and the train crew that a stop signal overrun took place?

- ❑ The crew called the dispatcher
- ❑ The dispatcher notified the crew
- ❑ Other ___________________________

Which crewmembers were calling out signals?

- ❑ Engineer only
- ❑ Conductor only
- ❑ Both engineer and conductor
- ❑ Neither
- ❑ Other ___________________________

Which crewmember(s) correctly identified the stop signal prior to passing it? (check all applicable)

- ❑ Engineer
- ❑ Conductor
- ❑ Other ___________________________

Was there any miscommunication or confusion between crewmembers?

❑ Yes ❑ No

If yes, please describe the miscommunication or source of confusion:

____

Did they read the wrong signal (e.g., read through to the following signal, or believe that an adjacent signal was the controlling signal)?

❑ Yes ❑ No

If yes, please explain which signals the crew misread:

____

For the previous signal(s), please indicate whether the crew adjusted speed correctly in response.

Signal identifier:	Signal aspect:	Crew correctly adjusted speed?	
_____________	______________	❑ Yes	❑No
_____________	______________	❑ Yes	❑No
_____________	______________	❑ Yes	❑No

Attention / Task Demands

Did any factors inside or outside the cab draw the crew's attention away from the signal?

- ❑ Factors inside cab
- ❑ Factors outside cab
- ❑ Personal factors (e.g. mind wandering to internal thoughts)
- ❑ None

If yes to inside cab, indicate which factors inside the cab drew the crew's attention away from the signal, if any?

- ❑ Radio communication (describe: intra-train, with dispatcher, train-to-train, or overheard?)
- ❑ Cab signal
- ❑ Cab displays
- ❑ Equipment malfunction
- ❑ Visual alerts/warnings
- ❑ Audio alerts/warnings
- ❑ Reviewing paperwork
- ❑ Work-related conversation
- ❑ Non-work-related conversation
- ❑ Cell phone / PED use
- ❑ Other ____

Please elaborate on any factors checked above. For example, if "equipment malfunction" is checked, describe the malfunction that occurred, or if "radio communication" is checked, describe the nature of the communication and who was involved.

____

____

If yes to outside cab, indicate which factors outside the cab drew the crew's attention away from the signal, if any?

- ❑ Interaction with passenger(s)
- ❑ Wayside hazard (e.g. trespasser, wildlife, object on track)
- ❑ Other train or equipment
- ❑ Other signal (e.g. next signal after the stop signal)
- ❑ Switch points / switch alignment
- ❑ Other ____

Please elaborate on any factors checked above. For example, if "wayside hazard" is checked, describe the hazard.

____

____

If yes to personal factors, please elaborate:

____

____

Expectations

Was the crew anticipating a permissive signal?

- ❑ Yes
- ❑ No

If yes, why did the crew anticipate a permissive signal? (check all applicable)

- ❑ Did not see or respond to prior restricting signal
- ❑ Prior signal was not restricting
- ❑ Permissive signals are typical at this location

- ❑ Dispatcher did not communicate an unusual condition (e.g., a stop signal at a location where there is normally a permissive signal)
- ❑ Other ____

Was the crew anticipating a different route?

- ❑ Yes
- ❑ No

If yes, why did the crew anticipate a different route? (check all applicable)

- ❑ Current route is different than usual routing
- ❑ Dispatcher did not communicate different-than-usual routing
- ❑ Other ____

F: Crew Member Information (*one copy per employee)*

Name: ____________________[7]

Age: ________________

Gender: __________________

Occupation/Job title: ____________________

Employee number: ______________________

Experience and Current Assignment

Time in current craft: __________years _______ months _______weeks

Time at this railroad: __________years _______ months _______weeks

Seniority date: __________________

Date of last rules class: _____________________

Job assignment:

- ❑ Regular job
- ❑ Pool board
- ❑ Extra board

Time in current assignment: __________years _______ months _______weeks

Date most recently qualified on this territory: _____________________

When was the last time this employee was routed by this signal? ________________________

Was the employee ever tested on the signal that was overrun during an exam? ❑ Yes ❑ No

If yes, did it take them multiple attempts to correctly identify the aspect on the exam? ❑ Yes ❑ No

How much experience did the crew have operating this particular type of locomotive?

_________ years/months/weeks/days (circle one)

How frequently did the employee work on this particular portion of track (e.g., this yard, this route) prior to the incident?

- ❑ First time working this portion of track
- ❑ Rarely (did not work this track for over 6 months)
- ❑ Infrequently (less than once a month)
- ❑ Consistently (once per week or more)
- ❑ Always (all or most shifts)

[7] For railroad use only; black out this field to de-identify reports if shared externally.

Stop Signal Overrun and Rule Violation History

Has this individual had any prior stop signal overruns? ❑ Yes ❑ No

If yes, explain. Give dates or other incident identifiers.

____

____

Has this individual had other prior rule violations? ❑ Yes ❑ No

If yes, explain. Give dates or other incident identifiers.

____

____

Schedule and Rest

Shift start time on the date of the incident: ____:_______ AM/PM

Job assignment type (49 CFR Part 228.5): ❑ Type 1 ❑ Type 2

Day of work cycle: ____ of _____

Time off prior to shift: _________days ______hours

Total time on duty at the time of the SSO: _________hours ______minutes

Most recent turn time duration (if applicable): __________

Summarize the employee's sleep and work schedule over the past 72 hours prior to the accident:

____

____

Fitness for Duty[8]

Date of last medical exam: ________________

Did the employee have any known medical conditions that would impair his or her ability to perform this job?

- ❑ Hearing impairment
- ❑ Color deficit
- ❑ Other visual impairment
- ❑ Sleep apnea
- ❑ Other sleep disorder
- ❑ Other: ______________

Was the employee using any prescription or over-the-counter medications that could affect their job performance?

❑ Yes ❑ No

[8] Railroads may wish to attach separate documentation of drug/alcohol test results, medical records, etc.

Was there evidence of drug or alcohol impairment at the time of the incident?

❑ Yes ❑ No

If yes to either of the above, please elaborate.

____

Actions related to the SSO

Could the crewmember see the signal from their location?

❑ Yes ❑ No

Did the crewmember recognize that it was a stop signal before passing it?

____

G: Dispatcher Information *(one copy per employee)*

Basic Information

Name: ___________________[9]

Age: _______________

Gender: _________________

Experience and Current Assignment

Occupation/job title: ___________________

Employee number: _____________________

Job assignment:

- ❑ Regular
- ❑ Extra board

Desk(s) dispatcher normally covers: _________________

Desk(s) dispatcher was covering at the time of the passed stop signal: ______________________

How long have they been qualified on this desk (s): _____________________________

Length of time working at this desk: __________years _______ months _______weeks

Length of time working in this craft: __________years _______ months _______weeks

Length of time working at this railroad: __________years _______ months _______weeks

Schedule and Rest

Time employee came on duty: ____:______

Time off prior to coming on duty: ____ days, ______ hours

Summarize the employee's sleep and work schedule over the past 72 hours prior to the accident:

____

____

Routing and Communications with Crews

Were there any unusual conditions affecting the train movement?

- ❑ Different route than usual
- ❑ Maintenance issue (e.g. dark signal)
- ❑ Meet or pass at different time or location
- ❑ Other: ____________________________

[9] For railroad use only; black out this field to de-identify reports if shared externally.

If yes, did the dispatcher contact the train crew ahead of time to let them know of the unusual conditions?

❑ Yes ❑ No

Did the last train that passed the signal note any abnormalities related to the signal or route?

❑ Yes ❑ No

If yes, please describe:

____

How long did it take from the time the passed stop signal occurred to the time the dispatcher became aware that a passed stop signal occurred?

____

How did the dispatcher first become aware that the stop signal was passed?

- ❑ Contacted by train crew that passed stop signal
- ❑ Contacted by some else: ___________________
- ❑ Audio/visual alert or indicator on dispatch computer system
- ❑ Overheard radio communication

What actions did the dispatcher take upon becoming aware of the passed stop signal?

____

Technology Factors

Did the dispatcher's computer system display an indication of the passed stop signal?

- ❑ Visual
- ❑ Audio
- ❑ Both
- ❑ Neither (no indication)

If so, did the dispatcher detect the audio or visual indication of the passed stop signal on the computer system display?

- ❑ Yes, immediately
- ❑ Yes, but delayed
- ❑ No

Did the dispatcher correctly interpret the visual/auditory indication?

- ❑ Yes, immediately
- ❑ Yes, but delayed
- ❑ No

Were there any anomalous, erroneous or misleading indications on the dispatcher computer system at the time that the train passed the stop signal?

____

Was there visual or auditory indication that a passed stop signal occurred on anyone else's computer system (e.g., computer system of supervisor or manager)?

____

H: Employee Narratives (*one copy per employee)*

To be filled out by crewmembers, dispatcher, and any others with knowledge of the incident.

Basic Information

Name: ___________________________ Date recorded: _______________

Employee Number: ________________ Time recorded: _____:_________

Occupation/Job Title: _______________

Narrative

Please describe, from your own perspective, the events leading up to the stop signal overrun (use the backside of this sheet or additional sheets if needed.)

____
____
____
____
____
____
____
____

How did you identify or learn about the stop signal overrun?

____

What actions (if any) did you take after becoming aware of the stop signal overrun?

____
____

Please list any factors you observed that you believe contributed in any way to the stop signal overrun. (These may include environmental factors, characteristics of the territory, technology or infrastructure, organizational factors, etc.)

____
____
____

Please describe any suggestions for how to address the factors you listed above to prevent future stop signal overruns.

____
____
____

I: Incident Severity[10]

Was the incident reported to FRA?

- ❑ Yes ❑ No

Select incident type (check all that apply):

- ❑ Stop signal overrun
- ❑ Repeat stop signal overrun at signal
- ❑ Near miss—PTC enforcement prevented stop signal overrun

Was there an obstruction on the tracks?

- ❑ Yes ❑ No

If yes, specify what the obstruction was: ____

Did the crew pass the point of danger (e.g. ran through switch or hit obstuction)?

- ❑ Yes ❑ No

Distance past signal: __________ft.

Distance from point of danger: ___________ft.

Select any accidents that occurred as a result of the stop signal overrun, if applicable:

- ❑ Derailment
- ❑ Head on collision
- ❑ Rear end collision
- ❑ Side collision
- ❑ Raking collision
- ❑ Broken train collision
- ❑ Other (please describe) ____________________

[10] Some of this information may already be collected on FRA forms in the case of a more serious accident following a stop signal overrun. However, by collecting it here it can be used to populate additional forms as needed.

Derailments

Locomotives derailed: ___________

Freight: Loaded cars derailed: _______

Unloaded cars derailed: _____

Passenger: Occupied cars derailed: ______

Unoccupied cars derailed: ____

Hazardous Materials

Were there hazardous materials onboard?

❑ Yes ❑ No

Number of hazmat cars damaged/derailed: ___

Number of hazmat cars releasing product: ____

Number of people evacuated: _____________

Damage Estimates

Estimated equipment damage:

$_______________________

Estimated track, signal, and way damage:

$_______________________

Estimated structure damage:

$_______________________

Estimated cleaning costs:

$_______________________

Injuries and Fatalities

Number of fatalities: _____________

Employee fatalities: _______

Passenger fatalities: _______

Other fatalities: _______

Number of injuries: _____________

Employee injuries: _______

Passenger injuries: _______

Other injuries: _____

J: Incident Diagram

Sketch train positions, signal positions, switches and interlockings—or attach photographs, track charts etc. as needed to illustrate the incident.

Abbreviations and Acronyms

Abbreviations & Acronyms	Definition
AREMA	American Railway Engineering and Maintenance-of-Way Association
CFR	Code of Federal Regulations
EMU	Electric Multiple Unit
FRA	Federal Railroad Administration
MTM	Million Train Miles
NTSB	National Transportation Safety Board
OJT	On the Job Training
PASS	Passing a Stop Signal
PTC	Positive Train Control
RSIA	Rail Safety Improvement Act
SPAD	Signal Passed at Danger
SSO	Stop Signal Overrun
SSV	Stop Signal Violation