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Transportation

**Federal Railroad
Administration**

An Investigation of Passing Stop Signals at a Passenger Railroad

Office of Research
and Development
Washington, DC 20590



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13. ABSTRACT (Maximum 200 words) This report documents the findings and recommendations from an investigation into stop signal violations at an American passenger railroad. The investigation was requested by the Federal Railroad Administration (FRA) and the passenger railroad, and sponsored by FRA's Office of Research & Development (ORD). This investigation assisted the passenger railroad in understanding why stop signal violations occurred in the terminal and helped it develop effective corrective actions to prevent or mitigate their occurrence in the future. In addition to making recommendations for the railroad, this report discusses opportunities for the FRA to improve the risk management of passing a stop signal (PASS) across railroads. These improvements include recommending more systematic collection and analysis of PASS data; changing FRA compliance and enforcement practices to encourage more open and complete reporting of PASS incidents; and performing additional field and simulator-based research to strengthen the empirical foundation for linking systemic factors to PASS.				
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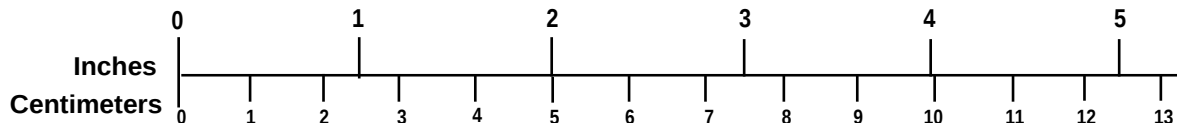
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LENGTH (APPROXIMATE)	
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1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)
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1 square foot (sq ft, ft ²)	= 0.09 square meter (m ²)
1 square yard (sq yd, yd ²)	= 0.8 square meter (m ²)
1 square mile (sq mi, mi ²)	= 2.6 square kilometers (km ²)
1 acre = 0.4 hectare (he)	= 4,000 square meters (m ²)
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1 pound (lb)	= 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)
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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 yard (cu yd, yd ³)	= 0.76 cubic meter (m ³)
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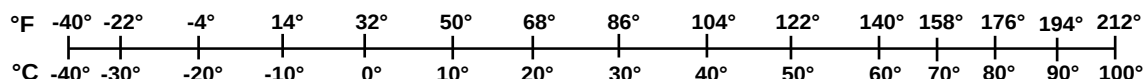
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LENGTH (APPROXIMATE)	
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1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (km)	= 0.6 mile (mi)
AREA (APPROXIMATE)	
1 square centimeter (cm ²)	= 0.16 square inch (sq in, in ²)
1 square meter (m ²)	= 1.2 square yards (sq yd, yd ²)
1 square kilometer (km ²)	= 0.4 square mile (sq mi, mi ²)
10,000 square meters (m ²)	= 1 hectare (ha) = 2.5 acres
MASS - WEIGHT (APPROXIMATE)	
1 gram (gm)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t)	= 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)	
1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m ³)	= 36 cubic feet (cu ft, ft ³)
1 cubic meter (m ³)	= 1.3 cubic yards (cu yd, yd ³)
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Executive Summary

A stop signal violation or passing a stop signal (PASS) occurs because of conditions created by the physical environment, the operating environment and organizational pressures, technology, as well as individual and team factors. Some of the systemic factors which create the conditions that may cause PASS include:

- Signal system design, including the layout of the physical infrastructure
- Locomotive design
- Planning and scheduling practices
- Practices by which employees are assigned to jobs
- Increasing number of trains and organizational pressure to maintain schedule
- Decreasing levels of experience across the organization due to increased number of retirees
- Dispatcher routing strategies
- Training practices
- Operating rules and employee compliance with them.

This report documents the findings and recommendations from an investigation into PASS at a U.S. passenger railroad. The investigation was requested by the Federal Railroad Administration (FRA) and the passenger railroad, and sponsored by FRA's Office of Research & Development. Since the majority of stop signal violations experienced by this railroad occurred in the terminal, this project focused on PASS in the terminal. The goal of this investigation was to assist the passenger railroad's efforts to understand why stop signal violations occurred, and develop effective corrective actions to prevent or mitigate their occurrence in the future. Not only does this report make recommendations for the railroad, it also discusses how FRA can potentially improve the risk management of PASS across railroads.

Incidents in which train crews pass stop signals, while rare, occur at railroads in the U.S. and internationally. In the international literature, a stop signal violation is referred to as a Signal Passed at Danger (SPAD), largely because the term provides a value-neutral description of an unwanted outcome (May & Horberry, 1994; Lowe, Li & Lock, 2004). In this report, we refer to stop signal violations as Passing A Stop Signal (PASS) to avoid the negative connotation associated with the phrase stop signal violations.

The project consisted of three mutually reinforcing activities:

- (1) A literature review of factors that contribute to PASS;
- (2) A review of the railroad's historical data describing PASS events and analyses of these events; and
- (3) A series of in-depth interviews, conducted with railroad staff during two site visits to the terminal with follow-up phone calls, which examined factors that potentially contributed to PASS on the railroad.

Because unwanted outcomes such as PASS are rarely attributable to a single cause, a systems framework guides the investigation and analysis contained in this report. This framework

includes the physical environment, the organization, the technology, and the task, as well as individual and team-related behavioral factors. To understand the contributing elements, we conducted interviews with railroad employees at all organizational levels, then performed observations in the terminal and the operations control center where the dispatchers worked.

The inquiry determined that there is a need for more effective PASS event reporting and analysis systems. Collecting additional data will allow the railroad to better understand why PASS occurs and identify effective corrective actions to address them.

While the specific findings and recommendations in this report apply to a particular passenger railroad, we believe that they will be relevant to other railroads as well. FRA should perform similar analyses for other passenger railroads so it can better assess the report's findings and recommendations, and build a stronger empirical foundation for identifying and mitigating factors that contribute to PASS.

FRA could improve the risk management of PASS across railroads by changing FRA compliance and enforcement practices so they encourage more open and complete reporting of PASS incidents and performing additional field and simulator-based research to strengthen the empirical foundation for linking systemic factors to PASS.

1. Introduction

This report documents the findings and recommendations from an investigation into stop signal violations (SSVs) at a U. S. passenger railroad. The investigation was requested by the Federal Railroad Administration (FRA) and the passenger railroad and sponsored by FRA's Office of Research & Development. The goals of this investigation were to help the passenger railroad understand why stop signal violations occurred and to develop effective corrective actions that prevent or mitigate the occurrence of violations in the future¹.

Historical data on stop signal violations, which was provided by the passenger railroad, indicated that 55 percent of stop signal violations occur in the terminal. The railroad asked the Volpe Center to focus its efforts on stop signal violations in the terminal due to the frequency of stop signal violations in the terminal within a relatively short timeframe.

While train crews rarely pass stop signals, it happens in the U. S. and internationally. In the international literature, stop signal violations are referred to as Signals Passed at Danger (SPAD) (May & Horberry, 1994; Lowe, Li & Lock, 2004). When the phrase "stop signal *violation*" is used, it contains a value judgment that the unwanted outcome is the result of the employee's behavior. The word "violation" implies that the employee intentionally behaved in a way that is counter to established regulations. For this report, we will use the phrase "Passing A Stop Signal" (PASS) to avoid being judgmental.

The phrase "signal passed at danger" and "passing a stop signal" are value-neutral and simply describe the unwanted outcome. A large body of research (Barton and Haliday, 2008; Li, 2003); Lowe, Li, and Lock, 2004; Naweed, 2014; Newman et al., 2007; Newman 2003; Phillips and Sagberg, 2013; Wisawayodhin et al., 2007; Wood et al., 2005; Wright et al., 2007) indicates that these events occur as the result of multiple factors involving the design and operation of the system. For the remainder of the report, we will use "passing a stop signal" or "PASS" in place of the phrase "stop signal violation."

To understand the numerous contributing factors at all system levels, we conducted interviews with railroad employees at all 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 PASS occurred.

Because unwanted outcomes such as PASS are rarely explained by a single cause, we adopted a systems framework to guide the investigation and analysis of PASS that occurred at the passenger railroad's terminal. The systems framework included the physical environment, organization, technology and task, and both individual and team factors. Section 1.1 describes this framework and its rationale in greater detail.

The remaining two sections of the introduction provide the additional background information that guided our analysis. Section 1.2 summarizes factors derived from the literature review that

¹ Passing a stop signal occurs when an employee operate a locomotives or train past a signal indication, excluding a hand or a radio signal indication or a switch, that requires a complete stop before passing it.

have an impact on PASS. Section 1.3 summarizes the passenger railroad's own analysis of factors that contribute to PASS in the terminal.

Section 2 provides more details on the study methodology. Section 3 presents our analysis of the PASS data provided by the railroad and our recommendations to the railroad for future data collection methods. Section 4 discusses our findings and recommendations from the observations and interviews. (A consolidated list of recommendations can also be found in Appendix C of this report.) These findings and recommendations, while specific to the railroad we studied, are probably relevant to other railroads as well.

Section 5 provides FRA with recommendations intended to help improve the risk management of PASS. These include 1) improving FRA data collection and analysis of PASS under existing laws and regulations; 2) considerations for potentially changing, updating, or improving upon FRA regulatory, compliance, and enforcement practices, and 3) performing additional research necessary to strengthen the empirical foundation for understanding and mitigating PASS risk. In particular, it is suggested that FRA should expand the field research to additional railroads so it can determine whether the findings at the current railroad apply more broadly and strengthen the empirical foundation that links systemic factors to PASS. Section 6 provides this project's conclusions.

1.1 Identifying Contributors to PASS: A Systems Approach

PASS occurs when a locomotive engineer fails to stop the train prior to a stop signal. An extensive body of human factors literature describes the factors that contribute to unwanted outcomes such as accidents and incidents and ways to prevent them (e.g., Reason, 1990; 1997; Woods, Dekker, Cook, Johannesen & Sarter, 2010). One of the primary insights from the literature is that unwanted outcomes are rarely the result of a single factor. Generally, unwanted outcomes are the result of multiple factors that combine to create the adverse event or sequence of events. These factors include those affecting the individual(s) involved (e.g., lack of knowledge or inattention), the immediate situation (e.g., poor visibility, distractions), and the broader system, including management and organization (e.g., production pressures that might lead workers to feel they have to rush or take short cuts). As a consequence, a broad, systems-oriented approach is needed (Moray, 2000, Levison, 2012) when understanding the multiple factors that are collectively increasing the probability of unwanted outcomes.

When a train encounters a signal, several different groups influence when and how the train crew and the signal system interact:

- The signal system's performance is affected by its design and maintenance, while the communication and signal department support either or both the design and maintenance of the signal system.
- The dispatcher, chief dispatcher, yardmaster and operations department all play a role in routing trains and determining which trains receive priority as they move through the system.
- The train crew, both engineer and conductor, play a role when encountering signals. The engineer has the primary responsibility for complying with the signal system, but the conductor may play a supporting role in reading signals and preventing the engineer from misreading or missing a signal.

- The training department influences the strategies by which train crews operate their trains, understand how the signal system operates, and comply with all pertinent, codified operating rules and procedures.

Other factors that may contribute to PASS include: crew scheduling, the design of collective bargaining agreements, and the design of the locomotive. The interdependencies between these variables, along with a multitude of factors, contribute to how the railroad system functions and can influence how PASS can occur.

Figure 1 shows a systems framework which classifies factors that contribute to PASS. This framework includes the environmental, organizational, technological, task-related, and individual and team factors that can impact PASS. When combined under certain circumstances, these factors increase the potential for PASS (though the figure does not explicitly state this). The authors developed this framework from a review of the human factors literature on contributors to human error, as well as the literature that specifically addresses the factors that contribute to PASS. This systems framework was used to structure interview questions as well as organize our findings and recommendations. Although the framework suggests that factors are nested within factors, feedback loops also exist within layers as well as between the layers. The hierarchical relationship indicates that the higher order factors (such as “Regulatory Mechanisms”) influence the factors that occur in lower layers (such as “Task & Technology”). In turn, the lower level factors provide information to the factors above them to create interdependencies between layers. Also, interdependencies take place between factors that are inside a layer.

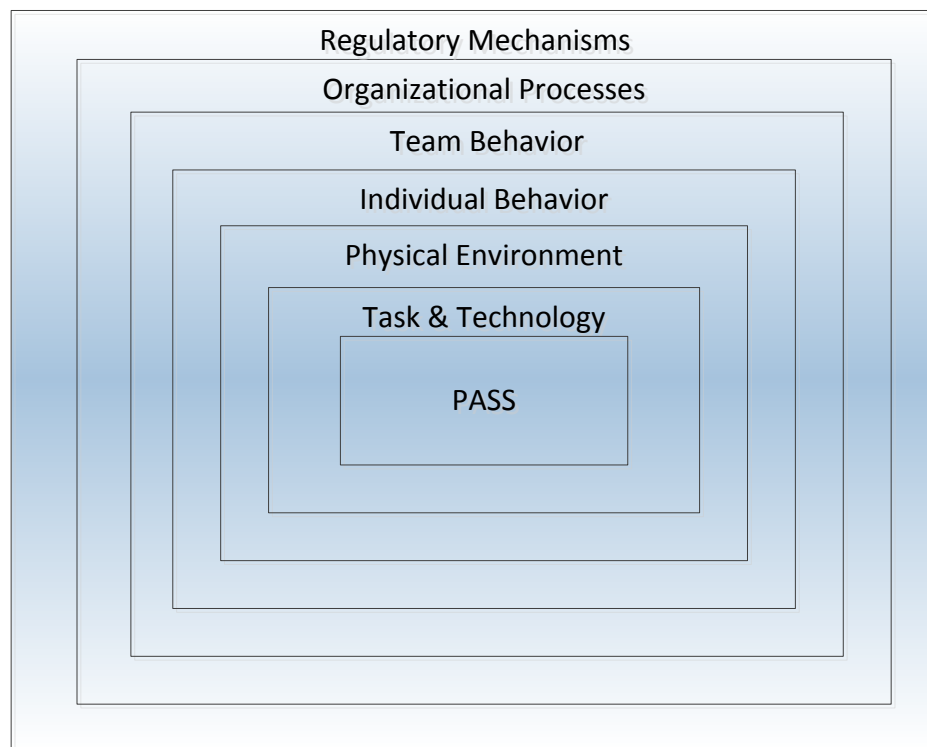


Figure 1. A systems framework for classifying factors that can contribute to PASS

1.2 Known Factors Contributing to PASS

As our first task, we reviewed the human factors research literature on PASS. Much of the relevant research has been conducted in the United Kingdom and Australia following the Southall and Ladbroke accidents, which both involved PASS and resulted in multiple fatalities. The Rail Safety & Standards Board (RSSB), a British industry-sponsored safety organization, maintains a database that summarizes and categorizes a broad range of PASS human factors literature (Lowe, Li & Lock, 2004). There is also growing research base on PASS in Australian and New Zealand railroads (Naweed, 2013, Naweed 2014). Some notable factors that the literature cites as contributing to PASS include:

Physical Environment

- Physical characteristics of signal aspects² and their location (e.g., signal locations that reduce sighting distance such as signals around a curve)
- Other signals in the locomotive engineer's line of sight (e.g., reading an adjacent signal due to line curvature or reading through to the next signal)
- Train density (i.e., number of trains that pass through an intersection)

Organization and System Factors

- Production pressures (i.e., on-time performance is over-emphasized)
- Time of day (i.e., there is some evidence of more PASS incidents during 8am to noon, 6pm – 10pm, and midnight to 6am. These may reflect multiple factors including train frequency during different time periods, as well as circadian rhythms.)

Tools, Technology and Task Factors

- Distractions (e.g., communications, unusual events or circumstances)
- Expectations based on prior experience (e.g., in the past the signal has generally been clear so it was expected to be clear this time)

Individual and Team Factors

- Age and experience level (e.g., new locomotive engineers tend to have more PASS incidents)
- Time on duty (e.g., some evidence of more PASS incidents in the 4th and 5th hour into a shift)

² The appearance of a signal conveying information about speed, as seen from the direction of the approaching train or engine

Other³

- PASS tends to occur more after several days off-duty
- PASS tends to occur more in May through August

Based on these findings, the Rail Safety Standards Board of the United Kingdom developed an online management tool (Online SPAD Management Tool Database, <http://opsweb.co.uk/TOOLS/tools-spad.html>). The online tool consists of the following components:

1. Common Factors in SPADs Database
2. SPAD Risk Management Support Tool
3. SPAD Hazard Checklist
4. SPAD Mitigations (searchable database)
5. Human Factors Signal Sighting Framework

We consulted these databases, tools and checklists as we formulated our interview topics, interpreted the results of our interviews, and developed recommendations.

1.3 Passenger Railroad's Analysis of Factors Contributing to PASS

After the sponsoring railroad dealt with a string of PASS events in 2010, 2011, and 2012, it decided to conduct an internal analysis of the occurrences from 2005 through 2012 to identify potential trends and patterns, and develop recommendations to reduce the frequency of PASS. The results of this work were documented in two internal reports. During the selected review, 46 PASS events occurred (an average of 7 per year).

Below we summarize the findings identified by the railroad (organized around the systems framework categories):

Physical Environment

- The terminal experienced 55 percent of PASS events
- Sun on signal

Organization and System Factors

- The two four-hour blocks that have the most PASS events are 8am – 12pm (35 percent) and 4pm – 8pm (27 percent)

Technology and Task Factors

- Distraction accounted for 20 percent of all PASS events. Sources of distraction included:
 - Locomotive computer screens
 - Lights of another train

³ The relation of these factors to the high level classification of factors is unclear. For example, PASS occurring more in May-August may reflect shifts in weather (Physical Environment) or change in train density or train schedule (Organization and System Factors), other factors and/or a combination of factors.

- o Reading timetable
 - o Talking to another employee
 - o Cab door opened
- Anticipating the signal/route and looking past the closest signal to the next signal accounted for 22 percent of PASS events.
- Most PASS events happened in the first half of an employee's shift, with 5 (11.3 percent) happening within one hour of starting work;

Individual and Team Factors

- Employees with 5 or less years of experience (27 percent of the roster) had 52 percent of the PASS events

Other

- The majority of PASS events (28) occurred in April, May, June and October
- Over 67 percent happened in the first or second workday
- Six employees (15 percent of employees involved in PASS) experienced two PASS events accounting for 26 percent of the incidents.

The list of contributing factors conforms fairly well with the PASS-related factors that are reported in the literature. Some of the challenges faced by this passenger railroad when it was mitigating PASS were identified in the research literature cited earlier. This existing literature identified corrective actions that a railroad can use to address these challenges. Also, it is worth noting that the railroad's own internal analysis was in-depth when it examined potential individual factor characteristics (e.g., age, years of experience, prior type of job), but it did not explore other potential contributing factors such as physical environment, task, technology, teamwork, and organizational and system factors to the same extent.

For example, potentially relevant physical environment factors could include signal location and the multiple signal aspect coding convention used in the terminal, while potentially relevant organizational and system factors could potentially include the dispatcher train routing strategies that may influence exposure to PASS. As one of the supervisors in the dispatch center pointed out to us, if there are no stop signals in the terminal then there would be no possibility of PASS. While PASS may not be completely eliminated, dispatcher train routing strategies can influence how often locomotive engineers are routed in a manner that exposes them to PASS (i.e., creates 'traps' for the locomotive engineers). Similarly, the railroad's analysis did not examine the potential impact of organizational goals and pressures on the performance of locomotive engineers. One of the objectives of this analysis was to broaden the set of factors explored so they included the possible influence of physical infrastructure, tasks, the team, the organization, and related systems.

2. Methods

As discussed earlier, a systems approach was used to understand the factors that collectively increase the probability of human error (in this case, focusing on PASS in the terminal) and it encompassed the following areas: physical environment, organization and system, technology and task, and individual and team factors. To understand all of the contributing factors, interviews were conducted with the railroad employees at all organizational levels and observations were performed in the terminal and the operations control center where the dispatchers worked.

Kick-Off Meeting

The project started with a kick-off meeting that included two out of three Volpe Center team members, several management level railroad employees (including former members of a task force on PASS) and the FRA Regional Administrator. This meeting served as an introduction to the railroad's PASS issues and included a short synopsis of the measures the railroad had taken to mitigate PASS.

Phone-Based Interviews (outside perspectives)

Following the kick-off meeting, we conducted two informal phone interviews to solicit outside perspectives on the issue and obtain a preliminary understanding of the signal system in use at the railroad terminal. The interviews were with an FRA Operating Practices Inspector and a Road Foreman from a different passenger railroad, both of whom had previously worked as locomotive engineers and were familiar with the passenger railroad's operations.

Railroad Data Review

Next, we reviewed historical data compiled by the passenger railroad, which included a review of previous PASS events in the terminal and information about the terminal's signal system. Data included PASS reports and spreadsheets from 2005 through early 2014 and included the following:

- Stop signal violation report documents, including the railroad's internal investigation reports
- A stop signal violations data analysis report
- A stop signal violation investigation committee report
- Terminal track charts
- The terminal's signal system design
- Signal data within the terminal for a 24-hour period.

This information allowed us to identify potential factors that need to be explored in more depth and the knowledge needed to assess the factors that contribute to PASS occurrences at this terminal.

PASS Literature Review

Not only did we review nearly a decade's worth of the railroad's system-wide PASS history, we also reviewed the literature on PASS (including contributing factors and mitigation strategies).

The literature review pointed to physical, organizational and systemic, as well as individual factors that are contributors to PASS and it provided the basis for the broad scope of our investigation into PASS at the terminal.

Site Visit #1

On this site visit, we developed interview questions that were based on information gathered from the literature and railroad data review. Interviews were held with the following groups of employees:

- Locomotive engineers (3 groups):
 - 4 engineers with less than 5 years of operating experience
 - 4 engineers with a minimum of 10 years of service as a locomotive engineer
 - 4 engineers with stop signal violations in the terminal
- Dispatchers who manage the terminal territory
- Deputy Director of Training & Development

Interviews with locomotive engineers lasted approximately 2 hours each and a union representative was present at each session. The following topics were included:

- Near misses, actual PASS experiences, and hypothetical PASS events
- Factors that contribute to PASS inside the terminal
- Role of experience in mitigating risk for PASS
- Discussions of the railroad's PASS mitigation strategies
- Suggestions for ways to mitigate PASS, including discussion of the current signaling system

Discussions with dispatchers occurred in the dispatch center at their workstations during periods of low workload over a 1.5 hour period. The following topics were included:

- Strategies that dispatchers use to manage train movements
- Challenges that dispatchers face
- Their general knowledge of the terminal
- Challenges affecting locomotive engineers
- Questions about dispatcher communications with train crews

Discussions with the Deputy Director of Training and Development lasted approximately one hour. Topics included:

- Training and certification for locomotive engineers
- Changes to training and the terminal due to the SSV task force
- Opinions on the terminal's signaling system

As part of this site visit, we observed dispatchers managing trains in and out of the terminal and spoke with dispatch center supervisors, who oversee train movement across multiple territories, about dispatching work and the supervisors' strategies for coordinating and managing work across the entire territory. In addition, we rode with road foremen in a locomotive cab inside the terminal to see the signal system and examine signals where locomotive engineers have passed a stop signal. Also, we toured the railroad's training facility where training simulators were located.

Site Visit #2

After reviewing data from the first site visit, we determined a second site visit to be necessary. The second site visit followed the same approach as the first site visit and included interviews and observations in the dispatch center. We conducted interviews with the following employees:

- Four conductors with experience in the terminal
- Four locomotive engineers
- Two Communications & Signal (C&S) supervisors
- Two training department employees
- One general road foreman
- One expert dispatcher

The conductor interview lasted 1.5 hours and featured conversations with 2 yard and 2 passenger conductors who have worked with locomotive engineers in the locomotive cab or electric motive unit (EMU) inside the terminal. Topics covered during the interview included:

- Roles of the conductor, with an emphasis on communicating with the dispatcher
- Conductor training, with an emphasis on training on signals in the terminal
- Opinions on riding as a conductor in the head end within the terminal
- The terminal's signaling system

The engineer interview also lasted 1.5 hours and included 4 engineers. Topics covered during the interview included:

- The engineer's roles and responsibilities
- The terminal's signals and signal aspects
- Dispatching within the terminal
- Distraction and fatigue

The interview with C&S supervisors lasted 2 hours. Topics covered during the interview included:

- Signal placement
- Using event recorder data in SSV investigations
- The terminal's signaling system
- Evolution of the terminal signals and track layout
- Installing LED lighting and warnings for signals that have moved out of position or have fallen after being hit by moving equipment along the right of way

The interview with training department employees lasted 1 hour and included the following topics:

- Engineer training
- Conductor training
- Bidding/schedule changes
- The terminal's signaling system
- "Reserve engineers" who operate primarily within the terminal but also provide service for outbound trains if the original train crew arrives late.
- Discussion of diesel vs. electric trains, and newer vs. older electric locomotives

The interview with the General Road Foreman lasted 1.5 hours and included the following topics:

- The terminal's signaling system
- Engineer training
- Investigations into stop signal violations

The interview with an expert dispatcher lasted 2 hours and included the following topics:

- Strategies for managing trains
- The effect of experience and expertise on train routing
- Dispatcher training
- The signaling system
- Dispatcher communication

Supplemental Phone Interviews

Due to schedule constraints, the second site visit was supplemented with several phone interviews. Phone interviewees and topics are shown in Table 1.

Table 1. Phone Interviews that Supplemented Second Site Visit

Interviewee	Topic(s)
Author of a Signal Sighting Data Analysis Report	Methods for data analysis, clarification on stop signal violation classification
Member of a committee looking into stop signal violations at the railroad	Committee members, tasks and stop signal violation mitigation recommendations
Operations planning staff	Train schedule development, turn-time built into schedule, ad hoc schedule changes and complexity to scheduling
Crew scheduling staff	Twice yearly crew pick, turn-time, crew assignment, reserve engineers
Transportation Department Superintendent	Events that cause disruptions in train schedules, Transportation Department roles and responsibilities, impact of delays on crew and train scheduling, reserve engineers
Operating Rules Director	Signaling system in the terminal, engineer operating rules for signal compliance

3. Analysis of PASS Frequency Data and Data Collection Recommendations

As part of our initial efforts to understand PASS, we analyzed the railroad's available data on PASS and compared its data to similar passenger railroads. We also examined the connection between PASS and the terminal's operational tempo by examining the relationship between the number of trains operating in the terminal and the number of stop signals.

To put the railroad's data on PASS in context, we compared it to PASS rates from six other passenger railroads which are similar in size and scope (

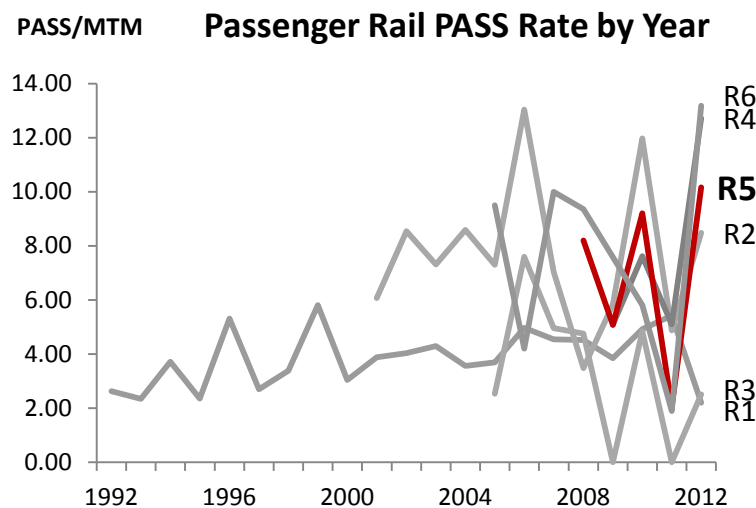


Figure 2). The PASS rate is normalized by million train miles. The number of data points varies because FRA does not specify how many years of data must be reported by railroads. The chart has wide year-to-year variations in the PASS rate, and the red line indicates that the passenger railroad (R4) we worked with is similar in performance to the other five railroads. For the railroad we worked with, the PASS rate varies from a low of 1.9 PASS/million train miles to a high of 10.1PASS/million train miles; several railroads show similar year-to-year variations. Given that the railroads in Figure 2 represent comparable passenger railroads in the U.S., R4's PASS rate is consistent with other passenger railroads.

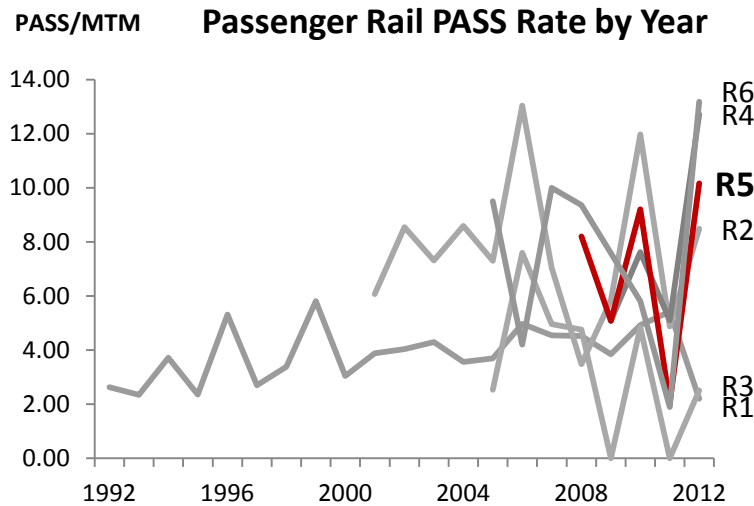


Figure 2. PASS /million train miles by year for six passenger railroads

Figure 3 shows the same data based on the mean PASS rate with 95 percent confident intervals. This chart confirms that Railroad 4 is similar in performance to the other five railroads.

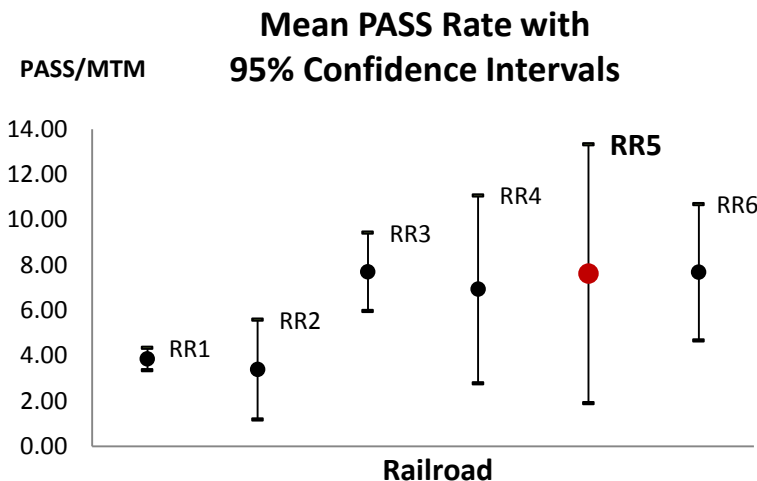


Figure 3. Mean PASS/million train miles with 95 percent confidence intervals

3.1 Terminal PASS Analysis

There may be some trends that can help us understand what factors may lead to these unwanted events. Figure 4 shows all the PASS events that occurred between July 2008 and February 2014. Because the railroad was interested in the PASS within the terminal, they were separated into two categories: PASS that occurred inside and outside the terminal limits. The red line represents the number of PASS events inside the terminal and the black line represents the number of PASS events that took place outside of the terminal environment.

Figure 4 displays the time between PASS events in days; when data points are spaced more closely together with a steeper slope, PASS events are occurring at a greater frequency. Although the number of events that are taking place inside (23) and outside (19) of the terminal environment are similar, the pattern differed between the two environments. After the railroad

began to investigate PASS, the PASS rate outside the terminal decreased and remained steady following the investigation. Outside of the terminal environment, PASS occurred, on average, every 70 days between February 2008 and June 2010. Next, the rate decreased by half to an average of 205 days between June 2010 and October 2013.

We observed a different pattern in the terminal environment. Inside the terminal, the PASS rate decreased after the railroad initiated its PASS investigation and then it rose back to levels that had been seen before the investigation. From October 2009 until May 2010, PASS occurred every 33 days on average and from May 2010 until April 2012, the PASS rate declined to an average of 235 days between PASS. The rate then increased to an average of 40 days between PASS. Despite efforts to correct the problem, increases in the PASS rate inside the terminal continued, which led the railroad to request help in identifying and mitigating this issue.

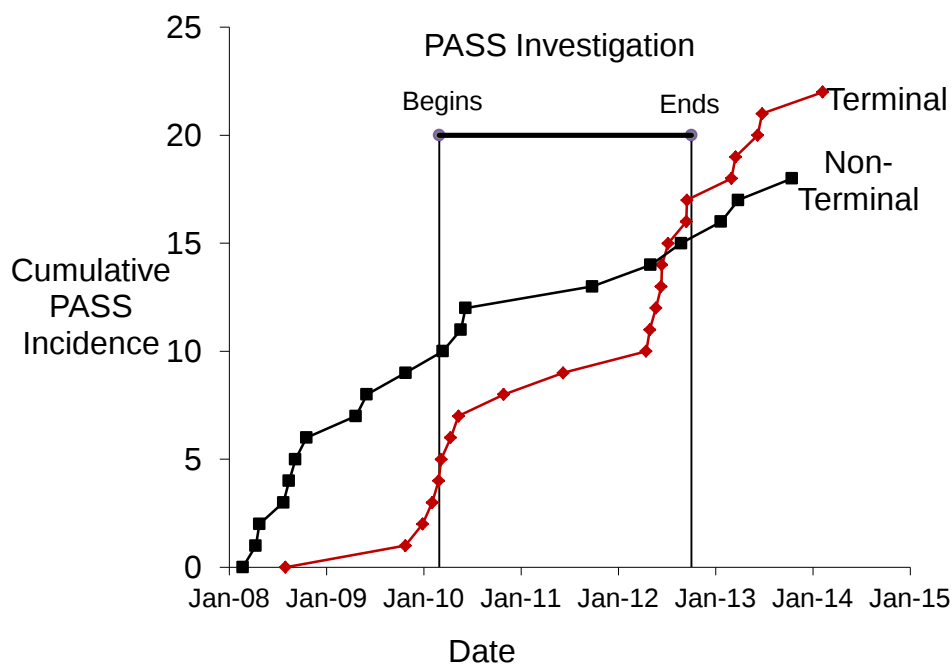
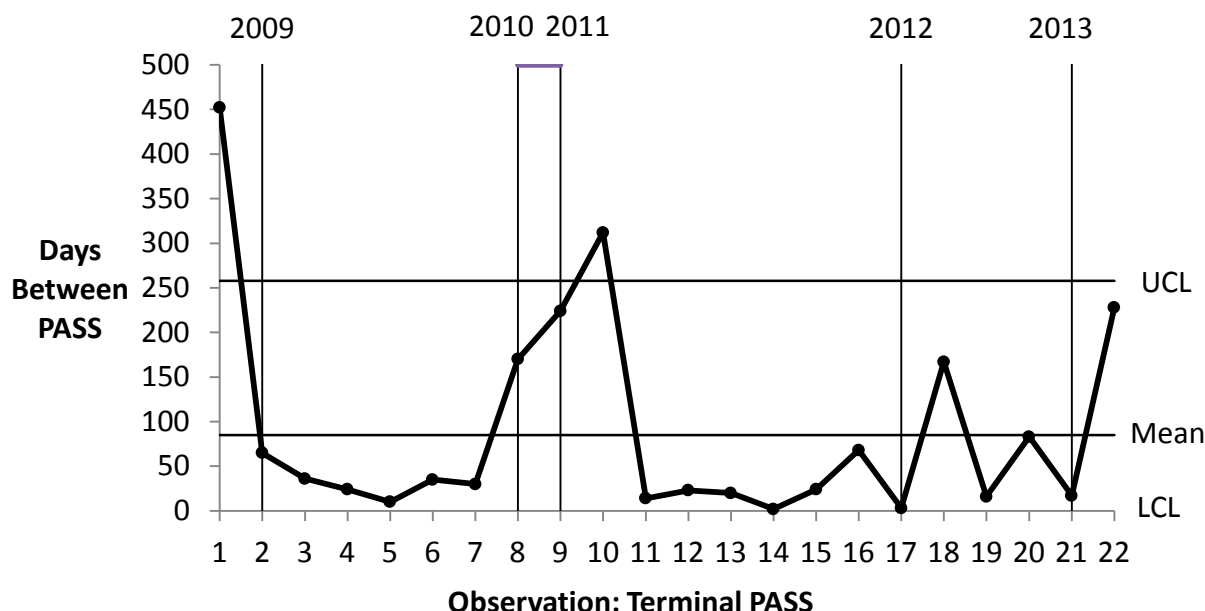


Figure 4. Comparison of PASS between terminal and non-terminal environment

When the PASS rate declined in the terminal and non-terminal environments between March 2010 and October 2012, this period appears to coincide with the railroad's investigation, in which it explored why the PASS rate increased and looked to implement corrective actions to mitigate the rate. While the PASS rate appeared to increase after the investigation ended in the terminal environment, the rate stayed the same in the non-terminal environment. Beginning in June 2013, the PASS rate in the terminal environment appears to decline again, and it is unclear what factors account for this decline. It is also unclear why the PASS rate for the non-terminal environment remained constant beginning in March 2010 while the PASS rate inside the terminal increased during this period. Did the results of the investigation influence the non-terminal environment positively without affecting the terminal environment? Because the report's investigation focused on the terminal environment, we don't know why the time between PASS remained relatively constant outside the terminal environment but fluctuated within the terminal environment.

Since the railroad was concerned with PASS in the terminal environment, the remainder of this analysis will focus on that environment. **Error! Reference source not found.** displays the time between the terminal environment's PASS in a process behavior chart; instead of a cumulative distribution, the figure shows each PASS event. The upper control limit (UCL) represents the upper bound for the 99% confident interval within which PASS events are expected to fall, while



the lower control limit (LCL) represents the lower bound for the 99% confidence interval within which PASS are expected to fall. Since the number of days between events cannot be less than zero, the LCL level is zero. As in Figure 4, the time between PASS averaged between 33-40 days from 2008-2010 and increased while the railroad investigated why PASS events were occurring. During the investigation period (observation 8-10), the intervals between PASS increased and after the investigation, the interval then returned to the baseline rate. This behavior suggests that the investigation may have interrupted the processes that contribute to PASS but did not change the underlying factors that cause PASS. The chart in **Error! Reference source not found.** suggests that the PASS rate reflects common cause variation as a result of normal operations. If you want to reduce the number of PASS, then the processes which underlie normal operations need to be changed; the challenge is determining which processes need changing. Section 4 of this report describes our findings documenting some of the processes might account for this behavior.

Figure 5 Number of days between PASS events in terminal environment: 2008 - March 2014

So how might normal operations contribute to PASS events? Does operational tempo impact PASS? More stop signals occur as more trains are operating. To examine this question, we examined how the number of trains has changed over time. Figure 6 shows the average number of trains operating each day from 2000 through 2013 and it includes both revenue service trains and non-revenue service trains. Except for a dip in the number of trains during 2003, the number of trains has increased from under 700 in the year 2000 to over 850 in 2013. When the railroad collected data on PASS events (from 2008 through 2013), train traffic increased from 810 to 850

trains per day. Figure 7 shows how the frequency of PASS events varies by year. The correlation between the number of stop signals and the number of daily trains is 0.25 and is not statistically significant.

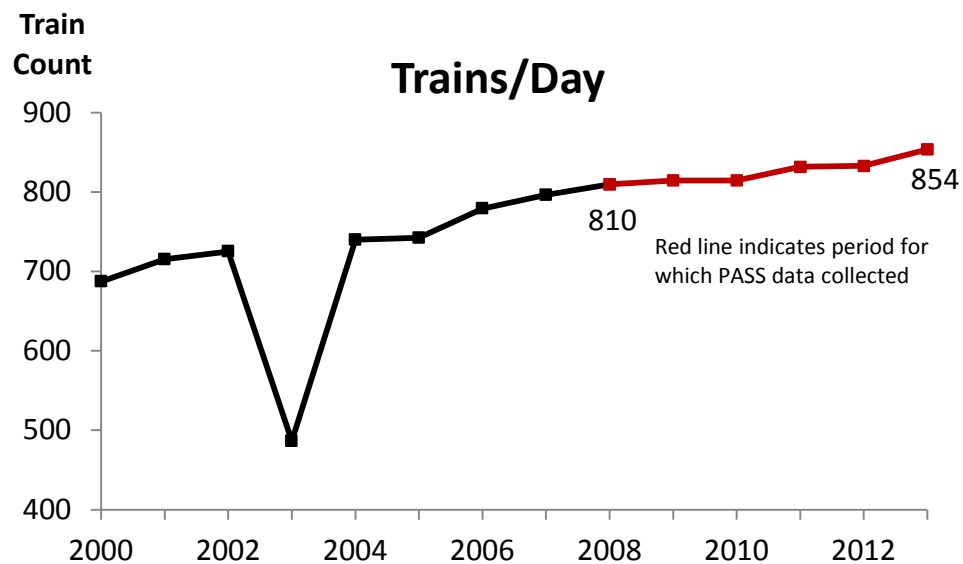


Figure 6. Average number of trains/day from 2000-2013

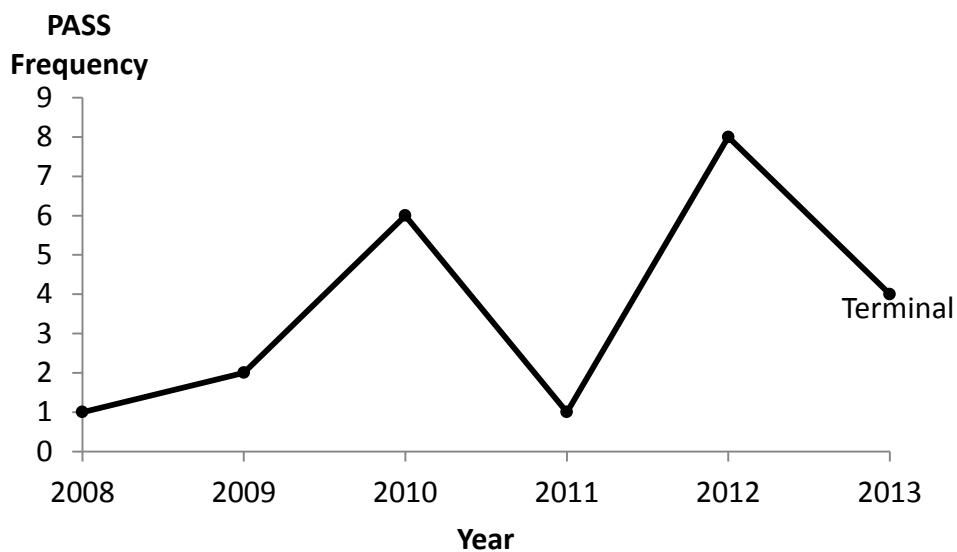


Figure 7. PASS Frequency in Terminal Environment

Several employees suggested to us that the terminal is approaching capacity during the morning and afternoon periods, which would impact railroad operations in ways that may influence the potential for PASS. We recommend that the railroad determine how close the terminal is to exceeding capacity, under what conditions does it exceed capacity, and the frequency that this phenomenon occurs.

The frequency with which stop signals occur in the terminal plays a role in understanding how PASS happen, since PASS cannot occur unless a train or piece of moving equipment is approaching a stop signal. Specifically, we needed to determine when a train approaches a stop signal, but the railroad's information systems do not currently store any information about such situations, so we cannot estimate the risk exposure under current conditions. We recommend that the railroad find ways to collect this information so that it can properly estimate the risk of PASS. As a substitute, the railroad provided us with the number of stop signals that occur per hour in the terminal.

Due to the nature of the information systems, we only received this data for one 24 hour period (June 24, 2014). With only one day of data, we do not know whether this sample represents stop signals that occur during other days of the week or other time periods. Any inferences that are drawn from this data should be verified by collecting additional data and ensuring that this sample is representative of normal system operation. Figure 8 shows the number of stop signals by hour over the course of a 24 hour period. The frequency of stop signals follows the pattern of daily train frequency, with stop signals increasing during the morning and afternoon peak periods and declining in between the peak periods.

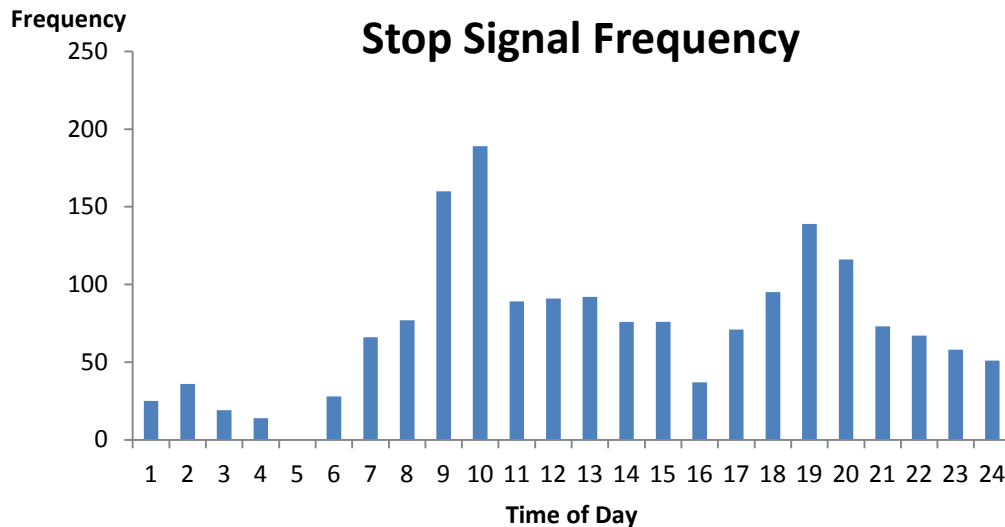


Figure 8. Stop signal frequency by hour

Figure 9 displays the frequency of PASS by the hour, which corresponds to the frequency with which stop signals occur throughout the day. PASS frequency increases during the morning and afternoon peak periods with spikes that match the same time periods as stop signal occurrences.

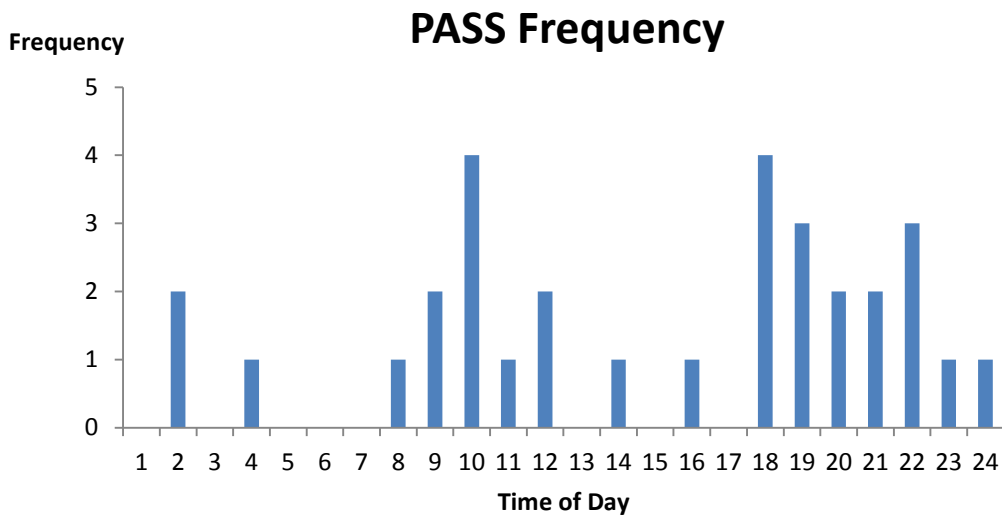


Figure 9. PASS frequency by hour

This suggests that as the number of stop signals rise, there are more opportunities for PASS to occur. Figure 10 shows this relationship between stop signals and PASSs. As the number of stop signals increase, the number of PASS increases as well. There is a correlation of 0.639, which is statistically significant ($p < .01$, $df = 20$).

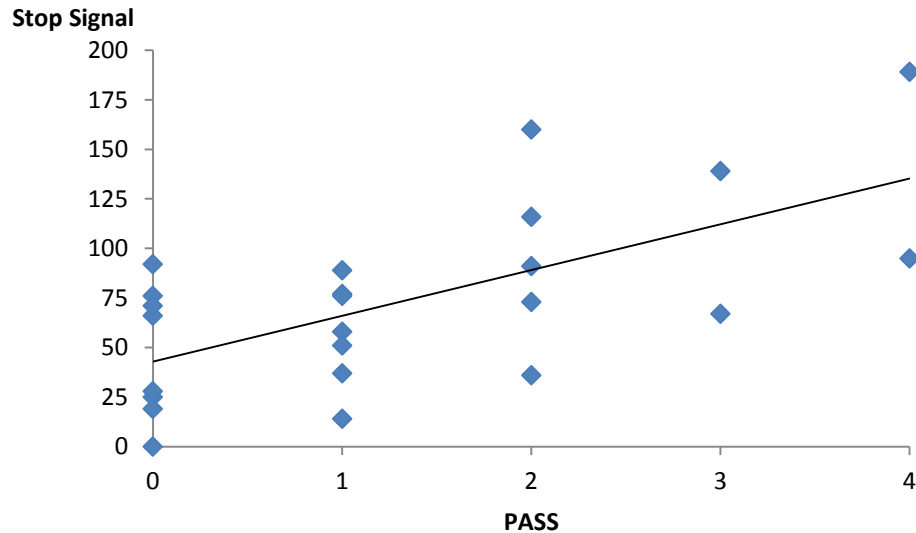


Figure 10. Relationship between stop signals and PASS

One challenge in interpreting this data is that the opportunities for a train to encounter a stop signal are smaller than the number of stop signals displayed by the signal system. Although a stop signal represents an opportunity for a train to proceed past it, in practice, there are many situations in which a train is not in a preceding block approaching a stop signal. So when a dispatcher routes a train one direction (e.g., north), to proceed through four blocks, the train crew will see 4 permissive signals before encountering a stop signal. To prevent that northbound train

from encountering a train traveling in the opposite direction (south), the signal system displays a stop signal for each signal in each of the four blocks in the opposite direction (southbound). In this situation, a train moving southward on the same track would encounter only the first stop signal. Assuming it stopped as required, it would never encounter the subsequent three stop signals.

If the data from the signal system provided from the one day sample is representative of normal system operation, the number of permissive signals is roughly equal to the number of stop signals in the terminal environment. For this sample, the number of permissive signals was 1745 compared to 1734 stop signals. Acquiring information about how many trains were in a position to encounter a stop signal would provide a more accurate assessment of the risk exposure (e.g., opportunity for an unsafe event to occur). We recommend that the railroad find a way to collect and track this metric.

When we examine how PASS varies when normalized by the number of hourly stop signals, a different perspective on when risks emerge.

Figure 11 illustrates the relative statistical risk of PASS normalized by the number of stop signals in four-hour blocks. The Y axis (relative risk) represents the proportion of PASS divided by the proportion of stop signals in 4 hour time blocks. A relative risk of 1 is neutral; the risk of a PASS is the same for employees who are exposed as for those who are not exposed during a particular time block. When the relative risk is greater than 1, PASS is more likely to occur. When the relative risk is less than 1, the risk of a PASS occurring is less likely. In this situation, the greatest risk of PASS occurs in the early morning hours (from 0100-0400) followed by the late evening (from 2100-2400). The factors that contribute to PASS in the early morning hours (e.g. fatigue, cognitive underload) may be different from the factors that contribute to PASS during the morning and evening rush hours (e.g., time pressure, cognitive overload). While it is dangerous to generalize from such a small sample, the data suggests where interested parties may explore further.

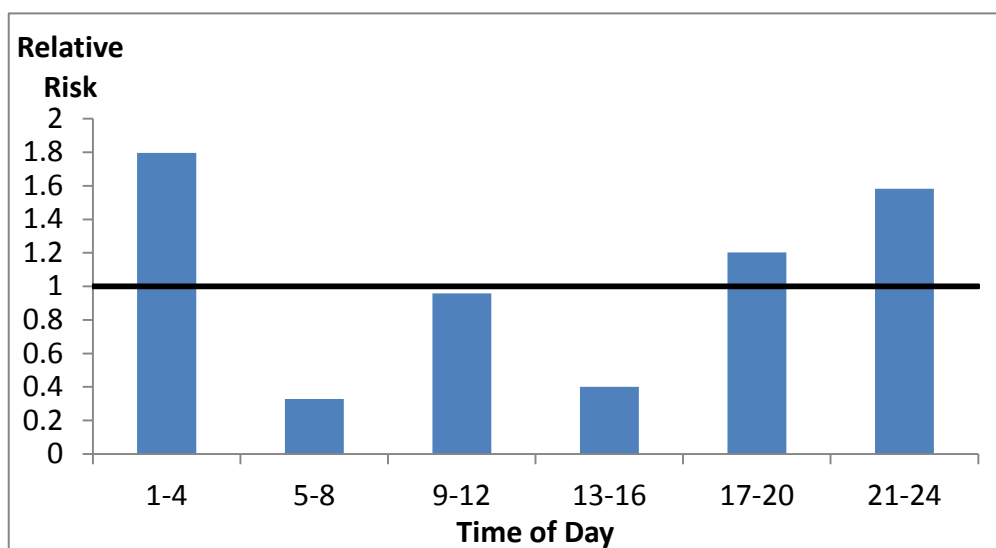


Figure 11. Relative risk of PASS by stop signal frequency
(Horizontal line indicates neutral relative risk)

3.2 Data Collection Recommendations

Though we would have liked to complete additional analyses, we were limited by the data collected by the railroad and made available to us. In the future, we recommend that the railroad amend its data collection methods in the following ways:

- Enable railroad information systems to collect signal system data that will help better explain why problems with PASS occur. For example, they should collect the signal aspect for specific trains and record how many trains were in a position to encounter a stop signal. An analyst should be able to transfer this data to other software for analysis.
- Collect information on the state of train routing (dispatching) and exception handling (equipment failures, crew scheduling, normal operations) for the purpose of analyzing current state of operations for safety and efficiency.

When analyzing aggregate (trend) data on PASS, the data should be normalized to account for the impact of exposure, or else the risk may not be properly estimated whenever exposure plays a significant role contributing to the number of PASS events. As exposure increases, the risk will be overestimated if the data is not normalized.

Figure 12 illustrates how exposure can impact risk assessment; the top chart shows how PASS is distributed by years of experience, while the bottom chart shows the same data normalized by the experience level of the participant group. When the data is not normalized, the PASS rate is highest for the least experienced groups. However, if the data is normalized by years of experience, a different experience level has the highest PASS rate.

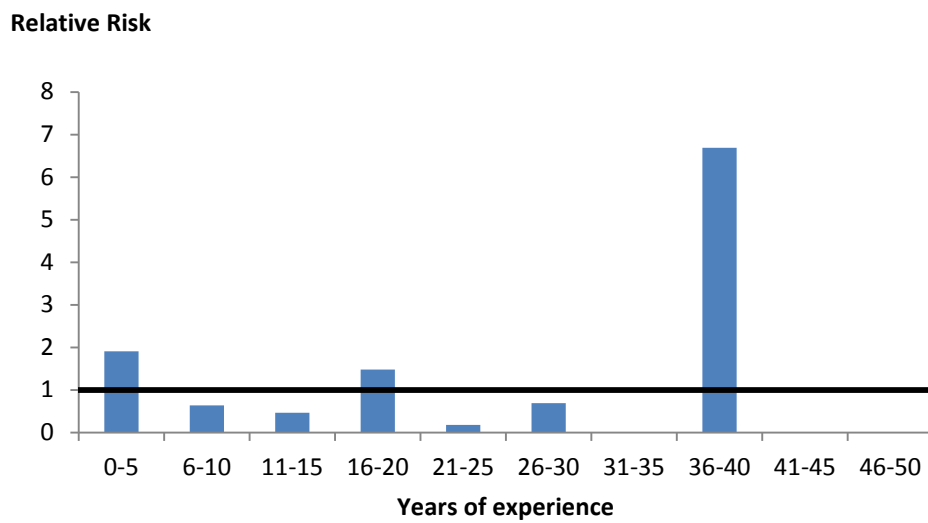
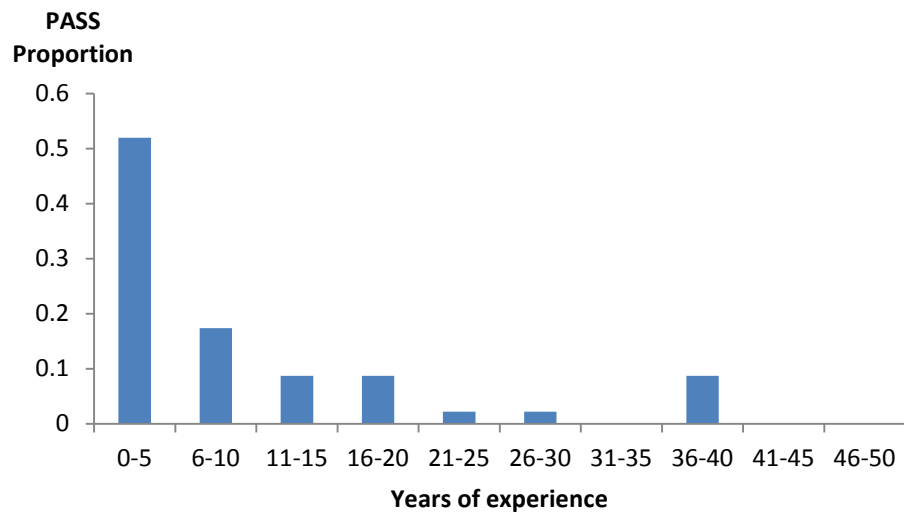


Figure 12. Impact of locomotive engineer years of experience on PASS risk

4. Contributors to PASS: Findings & Recommendations

This section presents our findings and recommendations regarding factors that potentially contribute to PASS events. These findings and recommendations are largely based on the interviews that were conducted with the passenger railroad's employees and the observations that were made in the terminal. The findings and recommendations are organized around the systems framework that was introduced in Section 1.

4.1 Physical Environment (Infrastructure) Factors

The terminal's track configuration challenge the train crew because it requires them to take purportedly awkward routes (ladders that cross several tracks, tracks with deep curves, and crash walls that obscure signals and equipment on the track), navigate platforms that are too short for today's train lengths, and deal with non-optimal signal placement. The ideal way to mitigate these hazards is to re-design the terminal. We understand the railroad cannot make significant changes to the terminal's physical layout; however, our findings from interviews and observations suggest that the layout is a strong contributing factor to signals passed at danger and signal placement can be improved within the terminal so these hazards are mitigated. Also, changes to signal aspect design may help the train crew avoid signals passed at danger. See Table 2 for a list of physical environment findings by category.

Table 2. Physical Environment Findings by Category

Signal Placement	Signal Aspect
Placement of signals at platforms	Confusing/ambiguous meanings of signal aspects
Signals located around curves	Omnipresent red light in all signal aspects
Signals imbedded in walls	Yellow aspect flash rate
Closely spaced, inconsistently or ambiguously placed signals	
Fallen signals	

The signals within the terminal were modified in 2011 and these changes were documented in the railroad's Stop Signal Committee Final Report. We agree with many of the findings of the report and also agree with the changes to the terminal physical plant; however, the railroad can do more to avoid creating conditions that contribute to errors for locomotive engineers within the terminal. The section below discusses findings and recommendations involving the physical environment. Though we know not all of these recommendations may be feasible, whether due to cost and/or physical infrastructure limitations, we believe that implementing them to the fullest extent possible will help mitigate PASS.

4.1.1 Signal Placement Findings

With regard to signal placement, we found that the following challenges to the locomotive engineers operating within the terminal.

Placement of signals at platforms

Some signals at platforms are placed in problematic areas. Specifically, signals at platforms within the terminal can be located too close to the edge of the platform (and can therefore be too close to, or behind, the front of the locomotive and out of the engineer's line of sight) or too far out from the platform (and again out of the engineer's line of sight). Poor placement increases the complexity of operating inside 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 do not have cues to help the locomotive engineers decide where to stop the train at the platform, which determines if the signal is in view for the engineer who will take the train out of the terminal. Some engineers use adjacent trains as a cue for where to stop the train. Placing signs at station platforms would enable the engineer to quickly determine where to stop the train (given different car lengths).

Signals located around curves and/or embedded in walls

Signals located around curves or embedded in walls reduce the amount of advanced viewing time that engineers need to see, interpret, and respond to that signal. Many of the signals embedded in walls also tend 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. Also, since operating rules require the engineer to be able to stop within half the visual range of the signal, the engineer may need to travel at speeds lower than the maximum to safely stop the train when the signal is located around a curve.

Since the engineers are qualified in the terminal, they should know the location of every signal within the terminal. However, relying on locomotive engineers to know where all the signals are is one of the least effective strategies for mitigating PASS. If a locomotive engineer has not recently operated in the terminal or has not been recently routed through that particular portion of track, he or she may not remember the exact location of the signals.

Even if the engineer knows that a signal is located around a curve, the engineer must reduce his or her speed to ensure that the train can be stopped if necessary. In the worst case scenario, the engineer may not expect a signal around the curve and is traveling at the maximum allowable speed. If the signal is stop, the engineer may run the risk of PASS. Based on a maximum speed of 10 mph and the braking profiles of the locomotives operated by the railroad, the engineer must be able to brake at least one car length (85 feet) from the signal to avoid passing it. This stopping distance assumes the engineer makes a full service or emergency brake application and does not include the time needed to detect and then react to the stop signal. Depending upon the train's speed, the engineer needs an additional 2.5 to 4 seconds to respond safely to a stop signal.

Closely spaced, inconsistently, or ambiguously placed signals

Closely spaced signals pose a challenge to engineers because they can look past the first signal towards the second signal. The possibility of "looking through" to the next signal is increased when a closer signal is positioned in such a way that it is obscured or placed in a non-standard (inconsistent) location that is difficult to quickly detect when scanning out the window. If the first signal is stop and the second signal is green, and the engineer looks through the first signal towards the second signal, the stop signal will be passed.

Inconsistent and ambiguously placed signals also provide additional difficulties for engineers inside the terminal. As mentioned above, relying on engineer knowledge of where each and every signal within the terminal is located is one of the least effective mitigation strategies for preventing PASS, due to the large footprint of the terminal and the variability of routes. Placing signals in consistent locations allows engineers to anticipate where signals are as they move through the terminal. Similarly, ambiguously placed signals can confuse engineers even if their locations are emphasized during training, especially if the engineer does not encounter them frequently. Inconsistent and ambiguously placed signals are also more liable to be “looked through” to the next signal, which may increase the potential for PASS.

Fallen signals

If a signal falls down in the terminal, that is a rare, but possible, event (e.g., the signal can be physically knocked down by moving equipment). If a locomotive engineer encounters a downed signal, he or she is expected to notice it because they should know the exact location of the signal. Next, the engineer should treat the downed signal like a stop signal, stop the locomotive, and call the dispatcher for instructions.

However, relying on the locomotive engineer’s long-term knowledge of signal locations is not an effective mitigation strategy for PASS. This may be realistic expectation on the mainline, or for an engineer who is familiar with that particular route within the terminal. However, compared to the mainline, the number of routes in the terminal is much larger, so a train crew may not be familiar with all the routes. They may see some routes frequently and some infrequently. Consider a locomotive engineer who is routed the same way most days until, because of track maintenance, the dispatcher routes this engineer a new way, which exposes the engineer to a different set of signals. In this example, because this may be the first time in several years that the engineer is traversing the terminal along this route, a fallen signal may go undetected.

4.1.2 Signal Placement Recommendations

Signal Placement (General)

- Determine how signals become out of position (e.g., fallen signal) and prevent them from being shifted. If signals are knocked out of position when equipment is moved, provide training or methods of moving equipment that minimize these occurrences.
- When a signal is down, malfunctioning, or has a bulb burnt out, dispatchers should immediately communicate this information to train crews.
- Raise the profile of the alert which informs the dispatcher that a signal bulb has burned out.
- Use sensors to alert dispatchers and the C&S department that a signal has been moved out of position (e.g. knocked down).
- Enable engineers to easily recognize that signals have fallen or been knocked over by providing them with easily detected visual cues. Given the terminal’s complexity and the difficulty of detecting the absence of signals, train crews could be alerted to a missing signal with visual cues that could be easily seen even if the signal is knocked down).
 - The C&S department suggested that a mercury switch in the signal post, which would indicate it has fallen, may be a relatively inexpensive option.

- Also, the signal's post could be painted with a color that will be visible on the ground if the signal is knocked down.
- Re-examine problematic signals and indicate that each one is ahead of a train by placing visual cues in a prominent and visible location ahead of every signal – which is analogous to road signs that indicate there is a stop light or stop sign ahead.

Location of Signals at Platform

- Place signals at train platforms in consistent locations in front of the longest train that the platform can accommodate and are within seeing distance. Always position signals in front of the train, because a locomotive engineer cannot see a signal located behind the locomotive engineer's location and the signal may be missed.
- If trains are routed onto platforms that are too small for the trains, there are consequences for the crew that is bringing the train into the terminal and the subsequent crew that is taking the train out.
- If possible, extend the length of the platform to accommodate the longest expected train.
- Automatically notify dispatchers when they are matching a train with a platform that is too short.
- When crews are being switched, the departing train crew should verify that the signal is in front of the train. If the signal is not visible, the departing crew should communicate to the new crew that the signal position is located behind the engineer.
- Every platform should have a series of signs that show the engineer where to stop the train for different train lengths. This will help to avoid the situation described above, where the train has not been pulled up far enough and the signal ends up behind the engineer (at the other end of the train).

Changes to signaling system software

- For problematic signals, such as signals imbedded in walls, located around curves, or closely spaced signals, the signals could be electronically coupled so that the two signals are always both stop or are always more favorable than stop. (The Stop Signal Violation Committee Report stated that this was done for two signals in the terminal.)
 - Experienced dispatchers typically do this activity, but it is better to automate it within the system.

4.1.3 Signal Aspect Findings

With regard to the signal system, we found that certain signal aspects and indications may create challenges for the locomotive engineer operating within the terminal.

Confusing/ambiguous meanings of signal aspects

The terminal's signal aspect system has multiple, visually distinct, signal heads (i.e., that use distinctly different colors and flash rates) that are defined in exactly the same way in the operating rules but, in practice, carry different information about what to expect ahead. Appendix C displays the signal aspects and indications that were in use during this study. In the past, the operating rules defined the signal aspects differently, and each indicator provided different look-ahead information to the train crew, and the crew would learn when the next signal would be stop. But, at some point, the operating rules were

changed and the new training curriculum directed crews to operate trains in exactly the same manner no matter which signal aspect was shown (with *stop* always meaning stop). While the curriculum changed, the underlying signal system did not change. Our understanding is that the change in guidance was due in large part to the fact that the look-ahead information cannot always be relied upon. When the guidance changed, a consequence was that the meanings and intent of the signal aspects could be ambiguous and confusing.

Engineers are trained to expect that the next signal could be stop no matter which multiple permissive signal aspect is shown. However, when probed further, many engineers admitted using information garnered from the signal indications. In particular, train crews indicated that when they see what in practice is the most permissive signal aspect (which indicates that the next signal would be more permissive than stop) they often operate closer to the maximum allowable speed because they expect that the next signal aspect will probably not be stop. This behavior is consistent with Bayes Theorem and signal detection theory, which states that knowledge about past events influence future behavior (Gelman et al. 2003; Green and Swets, 1966).

A different signal aspect (which was also defined by the current operating rules as identical to other aspects) would cause the train crew to exercise particular vigilance. While the crews could not always describe the full set of conditions that would cause this signal aspect to appear, they stated that this signal aspect would cause them to be more vigilant. Thus, while train crews are trained to treat all signal aspects identically (other than stop), many crews use their understanding of how the signal system works and their experiences with the signal system to guide their responses to different signal aspects.

Some engineers described an alternative strategy which treated all permissive signals within the terminal environment as if they are changing to stop. This strategy is more conservative and the possibility of passing a stop signal is minimized, though the trains move less efficiently through the terminal. We do not know how many engineers use either strategy or if some of them shift back and forth between them depending upon circumstances.

To accommodate increased throughput in the terminal, the signal aspects used in the terminal replaced simpler two-aspect signals (stop and proceed at restricted speed). Because the railroad provides look-ahead information via the different signal indications but tells the engineers to treat all the signal aspects (other than stop) identically and ignore the (generally reliable) information provided by the signal aspect, a potential “double-bind” for the train engineers occurs, since the crew is under pressure to maintain the train’s schedule. The railroad’s directive to treat all signal aspects other than stop in the same manner as directed by operating rules is opposed to the crew’s desire to act on the generally reliable predictive information from each signal aspect, which reflects the tension between two important goals: meeting the schedule and safety. Balancing these two important goals will inform the decision whether to make any changes to the current signal system.

Omnipresent red light

All of the signal aspects at this railroad have a red light that is always on, and we are told that the omnipresent red light is often used in terminal environments. When a stop is indicated, the red light is the only light lit. If a signal has multiple permission indicators, one of the two lights below the red light (a yellow or a green light) is also lit. The red light can confuse engineers and provides no information with regard to operating the train, because the absence of a green or yellow light informs the engineer that the aspect is stop (not the presence of the red light). This may contribute to an increase in reaction time, which would allow the engineer to detect and respond to a stop signal.

Yellow aspect flash rate

The rate the yellow aspect flashes on one of the signal aspects may cause confusion regarding whether the signal is switching to stop or just flashing.

Using two bulbs in a signal

Engineers like the redundancy of having a second bulb lit up on the signal, as it decreases the chances of missing a signal due to a burned out bulb.

4.1.4 Signal Aspect Recommendations

Signal Indications

- The railroad should align the signal system with its engineers' operational goals.
 - Our findings suggest that when formal operations manuals and railroad training directs train crews to treat the permissive signal aspects identically, even though the different signal aspects in fact indicate different operating conditions, a "double-bind" situation could occur and this should be avoided.
 - If the railroad expects engineers to operate the train differently based on the signal indication (i.e., based on expectations about what the next signal will be), then keeping the current signal system makes sense.
 - However, if engineers should operate the same regardless of what the permissive signal is (as is specified in training and in the rulebook), the signal system should only show two indications (*stop* and *go*).
 - Factors that should be considered before switching to a two-indicator system:
 - Going to a two-indicator system may result in reduced efficiency. Engineers should, and will, go slower in the terminal if they have no indication of what is ahead.
 - Removing look-ahead information for diesel trains may pose a problem, because diesel operators need to have this information; it allows the engineer to operate the train and not lose power.
 - In a two-indicator system, dispatchers may always need to give diesel trains clear routes. (We understand dispatchers typically do this anyway.)
 - One employee suggested adding third rail shoes on all rail cars connected to a diesel locomotive to minimize the potential for losing power.

- Currently, there is a signal aspect which indicates a condition that requires crews to be extra vigilant. In Appendix C, this signal is labeled as “Proceed at restricted speed. Block ahead is occupied”. If the railroad goes to a two-signal aspect system, then the engineers will no longer know that the upcoming track requires extra vigilance. The railroad did not specify exactly what situations currently result in engineers seeing this signal. It occurs when there is a train in the block they are about to enter, but we were also told that there were other circumstances that generated the same signal aspect. The situations that currently lead to this aspect need to be clearly identified, and the railroad needs to determine if it is important to maintain the distinction between situations indicated by the most permissive signal aspect and those that are indicated by the least permissive signal aspect (which would cause the locomotive engineers to become extra vigilant when encountering it). If the distinction is important, it is recommended that the railroad make clear to locomotive engineers what situations lead to this aspect via training, and formal documentation (e.g., the rule book).
- Conduct additional research to determine the consequences of switching from the current signal system to an alternative signal system.
- We recommend answering the following questions before changing the signals aspects and determining what signal aspects should be chosen:
 - Does the current signal system used in the terminal create expectations about whether the engineer will need to stop or proceed?
 - In designing a signal system for use in the terminal, how many signal aspects are needed to support the engineer’s task for controlling the train?
 - What should the signal aspects look like to facilitate the engineer’s task (what colors should be used, should flashing-coding be used, etc.)?
 - Should these new designs be used only in the terminal or should they be used in other locations (such as the yards)?
 - How will a different signal system influence operation within the terminal? Does it have consequences for diesel trains?
- When the railroad considers the current signal system, one question that needs further study is whether look-ahead information increases the potential for PASS. The engineers indicate that signal indications provide route information that can help them anticipate how they will control their train. If engineers expect that the next signal is not likely to be a stop signal, it may lead to increased efficiency in operating the train but such expectations can also increase the possibility of a PASS in cases where the next signal is stop. Since the engineer is not anticipating a stop signal, the response time to detect the stop signal and stop the train may be slower than if the engineer had no expectations (thus increasing the possibility of a PASS in cases where expectations based on look-ahead information turned out to be violated).

Note that while this argument suggests that the signal aspect system could plausibly contribute to PASS, our review of the railroad’s PASS data as well as the results of our interviews and observations do not provide objective evidence that the multiple signal indications and the related ambiguity actually caused any

of the PASS within the terminal. A formal study could help determine whether this type of signal system sets expectations and impacts reaction time (which could increase the possibility of PASS). Before recommending a modified set of signals, we recommend that the railroad conduct research into multiple signal aspect systems; how they impact engineer operations; how engineers would respond an alternative signal aspect system; and how to minimize the potential for creating new problems associated with the design of a new signal system.

- Understand the engineers' perspectives on this issue. At the very least, working with engineers and union representatives will help to give engineers ownership of the signal aspect decision.

Signal Aspects, General

- Light the top red signal only when the signal indicator is stop. The signal system should either display a red light or a permissive signal. If the top red light is always on, it provides no information. Showing a red light and displaying a permissive signal at the same time reduces the association between the red light and the need to stop.
 - Unfortunately, if a bulb burns out the engineer may risk missing the signal.
 - Consider using Light-Emitting Diode (LED) lighting instead of incandescent bulbs, since LEDs bulbs last longer. This will reduce the possibility of bulb burnouts. LEDs allow for color-changing bulbs, which may be beneficial, but they are typically brighter than non-LED bulbs, which may be detrimental within the terminal. Before implementing LEDs, they should be tested in the terminal to ensure appropriate luminance. If a railroad chooses to introduce LED bulbs, they should avoid mixing incandescent and LED bulbs in the same geographic proximity to avoid mistakenly responding to the brighter more distant LED bulb when it displays a clear aspect. LED railroad signals may mask nearby incandescent signals, preventing incandescent signals from being visible to train crews (NTSB, 2014).
 - Use of color-changing bulbs could serve as a possible mitigation strategy for missing signals. For example, a redundant red signal could allow the stop signal to show two red lights (See Figure 13). This will mitigate the concerns that bulbs will go dark, which would cause engineers to miss signals, and they may provide engineers with more look ahead information from awkwardly placed signals (e.g., if certain position lights – top or bottom light for example - are easier to see from afar because of, for example, curves or imbedded walls).

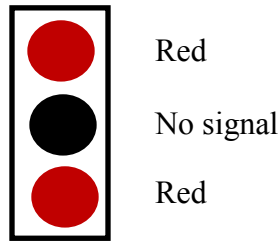


Figure 13. Example of redundant lighting in stop signal

- For signal aspects that use a flashing light, consider adjusting the flash rate so that it dims and brightens, rather than disappears completely during the flash.

4.2 Organizational and System Factors

The discussions with railroad employees and the review of railroad operations suggest that the following system factors contribute to PASS:

- An increase in the number of trains passing through the terminal
- Production pressure changes in the workforce
- Organizational policies and procedures, including policies with respect to training requirements, staffing and scheduling

Our findings, discussed below, are not unique to this railroad. The literature suggests that similar organizational factors contribute to PASS (and unsafe behavior) in the United States and abroad.

Table 3. Organization & System Factors Findings by Category

Organizational Policies and Procedures	Production Pressures
Employee Training	Short Turn Times
Crew Scheduling	Train Frequency
Incident Reporting & Discipline	Dispatcher Train Management

Our findings led to a series of recommendations, which are discussed in this section. We strongly suggest that the railroad consider these recommendations; we believe implementing them to the fullest extent possible will help mitigate the occurrence of PASS.

4.2.1 Organizational Policies and Procedures Findings

Employee Training

An entire generation of the railroad's workforce began retiring in large numbers; this phenomenon has been occurring across the industry. Thus, a large number of employees are being hired at the same time. Managing this change effectively has placed a significant strain on the organization and from our discussions with railroad managers, there was no plan to manage the expected turnover in staff and the railroad decided to replace the retirees with new and less experienced employees.

As the railroad seeks to ensure safety and efficiency, training programs at the railroad are of great importance for a less-experienced workforce. The increased demands on training personnel are further complicated by the fact that, along with the rest of the railroad, retirements have affected the training department itself.

As with other railroads, training for transportation crafts takes place in two stages. The first stage consists of several weeks of classroom training where employees learn the operating rules, the jargon, and how the railroad operates. They may receive simulator training as well. The second stage consists of on-the-job training where student employees observe a mentor perform the jobs they will perform. The mentor observes and coaches the student employee in performing his or her duties. This training takes several months and it is followed by a test that determines whether the employee can safely perform his or her duties.

Our investigation examined the training received by engineers, conductors, and dispatchers, and training-related factors that contribute to PASS are listed below. These findings reflect the conditions that were in place when we conducted our interviews and observations. We understand that initiatives to improve the quality of training have been implemented since our investigation took place.

Engineer Training

- Training department resources at this railroad have been strained by the abrupt increase of new hires. As a result the department was reportedly using outdated materials (e.g., outdated track charts, discrepancies between training and actual physical characteristics).
- Simulator training may be outdated and/or not practical if the goal is to teach new hires about signal sighting. The simulator software has not kept up with the changes to the physical infrastructure and the scenes in the terminal environment do not match the actual physical environment. It is our understanding that the railroad's simulators are currently being updated and redesigned to better represent the railroad's track, including routes within the terminal. However, at the time of this investigation the simulators we saw were not realistic job aids for mitigating missed signals.
- Engineers do not receive periodic or scheduled refresher training on the terminal physical layout after initial training.
- Training instructors have less experience than training instructors in past years.

Conductor Training

- The railroad offers Passenger and Yard conductor certification. Conductors have indicated that, though they are trained on the terminal's physical characteristics and signal system, they feel that they lack proficiency in the terminal track layout, including the exact location of switches and signals. When operating in the terminal environment, they may provide incorrect information and/or be a distraction while in the head end, particularly when they operate over track that they have not traveled on recently. Yard conductors, unlike passenger conductors, operate in the terminal often and therefore have more experience with the physical characteristics of the terminal, such as the location of signals and switches.

Dispatcher Training

- Just as in the case of locomotive engineers and conductors, the dispatch center experienced an increase in staff with less experience. In contrast to train crews who undergo formal classroom and field-based training, dispatchers train new dispatchers with the “apprentice” model. New dispatchers sit with more experienced dispatchers, who are responsible for teaching them railroad policies and procedures as well as strategies for managing trains in the terminal. Our interviews and observations suggest this approach may lead to inconsistent training, since it varies widely depending on which trainer is assigned to which trainee. As a result, some dispatcher staff may “graduate” to full dispatcher status before they are fully ready and since students will be modeling the behavior of different mentors, they will apply different strategies when they control the movement of trains. Unless trainers receive formal guidance on which strategies should be taught, different trainers will teach different ways to solve the same kind of problem.
- Dispatcher training has been reduced from 11-12 months to 7-8 months. Several individuals raised concerns that the reduced training period may not be sufficient, and that some dispatcher trainees may be asked to take on full dispatcher responsibility before they feel fully ready. They may not be given enough training in the terminal, which would allow them to understand the traps engineers face when they deal with the terminal’s physical layout and its different routing methods. We recommend that the time needed for training should be determined by the time needed to learn how to do the job effectively and the amount of training time should be determined by objective performance criteria. Since individuals may vary in the time needed to learn to perform this job, the training should accommodate individual differences in the rate of learning.
- When a less experienced dispatcher moves trains, pressure to maintain a schedule can lead him or her to move them in a way that is optimized for meeting on-time performance metrics instead of employing a train routing that is more efficient overall. This type of routing may result in trains experiencing unnecessary stop signals in the terminal.
 - For example, we were given examples of trains that were directed out of the terminal prematurely (so the train would not be declared late out of the station), only to have those trains receive a stop signal at a later point in the terminal, causing more congestion and reducing routing degrees of freedom for other trains.
- More experienced dispatchers have developed train routing strategies that emphasize efficient movement across the terminal and prevent trains from receiving unnecessary stop signals. It is important that dispatchers are trained on routing strategies that consider the larger system over on-time performance.
- Other PASS-related consequences of lack of training and experience that we observed or were told about include:
 - Forgetting a train at the station (and expecting the train crew to remind them that they have been forgotten resulting in a train schedule delay)

- o Making a routing error that they then need to correct, resulting in changing a signal from a more permissive signal aspect to stop after the train crew had passed a prior signal suggesting the next signal would not be a stop. This is referred to as “dropping a signal in front of a train.”

Crew Scheduling

Train crews on this railroad choose jobs based on seniority during the twice yearly “pick,” which occurs in April, May and October. Crews choose jobs based on seniority due to a collective bargaining agreement with the labor union that represents the railroad employees and this policy is not unique to this passenger railroad. However, this seniority policy has the unintended consequence of assigning less experienced (low seniority) engineers those jobs that which may have higher PASS risks. Because they choose last, less experienced engineers are often left with the least desirable jobs, which can include jobs with more route variability and scheduling variability. Because they also have less experience than their more senior colleagues, they have less capability to deal with unexpected events. They are at greater risk of making mistakes than their more senior colleagues.

Jobs with more route variability have additional complexity because engineers on these jobs are generally less likely to traverse the same routes every day (and are less able to be intimately familiar with their routes as engineers who operate over the same routes). As discussed in Section 4.1 (Physical Environment Factors), locomotive engineers who are unfamiliar with the track that they traverse are more likely to experience difficulty in recalling the location of the signals. As these jobs are less desirable, low seniority engineers must often choose these types of jobs and combine the above factors with their inexperience overall (not only in the terminal but as engineers in general), these scheduling practices may make them more susceptible to PASS.

Less experienced engineers are also often assigned to jobs with more variability in scheduling (i.e., non-routine work schedules), given that senior engineers typically have already chosen the most desirable jobs – those with regularly scheduled runs that best fit a traditional work schedule. Less experienced engineers are often assigned to the extra list, which is similar to being “on call.” This type of shiftwork (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, especially coupled with the engineers’ inexperience overall, has the potential to contribute to PASS.

Incident Reporting & Discipline

When an engineer passes a stop signal at the railroad, the locomotive is immediately stopped and the engineer is taken out of service and tested for drugs and alcohol. The investigation is completed by the local road foreman, who asks the engineer questions about actions prior to the incident and takes a written statement from the engineer and other crew members in the head end, if available. From this point on, a union representative is assigned to the incident, and the engineer and railroad do not have additional interactions during the investigation.

Findings from our discussions with road foremen and examinations of stop signal violation investigation write-ups indicate a wide variability in incident reports. There is no standard template for investigations and road foremen vary widely in the scope of questions they ask and

the thoroughness of their documentation. For example, some stop signal violation report write-ups included information about previous signal aspects and prior time on duty, where other investigations did not.

Additionally, discussions with engineers indicate that they are dissatisfied with the investigation process. One engineer described feeling “guilty until proven innocent” and expressed frustration at not being included in the process of defending himself or being able to see stop signal violation “evidence” such as event recorder downloads or alleged broken switches. Engineers also expressed a desire for the railroad to do a more thorough investigation and look further into others who may have contributed to the violation, for example the dispatcher or the previous engineer operating the train. However, the structure and process for such investigations are governed largely by collective bargaining agreements negotiated by railroad management and the labor union officials who represent the employees.

Aside from the engineer’s perspective, the discipline process creates an environment that, some contend, makes it difficult to learn from the engineer what happened. Since information collected from the engineer may be used to punish (decertify) the engineer, some claim there is little incentive for the engineer to report their story fully. We do not see the railroad investigating factors related to the physical design of the signal system, operating practices, training procedures, dispatcher practices and other elements that research has repeatedly identified as contributing factors to understand why PASS occurs. The two reports produced by the railroad represent special circumstances in which an effort was made to look beyond the usual practices to find an explanation for these unwanted outcomes. The normal practices do not appear to be consistently effective in finding and fixing the PASS events occurring at the railroad. Since PASS is the result of multiple contributing factors, finding these factors will require investigations that are more thorough than the railroad’s current approach to investigating signal incidents.

4.2.2 Organizational Policies and Procedures Recommendations

Employee Training

- In the terminal, educate conductors and engineers in the use of “sterile cab” procedures. (Sterile cab is a term that is borrowed from the aviation industry that uses the phrase ‘sterile cockpit.’ It refers to the policy of having only safety related discussions between train crew members while operating in the terminal⁴.) Non-work related conversations can distract the crew from attending to safety critical tasks.
- For crews operating in the terminal, provide Crew Resource Management (CRM) training on what the roles and responsibilities of each member are and how they will communicate with each other. This may be particularly helpful in getting locomotive engineers to speak up as needed to dispatchers and conductors (to institute “sterile cab”). The FRA has produced a number of technical reports that can provide useful information on CRM training development and implementation (Morgan, Olson, Kyte, Roop, and

⁴ We understand that the term “sterile cab” may mean “Engineer Only” at the passenger railroad. If using the term “sterile cab” will provide confusion among railroad employees, we suggest using a different term.

Carlisle, 2006; Morgan, Olson and Kyte, 2007; Roop, Morgan, Kyte, Arthur, Jr, Villado and Beneigh, 2007; Morgan, C., Olson, L., Kyte, T., and Roop, 2007)

- Train crews (engineers and conductors) should receive periodic recurring ‘refresher’ training on physical characteristics in the terminal and demonstrate knowledge of the terminal through testing, particularly areas where they do not regularly travel. Consider providing refresher training during the April/May and October schedule changes (when employees select new jobs) for those employees who take on new jobs where they will travel over parts of the terminal for which they are not familiar. As an alternative, employees could demonstrate proficiency through testing to indicate that they have the requisite knowledge to operate safely.
- Discussions with interviewed engineers suggested that training instructors have much less experience than in the past, and they reported learning outdated information during training. Training instructors should ensure that training materials are kept up to date reflecting latest changes in rulebooks and operating procedures and changes to the terminal physical layout. **Note:** Our discussions with the training department suggested that these issues may already have been addressed.
- There is a need for more systematic training of dispatchers and objective criteria that indicates when these training objectives have been met. This can best be achieved by performing a formal job analysis, identifying skills and strategies required for safe and efficient routing, and developing formal training syllabus, as well as objective evaluation criteria.
- Put together a syllabus for dispatcher training which ensures dispatchers are trained up on the same expert strategies. (Ideally, an expert dispatcher who can best articulate those expert strategies should assemble the training.)
 - In order to better understand challenges within the terminal, it is important that dispatchers train on the terminal’s characteristics.
 - Crew Resource Management training for dispatchers may be beneficial as well. At the very least, discussions between dispatchers and engineers could facilitate better communication and identify knowledge gaps.
- Teach dispatchers strategies for routing trains that meet on-time performance pressures without sacrificing global efficiency or creating ‘PASS traps.’
- Use the dispatcher replay capability, which can provide ongoing training to dispatcher staff on particularly effective and ineffective train routing strategies. Dispatcher management and/or training personnel can select notable routings to review with the staff via replay (e.g., hold a review session once a week).
- Establish objective criteria that determine when a dispatcher trainee has developed sufficient skills to route trains safely and efficiently under dynamic, high pressure conditions. The time needed for training should be determined by the time needed to learn how to do the job effectively, as determined by meeting objective performance

criteria. Since individuals may vary in the time needed to learn to perform this job, the training should accommodate individual differences in the rate of learning.

- Document the strategies that experienced dispatchers use to route trains and incorporate them into the dispatcher training program. The ability to effectively and safely route trains depends in large part on developing a mental model of how the system operates and learning the impact of different routing strategies on system performance. Capturing these strategies from experienced dispatchers and helping the students to learn these strategies may accelerate their understanding of how the system operates and when to use different routing strategies. It is our understanding that the railroad has one person remaining who is currently working as a dispatcher with the deep knowledge of how the system operates and strategies for managing trains under uncertainty. We recommend capturing these lessons before this individual retires.
- Provide decision support aids to minimize common dispatcher problems (e.g. forgetting a train at a station).

Crew Scheduling

- Understand that the types of jobs to which less experienced engineers are assigned may contribute to the higher percentage of PASS found for less experienced engineers.
- 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.

Incident Reporting & Discipline

- According to train crews involved in signal violations, all they provide is a written statement for the investigation. Giving the involved employees an opportunity to play a role in the investigation (providing information) would lead to a better understanding of why the event occurs and increase the employee's confidence in the discipline process.
- When PASS occurs, the train crew in the head end is disciplined. However the actions by other employees and conditions outside the control of the train crew contribute to PASS. While railroads have discretion to investigate these other factors, in practice, these other factors are frequently not considered. Consider these additional factors when investigating PASS and deciding whether to discipline the train crew.
- Create an improved incident investigation & report template, which will allow investigators to better determine the underlying causes behind the missed signal and keep better records of this data. Include, for example, other factors that may have contributed

to the missed signal (as discussed in the bullet above). See Appendix A for PASS investigation report recommendations and Appendix B for an example PASS Hazard Checklist.

- To understand when PASS will take place, one not only needs to know the frequency with which PASS occurs, but also the frequency of opportunities for PASS to occur (i.e., exposure rate). For example, one reason there are more PASS during the morning and afternoon peak hours may be that there are more trains passing through the terminal and more stop signals – so the exposure rate (i.e., opportunity for PASS) is higher. It is important to keep track of information on exposure rate and to normalize the events that are being tracked by exposure rate when the risk associated with PASS and their contributing factors is estimated. Seeking more thorough data, and data that spans more years, will help when the railroad analyzes historical data relating to PASS in the future.

4.2.3 Production Pressures Findings

Short Turn Times

Keeping trains on schedule is an important part of railroad operations, particularly for passenger service. The Planning and Operations departments suggest that if all trains are running on schedule, train crews are allotted (at a minimum) approximately 15-20 minutes between trains. When everything goes according to schedule, engineers may have enough time to complete the necessary personal and safety-related tasks they have in between trains.

However, due to extraneous circumstances (e.g. equipment malfunctions, passenger emergencies on the mainline, etc.), schedules are not always kept and trains and crews may therefore arrive in the terminal later than scheduled. The railroad's current policy is to evaluate these instances on a case by case basis, with the aim of minimizing train delay. The railroad operations staff estimates that meeting the schedule over the course of a 24 hour period occurs 2% of the time. The rest of the time (98% of the day), disruptions occur which require the Operations Department to make adjustments to the system. Operating trains with so little slack in the system creates the need to take short cuts and address production pressures.

In these examples, the engineer may not have sufficient time to complete the required turn-time activities:

- A new crew is assigned to take the outgoing train out of the terminal.
- When a train is ready to depart but a crewmember is arriving into the terminal late on an inbound train, another engineer is dispatched to complete turn-time activities for the engineer who is scheduled to take the train out. (**Note:** Our findings suggest that some engineers oppose this practice, as they felt uneasy not testing the brakes themselves.)
- An engineer arriving late remains assigned to his outgoing train and therefore has less than the allotted 15-20 minutes turn-time.

Engineers anticipating short turn times may skip some turn-time activities completely, or use some time on their current trip to prepare for their next trip. They may also shift some activities

they would normally be expected to perform prior to leaving the station, to during their next trip (e.g., reviewing paper-work on upcoming stations). This can divert attention from operating the train and scanning outside the window and may mean the engineers are not as focused on current activities as they would be otherwise. Further, the need to explain to the dispatcher why the train is late, and stress from that, is another distraction. These distractions are all potential contributors to missing signals within the terminal. Telling engineers to avoid these types of behaviors is not an effective mitigation strategy for dealing with production pressures. Finding ways to reduce the production pressures is a much more effective approach to eliminating associated distractions that can contribute to PASS.

Related to this is the railroad's new policy of prohibiting recently hired "reserve engineers" from operating trains in the terminal. Reserve engineers are a useful resource for the Operations Planning Department if trains are delayed, as they can alleviate the consequences of short-turn times by completing turn-time activities in the engineers' place, or completely replacing a late arriving engineer. The policy of prohibiting recently hired reserve engineers from operating trains in the terminal decreases the slack, or buffer, in the system when things go wrong, since there are fewer reserve engineers available to respond to unanticipated events.

Train Frequency

As revenue service at the railroad has increased, the terminal's capacity has not, which means that train frequency at the railroad is at an all-time high and more trains are operated in the same amount of space, resulting in trains that are spaced closer together (in the literature, this is often referred to as "train density"). During rush hour, when nearly all platforms and tracks are occupied, trains are constantly being moved in and out of the terminal with little slack in the system. As a result, engineers are seeing more stop signals within the terminal than ever before because opportunities for dispatchers to give clear routes become fewer as train frequency increases. Statistically speaking, the more stop signals engineers encounter, the probability of PASS increases.

Dispatcher Train Management

Production pressures are also felt by dispatchers. For example, discussions with dispatchers and observations in the operations control center revealed that many dispatchers would rather send trains out as soon as possible to ensure an on-time departure out of the platform (even if it means the train must then sit and wait at a stop signal in the terminal) rather than wait and delay the train's departure in order to give the train a better (i.e. a route with fewer stop signals) and ultimately faster route out of the terminal. This is because dispatchers are evaluated on their ability to get trains in and out of the terminal on schedule, rather than on providing engineers with optimal routes.

Similarly, because of pressure to keep trains moving, dispatchers may provide trains with more "stop and go" routing throughout the terminal – i.e., advance trains one block at a time – resulting in engineers encountering more stop signals within the terminal, increasing the opportunity for PASS.

According to dispatch center managers and experienced dispatchers, these behaviors are also due to dispatcher inexperience and non-uniform training among dispatchers (as discussed above under Section 4.2.1, Employee Training). There are effective routing strategies that experienced dispatchers know and are able to implement successfully to keep trains running smoothly,

despite production pressures. These strategies breed more efficient routing into and out of the terminal and should be used when less experienced dispatchers are trained.

Our findings suggest that dispatchers (particularly less experienced dispatchers) may not be aware of the pressures that engineers face within the terminal, and are not familiar with the terminal's characteristics. As a result, they may assign trains to difficult routes, such as routes that cross many tracks, routes with signals that are very close together and/or around curves, or routes that could cause stalls on steep grades for diesel trains (which are all contributors to PASS). Also, the dispatcher can only see whether the signals are in two states: stop or permissive, and while the dispatcher does not need to understand the signal aspect for train routing, this knowledge can facilitate communication between the dispatcher and the train crew.

Finally, many engineers stated that dispatchers can drop signals (i.e., change the signal to stop from a more permissive signal aspect) while their train is already occupying the block. We understand that this is taken into consideration during an investigation, and the engineer is not at fault if the investigation reveals that there was a dropped signal. However, several engineers mentioned dropped signals (both inside and outside of the terminal) had happened to them at one point during their career, but PASS did not result. Since the railroad does not store data on dropped signals resulting in violations, it is difficult to ascertain how common these occurrences are. However, it remains a significant finding about the relationship between dispatcher train management and PASS.

4.2.4 Production Pressures Recommendations

Short Turn Times

Crew schedules and procedures are often created for “normal” or “ideal” circumstances, which is very often not the case in the railroad industry. We recommend adjusting the schedule to give train crews more time for turn-time activities. A study should be conducted to identify the distribution of train times, and then the railroad should use the study and modify the schedule to allow adequate time for train crews to turn their trains and perform all the required activities as conditions dictate. (**Note:** The railroad has acknowledged this issue and they adjusted their train schedules in May 2014. Because we have not analyzed their adjusted schedule and do not know if any analysis was performed when they created it, we are keeping these recommendations.)

For example, here is an exercise that will help identify how to adjust the schedule:

- Identify the safety and personal activities that train crews need to perform and then determine the time needed for each activity.
 - Employees who are required to dead head into the terminal—particularly those dead-heading on empty equipment—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.

- o Allow for some slack in the system based on historical data for late trains.

Train Frequency

- Increased train frequency within the terminal is a significant contributor to PASS because it results in fewer clear routes (more stop signals) for the engineer. Adjust the schedule to space trains so that fewer trains are in the terminal at once.

Dispatcher Train Management

- Emphasizing the importance of routing trains efficiently and safely, instead of focusing on on-time departure and arrival rates, could minimize the potential for PASS.
 - o If the railroad emphasizes the importance of time-tables, some dispatchers may prematurely route a train out of the platform and that train will sit at a stop signal while blocking other tracks.
 - o According to expert dispatchers, efficient routing helps move trains in and out of the terminal more quickly as well.
- 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.

Managing Dynamic Demands

As congestion continues to increase, the number of stop signals will rise. Congestion reduces throughput and can contribute to production pressures, which can cause railroad personnel to take shortcuts across the system and reduce bottlenecks. Without enough spare capacity in peak periods, the system is more brittle and experiences greater difficulty adjusting to unexpected conditions. Our findings suggest that unexpected conditions occur regularly.

The lack of spare capacity under high workload demands during peak periods (meaning less time, more information to process, and more decisions to make) create conditions in which railroad personnel (dispatcher, train crews, yardmasters, Operations Planning Department) are more likely to make mistakes. In this scenario, it is more difficult to plan ahead, more difficult to communicate (due to congested communication channels) and employees may get distracted by multiple competing demands for their attention. Thus, identifying ways to reduce the demands across the system is important, so that there is sufficient slack in the system to enable employees to recover from mistakes without compromising system safety.

The Operations Planning Department has responsibility for making adjustments to train operations, as unexpected problems occur. They use a variety of mechanisms to introduce slack into the system, such as calling reserve engineers and reserve conductors to replace trains that break down or are delayed or providing crew members to operate trains when the original crew for the waiting train is delayed. We recommend that managers work with the Operations Planning Department to document reserve capacity, determine how well different strategies work for creating enough slack in the system for safe operations, and discover the effectiveness of these strategies under different conditions. Documenting these strategies and evaluating their impact will enable new staff to take over these tasks as experienced staff leave or retire, and it will lead to new thinking about what ways to improve the amount of slack in the system.

We also recommend that the railroad reassess its ability to determine how close it is to exceeding capacity (and under what conditions). It should also examine the frequency with which the over-capacity scenario occurs.

4.3 Technology and Task Factors

In addition to monitoring for signals by looking out the window of the cab, the train crews that enter and depart the terminal also operate the locomotive, respond to alerts in the cab, and complete operational tasks (for example, communicating with the dispatcher and attending to paperwork as necessary). These activities are all part of normal railroad operations, but if done concurrently they may cause situations of high workload and distraction. Such situations can contribute to PASS, particularly in the terminal, where engineers must remain vigilant and focused on monitoring the terminal's signals.

In this section, we consider aspects of the locomotive and cab technology as well as formal tasks that locomotive engineers must perform and contribute to workload or otherwise reduce the ability of locomotive engineers to focus out the window.

Table 4. Technology and Task Findings by Category

Locomotive & Cab Technology	Operational Tasks
Locomotive Type	Communication Requirements
Displays & Alerts	Paperwork Requirements

4.3.1 Locomotive & Cab Technology Findings

Locomotive Type

Equipment type was not specified in the railroad's stop signal violation data. As a consequence, we have no quantitative data on the relative frequency of PASS across different types of locomotives. However, discussions with engineers, road foremen, and training instructors suggest that, at least in recent years, PASS most often occurred on Electric Multiple Units (EMUs) as opposed to locomotives, and specifically with engineers who operate newer models of EMUs⁵. Because we lacked quantitative data, we do not know whether the reports we received are due to the larger number of these EMUs in the fleet or because the EMU's design creates the conditions for PASS to occur. Our observations, as well as our discussions with railroad management and locomotive engineers, indicate that locomotive designs behave differently and that may create opportunities for PASS. Below we discuss findings based on our interviews that discussed how equipment types could be possible contributors to PASS.

Locomotives

According to railroad employees, none of the signal violations occurred on locomotives from 2005 onward. This is probably caused by following factors:

⁵ An Electric Multiple Unit is a multi-unit train with self-propelled rail cars using electricity for power.

1. Engineers operate more cautiously with locomotives (because of concerns related to gapping and losing power) in the terminal environment.
2. Dispatchers tend to give trains with locomotives clear routes (routes with fewer stop signals), which means that they are less likely to encounter a stop signal and the chances of stopping at a location where there is no electrical contact with the locomotive is minimized. Therefore, the probability of encountering and violating a red stop signal is lower while operating a locomotive than an EMU. This hypothesis could be tested if the railroad could collect data on the number of stop signals that different train types encounter. At present, we do not believe that the railroad has this capability.
3. The railroad's fleet has more EMUs than locomotives, so overall exposure to stop signals within the terminal is lower for locomotives.

Newer EMUs vs. older EMUs

Railroad employees suggested that cab configuration and train operation in newer EMU models may contribute to PASS. Interviewees mentioned several factors that may make it more challenging for locomotive engineers to rapidly detect and respond to a stop signal when operating newer EMUs.

One factor may be the ergonomic design of the cab, which encourages engineers to sit back in their seat to better see and operate the in-cab displays. This seating position provides a different view out the window than if the engineer was sitting in a more vertical posture. If the engineer is sitting back, it can be more difficult to look out the window, as they have to look over the displays in front of them. This may reduce the ability to see signal aspects, especially ones that are positioned lower to the ground. Also, the simpler display interface and the design of the controls in new EMUs are easier to operate than the older EMU models and the locomotives. These controls may lead the engineer to be less vigilant or take longer to respond to unexpected conditions.

In contrast, the control of the throttle on the older EMUs was "spring loaded," meaning the engineer must apply continuous pressure to the throttle. In the words of one employee, this means the operator "has to sit up straight and use both hands" and "is forced to remain seated while operating the locomotive." The need to sit up straight may make it easier to see signal aspects, and the need to place continuous pressure on the throttle reduces the possibility that the engineer will be moving around the cab, looking through paperwork, etc. Another advantage of a spring loaded throttle is that the engineer can more quickly stop the train because it comes to a stop when the engineer lifts his or her hand from the throttle. In contrast, the newer EMU models require the engineer to take the extra step and physically put the train into emergency.

Displays & Alerts

Displays and alerts within the cab may also contribute to signals passed at danger. (This finding is also noted in the railroad's report analyzing PASS.) Discussions with locomotive engineers and road foremen suggest that newer EMU cab displays sometimes present non-safety/non-critical alerts that can be disruptive. These alerts may sound continuously when triggered rather than shutting off once acknowledged, generating annoyance and distraction

for the engineer. Engineers often stated that these alerts are meant for maintenance rather than for the train crew and expressed a desire to be able to permanently silence them.

4.3.2 *Locomotive & Cab Technology Recommendations*

Locomotive/EMU Type

- The railroad may want to perform an ergonomic analysis on the newer EMUs to assess the engineer's ability to look outside the window and look at in-cab displays from a given seated position.

Displays & Alerts

- Within the terminal, particularly during times of high workload, an engineer's attention should be focused only on monitoring signals outside the cab. Therefore, only safety-critical alerts should be displayed in the cab. Non-safety critical alerts, such as maintenance reminders, should only be shown during times of low, or no, workload.
- Reduce the number of non-safety related alerts on the newer locomotive models. Let engineers control when the non-safety alerts are displayed.
- Provide ways for engineers to acknowledge and silence alerts.

Data Collection and Tracking

- Include "type of locomotive/EMU" as one of the factors to be recorded and tracked when PASS occurs so as to better understand how this factor contributes to PASS.
- Keep track of train exposure rates, specifically, the frequency with which train locomotives of different types are given stop signals within the terminal.

4.3.3 *Operational Tasks Findings*

Communication Requirements

Some engineers described how radio communication was a distraction or caused errors. For example, when dispatchers are calling engineers to ask why the train is late arriving to the terminal, the engineer is often stressed about the late arrival and responding to the dispatcher may distract the engineer. The dispatcher's request also increases the pressure to get the train to the platform. Other general radio communications may have the same effect – particularly during times where constant vigilance is needed to monitor for signals – which causes the engineer to be distracted or take his eyes off the signal. As an example, one engineer recounted a signal violation that occurred on the mainline when the engineer was adjusting the radio and communicating with the dispatcher.

Radio checks – specifically, when the conductor initiates a radio check with the dispatcher without regard for others communicating on the channel – were also mentioned as a distraction for engineers. In this situation, engineers may turn the radio off or change the channel. If the radio is not turned back on or tuned to the wrong channel, that engineer (or the following engineer in the cab) may miss important calls from the dispatcher.

Paperwork Requirements

- As discussed in Section 4.2 (Organizational and System Factors), engineers stated that, when they were arriving or departing late, they have reviewed paper work while en route in the terminal. While the railroad does not assign this task to engineers in the terminal, time pressure (e.g., short turn times) may create the conditions for this to occur. Looking at paperwork in the terminal can be a distraction and results in more “heads down” time, less “heads up” time monitoring for and responding to signals.

4.3.4 Operational Tasks Recommendations

Communication Requirements

- Inside the terminal, the engineer’s focus should be on monitoring and responding to signals as well as operating the locomotive. Communicating with the dispatcher should be avoided if possible, or the task should be assigned to the conductor, as stipulated in the railroad’s operating procedures.
- Implement a “quiet cab environment” in the terminal environment, in which only safety critical communications with the dispatcher and conductor take place. Prohibit all other communications until after the train has arrived at the station platform or exited the terminal. This is further discussed in the section on individual and team factors.

Paperwork Requirements

- Provide sufficient time during train turn-around for train crews to perform all turn-around activities, including reviewing paperwork.

4.4 Individual and Team Factors

In discussing contributing factors to PASS, we must consider the role of the individual (engineer), additional crew members (conductors) and others contributing to safe travel through the terminal (dispatcher, Operations Planning, road foremen). Although we spoke with Operations Planning and road foremen, we focused on the train crew (engineer, conductor) and dispatcher, individually and together as a team, when analyzing PASS risks.

Table 5. Individual & Team Factors by Category

Individual	Team
Experience & Route Knowledge Expectations	Communication & Teamwork

4.4.1 Individual Findings

Figure 11 in section 3.1 suggests that fatigue may contribute to PASS events, which have a pattern that follows the circadian rhythm. While fatigue may play an important role in adverse events, we could not find evidence for how it may have contributed to the reported PASS events that we investigated. After interviewing train crews and the managers that are responsible for

scheduling the train crews (and reviewing the railroad reports), we could not find evidence for how fatigue contributed to the PASS events.

Experience & Route Knowledge

The relationship between experience and likelihood of PASS is a complex one. The railroad's SSV Data Analysis Report notes that the majority (52%) of stop signal violations from the period of 2005 to 2012 were made by engineers with 5 years or less experience. As noted in Section 3.2, when this data is normalized for exposure it points to engineers with 36-40 years of experience as being at greatest risk for PASS. Thus, years of experience, in itself, is not necessarily a good predictor of likelihood of PASS.

At the same time, route knowledge, built up through experience with a particular routing, is likely to reduce PASS, by making it more likely that the locomotive engineer will be aware of potential PASS "traps" on the track and know how to mitigate them. While all engineers are qualified on the territory they travel over, it cannot be assumed that the engineers have the ability to retain a detailed knowledge of signal locations and other route characteristics, particularly if they rarely, if ever, are routed along a particular branch.

Engineers who are qualified on a territory inside the terminal may not recall the knowledge for that qualification if their job only requires them to cover a portion of the territory. An engineer may forget the knowledge required to operate safely over a part of the terminal that they rarely or never travel. For example, we know that senior engineers often hold steady, regularly scheduled jobs with little route variability and they may become very familiar with their route, but forget the knowledge required to operate safely in other parts of the terminal. New (less experienced) engineers who recently came out of training may be more familiar with the terminal and therefore less at risk for passing a signal at danger regardless of where they are operating within the terminal. Regardless of overall experience, engineers who are most familiar with the intricacies of the terminal and the "trouble spots" (i.e. signals located around curves, imbedded into walls, located too close or too far out at platforms) are less likely to miss signals.

In addition to route knowledge, experience-based strategies can be important contributors to safe train handling. Therefore, during interviews with engineers we inquired about the role of experience in mitigating PASS. Our findings suggest that engineers have developed strategies for reducing the chances that a PASS will occur. For example, one experienced engineer would put the train into neutral at platforms where he knows the signal is behind him. Another engineer would put a glove on the locomotive's controller as a reminder not to go until given a green signal. These strategies, which are not necessarily taught in training, help the engineers avoid missing signals in situations in which PASS has a higher probability of happening. Experienced engineers 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 that are in front of them.

While our findings suggest that experience improves route knowledge and produces strategies for preventing PASS, it is important to re-iterate that there is no compelling evidence that years of experience per se is an important predictor of PASS frequency. As we pointed out above, when the railroad data is normalized, there is no clear relationship between number of years of experience and PASS rate. Also, even if there were a significant positive correlation between

years of experience and PASS rate, it would not necessarily indicate that it is the lack of experience per se that is the cause. As is pointed out in Section 4.2 (Organization and System Factors), less experienced individuals have less seniority. They may be assigned routes and schedules that make PASS more likely and work jobs with high route and schedule variability which adds complexity to the job and may make less experienced engineers more susceptible to PASS.

Expectations

Expectations based on experience can have both positive and negative impacts on the likelihood of PASS. As explained in the previous section, route familiarity can reduce the possibility of PASS. For example, knowing when to expect signals can help engineers anticipate the potential need to stop and knowing that a signal is located under a platform can help the engineer avoid the trap of missing that signal. Conversely, less traveled routes can lead to surprises because knowledge of the route is absent.

Expectations are not always helpful, however. If expectations are violated, they may negatively impact operations. For example, if the engineer is almost always routed in one direction at a given signal/switch location, and one time the engineer is routed in another direction (e.g., straight ahead instead of to the right), their expectations based on prior experience may lead them to miss or misinterpret the signal because the engineer may be looking ahead to the next signal he or she is anticipating, rather than paying attention to the current signals and seeing where the switch is lined. Another example is when the dispatcher typically gives the engineer clear (permissive) signals along a route 99% of the time; however, one day those same signals that have always been clear are now stop signals. Because the engineer is expecting to see permissive signals he or she may run past the signal.

Expectations also affect attitudes towards the current multiple aspect signal system. Despite being trained to operate as though the next signal could be stop, train crews expect what the next signal state because they have signal indicators that provide look-ahead information. Since expectations tend to shift reaction time and vigilance level when expectations do not match reality, errors (PASS) may be more likely to occur. This relationship is well established in the psychology literature. For example, research using signal detection theory has shown that bias to respond one way or another is partly determined by expectations formed based on prior experience with the likelihood of different outcomes occurring (McCarley & Benjamin, 2013).

4.4.2 Recommendations for Individuals

The two most common ways to mitigate individual contributions to PASS are admonition and training. Training is a much more effective and permanent solution because admonition (reminding locomotive engineers of dangers and telling them to pay careful attention) often does not work in the long-term, because many of the behaviors that railroads wish to change may be caused by automatic unconscious behaviors. Many of the forces that drive behavior occur below the level of conscious awareness and if the railroad wishes to modify them, they will need to change the factors that influence those behaviors. This explains why telling crews to “pay attention” or “be more careful” is not always an effective strategy.

Experience & Route Knowledge

- Provide training for crews that will accelerate the absorption of experience and knowledge, particularly within the terminal. Consider providing additional on-the-job training inside the terminal when engineers are first hired, and give refresher training which ensures that they maintain familiarity with all routes within the terminal.
- Determine how long it takes to lose the knowledge required for qualification in the terminal.
- Provide recurrent training that will refresh the engineers' knowledge of signals, switches and platform lengths, or require that engineers switch jobs frequently enough to retain the appropriate qualifications to operate safely.
- Track how often engineers cover territory in the terminal.
- Instead of qualifying for the entire terminal, consider qualifying engineers for smaller geographic units inside the terminal.

Expectations

- As discussed in Section 4.1 (Physical Environment Factors), acting on expectations that are based on prior experience is a fundamental aspect of human cognition and it cannot be changed through counseling or admonition.
- A better strategy is providing countermeasures to combat incorrect expectations. For example, encouraging additional communication between the engineer and dispatcher. The dispatcher might call the train crew to inform them when they will be given a different routing from usual, or when they will be stopped at a signal where they would normally proceed.
 - It may be possible to inform train crews how they are being routed with visual indicators in the cab. They would eliminate the need to add workload (radio communication) to the dispatcher and train crew, since the dispatcher may not have time to communicate with the train crews. FRA should perform research into safely implementing visual route indicators in the terminal environment before this can become a viable option.

Fatigue

- Examine scheduling practices to evaluate their impact on fatigue and analyze the possibility that scheduling practices contribute to PASS.

4.4.3 Team Findings

Communication & Teamwork

To safely operate a train, the engineer must work jointly with the conductor and the dispatcher. While communications and teamwork activities are opportunities to improve efficiency along the railroad, they may also serve as a source of distraction in the cab and contribute to PASS.

For example, the need for teamwork influences safety 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, along with the railroad's PASS data, suggest that this strategy can create a new source of distraction. Some engineers complained that conductors in the cab would engage in non-work related discussions, and the training that directed them to solely discuss signal calling and safety-critical issues was ignored. Conductors also stated that calling out signals can be difficult because they did not receive the same training as engineers and lacked the level of knowledge about the territory that the engineers had, which means that conductors might miss or misinterpret signals. The railroad's PASS data shows that implementing this practice did not prevent PASS.

During times when the workload is high, radio communication between the engineer and the dispatcher can improve safe operation and degrade safe operation. If it serves as a source of distraction, safety is degraded. Required communication tasks are discussed in Section 4.3 (Technology & Task Factors). Our findings show that engineers take on additional communication responsibilities that are not formally required by the rules and procedures. For example, engineers described situations when the dispatcher was proactively called 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 in which they pre-emptively call the dispatcher to explain why they may be late. These are not communication requirements, but rather additional tasks engineers take on proactively in order to avoid perceived complications in the future. The messages enable the dispatcher to better manage routing trains on his or her territory and they are important communications that should not be discouraged. However, these kinds of communications may distract the engineer from monitoring signals during high workloads.

Also, we identified opportunities where more effective communication could facilitate movement within the terminal and avoid PASS. For example, engineers and dispatchers described a situation where the dispatcher may have forgotten about a train at a signal; dispatchers said that these situations occur when the dispatcher is dealing with high workloads and they wanted engineers to call and remind them that they have been sitting at a signal for several minutes and were late as a result. Similarly, dispatchers can call the engineer and provide additional information to them. For example, if the dispatcher holds the train at a signal for a prolonged time, the dispatcher could call to let the engineer know why. Alternatively, if the dispatcher routes the engineer a different way than normal, telling the engineer can reduce the engineer's route expectations, thus reducing the possibility of PASS.

4.4.4 Team Recommendations

Communication & Teamwork

- Institute a "sterile cab" in the terminal, in which train crew members only discuss safety-related issues related to train operations while they are in the terminal. Non-work related conversations 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.

- Make explicit the recommended communications between dispatchers and train crews (shown in Table 6 below). 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 6. Recommended communication between Dispatcher and Train Crews

Dispatcher to Locomotive Engineer	Dispatcher is holding the train at a signal; routing the train differently than normal; or “dropping” a signal
Locomotive Engineer to Dispatcher *	Dispatcher left train at signal for prolonged duration
Locomotive Engineer to Dispatcher *	Train will be late and why
Locomotive Engineer to Dispatcher *	Operating a different size train than expected

- Providing Crew Resource Management (CRM) training to train crews (locomotive engineers and conductors) and dispatchers will help with the previous two recommendations. CRM training educates crews regarding the roles and responsibilities of each member and defines how team members will communicate with each other. This should be helpful in getting locomotive engineers to speak up as needed to dispatchers and conductors, instituting “sterile cab,” and providing guidance for constructive communication among team members. (CRM is discussed in Section 4.2, Organization & System).

5. FRA and Improving the Risk Management of PASS

5.1 Historical Context for Analysis of PASS

PASS management approaches in both the United States and the United Kingdom have historical roots in three major accidents:

- In 1987, an accident occurred in Chase, MD when a Conrail locomotive consist proceeded past an approach signal (Rule 285) and the subsequent stop signal (Rule 292) onto track occupied by a fast approaching Amtrak passenger train. The Conrail locomotive engineer made an emergency brake application, stopping on the track in advance of the approaching Amtrak train. The Amtrak train collided with the Conrail locomotive consist. This accident, in which the Conrail locomotive engineer was found to be impaired due to the use of marijuana, provided the context for current PASS management practices.
- In the United Kingdom, the 1997 Southall accident and the 1999 Ladbroke Grove accident established the country's SPAD management policies.

The US and UK took two different approaches to SPAD management, and understanding both approaches offers lessons for moving forward to better manage PASS.

To understand how these accidents affected the methods and tools for mitigating PASS, it is helpful to describe these accidents and how governing bodies responded to these accidents. The National Transportation Safety Board (NTSB) attributed the Chase, MD accident to multiple factors that included:

- Impairment of the Conrail engineer due to marijuana.
- Not requiring Conrail to use the automatic control system (ACS).
- The brakeman's failure to observe the signal aspects and alert the engineer.
- Muting of the automatic control system alert whistle.

After this accident, Congress passed the Rail Safety Improvement Act of 1988, which required FRA to implement many of the NTSB accident report recommendations and create several new regulations. One regulation (Part 240) required the certification of engineers to operate locomotives. As part of this new regulation, engineers could be decertified and lose their license to operate if they proceeded past a stop signal. It also made operators liable for willful violation of Federal safety regulations (MacDonald, 1993). The focal point for mitigating PASS revolved around investigating and disciplining locomotive engineers. The law also required FRA to create a regulation for railroads to adopt locomotive event recorders and make it illegal to tamper with a safety device. The accident did not lead to any FRA support for research on why PASS occurs and how to prevent or mitigate it. Most recently, with the approval of 49 Part 242 in 2013, conductors are also certified and are at risk of losing their certification if the train passes a stop signal.

In the United Kingdom, two accidents involving SPADs occurred close in time to each other: the Southall accident took place in September 1997; the Ladbroke Grove accident took place in October 1999. In the Southall accident, the engineer proceeded through a stop signal and rear ended the train in front of it. In addition to the locomotive engineer missing the signal, the

automatic warning system (which serves a purpose similar to the ACS in the United States) failed to alert the engineer to the missed signal. In the Ladbroke Grove accident, the locomotive engineer proceeded past a stop signal and collided head on with a train proceeding in the opposite direction. In the Ladbroke Grove accident, the signal's design and physical location as well as inadequate engineer training contributed to the event. In response to these two accidents, the inquiry authors recommended a more holistic approach to the design and management of signal systems. They (HSE, 2000a) specifically recommended that there is "no presumption that locomotive engineer error is the sole or principal cause".

In the aftermath of these two accidents, the Rail Safety and Standards Board (RSSB) launched a multi-year research program to identify the factors that contribute to SPADS and developed mitigation strategies to address these factors. This research and the recommendations from this body of research were used to develop the systemic factors we examined in this report. Next, the RSSB collaborated with Network Rail, the owner of the UK rail infrastructure, to develop a variety of tools that support the prevention and mitigation of SPADs. The RSSB also began tracking the occurrence of SPADS in its safety management system along with the factors that contributed to these events across the railroad industry. This included a broad set of factors as illustrated in Table 7. The RSSB assess the risk of different contributing factors to SPADs and allocates resources to help the industry target these in a risk informed way.

Table 7. Example of SPAD data collected in UK Safety Management System

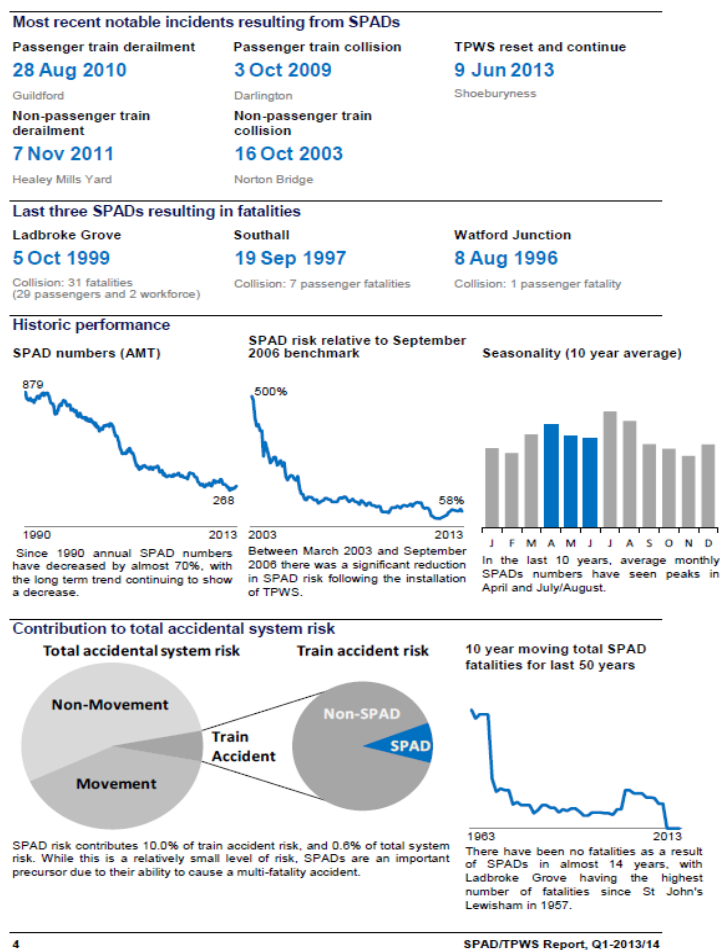
<i>Event Date</i>	<i>Train Class</i>
<i>Signal Box Description</i>	<i>Overrun Yards</i>
<i>Signal Number</i>	<i>Overlap Yards</i>
<i>Location Description</i>	<i>Signal Total SPADS</i>
<i>Territory Description</i>	<i>Previous SPAD Date</i>
<i>Route Description</i>	<i>Driver Number SPADS</i>
<i>Train Company Name</i>	<i>Driver Date Previous SPAD</i>
<i>Train Company Org Type</i>	<i>Error Category Description</i>
<i>Traction Type Code</i>	<i>SPAD Class Sub Type Description</i>
<i>Traction Identifier</i>	

Figure 14 (Rail Safety and Standards Board, 2013) shows the kind of data that the RSSB shares regularly with the public. The report provides a snapshot of recent events as well as SPAD trends over time, using several benchmarks so the reader can put the current data in context. It shows the relationship of SPADs to the risks of train collisions as a whole.

5.2 Improving FRA Data Collection and Analysis of PASS

Currently, FRA does not collect information that allows it to systematically identify current PASS risks or the source of these risks. FRA receives annual reports from the railroads on the number of PASS events that occur when an engineer is decertified. It also receives information when train crews request relief from decertification. However, this information is not stored in a centralized database where the data can be aggregated and trends identified over time. Since FRA only collects the number of events, it lacks information that might address why these events are taking place. The data addresses the discipline process instead of focusing on why unwanted outcomes continue to occur.

We recommend that FRA move toward the approach to PASS prevention and mitigation taken by the RSSB to the furthest extent possible, consistent with its existing statutory authority. Centralize the collection of PASS data so that it can be aggregated and analyzed by FRA staff, interested members of the railroad community, and the public. We also recommend that the FRA collect additional data from the railroads on the nature of PASS events so that interested parties can analyze the data, identify the factors that contribute to these events, and determine whether the mitigation strategies adopted to address them are effective. Appendixes A and B illustrate the data that needs to be collected.



4

SPAD/TPWS Report, Q1-2013/14

Figure 14. Excerpt from UK quarterly SPAD report

5.3 Improving the Railroad PASS Incident Reporting Process

When PASS occurs, the railroad investigates the event to learn what happened and determine whether to charge the locomotive engineer with a stop signal violation. Based on our interviews with management at one railroad site, the investigation is cursory, non-systematic, and focused on the behavior of the train crew.

In this railroad, the road foreman at the location of the event investigates the stop signal violation. There is little consistency in the questions that are asked and the answers that they

report in the written narratives. Most narratives simply describe the events preceding the violation and what happened after the stop signal was reported. While the reports do note which signal was passed, they seldom provide additional background information to understand the context for what occurred. There is no information indicating how interactions with others such as dispatchers, yardmasters, operations managers or maintenance employees may have played a role in the event. The engineer involved in the event may be asked to provide a written statement, but is often excluded from the investigation.

While excluding the locomotive engineer from the investigation may make sense given the assumption that the employee bears primary responsibility for PASS, the current process makes it more difficult to learn about contributing factors. In an environment in which engineers expose themselves to harm by telling their story, they minimize the information that they share with the investigators. By focusing the investigation on the train crew alone and the disciplinary process, the railroad misses an opportunity to learn from this failure.

The requirements for compliance with 49 Part 240 bias the investigation in favor of confirming the need to decertify the engineer rather than to learn what factors contributed to PASS. This behavior creates the demand for programs like the FRA's Confidential Close Call Reporting System (C³RS and Clear Signal for Action) so that employees can tell their story about what happened or peers can identify at-risk behaviors without fear of harm.

5.4 Improving How PASS Rates Are Computed

Another problem with the current approach to collecting PASS data is that train miles are the denominator when the PASS rate is calculated. While this is currently the best metric the FRA and the railroad industry collects, the risk may be misstated because the number of train miles may not bear any relationship to the number of signals in that mile.

For example, large passenger railroads operate in smaller geographic areas than the large freight railroads and space their signals closer together to maximize throughput in territories with multiple converging and/or interlocking tracks. Freight railroads operate under a different set of constraints and may not require the same number of signals within the same track mile. As a result, when a PASS rate is calculated using train miles in the denominator, it may overestimate the risk for passenger railroads and underestimate the risk for freight railroads.

A better metric would use the total number of signals in the territory, and an even better metric would indicate the total number of times a signal displayed stop when a train was approaching for the territory being evaluated. Nickandros and Tombs (2007) make the case for this metric in a conference paper on safety critical systems and software. At present, the US railroad industry does not collect this information.

5.5 Changes to FRA Compliance and Enforcement Practices

We recommend that the FRA consider several changes to its compliance and enforcement practices associated with 49 CFR Parts 240 and 242. Since the research indicates that PASS results from multiple factors, the railroads need to expand their investigations so they can examine the known factors and be open to others that may not have been previously identified. The current incentives associated with Part 240 and 242 discourage the railroads from seeking to identify these other factors. There is no evidence that decertification reduces the incidence of PASS.

Complying with Part 240 for PASS inhibits investigations into the systemic factors that contribute to PASS and causes them to focus on the behavior of the locomotive engineer. The decertification process creates an adversarial environment in which the employee and union representatives battle management in a quasi-courtroom setting to determine the degree of culpability in passing the stop signal. Unfortunately, this process is counterproductive if the investigation is attempting to identify the systemic factors that contribute to PASS.

The language used in the phrase “stop signal violation” illustrates that the bad behavior of the locomotive engineer is emphasized, while the phrase “signal passed at danger,” as used in the United Kingdom, or “passing a stop signal”, as used in this report, represents neutral language that does not imply inappropriate human behavior. We suggest that FRA replace the phrase “stop signal violation” with neutral language in its official language and documents.

As our knowledge and understanding of the systemic aspects of PASS evolves, we recommend giving the railroad industry guidance on the factors that contribute to PASS. FRA can help them learn how they can identify and prevent PASS prior to PASS occurring or how to mitigate them when they do occur. Consider developing tools such as checklists or guides that include questions or issues to address during system design or when conducting a PASS investigation. Promoting these tools will be an important element in facilitating their adoption. We recommend identifying incentives for the railroads to investigate the kinds of factors that the research indicates play a role in contributing to PASS. Second, consider changing (narrowing) the circumstance under which an engineer is decertified. When focusing on the role of train crew in contributing to a PASS, identify positive ways to minimize the likelihood of these events in the future. Measures could include coaching, Crew Resource Management (CRM), use of checklists, establishing a “sterile cab” environment, as well as modifying the environment (e.g., the locomotive cab, wayside signals) and operating practices that better support the train crew in avoiding PASS.

We recommend that railroad industry stakeholders rethink the conditions for the use of punishment (decertification, civil penalties), since punishment can create unintended consequences that decrease safety rather than improve it. In the case of train crews, decertification suppresses the open sharing of information that would help the FRA and the railroads to understand why complex systems fail. Individuals may be able to purchase “insurance” to protect their pay while they are decertified. Rather than changing behavior in a way that reduces PASS, the decertification process creates mistrust between labor and management and short circuits the process for identifying why these events occur.

The decertification process does not distinguish between conscious and unconscious behaviors involved in PASS. Many locomotive engineer behaviors are based on skilled, automatic behaviors that are not subject to conscious control. If the goal is discouraging deliberate attempts to pass a stop signal without authorization, punishing behavior that is not subject to conscious control may not have the desired effect. Changing the behaviors that produce PASS events requires understanding the conditions that produce these behaviors and changing the conditions.

If civil penalties are applied, a mixed message is sent about their intended purpose when railroads can negotiate how much they actually pay. The dispute process is controlled by the Railway Labor Act and the FRA complies with the Act's procedures governing this dispute process. Both decertification and civil penalties lose their effectiveness in changing behavior

because there is a significant time lag between the unwanted behavior and the punishment. Before an engineer or conductor is decertified, the labor union and management conduct disciplinary hearings which can be appealed to the FRA. This creates a delay between the observed behavior and the application of the punishment. Civil penalties are negotiated between FRA legal counsel and the railroads' legal counsel at annual meetings, resulting in a time lag between the observed behavior and the punishment. Punishment is effective under limited conditions in suppressing behavior, not eliminating unwanted behavior (Axelrod, 1983). For punishment to be effective, it should be administered swiftly, so that it is closely associated in time with the behavior that the organization wishes to suppress. To the extent that the unwanted behavior occurs in the absence of punishment, this method decreases in effectiveness. To change the process by which punishment is administered would require a change to the Railway Labor Act.

In the meantime, the FRA can clarify what decertification's goal is and then propose criteria for the conditions that need to be met for employees to be decertified. Is it to deter unwanted behavior? Is to remove individuals that pose a danger from service so they don't compromise system safety? How do you distinguish between the willful disregard for safety in passing a stop signal and someone who is not willfully disregarding safety when passing a stop signal? Given that the system design and its operation can create traps that contribute to PASS, how are others within the system held accountable? What form should this accountability take?

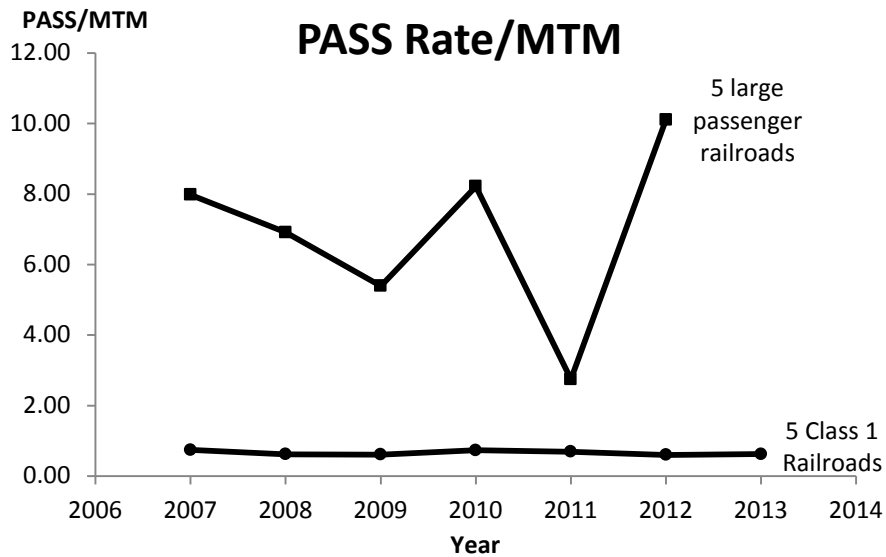
Together these recommendations could lead to greater collaboration between the train crews, who represent the last line of defense in preventing PASS, and the other employees responsible for overall system safety. The focus on decertification should be reduced and the focus on accountability should be expanded by understanding the multiple factors involved in PASS, while mitigation strategies can lead to more effective solutions than the current approach. A solution that includes collecting data on the mitigation strategies and their impact will provide feedback to each railroad, so they can tailor their responses to those strategies that work and discard those strategies that fail. This approach will fit nicely into the framework of the proposed System Safety Program regulation and the Risk Reduction Program regulation that FRA plans to implement in the near future.

5.6 Conduct Additional Research to Expand the Empirical Research Base

A limitation of this study is that some of the findings rely on data collected from just one railroad. In particular, the analysis of PASS frequency data was severely limited because there were too few PASS events included in the available database for meaningful statistical analysis.

We recommend conducting additional field research to determine whether the findings at the current railroad apply elsewhere and expand the understanding of how systemic factors contribute to PASS. **Source: Federal Railroad Administration, Office of Safety**

Figure 15 compares PASS rates for several passenger railroads to several large freight railroads. The PASS rate is consistently higher for the passenger railroads. We noted earlier that the difference in frequency of PASS between freight and passenger railroads may reflect differences in exposure rate (i.e., differences in the number of signals, and number of signals showing stop per mile traversed). Nevertheless, it suggests that passenger railroads provide the greatest opportunity for better understanding the contributors to PASS and reducing PASS risk. We therefore recommend directing attention first to additional passenger railroads, followed by an examination of one or more freight railroads.



Source: Federal Railroad Administration, Office of Safety

Figure 15. Comparison of US PASS rates between passenger and freight railroads

We also recommend evaluating if locomotive designs, particularly newer cabs and ones still under development, may affect a crew's ability to detect and respond to wayside signals. This research would provide valuable input to development of guidelines and standards in support of next generation cab designs (Einhorn, Sheridan, and Multer, 2005; Multer, Rudich, and Yearwood, 1998; Reinach and Zaouk, 2010). Research areas should include physical ergonomic issues, such as whether the locomotive engineer's position in relation to the displays impact their ability to see and respond to visual indications (including signals) outside the cab. Our findings also suggest that locomotive design impacts how the engineer allocates their attention.

There is a need to examine how current and new cab displays may impact attention allocation. Understanding how design changes influence attention can provide insight into unintended consequences that may create adverse safety outcomes. For example, providing additional route guidance to the locomotive engineer via a visual display in the cab (as it does in some PTC systems) may reduce the communication load for the engineer and the dispatcher, but it may also distract the engineer from seeing hazards outside the cab or monitoring wayside signals. Another important research topic is the design of visual and auditory alerts in the cab and their potential as a source of distraction. Our interviews suggested that non-critical alerts may come on at inappropriate times. Poorly designed alerts and alarms are well-known human factors problems that arise across industries, including aviation, process control, and healthcare (Meyer & Lee, 2013), which is why there is a need to investigate and provide better guidance for design of alerts and alarms in advanced cab displays.

Finally, there is a need to investigate the impact of mode transitions on the ability of locomotive engineers to detect and respond to outside signals (Wreathall, Woods, Bing, and Christoffersen, 2007). In the railroad we studied, the locomotives displayed cab signal indicators on the mainline but not in the terminal. Relying on in-cab signal indicators while traveling on the

mainline (one mode of operation) may have unintended negative consequences when transitioning to another mode of operation (e.g., terminal operations). The FRA's Cab Technology Integration Laboratory (CTIL) would serve as a good vehicle to answer these types of questions.

Over the last few decades, the US wayside railroad signal systems have changed little in terms of how it operates. Developments in the underlying technology provide opportunities for rethinking how the US system operates. The existing system employs a multitude of signal systems that create significant cognitive complexity for the train crew. How do these different signal systems affect system safety? Do these legacy systems still have a role in a modern railroad system or are they outmoded? Can we create a more consistent, uniform signal system that reduces the cognitive load for the train crew without compromising other railroad interests?

When highway designers create traffic signals and signs, they follow the Manual on Uniform Traffic Control Devices (MUTCD). The MUTCD has a set of standards that define how traffic control devices are presented. This standardized system enables motorists to drive throughout the country in all states with the training and experience that they have acquired in their home state. However, locomotive engineers who cross into different territories may encounter signal systems that differ from their "home" territory, and these systems may have different methods for conveying the same information or feature signals which look the same but have different behaviors. A uniform signal system can contribute to a simpler system that reduces the potential for operators to make mistakes.

Advances in technology (e.g., lighting, sensors, and communications) allow both government and industry to rethink how the signal system conveys information to the train crew. For example, LED technology allows the same bulb to display multiple alternative colors and change in intensity, which opens up new visual coding possibilities. Are there opportunities for improved system design and how will the new technologies impact safety? The FRA may want reexamine signals systems to better support human capabilities rather than asking train crews to adapt to the existing technology's limitations.

Also, there are opportunities to conduct research into new forms of displays and decision-aids that can improve safety, such as new forms of in-cab visualizations that could reduce the need for verbal communication between the dispatchers and the train crew (which our findings suggest can be a source of train crew distraction). For example, in-cab route indicator displays could be implemented for the terminal environment. These displays would allow the train crew to know where they will be routed without requiring verbal communication with the dispatchers.

Our findings and others' findings strongly suggest that violated expectations, formed based on consistent prior experience, are an important contributor to PASS. If the dispatcher decides to route the train differently than usual or stop the train at a signal that normally is more favorable than *stop*, there is a greater possibility of PASS because the train crew was not expecting those situations. In-cab route indicators would let the train crew know how they will be routed and what the next signal aspect will be, which would eliminate the need to operate based on expectations and reduce the possibility of PASS due to violated expectations. In addition, the technology could allow the train crew to catch and correct dispatcher routing errors (such as being routed to a platform that is too short for the train). As pointed out earlier, there is the possibility that such in-cab displays would draw attention away from monitoring outside the cab.

Research would be needed to establish that the new displays would provide the needed information, while minimally impacting the ability to monitor outside the cab.

Finally the safety and efficiency of train movements can be enhanced by improving the tools that schedule trains and plan routes in real time. In our interviews and observations, it was clear that train delays and breakdowns routinely occur, which creates a need for train dispatchers and other planners to make real-time changes to their plans. Individual dispatchers, especially less experienced ones, may make moves that address the immediate local problem (e.g., the train is out of the station on time) but create additional delays in the overall system as a result or even create PASS traps (e.g., by letting a train out of the station only to present it with a stop signal soon after). Research and development efforts could lead to technologies such as advanced displays, real-time decision-support systems, and training aids, which would enable dispatchers and others involved in rapid schedule re-planning to generate plans that take a more global view of the planning space, minimize overall delays, and also minimize the number of stop signals that each train experiences.

6. Conclusion

For this project, we investigated and analyzed data related to PASS at a passenger railroad's terminal; this analysis was conducted from a sociotechnical systems perspective, in which unwanted outcomes like PASS are the result of systemic factors as well as individual factors. While the system's design and the organizational processes create the positive outcomes (efficient train service), they also produce bad outcomes (adverse safety events) such as PASS.

Section 4 presents our detailed findings and recommendations on the factors that were found to exist within the railroad, and in the terminal in particular, that can contribute to PASS. We identified multiple factors, including aspects of the physical environment, the organizational environment, system pressures, and the technology, as well as individual, task, and team factors. In each case, we provided specific, concrete suggestions for actions that the railroad can take to mitigate that particular factor.

Some of the systemic factors that may create the conditions which cause PASS include:

- Signal system design including layout of the physical infrastructure
- Locomotive design
- Planning and scheduling practices
- Practices by which employees are assigned to jobs
- Dispatcher routing strategies
- Training practices
- Operating rules

While the railroad identified attention and distraction as causal factors in their analysis, we did not identify attention or distraction as causal factors. Instead, we viewed attention and distraction as symptoms of the problem rather than a source. Attention deficits and distraction represent a consequence of the system design that does not support human limitations. Attention is a process that operates within its limits in the same way that equipment does. When equipment operates outside its limits or humans operate outside their envelopes, the equipment or the human will fail. Because humans can adapt to a wide range of conditions, we often neglect to consider human operating limits.

As the railroad increased the number of trains, the pressure to maintain the schedule increased and the operating envelope for safe performance narrowed. Greater constraints on resources lead to an increasingly fragile system, since there is less slack to accommodate unexpected events. In light of the current demands for service, the railroad must determine how to increase the safety margins and provide the space to adjust to unexpected events. Over the long term, if the system must accommodate increase demands for service, the railroad has to effectively balance the increased demands for service with the need to provide an adequate safety margin.

While the railroad is currently focused on reducing the current PASS rate, we recommend creating a long-range plan that manages the need for additional revenue service against the need to increase safety measures. If not carefully considered, an increase in demand and the current physical constraints imposed by the design of the terminal, along with normal cost constraints

will create unintended safety consequences. Addressing these competing demands will require making difficult trade-offs that will impact the railroad's stakeholders.

At the same time that demands for service increased, the experience level of the employees is decreasing as replacements are found for the industry's current generation of employees, who are retiring after 30 or more years of service. Much of the domain expertise across multiple crafts exists as tacit knowledge, which is undocumented; inexperienced employees will have to acquire this knowledge through hands-on learning rather than through classroom training or on-the-job training. This tacit knowledge will be acquired through trial and error, and some of the mistakes may result in unwanted safety outcomes. It has been known well in advance that the experienced work force would retire, and it was a missed opportunity to document this knowledge and pass on to the next generation of employees. As the railroad addresses current concerns, we hope that it will take advantage of foreseeable trends, like changing demographics, to anticipate and plan for future long range needs as well.

As we conducted our investigation, we encountered some of the same problems that were mentioned in the railroad's internal PASS data analysis report. The inconsistent and non-standardized recording of PASS causes by investigators, along with the absence of the PASS-related data which was needed to pursue hypotheses around factors identified in the research literature made it difficult to draw definitive inferences about some of the factors contributing to PASS at the railroad. Several of our requests for data related to the signal system could not be met because the system was not designed to record the needed information.

Both the railroad's investigation process and its PASS-related data need to be incorporated into a more structured process that acknowledges the existing research about how and why PASS occurs. Given the relative rarity with which PASS occurs (a good thing), railroads must obtain as much information as possible about how PASS happens and retain that information so that the individual records can be aggregated and studied along with the data that is generated by analyzing individual events. This information can also assist in determining if a corrective action is effective, and baseline data about operating performance can be compared to operating performance after implementing specific corrective actions.

Adopting a more flexible information system will improve the railroad's ability to analyze data from the signal system and enhance the quality of future analyses as well. In addition, given that PASS occurs infrequently, alternative performance measures can indicate whether the desired performance is taking place. As an example, minimizing the frequency with which stop signals occur when trains are approaching the signal can prevent PASS, and measuring the frequency with which this event occurs can serve as a performance indicator. If this approach is adopted, the railroad may need to record data that is currently not collected or stored, which will provide the basis for supporting a better understanding of why PASS occurs and identifying effective corrective actions to address them.

While the specific findings and recommendations in this report are targeted at a particular passenger railroad, we anticipate that many of the findings and recommendations may have relevance to other railroads as well. One of our primary recommendations to the FRA is that it should perform similar analyses for other passenger railroads so as to better assess the universality of the findings and recommendations and build a stronger empirical foundation for identifying and mitigating contributors to PASS.

This report discussed prospective opportunities for the FRA to improve the risk management of PASS across railroads. These included recommendations for more systematic collection and analysis of PASS data; potential updates, revisions, and changes to existing FRA compliance and enforcement practices to encourage more open and complete reporting of PASS incidents; and additional field and simulator-based research to strengthen the empirical foundation for linking systemic factors to PASS.

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Appendix A. PASS Investigation Recommendations

This appendix contains suggested data collection topics for PASS investigations. We strongly recommend that the railroad should create an investigation report template for use by the road foreman (or other investigators at the scene). These data collection topics, while not meant to be fully comprehensive, provide an overview of the topics that should be included in a template. An investigation report template standardizes data collection practices, which allows the railroad to collect important information and analyze contributing factors.

General/Demographics

- o Engineer Name, Age, Sex, Years of Experience, Hours on Duty
- o Conductor Name, Age, Sex, Years of Experience, Hours on Duty
- o Date/Time of PASS
- o Regularly Scheduled Run?
- o Locomotive Type
- o Location of PASS

PASS Contributing Factors

Physical Environment

- Factors that may have caused the signal to be *difficult to see*
 - o Sun on signal
 - o Lights of another train
 - o Obstruction (e.g., behind a wall)
 - o Around a curve
 - o Pulled up ahead of signal at platform
 - o Signal maintenance (signal down, signal bulb out)
 - o Engineer confused by other lights
 - o Other
- Factors that may have caused the signal to be *misinterpreted*
 - o Non-standard location caused engineer to believe it was intended for a different track / engineer thinks that the signal does not apply to his line because of unusual positioning or form of signal
 - o Known challenging locations
 - o Other
- Read through to subsequent signal

Organization & System

- Time pressure / stress
 - o Was the train late
 - o Other
- Dispatcher Routing
 - o Signal dropped

- o Other
- Other out of norm situational factors (e.g., the train consist length different than expected)

Technology & Task

- External Distractions:
 - o Radio communication
 - Necessary task or proactive communication?
 - o Reviewing paper work
 - Necessary task or proactive paperwork review?
 - o Talking with another employee (conductor)
 - o Cab display and audio warnings
 - o Cell phone
 - o Other

Individual & Team

- Expectations
 - o Anticipating Signal/Route:
 - Anticipating Different Route: Was this a different routing than usual for this train?
 - Anticipating clear signal)
 - Fixated on switch points
 - o What was the signal aspect of the immediately prior signal?
 - o Other factors influencing expectations
- Knowledge/Experience
 - o When was the last time (if ever) the crew was routed by this signal?
 - o How often has the engineer operated this train schedule (e.g., was this a new train schedule that the engineer had only recently started? Was this an engineer that was on the extra board?
 - o When was the last time the crew received training covering this portion of the track?
 - o Other relevant knowledge/experience factors
- Team Dynamics
 - o How many individuals in the cab?
 - o If there was a conductor in the cab, did the conductor call out the signal? Did the conductor call out the signal correctly?
 - o If the routing or signal aspect was different from usual, did the Dispatcher let the train crew know about this ahead of time?
 - o If the signal was dropped, did the Dispatcher let the train crew know about this ahead of time?

- o Other relevant team dynamics factors
- Internal Distractions
- Fatigue

Appendix B. PASS Hazard Checklist

This checklist is adapted from the Rail and Safety Standards Board (RSSB) OPSWEB online PASS Management Tool website. Therefore, note that some terms are specific to the UK rail environment. Nonetheless, this may be a helpful tool in generating a PASS investigation report template.

Source: <http://opsweb.co.uk/tools/hazard-cl/PAGES/start-checklist.html>

Personal Factors

1. Is the locomotive engineer under 25 years of age with less than 2 years of experience?
2. Does the locomotive engineer have less than 2 years of experience?
3. Is there reason to believe that the locomotive engineer may have been suffering from fatigue?
4. Was the locomotive engineer using any medication at the time of PASS that may have adversely affected his/her vigilance or reaction times?
5. Has the locomotive engineer failed a drugs or alcohol screening test applicable to the time of PASS?
6. Has the locomotive engineer received an inadequate degree of training and competency assessment?
7. Has the locomotive engineer experienced PASS before?
8. Is there evidence of inadequate route knowledge?
9. Has the locomotive engineer worked successive night shifts in the week prior to PASS?
10. Is there evidence of inadequate traction knowledge?
11. Is there evidence that personal events may have affected locomotive engineer concentration?
12. Did PASS occur on the locomotive engineer's first shift back after returning from annual leave or prolonged sickness?

Attention/Distraction Factors

13. Are multiple reminder aids displayed on the approach to the signal?
14. Was there any temporary equipment/ material or contractors working at the wayside which could have distracted the locomotive engineer's attention away from the upcoming signal?
15. Was the locomotive engineer distracted by a passenger: - standing too close the platform edge? - talking to the locomotive engineer through his window? - behaving abnormally on the platform? - attempting to board the train late? - causing noise or commotion on the train?
16. Was there anything relating to the cab environment that could have distracted the locomotive engineer?
17. Could there have been an auditory distraction on approach to the signal?
18. Is there evidence that another person(s) in the cab distracted the locomotive engineer?
19. Was the locomotive engineer distracted by wayside information that was insufficiently visible?

20. Is the signal positioned soon after OLE neutral section or a section gap in the conduction rail?
21. Could complex track layout have distracted the locomotive engineer?
22. Was there a compelling but non-operational distraction on the wayside?
23. Is there evidence that the locomotive engineer was distracted by any in cab activity, such as reading a document (e.g. route diagram, newspaper, etc.)?
24. Was the locomotive engineer preoccupied with train speed control on a falling gradient?
25. Could the locomotive engineer have been distracted by line-side DOO equipment?
26. Did the route change, for example from a fast to a slow line, or vice versa?

Visibility Factors

27. Is the signal beam improperly aligned for the approach route?
28. Is the signal obscured by foliage?
29. Is the signal beyond a bridge or tunnel that restricts continuous and uninterrupted view of the signal on approach?
30. Is the signal occluded by station structures or furniture?
31. Is the signal obscured by OLE?
32. Was there fog, mist or rain (sleet or snow) at the time of PASS?
33. Was the locomotive engineer's view through the windscreen limited, e.g. by: - dirt on the glass? - rain on the screen? - the action of the windscreen wipers?
34. Is the signal located within 10 meters of a tunnel exit?
35. Was the signal lens dirty or fogged, which reduced the beam intensity?
36. When stopped at the CAR STOP sign or normal stopping position, is the starting away signal not visible?
37. Was the locomotive engineer's vision affected by direct glare from sunlight?
38. Could stanchions repeatedly occlude the signal on approach?
39. Does limited clearance (e.g., due to short platform length) cause the locomotive engineer to stop the train where the starting away signal cannot be seen?
40. Was the locomotive engineer's field of view from the cab restricted by a corridor connection gangway?
41. Is the signal beyond a curved approach that restricts continuous and uninterrupted view of the signal on approach?
42. Could wayside clutter prevent continuous and uninterrupted view of the signal on approach?
43. Was there any temporary equipment or material at the wayside which could have obscured the locomotive engineer's view of the signal?

Perception Factors

44. Is the signal set at a non-standard height with respect to the locomotive engineer's normal sightline (i.e. above 4.5m or below 3.3m)?
45. Was sunlight reflecting off the signal lenses or casing making the aspect difficult to perceive?
46. Is there evidence that a signal-like light would be in the locomotive engineer's field of vision on approach to the signal?
47. Is the edge of the signal backplate less than 100mm from the edge of the aspect?

48. If the signal is on an open approach with line speed above 20 mph, does the signal backplate have a light colored or hatched border?
49. Is the signal viewed against a dark or complex background e.g. bridge, buildings, foliage, etc.?
50. Is there any signage adjacent to the signal lenses that make the aspect more difficult to perceive?

Association with Line Factors

51. Is the signal height on the route inconsistent?
52. Is there irregular signal spacing on the route?
53. Has the signal layout been altered in the past six months?
54. Is the signal significantly less bright than adjacent parallel signals or signals ahead that can be seen on approach?
55. Does the number of lines visible to the locomotive engineer (including sidings) differ from the number of signals visible?
56. Is the signal located on the 'wrong side' or an otherwise unusual location relative to the track?
57. If signals are on a gantry, are they staggered?
58. Does the signal have an identical profile compared to adjacent signals?
59. On a curved approach, is there any possibility that a locomotive engineer could mistake a parallel signal as his/her own?
60. When the AWS horn is activated is another signal closer to the locomotive engineer's line of sight than the relevant route signal?
61. Is the track ahead obscured by ground vegetation?
62. Has unusual routing on a parallel track prompted read across to a more familiar (regularly encountered) signal?
63. Have recent changes been made to the landscape/non-operational infrastructure along the wayside (e.g. landmarks, buildings, advertisements)?

Read Aspect Factors

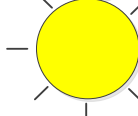
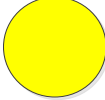
64. Is this signal normally (i.e. more than 75% of the time) encountered at a proceed aspect?
65. On high speed lines is reading time less than the MRT calculated?

Interpretation Factors

66. Did the locomotive engineer misinterpret the meaning of the signal?
67. Are flashing aspects used on the approach to this signal?
68. Does the gradient profile change on the approach to the signal?
69. Does the speed limit increase on the approach to the signal?
70. Did the locomotive engineer fail to account for low adhesion at the time and location of PASS?
71. Was the locomotive engineer departing from a station?
72. Was the locomotive engineer's estimate of their speed prior to PASS inaccurate by more than 10%?
73. Relative to previous signals, does this signal have a different aspect configuration?
74. Is AWS unusually close to the signal (i.e. less than 183 m)?

- 75. Did the locomotive engineer believe that he/she was authorized to move by a signaler or hand signaler?
- 76. Was the AWS magnet disconnected from the signal or suppressed for any reason?
- 77. Was the in-cab AWS equipment out of order?
- 78. Was it the locomotive engineer's first experience of an unusual/uncommon situation (e.g. severe weather conditions; emergency situation)?
- 79. Was the locomotive engineer facing time pressure?
- 80. Did poor cab design cause a delay in locomotive engineer action?
- 81. Did the locomotive engineer fail to set the DRA (where appropriate)?
- 82. Could the locomotive engineer have cancelled a train protection system erroneously (i.e. TPWS reset and go)?

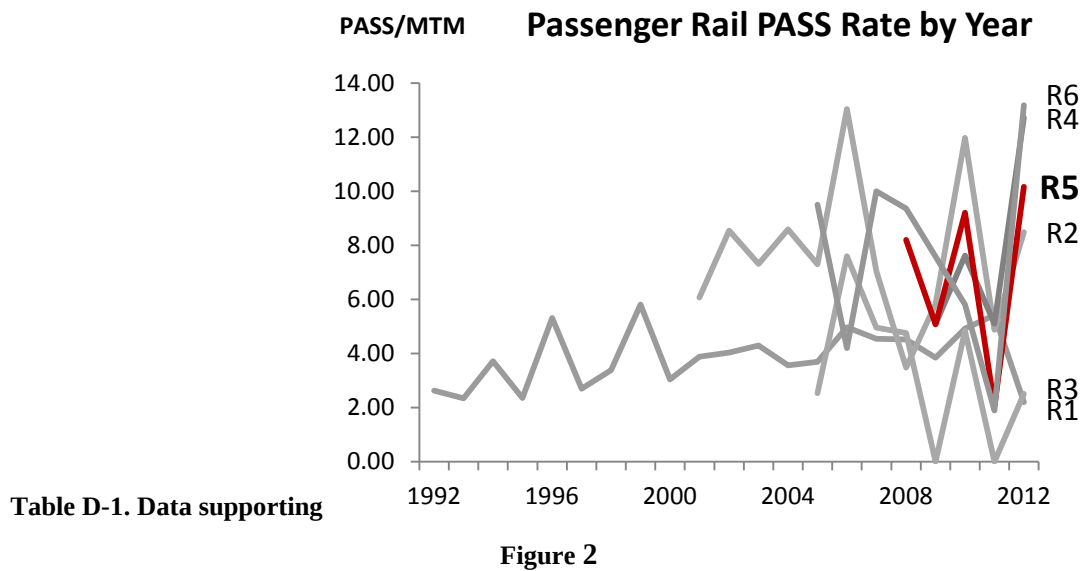
Appendix C. Railroad Signal Aspects and Indications

Signal Aspect	Signal Indication
 Red	Proceed at restricted speed Signal ahead is currently not at Stop
 Green	
 Dark	
 Red	Proceed at restricted speed Signal ahead is currently at Stop
 Dark	
 Flashing Yellow	
 Red	Proceed at restricted speed Block ahead is currently occupied
 Dark	
 Solid Yellow	
 Red	Stop signal
 Dark	
 Dark	

These signal aspects were employed in the terminal when this study was conducted. The signal indicators reflect the railroad's intentions but at the time the study, they were described differently in the passenger railroad's rulebook. The signal aspects and the issues they raise are characterized at a more abstract level in this report to protect the identity of the railroad.

Appendix D. Data for Figures

The following tables include the data supporting each of the figures included in this report. The tables are ordered so each table number corresponds to the same numbered figure. Each table is preceded by a title indicating which figure it applies to.



Railroad	RR1	RR2	RR3	RR4	RR5	RR6
1992	2.63					
1993	2.34					
1994	3.72					
1995	2.36					
1996	5.32					
1997	2.70					
1998	3.39					
1999	5.81					
2000	3.05					
2001	3.89	6.07				
2002	4.04	8.55				
2003	4.30	7.31				
2004	3.57	8.59				
2005	3.70	7.31	2.54			9.50
2006	4.98	13.04	7.60			4.20
2007	4.55	7.04	4.97			10.00
2008	4.52	3.48	4.76		8.20	9.36
2009	3.85	5.84	0.00	5.09	5.08	7.59
2010	4.93	11.98	4.85	7.62	9.21	5.81
2011	5.43	4.88	0.00	5.10	2.05	1.90
2012	2.21	8.49	2.52	12.72	10.17	13.18

Table D-2. Data supporting Figure 3

Railroad	Lower CI	Mean	Upper CI
RR1	3.38	3.87	4.36
RR2	1.20	3.40	5.61
RR3	5.98	7.71	9.44
RR4	2.80	6.94	11.08
RR5	1.92	7.63	13.35
RR6	4.68	7.69	10.70

Table D-3. Data supporting Figure 4

Terminal	Non-Terminal
7/29/2008	2/20/2008
10/24/2009	4/9/2008
12/28/2009	4/23/2008
2/2/2010	7/22/2008
2/26/2010	8/12/2008
3/8/2010	9/5/2008
4/12/2010	10/17/2008
5/12/2010	4/21/2009
10/29/2010	6/1/2009
6/10/2011	10/25/2009
4/17/2012	3/14/2010
5/1/2012	5/21/2010
5/24/2012	6/7/2010
6/13/2012	9/28/2011
6/15/2012	5/4/2012
7/9/2012	8/27/2012
9/15/2012	1/24/2013
9/18/2012	3/30/2013
3/4/2013	10/18/2013
3/20/2013	
6/11/2013	
6/28/2013	
2/11/2014	

Table D-4. Data supporting Error! Reference source not found.

Days between	LCL	Mean	UCL	Vertical line position	Year
452	0	85	258		
65	0	85	258	350	2009
36	0	85	258		
24	0	85	258		
10	0	85	258		
35	0	85	258		
30	0	85	258		
170	0	85	258	350	2010
224	0	85	258	350	2011
312	0	85	258		
14	0	85	258		
23	0	85	258		
20	0	85	258		
2	0	85	258		
24	0	85	258		
68	0	85	258		
3	0	85	258	350	2012
167	0	85	258		
16	0	85	258		
83	0	85	258		
17	0	85	258	350	2013
228	0	85	258		

Table D-5. Data supporting Figure 6

Year	Daily
2000	687
2001	715
2002	725
2003	486
2004	740
2005	742
2006	779
2007	796
2008	810
2009	815
2010	815
2011	832
2012	833
2013	854

Table D-6. Data supporting Figure 7

Year	PASS
2008	1
2009	2
2010	6
2011	1
2012	8
2013	4

Table D-7. Data supporting Figure 8

Time	Frequency
1	25
2	36
3	19
4	14
5	0
6	28
7	66
8	77
9	160
10	189
11	89
12	91
13	92
14	76
15	76
16	37
17	71
18	95
19	139
20	116
21	73
22	67
23	58
24	51

Table D-8. Data supporting Figure 9

Time	SSV Frequency
1	0
2	2
3	0
4	1
5	0
6	0
7	0
8	1
9	2
10	4
11	1
12	2
13	0
14	1
15	0
16	1
17	0
18	4
19	3
20	2
21	2
22	3
23	1
24	1

Table D-9. Data supporting Figure 10

PASS	Red Signal Frequency
0	25
2	36
0	19
1	14
0	0
0	28
0	66
1	77
2	160
4	189
1	89
2	91
0	92
1	76
0	76
1	37
0	71
4	95
3	139
2	116
2	73
3	67
1	58
1	51

**Table D-10. Data supporting
Figure 11**

Time of Day	Relative Risk	PASS Proportion	Red Signals
1-4	1.80	0.097	94
5-8	0.33	0.032	171
9-12	0.96	0.290	529
13-16	0.40	0.065	281
17-20	1.20	0.290	421

21-24	1.58	0.226	249
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Table D-11 Data supported by Figure 12

Age	% PASS un-normalized	Age	Relative Risk	PASS Proportion	Proportion of Employees
0-5	0.52	0-5	1.90	0.522	0.273
6-10	0.17	6-10	0.64	0.174	0.273
11-15	0.09	11-15	0.46	0.087	0.188
16-20	0.09	16-20	1.47	0.087	0.059
21-25	0.02	21-25	0.18	0.022	0.123
26-30	0.02	26-30	0.69	0.022	0.032
31-35	0.00	31-35	0.00	0.000	0
36-40	0.09	36-40	6.69	0.087	0.013
41-45	0.00	41-45	0.00	0.000	0
46-50	0.00	46-50	0.00	0.000	0

Abbreviations and Acronyms

C&S	Communications & Signaling
CRM	Crew Resource Management
FRA	Federal Railroad Administration
EMU	Electric Multiple Unit
PASS	Passing A Stop Signal
RSSB	Rail Safety and Standards Board
SPAD	Signal Passed at Danger
SSV	Stop Signal Violation