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Why Do Passenger Trains Run through Switches in the Rail Yard?

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13. ABSTRACT (Maximum 200 words) This study examined why crews working in yard operations run through switches in the wrong direction or run through damaged switches. Running through a switch in the wrong direction can damage the switch. Operating through a damaged switch can derail the train. The authors worked with a railroad to collect data, interview employees, and observe yard operations to identify how and why moving equipment may run through a switch in the wrong direction. A hazard analysis called systems-theoretic process analysis was also conducted. The study identifies a complex, interacting set of factors that contribute to these events and offers recommendations for preventing these events from occurring in the future.			
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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
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)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
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)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
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

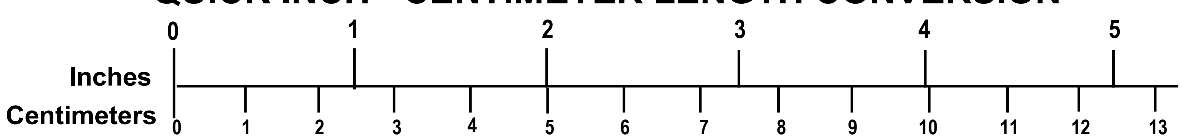
VOLUME (APPROXIMATE)

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)

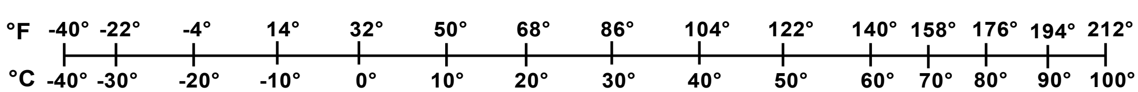
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



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

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Volpe would also like to acknowledge the systems-theoretic process analysis supported in part by the 2016 Liberty Mutual Safety Research Fellowship, included in this report with the consent of the Liberty Mutual Research Institute for Safety.

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Executive Summary

The Federal Railroad Administration (FRA) sponsored the John A. Volpe National Transportation Systems Center (Volpe) to identify the factors that contribute to run-through switch (RTS) events in yard operations at one passenger railroad and offer recommendations to reduce their occurrence. This project began in October 2016 and was completed October 2017.

The research team used a systems framework to understand the multiple factors that can combine to collectively increase the probability of human errors that result in RTS events in the yard at one passenger railroad. The team analyzed railroad RTS data which spanned an 11-year period and read through RTS investigation files. Researchers conducted two site visits, during which the team interviewed railroad employees at all levels of the organization to understand contributing factors to RTS events. The team also observed the yardmaster and train crews in the tower and crews switching in a major rail yard at a maintenance facility. Using these sources of information, researchers performed a systems-theoretic process analysis (STPA) hazard analysis to identify under what situations RTS events might occur.

The interviews and observations indicated that RTS events were rarely attributable to a single factor. Instead, they resulted from multiple interacting factors. These factors may have been at the organizational level or stemmed from cognitive factors involving individual and team behavior. Some of the factors identified that caused RTS events included:

- Crew knowledge, experience, and erroneous expectations
- Breakdowns in teamwork and communication
- Memory lapses
- Perceptual factors
- Task demands
- Switch location and yard design
- Training practices
- Crew assignment and scheduling processes
- Production pressure
- Technology

Because RTS events most often occur as a result of these interacting factors, railroads must address multiple factors to reduce RTS events.

Volpe identified a need for more effective investigations, data collection methods, and analysis of RTS events. The quantitative data provided by the railroad was insufficient to understand contributing factors to RTS events. Improving these processes will contribute to a much better understanding of why these unwanted events occur and the relative frequency with which contributing factors occur individually or in combination with other factors. By collecting better information, railroads can more effectively target interventions to mitigate the problems.

Because this study was performed at only one passenger railroad, more evidence is needed to assess the degree to which these findings apply to passenger railroads more generally.

Additionally, this study was performed at a passenger railroad with an above-average number of RTS events over an 11-year period when compared to 4 similar passenger railroads. Future work should include an analysis of RTS events at other passenger railroads, including those with fewer RTS events, to understand how their systems differ and to identify factors that may reduce RTS frequency.

Finally, Volpe also proposes additional work examining RTS events at freight railroads. Such work could examine whether the same factors play a role in RTS events in freight operations, and identify what RTS mitigations freight railroads have put in place.

1. Introduction

This report is the first study sponsored by the Federal Railroad Administration (FRA) to identify the factors that contribute to run-through switches (RTS) in yard operations. Run-through switch events occur when rolling stock (e.g., passenger car, locomotive) makes a “trailing-point” move—a movement from one of two converging tracks—through a switch not aligned for their current track. When this occurs, the equipment can damage the switch, leaving the switch points “gapped." When rolling stock then makes a “facing-point” move—a movement onto one of two diverging tracks—through a gapped switch, it could derail because when a switch is gapped, the wheels are no longer able to make contact with the both of the rails over which the rolling stock needs to operate.

FRA initiated this research when a passenger railroad requested assistance in understanding why it was experiencing a series of RTS events in yards over several years. FRA agreed to help the railroad identify why trains were running through yard switches and offer recommendations to mitigate them. This study documents the outcome of that research.

1.1 Background

1.1.1 The Role of Switches in Railroad Operations

In yards, train crews and yard crews move rail equipment through switches for a variety of reasons. Railroad switches serve a vital function, providing for the movement of trains from one track to another. On mainline tracks, switches provide operational flexibility and efficiency by enabling railroads to direct trains to various routes.

In passenger service, yards facilitate the storing of equipment when service demand is low, conducting inspections and maintenance activities, and making up and breaking up trains. In freight service, in addition to functions described for passenger operations, switches facilitate the movement of rail cars to separate tracks to make up and break up trains to move freight cars from origin to destination.

Yard operations occur at low speeds, typically not exceeding 15 mph, and may have signals only at the entrance to the yard. Switches may be operated manually or by some form of power. Where switches are operated manually, the conductor or assistant conductor operates the switches. In yards with powered switches, they may be operated remotely by the yardmaster. In either case, the safe movement of rolling stock depends in part on the ability of the yard crew to detect the switch position.

Switches represent a safety critical component of the railroad system. There are several types of switches, only one of which is examined in this study. This study examined the use of hand-thrown, or manual, switches.

1.1.2 Understanding How a Switch Operates and How to Read a Switch

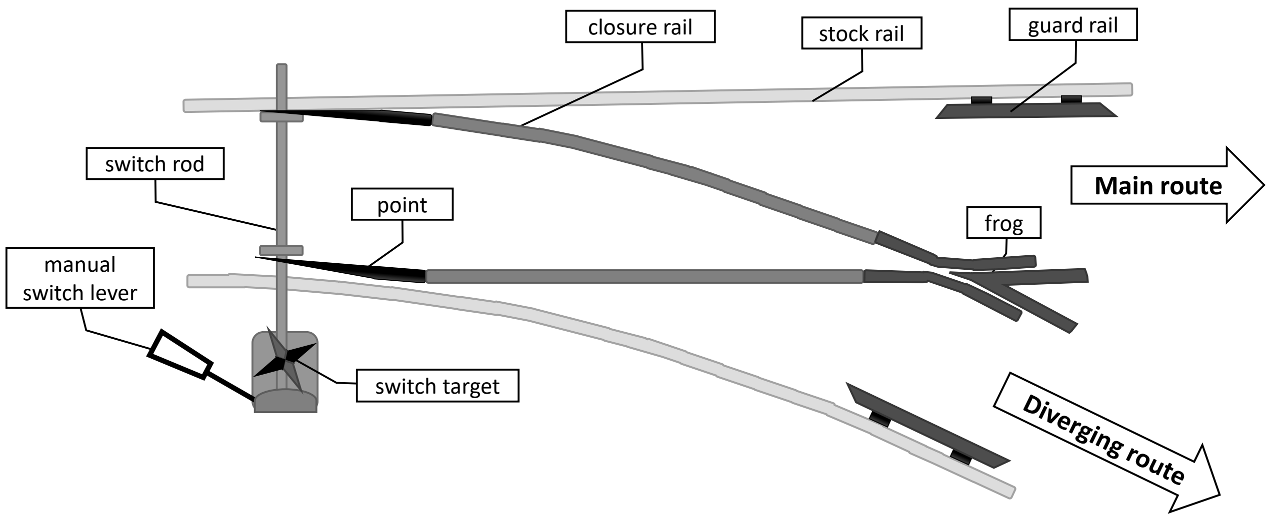

Figure 1. Railroad switch components for a right-hand turn out

Figure 1 shows a right-hand turn out with the components that make up a switch on the left side of the figure. The key elements of the switch are summarized below:

- **Points:** The switch points guide the train or equipment from one track to another.
- **Switch rod:** The switch rod moves the switch points from one position to another.
- **Switch lever:** For manual switches, a railroad employee moves a lever 180 degrees to shift the switch from one track to the other track. For powered switches, a motor replaces the lever to move the switch.
- **Switch target:** The switch may have a colored target to aid in identifying which track the switch is lined.[1]
- **Closure rails and frog:** The closure rails guide the wheels toward the frog where the two rails cross.
- **Guard rail:** The guard rail guides the wheels over the appropriate track on the side opposite the frog wheels and prevents the wheels from derailing.
- **Stock rail:** Running rails immediately alongside of the switch rails against which the switch rails lay when in the closed position.

[1] The term "lined" refers to aligning the switch with the appropriate track for a particular direction of movement.

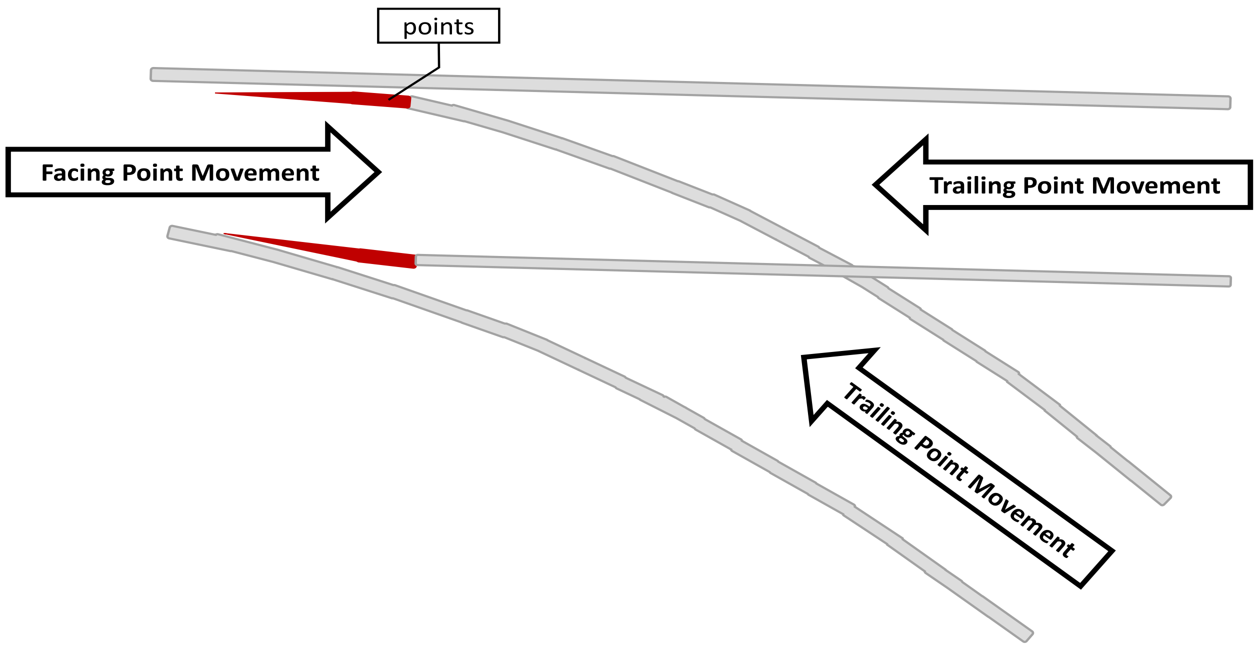

Figure 2. Facing point vs. trailing point movement

When moving through a switch, the switch points indicate whether the movement is a facing point movement or a trailing point movement. Figure 2 shows both facing point and trailing point movements.

In a facing point movement, the train will operate onto the track directed by the switch points. Facing point switches cannot be "run through."

In a trailing point movement, the train makes a convergent movement: multiple tracks converge into a single track. The type of manual switches examined in this study are designed so that a train can only safely make a trailing-point move from the aligned track. Making a trailing point movement through this type of switch from the unaligned track is called "running through" the switch. This damages the switch[2] and can cause derailments if the switch is not repaired.

To avoid running through a switch, the locomotive engineer or conductor must learn to read the switch points. The engineer or conductor may also use the switch target to read the switch position. However, the use of the switch target as an indicator of the direction of movement can be misleading when the switch target becomes misaligned. Misalignment can occur when the target is hit by moving equipment.

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[2] Certain kinds of switches are designed to allow trailing-point operation from the unaligned track without damage to the switch. With these switches, wheels on rolling stock operating from the unaligned track will push the switch points into alignment. The points may either remain in position after being aligned by the wheels, or spring back into place in the case of "spring switches." When using these switches, it is imperative that the entire train consist traverses through the switch before a reverse move is initiated; otherwise, a derailment could occur. This study will not discuss these kinds of switches in the body of this report because they were not used at the railroad studied.

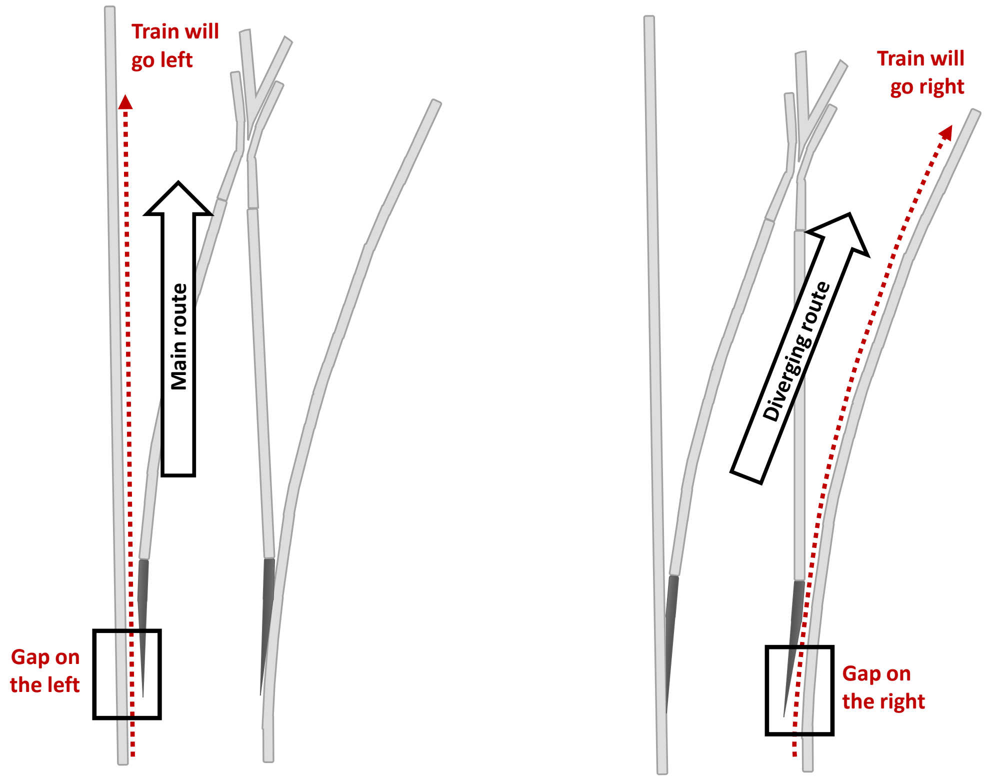


Figure 3. Reading the switch points for a facing point movement

Figure 3 shows how an observer can use the switch points to tell which direction the switch will direct the equipment for a facing movement. To identify the direction in which the switch will direct the train, the observer looks for the gap between the switch points and the stock rail. The stock rails are the rails immediately outside the closure rails against which the switch points touch, when in the closed position. In the left-hand illustration of Figure 3, the gap on the left side between the switch points and the stock rail indicates that the movement will continue on the left. In the right-hand illustration of Figure 3, the gap on the right side between the switch points and the stock rail indicates that the movement will diverge to the right.

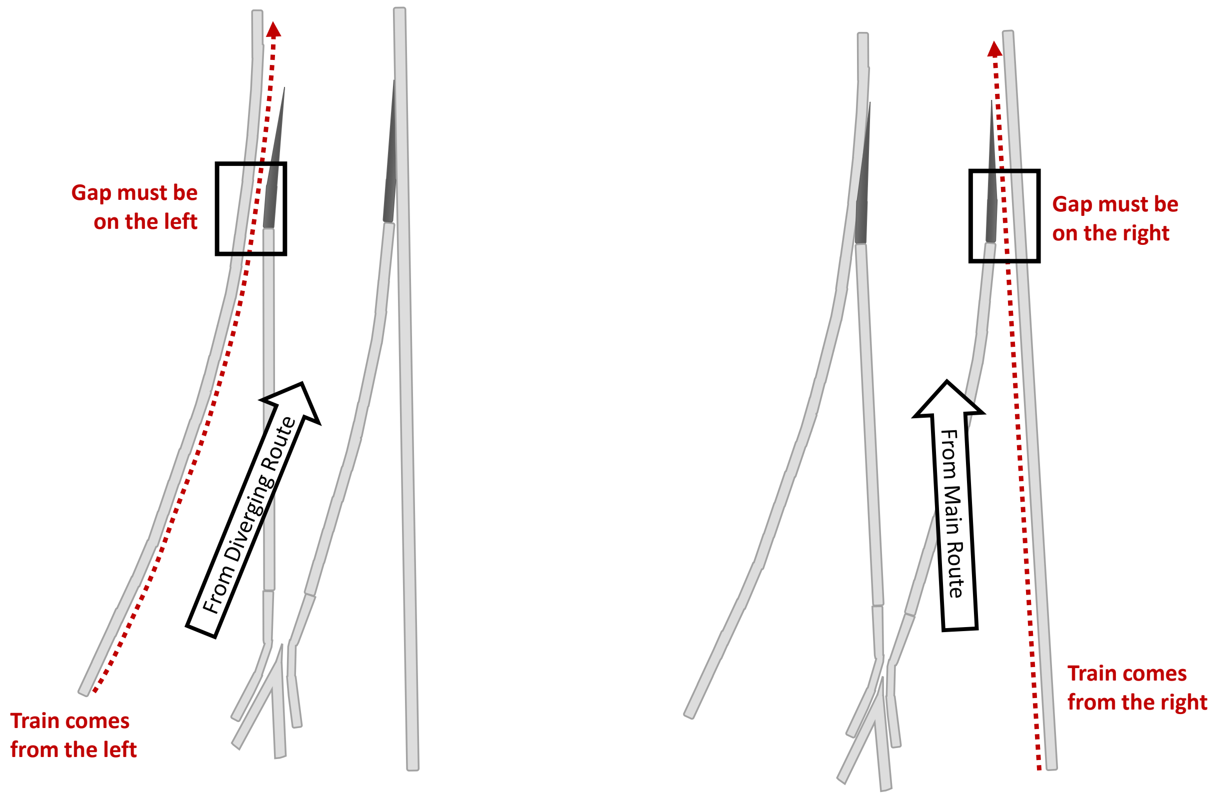
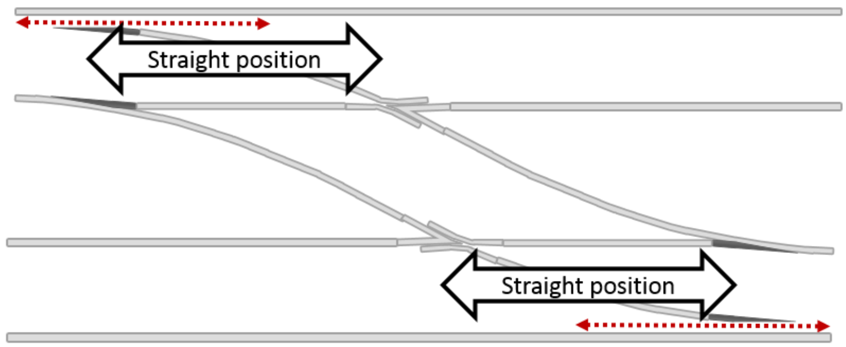
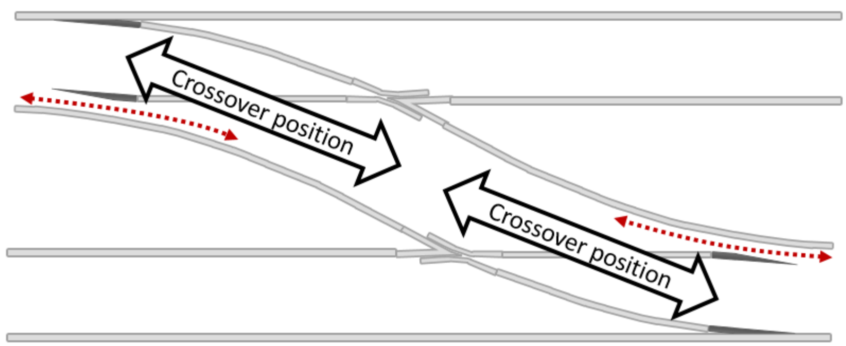


Figure 4. Reading the switch points for a trailing point movement

Figure 4 shows how an observer can tell from which track the switch is aligned for a trailing movement. To identify the track, the observer looks for the gap between the switch points and the stock rail. In the left-hand illustration of Figure 4, the gap on the left side between the switch points and the stock rail indicates that the movement is aligned for movements coming from the left. In the right-hand illustration of Figure 4, the gap on the right side between the switch points and the stock rail indicates that the movement is aligned for the movement coming from the right.



A. Both switches in this crossover are in the straight position. This is permitted. Trains may pass in either directions along both parallel tracks.



B. Both switches in this crossover are in the crossover position. This is permitted. Trains facing the crossover may pass through onto the other track.

Figure 5. Permissible Crossover Switch Alignments

In addition to enabling trains to take diverging or converging routes, switches also enable trains to cross from one parallel track to another. Called a crossover switch, this function is important when moving trains around each other to facilitate flexibility in train movements. Figure 5 shows permissible ways for crossover switches to operate. A crossover switch consists of a switch on each track that operate in synch with each other. One switch acts as a diverging route and the other switch acts as a converging route. Both switches need to be aligned (in correspondence) for the same movement so that the train can safely cross from one track to the other without damaging the switch or derailing.

Changing the switch position of only one switch in a crossover, without changing the other switch will put the switches out of alignment (or correspondence), and can result in the train running through a switch or derailing. Figure 6 shows a crossover switch that is out of correspondence.

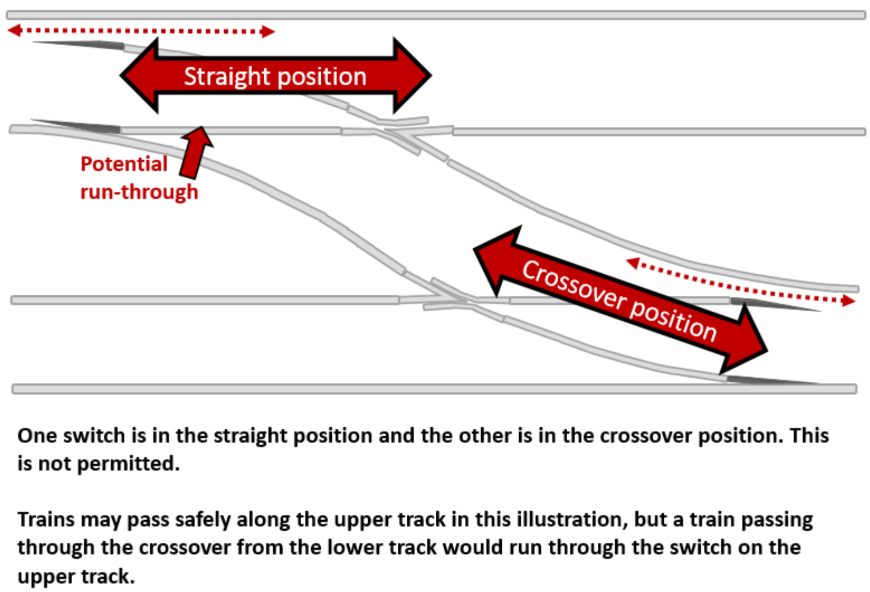


Figure 6. Non-permissible crossover switch alignments

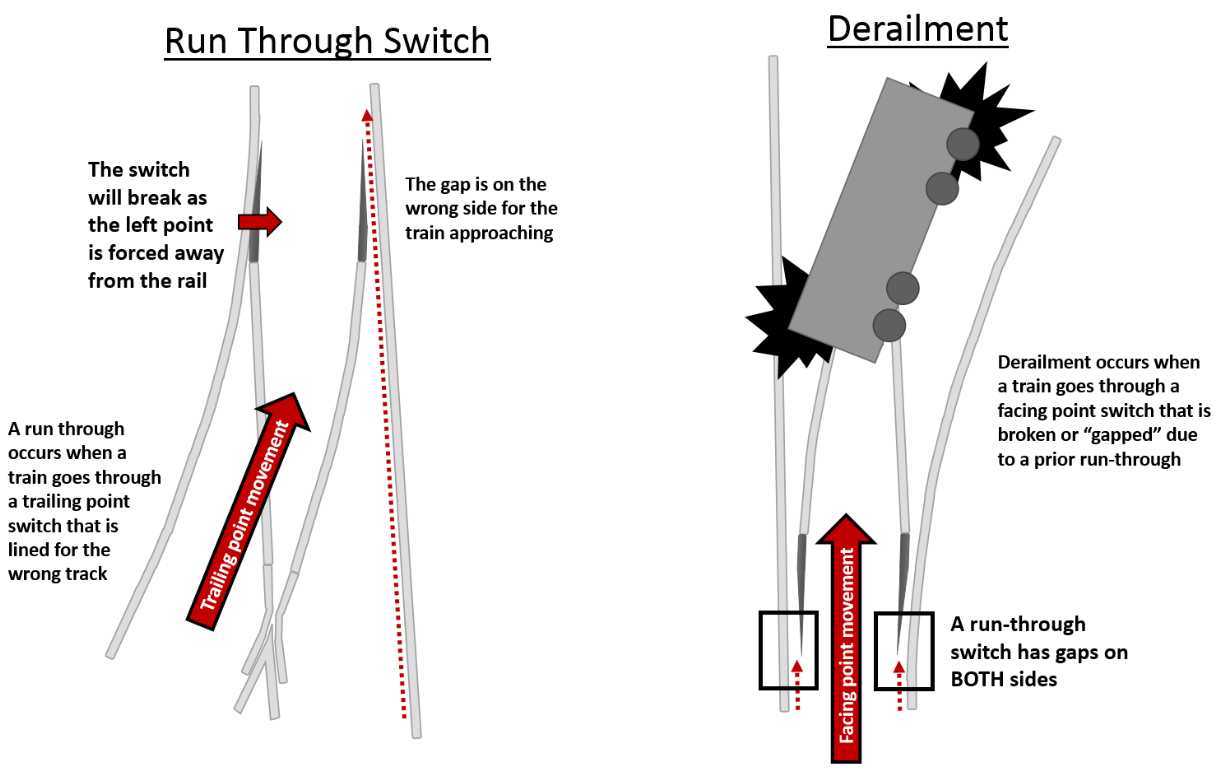


Figure 7. How a train runs through a switch and derails

To run through a switch requires the train or equipment to make a *trailing* movement through the switch that is aligned for the other track. The left-hand side of Figure 7 illustrates how a train runs through the switch and damages it. As the train moves through the switch, it pushes the switch points to the right, away from the stock rail on the left side, creating a gap toward the stock rail on the right. Running through the switch may also break the switch rod that moves the switch. In yard operations where trains and equipment move at speeds under 15 mph, the train will continue through the switch without derailing. However, the gaps in both switch points caused by the equipment running through the switch could create an unsafe condition for the next train or equipment making a *facing* point movement, causing it to derail. The right side of Figure 7 shows how the gap on both sides is too large for the train to navigate, causing the equipment to derail.

1.1.3 Managing Safe Switching Operations

All switches, regardless of type, are designed for specific maximum train speeds. Trains can operate safely as long as they do not exceed that speed. Exceeding that speed can damage the switch and derail the train.

Railroads manage safe switching operations through a variety of operating rules and control systems. On the mainline, switches may be operated remotely through control systems that dispatchers use to identify train location and direction. In many situations, the signal system provides the authority to operate on tracks and through switches. Remotely controlled switches respond to the commands from the control system and are aligned accordingly. A trailing-point move from an aligned track may receive a signal to proceed; a trailing-point move from an unaligned track would receive a stop signal prohibiting movement through the switch.

In mainline territory where there are no signals, the train crew receives verbal or written authority from the dispatcher to operate over particular track sections. In this situation, safe operation depends on the train crew understanding and complying with this authority. The train crew may operate the switch remotely from the train or operate them manually. For remotely powered switches, the train crew would control the switch position from the locomotive cab as the train approaches the switch. For manual switches, the locomotive engineer would stop the train and conductor would exit the train to manually operate the switch to the correct position for their train movement. In both cases, the train crew must examine the switch position to determine whether it is aligned for their movement.

In yard operations where there is a yardmaster, the yardmaster directs the yard crews, but may not be responsible for movement authorities. The yard crews must watch out for each other and read switch positions carefully to minimize the risk of accidents.

1.1.4 Why Examine Run-Through Switch Events?

While the reasons for how run-through switch events occur are clear, there is a gap in understanding why these events take place. The safe operation of manual switches depends in part on human performance, which is a function of system design and operation (Leveson, 2012). Making a trailing-point move through an unaligned switch damages the switch (run-through switch). Making a facing-point move through a switch that has been run through can derail a train, causing harm to people, property, and the environment. Run through switches contribute to inefficient railroad operations; railroads must repair the track infrastructure and equipment before resuming work. Railroads may also remove employees involved in RTS events from service, which increases staffing needs and the cost of railroad operations. Identifying the factors that cause run through switches helps to mitigate their frequency.

To date there has been a paucity of studies examining human factors issues that contribute to run-through switches. Volpe found one study that examined contributors to run-through switches in U.S. rail operations (Durso et al., 2015). This study examined run-through switches that occurred at one freight railroad. The study combined quantitative analyses of reported RTS events with qualitative analyses based on interviews of railroad workers at three yards. The study found that experience level affected the likelihood of a RTS. Individuals with less than 2 years' experience had the most run-through switches (43 percent). Frequency of run-through switches decreased with level of experience, with individuals with 6 to 10 years of experience having 18 percent of RTS events and individuals with 10 or more years' experience contributing 12 percent of the total number of run-through switches.

The study also found that run-through switches were more likely to occur in the first half of the shift, suggesting that fatigue was not necessarily a large contributor to RTS events. However, run-through switches were more likely to occur after a day off from work. The authors interpreted these two findings to suggest that it may take time on the job to become mentally situated in the work context, and thus avoid making run-through switches (a "head in the game" hypothesis). Weather, visibility and shift start time were not found to have an effect on run through switches. The results of interviews provided further insight into contributors to RTS events. Contributing factors suggested by the interviews included communication and coordination failures; cognitive factors such as distractions, interruptions, and memory lapses; unusual conditions; fatigue; downtime; and production (time) pressure.

These results suggest a number of potential factors that contribute to run through switches; however, the findings are limited in that they represent only a single freight railroad. One of the motivations of our study is to expand the current knowledge base regarding both individual and organizational factors that contribute to run through switches. Because the particular railroad in this study used manual switches in its yard, the primary focus of the report is on factors that contribute to running through manual switches.

1.2 Objectives

This study asked a single question: How does the railroad system contribute to trains and other railroad equipment running through switches in the yard? The research team defined the railroad system as the organizational practices, individual behavior, and the interactions between the structures and processes.

The team offers recommendations, based on its findings, that stakeholders can take to prevent or reduce the likelihood of these events occurring in the future.

1.3 Overall Approach

To understand contributing factors at all levels of the system, researchers conducted a case study at a single passenger railroad. They conducted interviews with railroad employees, observed yardmasters in the tower and yard crews planning and making yard moves in a complex yard, and walked through the yard to see the locations where trains previously ran through switches. They also reviewed railroad incident data involving trains that ran through switches.

1.4 Scope

This study focused on passenger yard operations. Since this railroad used manual switches throughout their yard operations, the study was limited to manual switches, in particular those which only allow trailing-point moves from the aligned track.

1.5 Organization of the Report

Section 2 describes the study methodology. Section 3 presents a descriptive analysis of the railroad's incident data. Section 4 includes a brief overview of manual switching work in rail yards. Section 5 presents the outcome of a systems-theoretic process analysis (STPA) hazard analysis. Section 6 presents:

- An analysis of the interviews and observations
- Individual and team contributing factors to RTS events
- Organizational contributing factors to RTS events
- Recommendations to mitigate or reduce the potential for these events to occur[3].

Finally, Section 7 provides a discussion and conclusion of the work, including improving data collection and analysis of incident data and opportunities for future research.

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[3] A consolidated list of recommendations can be found in Appendix C.

2. Method

Researchers used a systems framework to understand the multiple factors that can combine to collectively increase the probability of human errors that result in RTS events in the yard at one passenger railroad. They analyzed railroad run-through switch data over an 11-year period and read through RTS investigation files. The research team conducted two site visits during which they interviewed railroad employees at all levels of the organization to understand contributing factors to run through switches. They also observed the yardmaster and train crews in the tower and crews switching in a major rail yard at a maintenance facility. Using these sources, the team performed a systems-theoretic process analysis (STPA) hazard analysis to identify under what situations RTS events might occur.

2.1 Quantitative Analysis of Run Through Switch Incident Data

Researchers used the FRA accident and incident database to compare the frequency of RTS events in this case study railroad to the frequency of RTS events at similar railroads. Next, they reviewed historical data on run-through switch events compiled by the railroad, which included data on the frequency and location of all RTS events from 2006 through 2016. Finally, they reviewed a sample of the railroad's RTS investigation reports for incidents that occurred between 2014 and 2016. Data from these investigation reports served to identify potential factors to be explored during interviews. This analysis also served to identify opportunities for better data collection and analysis practices at the railroad.

2.2 Qualitative Analysis

2.2.1 Interviews and Observations

Researchers conducted two site visits to interview employees and observe switching operations at the passenger railroad. The first site visit consisted of group interviews with locomotive engineers and conductors as well as observations of train crews switching in the yard during the first shift (mid-morning). Observations lasted approximately 5 hours and included informal discussions with railroad employees with experience in the yard. Group interviews lasted approximately 2 hours and were held with the following groups of employees:

- Three low[4]-experience conductors, one low-experience locomotive engineer
- Five high[5]-experience conductors
- Five-mixed-experience engineers

The second site visit consisted of interviews with employees at multiple levels of the organization and observations in the yard tower of the yardmaster and train crews. Observations in the tower were held during the second shift (mid-afternoon) for approximately 4 hours and also consisted of informal discussions with a yardmaster and trainmaster. Additional interviews, which lasted approximately 1 hour each, were held with the following employees:

[4] For the purpose of this study, researchers defined low experience as less than 5 years in the craft.

[5] For the purpose of this study, researchers defined high experience as more than 10 years in the craft.

- Head of Crew Calling
- Director of Training – Rail Operations
- Assistant Executive Director – Human Resources
- Head of Labor Relations
- Lead of Mechanical
- Director – Rail Safety Division

Due to schedule and travel constraints researchers also conducted the following 1-hour interviews by phone:

- Deputy General Manager – Engineering
- FRA Office of Railroad Safety Specialist (with background as conductor and yardmaster in freight and passenger)

At least two of the study authors participated in all interviews and observations. Notes were taken in real time during the interviews and observations. In addition, audiotapes were made of the group interviews that could be referred to during the later data analysis phases.

Data from the group interviews was coded by a single coder and used to create a distribution of the contributing factors to run through switches that were discussed within the group interviews.

2.2.2 Hazard Analysis – Systems-Theoretic Process Analysis

In addition to performing quantitative analyses of RTS data, researchers performed a hazard analysis to examine systemic factors that contribute to RTS events, using STPA. STPA is a systems-based hazard analysis method that can be used to examine a particular work context and identify causal influences that may lead to accidents (Leveson, 2012). Researchers used the term "systemic factors" to refer to the combination of social, technical, and organizational factors within a system. Safety and efficiency are two examples of emergent properties that result from the interaction of multiple systemic factors.

Researchers used data from focus groups, interviews, and observations to inform this analysis, which included the following activities:

- Identify the major *accidents,* or losses, that may occur during rail switching operations as well as associated *hazards,* or sets of conditions necessary for such accidents to occur.
- Create a *safety control structure* (SCS) diagram that depicts the hierarchical relationships between human and physical system components, the necessary actions performed by each controller, and the feedback required for the system to function safely.
- Identify ways in which each action in the SCS could lead to a hazardous condition, and document them in an *unsafe control action* (UCA) table.
- Seek explanations for why unsafe actions were performed, and identify *causal scenarios* to summarize the possible combinations of system factors that could lead to an unsafe act.

For additional details on these steps and the terms underlined, see Section 4 and Leveson (2012).

3. Findings from Quantitative Analysis of Accident Incident Data

3.1 Comparison to Similar Passenger Railroads

To compare the RTS frequency at this railroad to similar passenger railroads, this study used data from FRA's accident and incident database to compare rates for two types of FRA-reportable switching accidents: (1) accidents involving improperly lined switches and (2) accidents involving previously run-through switches.

Figure 8 compares accident rates between the railroad studied for this report (Railroad 1) and four similar passenger railroads. This figure reveals that Railroad 1 experienced significantly more problems with switching operations than the other passenger railroads. For accidents involving improperly lined switches, Railroad 1 experienced four times as many accidents as its counterparts. For previously run-through switches, Railroad 1 experienced almost 20 times as many accidents as the other railroads over the 11-year period.

The magnitude of the switching problems at this railroad made it a good candidate to learn why problems with switching movements arise.

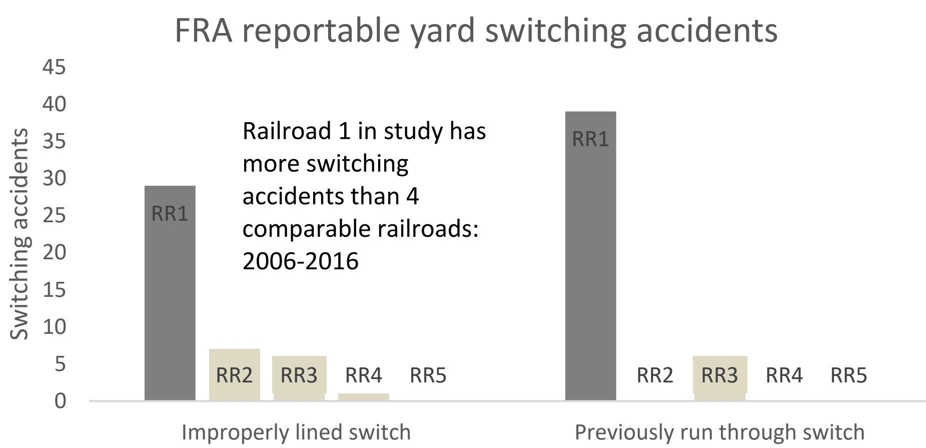


Figure 8. Comparison of FRA reportable switching accidents for five passenger railroads

3.2 Railroad Accident/Incident Data

This case study railroad provided event data, including date, division, equipment, and location. Table 1 shows field labels for the data received. Many fields had missing data, misspellings, and ambiguously worded data. Furthermore, the data lacked information that would be helpful in better understanding the nature of each event. The narrative data consisted of only a single sentence indicating that a RTS event occurred and its location; researchers did not receive any information about the work that was taking place at the time of the event, nor did they receive any information that would shed light on the context in which the event took place.

Table 1. Data fields provided by passenger railroad

Field
Date
Accident/Incident type
Division
Line
Location
Equipment
Narrative
Status: FRA reportable/non-reportable
Incident #
FRA accident code

Using the available data, the frequency with which these events take place and their location can be described. The following sections describe the research team's findings.

3.3 Frequency of RTS Events over Time

We examined the frequency of RTS events at this case study railroad for an 11-year period from 2006 – 2016, using both FRA accident and incident data and the historical run-through switch data provided by the railroad. Figure 9 shows the number of FRA-reportable switch accidents at the case study railroad during this period. Again, this included two categories of FRA-reportable switching accidents: accidents in which the switch was previously run through and accidents involving improperly lined switches. The black line in Figure 9 represents the annual totals for the two types of yard switching accidents.

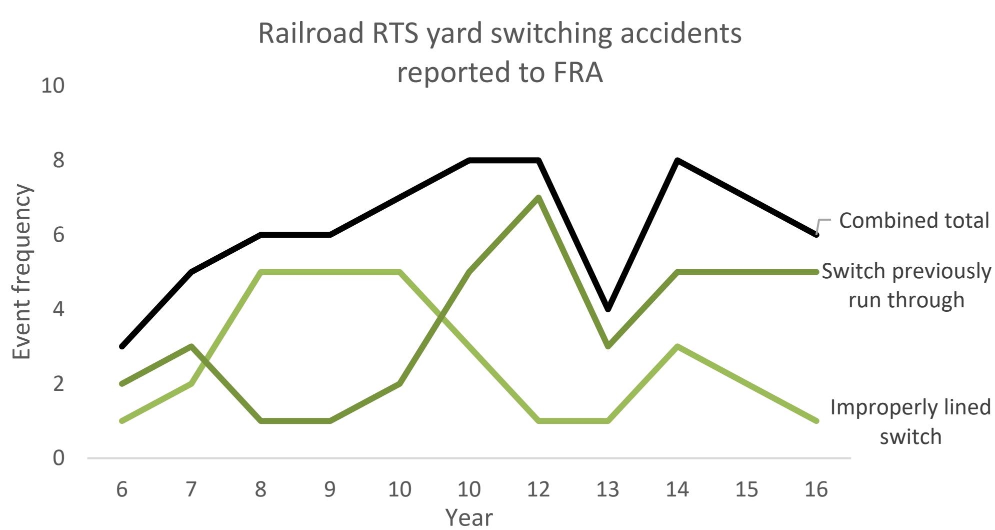


Figure 9. FRA reportable accidents involving run through switches

Next, researchers reviewed historical run-through switch data compiled by the railroad itself, which included data on the frequency and location of all RTS events from 2006 through 2016.

Figure 10 shows the annual frequency of RTS events from 2006 – 2016. Over this period, the number of RTS events averaged 40 events and varied between 36 and 42 events per year. The relatively small variation around the average of 40 events per years suggested consistent performance in switching operations over this time period.

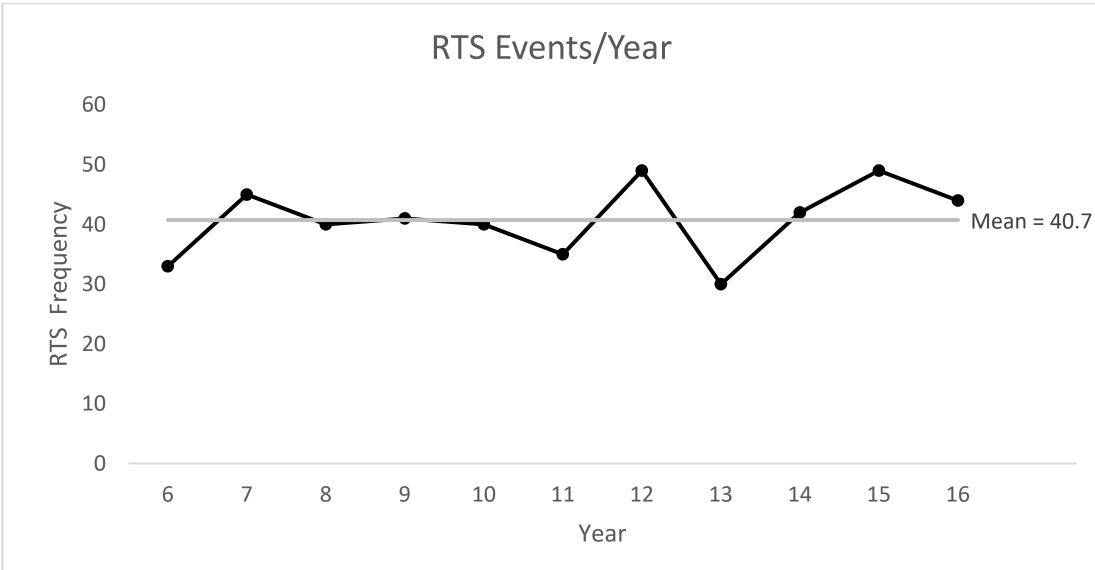


Figure 10. Yearly frequency of RTS events: 2006 – 2016

Note that FRA-reportable switching accidents, which average six per year at this railroad, made up only a small proportion of RTS events that occurred annually. In order to be FRA-reportable, an event must meet the FRA's reporting threshold, which varied between $7,700 and $10,500 during this 11-year period. Events where the damage was below this threshold were not reported.

3.4 Location of RTS Events

Finally, researchers used data provided by the railroad to examine the location of RTS events at the case study railroad. They began by examining which yards at this railroad experienced RTS events, and discovered that the majority took place in a small number of yards.

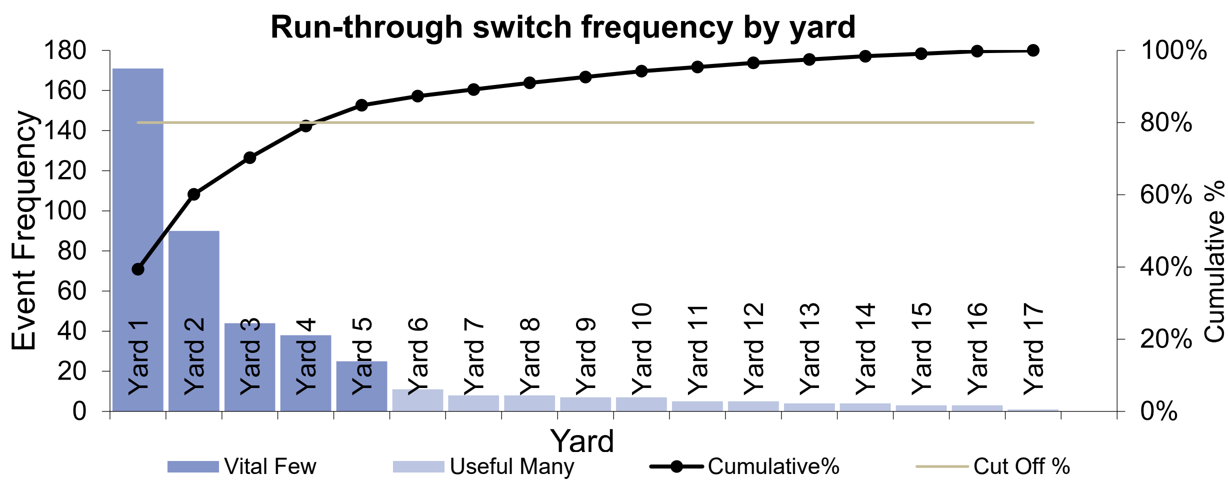


Figure 11. Location of run through switch events by yard

Figure 11 shows the number of RTS events by location for the 11-year period. Four yards accounted for 78 percent of the events. The yard with the most RTS events accounted for 39 percent of the events; this yard is a maintenance yard where the greatest amount of switching activity occurs. Because this maintenance facility received the largest number of RTS events, researchers chose to focus on this yard to investigate how and why RTS events occur. This maintenance yard is referred to as Yard 1.

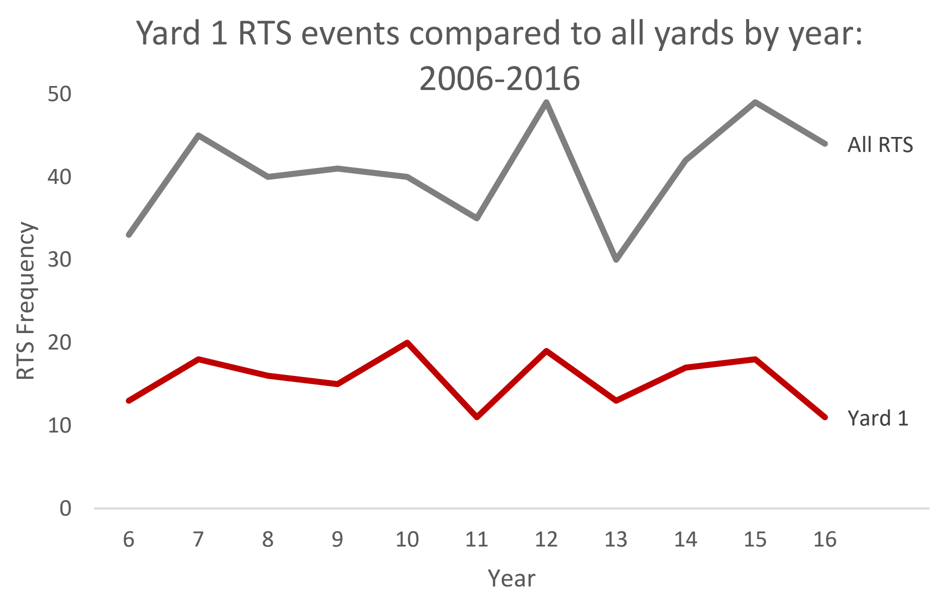


Figure 12. Yard 1 yearly frequency of RTS events compared to all yards: 2006-2016

The consistent performance across all yards was mirrored at Yard 1. The year-to-year variation for Yard 1 followed the same pattern as data from all of the yards combined; Figure 12 shows the number of RTS events per year in Yard 1 compared to the total number of RTS events. The number of run-through switch events in Yard 1 averaged 15.5 events per year over the 11-year period, with a low of 11 to a high of 20.

At Yard 1, researchers also examined the frequency of RTS events by switch number. The switch number represents the location of a switch in the yard, enabling the team to identify how many times yard crews ran through a specific switch. Figure 13 shows the number of time individual switches were run through over the 11-year period of this study.

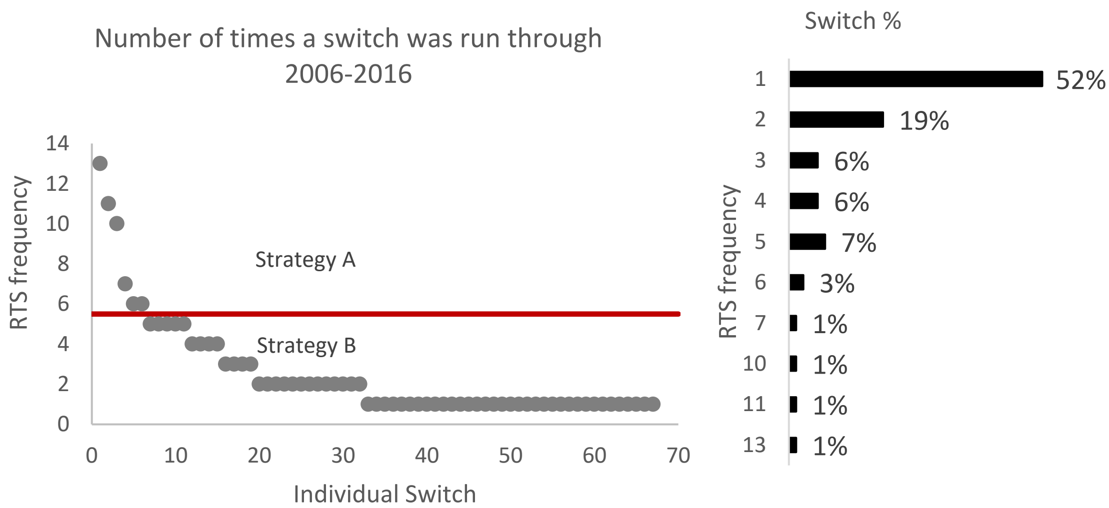


Figure 13. Number of times individual switches were run through

This chart shows that the vast majority of switches (71 percent) were run through only once or twice. A small percentage of switches (7 percent) experienced 6 or more RTS events over 11 years. Based on the differences in the number of RTS events at individual switches, researchers suggest two strategies railroads can use to identify why these events are occurring.

One strategy, labeled Strategy A in Figure 13, would apply in a situation where individual switches experience numerous RTS events. In Strategy A, the investigation would focus on the switch itself and the context in which the switch is used that makes it vulnerable to RTS events. A second strategy, labeled Strategy B in Figure 13, would apply to switches that are rarely run through. In Strategy B, the investigation would focus more attention on the system as a whole to understand why yard crews run through these switches. The decision of which strategy to use, as shown by the horizontal reference line in Figure 13, is not always clearly defined. In some cases, investigators may want to adopt both strategies to learn why these events occur.

In the case of this analysis, researchers applied both strategies; while the primary goal was to understand systemic influences on RTS events, a secondary goal was to note the reasons why certain switches may be experiencing high RTS rates. Figure 13 shows how the examination of locations within Yard 1 where RTS events occur particularly often can provide insight into why they occur.

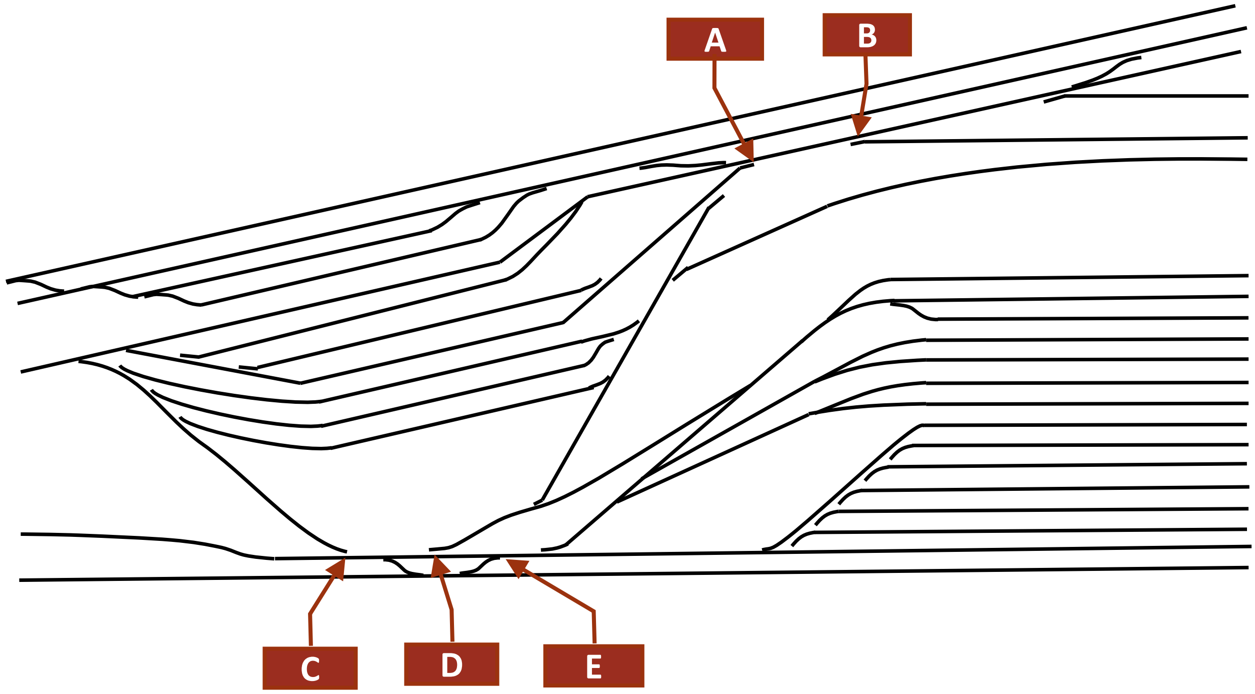


Figure 14. Location of switches with more than 6 RTS over an 11-year period

Figure 14 highlights five switches that each had more than 6 RTS over the 11-year period. All of these switches were in high-traffic areas of the yard that experienced an increased level of exposure to rail traffic entering and exiting the yard. These switches were also located close together and yard crews could have confused which switch they were looking at. While this information failed to reveal the underlying causes for RTS events, mitigating the factors that contribute to RTS events for these switches will significantly reduce the frequency of RTS events for this railroad.

To understand what makes manual switches vulnerable to operating through them in the wrong direction requires an understanding of the railroad switching operations and how organizational practices, technology, and human behavior interact to produce these events. The next section provides an overview of the context in which manual switching operations occur, and in the following sections this study discusses how the design and operation of the railroad system contributes to the production of RTS events.

4. Overview of Manual Switching Operations

To understand what makes manual switches vulnerable to operating through them in the wrong direction requires an understanding of railroad switching operations and how organizational practices, technology, and human behavior interact to produce these events. In this section, this study provides a brief overview of manual switching work in rail yards. In Sections 4 and 6 that follow, this study presents findings related to how the design and operation of the railroad system contributed to the production of RTS events and provides recommendations to mitigate their occurrence.

Researchers observed a maintenance yard where employees worked around the clock to move passenger equipment in and out of the shop for inspection, scheduled maintenance, and repairs. The majority of equipment movements within the yard were performed overnight, when the equipment was not needed for passenger service. Trains must be taken apart and put back together in time for the next day's work, replacing cars and locomotives that need work with those that are ready for operation. The equipment department keeps track of the location and status of equipment in the yard in lists, called "drill sheets," that the yardmaster and yard crews use to plan the work.[6]

Many yards were smaller than the one observed and did not perform maintenance work. In these yards, trains must still be taken apart so that any equipment that needs work can be taken to the maintenance yard, and then put back together with equipment that is ready for service. At the railroad studied, all yards used manual switches.

4.1 Role of the Yardmaster

The yardmaster is responsible for monitoring the locations of crews in the yard and the status of work. Not all yards have a yardmaster; in some, particularly smaller yards, these responsibilities are instead assigned to a terminal dispatcher. The site examined in this study had a designated yardmaster on duty at all times, located in a tower with windows overlooking the yard.

The yardmaster may be able to see crews out the window or on one of several stationary cameras; however, he or she more often relies on verbal communication with crews, either by phone or radio. Yardmasters also use a computer to exchange email, view passenger train schedules, and track the status of equipment moves based on updates from the yard crews on a "yard check" form.

The yardmaster communicates with dispatchers to make sure that trains can pass through the yard safely. If a switch breaks, the yardmaster contacts the engineering department so that an engineering crew can repair it. The yardmaster also communicates with the yard crews about activities and conditions that could affect their work, like broken switches, other yard crews operating near them, or passenger crews needing a clear route through the yard.

[6] The term drill is synonymous with the word "switch." This is a term of art used by some railroads.

4.2 Scheduling and Composition of Yard Crews

In a typical evening at the maintenance yard observed, between six and eight yard crews were working at a time. Their start times were staggered between 3:00 p.m. and 11:00 p.m.; however, the busiest times were after 10:00 p.m.

Yard crews were made up of two or three members, depending on the type of equipment being moved. Two-person teams were used to move locomotives only. These teams include a hostler (an engineer who is restricted to moving locomotives) and a conductor.

Three-person teams were used to move both cars and locomotives. These teams included an engineer, a conductor, and a rear brakeman. The rear brakeman is also known as an assistant conductor. The brakeman role may be performed by a second fully qualified conductor or by a less-experienced employee.

Employees at the railroad bid for jobs according to their seniority. Typically, yard employees on a regular schedule have upwards of 15 years of experience in the yard and work with the same crew each shift. However, there are changes that can disrupt an established crew: a more senior employee might displace someone from a regular crew through the bid system, or, if a member of a regular yard crew takes the day off (e.g., because of vacation or personal leave day). In that situation, the crew caller will call a replacement from the "extra list."

Workers on the extra list do not work on a regular schedule but instead are on call. They receive calls when jobs are available, resulting in an unpredictable schedule. At this railroad, there were two types of extra lists: the "utility list" and the "passenger list." The passenger list is longer, and primarily used to fill jobs for passenger service. The utility list is shorter, and includes more senior employees who are qualified to act as flagmen or in the yard. Because the utility list is shorter, utility list conductors are often called for flag jobs[7] during the day, leaving a shortage of conductors with yard experience to call in to work at night. When the crew caller runs out of employees from the utility list, passenger list employees are called to work yard jobs.

Members of the extra list must accept the jobs they are called for or use one of their sick days. They may be required to begin a shift as soon as 8 hours after the end of the previous shift, according to hours of service regulations. These regulations are summarized in Table 2.

[7] A flag job involves an employee who works with a maintenance crew to protect the crew while they perform their work by warning them when a train approaches or alerting the train to the presence of the maintenance crew.

Table 2. Crewmember schedules and hours of service regulations

<table>
<tr><th>Craft / Job Type</th><th>Role(s)</th><th>Typical Schedule</th><th>Hours of Service Limitations*</th></tr>
<tr><td>Engineer
Regular Yard Job</td><td>Works a regularly scheduled yard job with a consistent crew</td><td>Regularly scheduled 8-12 hour shifts with predictable rest days</td><td rowspan="4">Employees are entitled to:
• Shifts lasting no more than 12 hours except in emergencies
• 8 hours off before reporting for duty, or, 10 hours off before reporting for duty after working 12 or more continuous hours
• 2 consecutive days without initiating an on-duty period after 14 consecutive days of initiating on-duty periods
• 24 hours off-duty after 6 days of initiating on-duty periods, including at least 1 “Type 2” assignment (work between midnight and 4 am or otherwise deemed fatiguing per an FRA-approved fatigue model)</td></tr>
<tr><td>Engineer
Extra List</td><td>Works yard jobs when needed (e.g., filling in for absence of a regular crewmember)</td><td>Unpredictable schedule; work as needed up to the hours of service limitations</td></tr>
<tr><td>Conductor
Regular Yard Job</td><td>Works a regularly scheduled yard job with a consistent crew</td><td>Regularly scheduled 8-12 hour shifts with predictable rest days</td></tr>
<tr><td>Conductor
Passenger Extra List</td><td>Works passenger jobs as needed; works yard jobs only if the utility list is short.</td><td>Unpredictable schedule; work as needed up to the hours of service limitations.</td></tr>
<tr><td>Conductor
Utility Extra List</td><td>Works yard and flag jobs as needed</td><td>Unpredictable schedule; work as needed up to the hours of service limitations.</td><td>Same as above for yard jobs. Flag jobs are not covered by hours of service restrictions. Therefore, flag jobs do not count as initiating on-duty periods. Conductors may work flag jobs—but not yard jobs—without meeting hours of service requirements for rest.</td></tr>
</table>

* This is a summary of the FRA hours of service regulations for illustrative purposes only; the full regulations can be found in Hours of Service Railroad Employees (2011), and covers additional job types and operational nuances.

4.3 Coordination Within a Single Yard Crew

Each member of a yard crew performs a specific role, and their coordination is necessary for successful work. At the start of a shift, the crew will be given a drill sheet indicating the equipment to be moved (e.g., into or out of a maintenance shop). The conductor plans the crew's movements so that they can accomplish the work set out in the drill sheet. The engineer is responsible for operating the locomotive, controlling its speed and direction (forward or reverse). The rear brakeman (also called the assistant conductor) coordinates with the conductor to help plan and execute movements, including throwing switches.

The conductor and brakeman typically ride at the rear of the train to provide directions to the engineer while reversing (shoving moves). These two employees are primarily responsible for throwing switches. The employee at the front of the train (typically the engineer, but sometimes one of the conductors when reversing) is responsible for verifying that switches are correctly aligned before the train passes over them. If a switch is not correctly aligned, the engineer must stop the train so the switch can be thrown.

During yard operations, the crew members must stay in contact with each other at all times. Typically, communication occurs by radio, but if the radio frequency is crowded or unclear, crews will also use hand signals or communicate orally face-to-face. There was only one radio channel for all the crews in the yard, and there is no standardized language for communicating by radio. Crewmembers identify themselves using their crew's call sign, but regular employees typically recognize each other by voice.

Communication within crews is particularly important during reverse or shoving operations, when the engineer cannot see the track and needs to know when to stop. In this situation, the locomotive engineer is located at the rear of the movement and cannot see the track ahead and the switch position. The conductor or brakeman will estimate the distance the engineer has remaining before it is necessary to stop, and then give the distance in car lengths, known as the "car count." As a safety measure, the engineer is required to stop if he or she does not receive an updated car count after half the stated distance, e.g., if he is told "10 cars to a stop," they must stop after 5 car lengths unless there is an audible update from the conductor. Since several crews may be giving car counts over the shared frequency, it is important that an engineer recognizes their own conductor's message and does not follow instructions intended for a different engineer.

Over the course of a shift, employees estimated that a crew might throw over 100 switches, not including those already aligned for the desired track. Some of the switches a crew may encounter in the yard are more difficult to read than others, including switches placed on a curved section of track or very close to other switches. Some switches must be thrown frequently, while others are rarely changed. Sometimes the alignment of a switch can be predicted based on switches around it, though crews are always responsible for verifying this. A special category of switches, known as crossover switches, are found in pairs between parallel stretches of track to allow trains to move from one track to the other. These switches must always be aligned in corresponding directions: both to go straight or both to cross over.

Finally, the challenge of aligning switches is complicated by another factor: the presence of other yard crews.

4.4 Coordination among Multiple Crews

With six to eight crews working at a time, there are often multiple crews in the same area of the yard that need to pass through some of the same switches. Yard crews are required to communicate with the yardmaster before moving between areas of the yard, either by phone or radio. If this communication occurs by radio, it can be heard by all crews in the yard. If it occurs by phone, the yardmaster must separately notify the other crew(s) affected.

Crews must be aware of others' locations so that they do not interfere with their movements. If a conductor aligns a series of switches for a crew's movement, but a second conductor throws one of those switches, the second conductor has "taken away the line-up." This could cause the first conductor's crew to run through the switch if they do not realize the second conductor had thrown it out of the desired alignment.

Experienced crews may coordinate with each other to avoid such conflicts. For example, one crew might offer to let another pass through a switch first, or to throw a switch for the other when they are done passing through it. Crews are not trained in this type of coordination, nor is it part of any formal procedure. It is simply a courtesy that makes work easier.

5. Systems-Theoretic Process Analysis

STPA is based on a systems-theoretic accident model (STAMP), which asserts that accidents result from combinations of systemic factors, rather than a single root cause. Unlike traditional hazard analyses, which tend to focus on quantifying the risk of various accidents related to component failures, STPA also identifies causal factors which are social or organizational in nature, as well as system design flaws and potentially hazardous interactions between sociotechnical system components.

STPA relies on the assumption that human operators are doing their jobs to the best of their ability with the information and resources available; therefore, unsafe behavior is a product of its environment, not of human "failure." Rather than pinning accidents on the operator, STPA seeks to reveal underlying systemic issues that explain how accidents can occur.

The benefit of STPA is that it identifies causal factors and hazardous interactions that have the potential to cause accident, regardless of whether such accidents have occurred in the past. Thus, it can be used to anticipate potential accidents before they occur, and to make proactive changes to the system to prevent future instances of unsafe behavior that could lead to accidents.

5.1 Foundations of a Systems-Theoretic Analysis

5.1.1 System-Level Accidents

To use STPA to examine manual switching operations, researchers first set the scope of the analysis by identifying the set of accidents (undesired or unplanned events that result in a loss) that they wished to better understand.

For manual switching operations, the team identified three accidents:

- **Accident 1 (A1):** A derailment occurs, causing property damage, delays, and/or injuries.
- **Accident 2 (A2):** A run-through switch occurs, causing property damage and work delays.
- **Accident 3 (A3):** Yard work is not completed on time, affecting maintenance or operations.

The most severe accident associated with switching operations is a derailment (A1). Derailments result primarily in economic losses due to the associated property damage, but they can also delay other yard work. In a worst-case scenario, a derailment could injure or kill workers in the path of the derailed equipment.

The second most severe accident of concern is a run-through switch (A2). Run-through switches result in an economic loss due to property damage, though they are less costly than derailments. However, RTS events are of particular concern because they can cause a more serious accident—a derailment—if not addressed properly.

Finally, the team considered a third accident, yard work not completed (A3). Though this is not what many would consider a traditional accident, it can result in economic losses by delaying maintenance activities or passenger operations, and thus is something railroads hope to prevent.

5.1.2 System-Level Hazards

Once researchers identified the three accidents to study, the team identified the associated hazards, or sets of conditions, which could lead to those accidents under some set of environmental conditions.

Researchers identified three hazards which correspond to the accidents listed above:

- **Hazard 1 (H1):** A train passes through a facing point switch that is broken.

  This hazard may lead to derailment (A1).

- **Hazard 2 (H2):** A train passes through a trailing point switch that is not properly lined.

  This hazard may lead to a run-through switch (A2).

- **Hazard 3 (H3):** A yard movement is performed in an inefficient manner.

  This may result in yard work not being completed on time (A3).

The hazard associated with derailment (A1) occurs when a train passes through a facing point switch that is broken (H1). Often when a switch breaks, it occurs because of a RTS incident (A2). This relationship between these accidents means that preventing run-through switches is particularly important because it can prevent future derailments. Switches may also break due to ordinary wear and tear or excessive speed.

The hazard associated with a run through switch (A2) occurs when a train passes through a trailing point switch that is not properly lined (H2). The wheels force the switch points away from the rail and break, or “gap” the switch. If the switch is not repaired before the next facing point move, a derailment (A1) could occur.

The hazard associated with yard work not being completed on time (A3) is that a yard movement is performed in an inefficient manner (H3). This could be something as simple as passing through an improperly lined *facing point* switch, which will simply put the equipment on a different track than the one desired.

As noted above, the consequences of these three accidents are not equal; it is of greater concern to prevent costly and dangerous derailments than to prevent simple delays. Therefore, it is important to consider which hazard, and which potential accident, could result from an unsafe action. Throughout this analysis, the associated hazards (H1, H2, and H3) will be cited so that the potential consequences of an unsafe action may be considered. This can be used to identify and prioritize the implementation of solutions that will have the greatest impact.

5.1.3 Safety Control Structure Diagram

The next step required to perform a systems-theoretic analysis is to draw the safety control structure. STPA uses the term "control structure" because it depicts hierarchical control relationships within the system. "Controllers" in this structure may be human operators or computers. The physical system being controlled is also depicted. The actions performed and commands given by a controller are referred to as "control actions" because they constrain the behavior of lower-level controllers. Each controller also provides feedback to higher-level controllers which allows those controllers to monitor the system state and provide adequate control actions.

The safety control structure for a manual switching operation is shown in Figure 15 below. In this diagram, dark blue boxes represent human controllers within the system, while light blue boxes represent the physical system being controlled. Solid arrows represent control actions, and dashed arrows represent feedback channels.

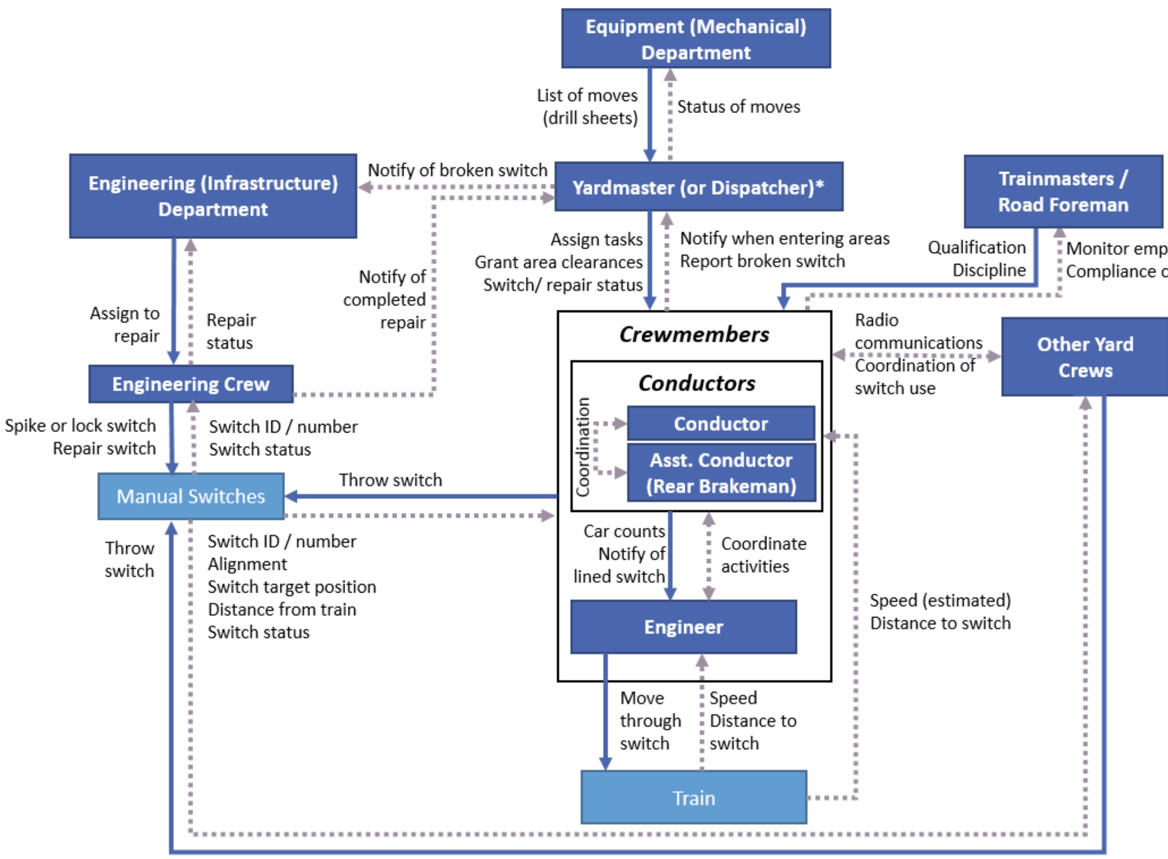


Figure 15. Safety control structure for operating manual railroad switches in the yard

Because the members of the train crew—the engineer, conductor, and assistant conductor or rear brakeman—are the ones most closely involved in manual switching operations, this analysis will focus on them as well as their interactions with the yardmaster who directly oversees these operations. However, it is important to note that this analysis is not intended to place blame on these employees; rather, it is meant to understand why systemic factors may lead them to perform unsafe actions.

5.2 Analyzing the System

5.2.1 Unsafe Control Actions

This study began the analysis of this system by examining each control action in the safety control structure to identify ways in which it could lead to a hazard. This is documented in a table of "unsafe control actions," or UCAs.

Each control action is listed in the leftmost column, along with the controller(s) who perform this action. In Table 3, only one control action is shown, but UCAs for each of the remaining control actions are included in Appendix A. Each UCA is numbered, with the first numeral identifying the control action.

UCA statements are listed in the four columns to the right of the control action column. These four columns correspond to the types of unsafe control action defined by Leveson (2012). They are labeled as follows:

- *Not Providing Causes Hazard:* A control action required for safety is not provided, leading to a hazard.
- *Providing Causes Hazard:* An unsafe control action is provided that leads to a hazard.
- *Wrong Timing or Order:* A potentially safe control action is provided too late, too early, or out of sequence, leading to a hazard.
- *Stopped Too Soon or Too Late*: A safe control action stopped too soon or applied too long leads to a hazard.

Additionally, each UCA statement is followed by one or more hazard numbers in brackets, e.g. "[H1]." These refer back to the hazards identified in Section 5.1.2.

Table 3. Excerpt of UCA table in Appendix A, showing UCAs for throwing a switch

Controller(s), **Control Action**	**Not Providing Causes Hazard**	**Providing Causes Hazard**	**Wrong Timing or Order**	**Stopped Too Soon or Too Late**
Conductor (or Brakeman) **1:** Throws switch	**UCA 1-1:** The conductor does not throw a switch when the train is approaching a switch lined for the wrong track. [H2, H3]	**UCA 1-2:** The conductor throws a switch when the train is approaching a switch which was already lined for the correct track. [H2, H3] **UCA 1-3:** The conductor throws a switch when it is part of a crossover without also ensuring that the other switch in the crossover is in a corresponding position. [H2, H3]	**UCA 1-4:** The conductor throws a switch too soon, when the switch is part of another crew's line up. [H2, H3]	**UCA 1-5:** The conductor stops too soon while throwing a switch, when switch is not fully thrown and secured. [H1, H2]

Within each cell, UCA statements are written with the four pieces of information shown in Figure 16: (1) the controller responsible, (2) the control action involved, (3) the type of unsafe action, as defined below, and (4) the context which makes the action unsafe (Thomas, 2013).

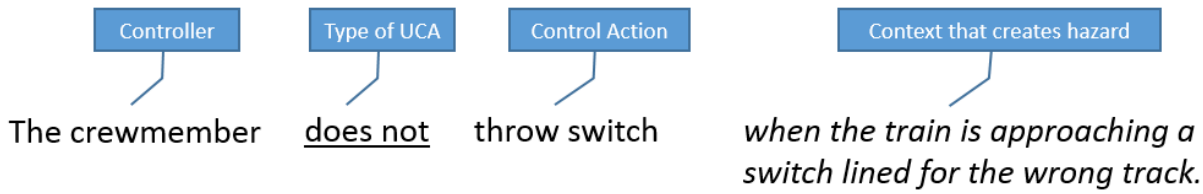


Figure 16. Four parts of an unsafe control action

The most important piece of each UCA statement is the context. The context identifies what must be happening in order for the controller's action, or lack thereof, to cause a hazard.

An unsafe control action does not have to be likely to be included in the table. In fact, many UCAs can be successfully prevented through system design constraints and will rarely, if ever, occur. However, the inclusion of such UCAs in the table denotes that it *would be* unsafe if such an action did occur, and thus it is important to consider how to prevent this action in the design and operation of the system.

In the following stage of this analysis, researchers considered how combinations of system factors could lead controllers to perform each of the unsafe actions listed in the UCA table.

5.2.2 Causal Scenarios

Causal scenarios describe the combinations of system factors that may cause an unsafe control action to occur. They provide explanations as to why a human operator may perform an unsafe action, given what the controller is trying to do, what he or she knows or expects about the system, and what information is accessible.

Each scenario represents only one of many potential ways that an accident could occur, and typically, several causal scenarios can be identified for each UCA.

In theory, one could write a near-infinite number of scenarios by including more and more causal factors and separately counting every possible combination of such factors. However, that is not the point of this exercise. The purpose of causal scenarios is to identify the factors that contribute to unsafe actions in such a way that the actions can be understood, and eventually, addressed through system changes. Thus, they must be complete enough to explain why an action might occur (which no single factor can explain) while remaining concise enough to be easily understood and addressed. To accomplish this difficult goal, scenarios are written from a top-down perspective.

Consider the following UCA as an example:

> **UCA 1-1:** "Crewmember did not throw switch when the train is approaching a switch lined for the wrong track."

At a very high level, two possibilities emerge: The crewmember was either near the switch or the crewmember was not.

If they were near the switch, what reasons might they have had for not throwing it? One of the first possibilities that comes to mind is that they may have misread the switch. Now, consider why that could have occurred.

Perhaps it was a matter of an inexperienced employee who did not often work in the yard:

> **Scenario 1-1-1:** The conductor could see the switch but did not realize it needed to be thrown. He misread the switch due to lack of experience reading switches from the cab. He lacked experience reading switches because he was a passenger list worker who was called to work in the yard, and had not worked a yard job since training.

Or, perhaps instead the crewmember was experienced but temporarily complacent and influenced by perceptual factors:

> **Scenario 1-1-2:** The engineer could see the switch but did not realize it needed to be thrown. He misread the switch because he was tired and feeling time pressure near the end of his run, and glanced at it too quickly to make out the points in the lighting of the yard. The switch was part of a ladder (a grouping of switches), nearly always lined for the main line, so the engineer expected that to have been the case and did not look closely.

Yet another possibility was that the crewmember may have been relying on an incorrect source of information when reading the switch:

> **Scenario 1-1-3:** The brakeman could see the switch but does not realize it needs to be thrown. He misread the switch because he was relying on the switch target, but it had been hit by equipment and was no longer reliable. He trusted the switch target because he was not confident reading switches, because he normally worked passenger jobs and was trained in the yard a long time ago.

These scenarios explain how a crewmember could misread a switch; but what if they were not looking at the switch at all? What reasons might they have had to skip over a switch they could examine closely?

It could be because they put their faith in someone else's work and did not double-check it, or they made an incorrect assumption:

> **Scenario 1-1-4:** The conductor did not realize the switch needs to be thrown because the brakeman told him it was lined. He did not verify that the brakeman's claim was accurate because he was under time pressure and believed the brakeman was adequately trained. However, the brakeman was new to working the yard and his read of the switch was inaccurate.

> **Scenario 1-1-5:** The conductor did not realize the switch needed to be thrown because it was part of a crossover, and the corresponding switch was lined correctly. She did not verify that both switches are lined because she was under

time pressure. She thought it is safe to make the assumption that both switches were lined correctly because of the rules regarding crossover switches; however a list worker on a different crew had forgotten the rule since his training and did not put both switches in corresponding positions.

What if instead of misreading a switch, or making an incorrect assumption, the crewmember mixed up two switches and either read or threw the wrong one?

Scenario 1-1-6: The conductor incorrectly believed the switch the train was approaching was lined because he accidentally read a different switch. He mixed up reading the switches because they were close together and not differentiated in a way that could be quickly identified in the yard lighting conditions.

Scenario 1-1-7: The conductor knew the switch the train was about to pass was not lined and intended to throw it, but accidentally threw a different switch. He mixed up throwing the switches because the switch handles were close together and not differentiated in a way that could be quickly identified in the yard lighting conditions.

At this point, if the possible explanations for this behavior under the first condition have been sufficiently exhausted, go back to the second high-level condition.

What if the crewmember was not near the switch? Why might they have been unaware that a switch needed to be thrown?

Perhaps he did not know that someone took away the lineup:

Scenario 1-1-8: The conductor did not realize a switch needed to be thrown because he had already aligned it for his crew, but someone from another crew took away his lineup. He thought that the engineer would double-check the switches and let him know if any of them needed to be fixed.

It could also be that he intended to throw the switch, but left the area and forgot:

Scenario 1-1-9: The conductor did not realize a switch needed to be thrown because he forgot that he had thrown it against himself to assist another crew. He intended to throw it back after the other crew had passed, but became caught up in planning his future moves.

Or perhaps he believed someone else would take care of it:

Scenario 1-1-10: The brakeman did not realize the switch needed to be thrown because he incorrectly believed the conductor was lining the crew's route and has already thrown the switch. The brakeman was not a regular member of the crew and did not understand the expectations the conductor communicated in the job briefing.

This covers all of the possible explanations the researchers could think of for this UCA.

In some cases, there may be a different unsafe control action that is closely related to the one being examined. Therefore, to avoid redundancy certain factors may only be expounded upon in one of the UCAs, not both. For example, a separate UCA examines reasons why the conductor may *tell* an engineer that a switch is lined when it actually is not. Scenarios for that UCA go into greater detail about why a conductor may not realize that another conductor has taken away the lineup.

The scenarios described above are just a fraction of the full set of scenarios covered in Appendix B; however, they illustrate a fairly wide range of contributing factors that could influence crewmembers. In just these examples, certain influences emerge: training; experience; scheduling; fatigue; time pressure; yard and switch design; time of day and lighting; communication within crews; and coordination between crews—and the scenarios in Appendix B cover even more factors.

Rather than trying to simplify the explanation to a single root cause, the scenarios explore how interactions among multiple systemic factors can lead to accidents. The following sections discuss these factors in greater detail. Though they are discussed individually in order to give each issue due attention, remember that these factors do not occur in isolation, and accidents do not result from single factors alone.

6. Factors Associated with Run Through Switch Events

Table 4 shows the frequency with which contributing factors were raised during group interviews along with the breakdown of issues within each contributing factor. The frequency with which issues were discussed guided us in understanding how the factors play a role in contributing to these events. Organizational factors accounted for almost 50 percent of the contributing factors. The majority of organizational factors that were discussed in group interviews included issues such as the job assignment process and scheduling, training, and production pressure. The contributing factors team behavior and individual behavior accounted for approximately 13.1 percent each followed by and individual characteristics, technology, and physical environment at approximately 9 percent.

Table 4. Contributing factors associated with running through switches

Contributing Factor	Percent	Count
Organizational Factors	**48%**	105
Crew Assignment and Schedule	31%	33
Employee Training	20%	21
Production Pressures	14%	15
Supervisory Practices	8%	8
Resource Constraints and Management	8%	8
Discipline	7%	7
Workforce Management	4%	4
Incident Investigation	3%	3
Rules - policies and practices	3%	3
Safety Blitz	2%	2
Data Collection and Analysis	1%	1
Team Behavior	**13%**	29
Communication	48%	14
Teamwork	38%	11
Inter-Team	14%	4
Individual Behavior and Characteristics	**13%**	29
Experience Level	52%	15
Fatigue	21%	6
Expectations	17%	5
Yard Knowledge	10%	3
Technology	**9%**	20
Radio Issues	40%	8
Locomotive Type	30%	6
Switch Design	10%	2
Equipment Malfunction	10%	2
Switch Targets	5%	1

Job Aids	5%	1	
Physical Environment	**9%**	19	
Lighting	26%	5	
Switch Placement	26%	5	
Switch Maintenance	16%	3	
Switch Type	11%	2	
Environmental Issues	11%	2	
Yard Layout	5%	1	
Gapped Switch	5%	1	
Task	**8%**	18	
Drilling	28%	5	
Planning moves	28%	5	
Switching	17%	3	
Pre-job checks	6%	1	
Communication Requirements	6%	1	
Situational Awareness	6%	1	
Catching a RTS	6%	1	
Passenger Train	6%	1	
Regulatory Activities	**1%**	1	
Data Collection Requirements and Analysis	100%	1	

The frequency data from Table 4 was the basis for the contributing factors we examined in understanding how RTS events unfold. Figure 17 shows the major contributing factors we focused on. Sections 6.1 and 6.2, below, discuss these factors in detail. In each case, we provide recommendations for mitigations that can be implemented to reduce RTS events. These recommendations are summarized in Appendix C.

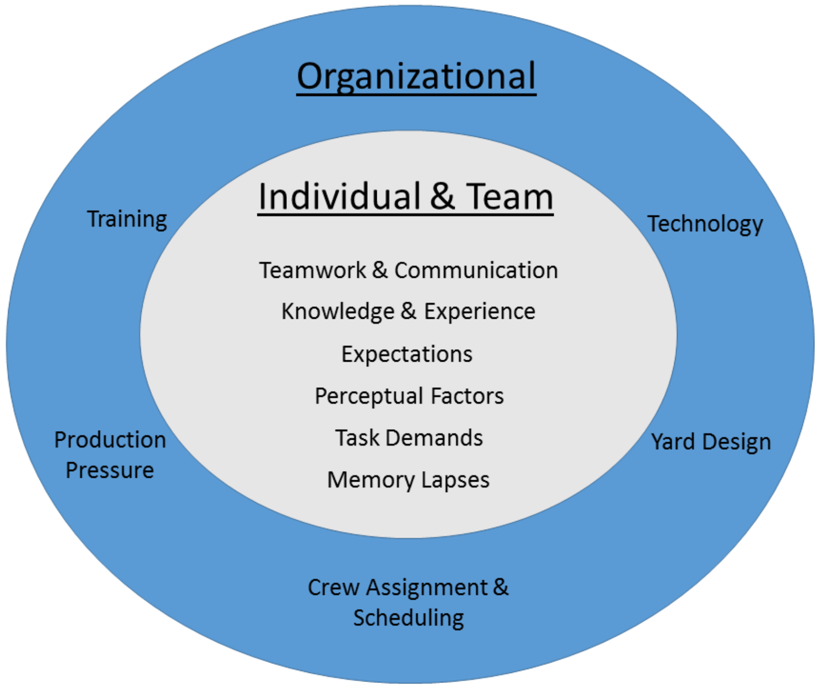


Figure 17. Contributing factors to RTS events

6.1 Individual and Team Factors

In this section, this study examines factors associated with individuals and teams that contribute to RTS events. In examining the contributors to run through switches there are two questions that need to be considered:

1) Why was the switch not correctly lined for the move?
2) Why did the person on the head end not recognize that the switch was in the wrong position and stop the train before going through the misaligned switch?

Qualitative analysis indicated that many of the same factors apply in both cases.

Researchers began by presenting a simplified model of the cognitive performance of an individual and discuss how factors drawn from this model combine with other organizational factors associated with railroad operations to create conditions for RTS events to occur. This is followed by a discussion of team factors that contribute to RTS. This includes factors associated with intra-crew communication and coordination (i.e., communication and coordination between individuals as part of a single yard crew) as well as inter-crew communication and coordination (i.e., communication and coordination between individuals that are part of different crews working in the same yard). In each case, this study recommends possible mitigations to reduce RTS.

6.1.1 Cognitive Factors Influencing Individual Performance

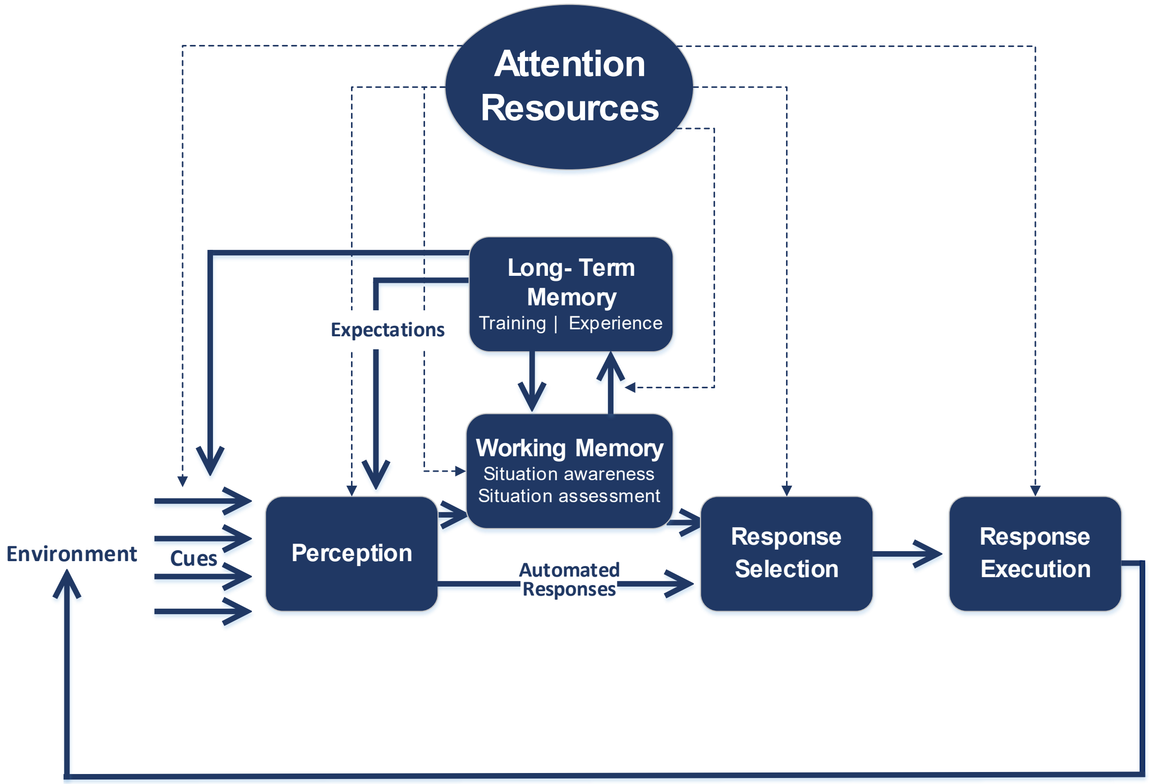
Figure 18 presents a simplified model of human cognitive processes adapted from a classic human engineering textbook (Wickens, Hollands, Banbury & Parasuraman, 2013). The model illustrates how information from the environment is processed to come up with assessments, make decisions, and take actions. A recent technical report on stop signal overruns provides a more detailed description of this model and of how cognitive factors influence performance in the context of railroad operations (Multer, Safar and Roth, 2019). This Volpe study provides a more abbreviated description of the model tailored to cognitive performance contributors to RTS.

While the elements of the model are iterative and mutually interacting, in the simplest case one can start with cues in the environment (e.g., an upcoming switch seen from the head end of a train). Perception entails detecting and recognizing information in the environment; for example, detecting how the switch is lined. Perception is influenced by physical characteristics in the environment such as lighting, track curvature, and obstructions.

Long-term memory contains facts, memories of past events, and skills and strategies for performing tasks. In railroad operations, this includes knowledge based on training, such as how to read switch points, yard layout, and operating rules. It also includes knowledge gained from experience, such as previous drill moves made that allows for planning and executing moves more efficiently, and the voice and communication style of coworkers that allows one to recognize and understand them more quickly over the radio.

Information in long-term memory is subject to memory loss. Facts and events are gradually forgotten if they are not constantly re-experienced. The greatest amount of forgetting occurs just after learning and declines gradually over time (Hoffman et al., 2014).

Knowledge from long term memory is used to generate expectations that can guide perception and action. People's expectations guide where they look, how quickly they perceive information, how they interpret the information, and what errors they make. For example, if crewmembers know a switch is coming up around a curve, they can start to slow down and look to where they expect the switch to be. Expectations can also lead to delays and errors. For example, if someone is expecting a switch to be lined for them because it has generally been correctly lined in the past, and this time it turns out to be lined against them, it will likely to take longer to recognize that the switch is misaligned and stop the train, possibly resulting in a RTS.



Note: Adapted from Wickens, Hollands, Banbury & Parasuraman (2013).

Figure 18. A simplified model of human cognitive processes

In addition to long-term memory, there is also working memory—information temporarily stored about a current situation, goals, and actions that need to be taken. For example, a conductor may have in working memory what the next equipment move must be, what switches are lined, and what switches still must be lined to accomplish the next move.

Human working memory is subject to *memory lapses*, where information held in short-term working memory is forgotten. Memory lapses are particularly likely under high workload conditions where other events intervene to "knock out" the information from working memory. One type of "memory lapse" is called a post-completion error, which occurs in tasks that include a final "clean up" step that must be taken after completing the main goal. A classic example is forgetting to remove the original document from a photocopier after making copies. Because the "clean up" step (e.g., removing the original from the copier) is peripheral to the main goal (e.g., getting the copies), it is vulnerable to be omitted (Reason, 2002; Byrne & Bovair, 1997). Post-completion errors can be contributors to RTS (McDonald & Durso, 2015). For example, an individual may change the position of a switch to complete some specific work (the main goal) and forget to return a switch to its prior position after making a move. Post-completion errors are especially likely to happen in situations that are mentally demanding and/or involve unexpected interruptions (Reason, 2002, Simon, Li, Cox, Blandford, Cairns, Young & Abeles, 2006).

A related point is that cognitive processing requires attention. Attention is a limited resource that can be diverted from a primary task, either as a result of external distractions or as a result of mind-wandering. For example, if a crew member is listening to relevant information over the radio, looking out the window at equipment, or thinking about the next move it may delay them in seeing and reading a switch coming up.

Note that distraction and mind-wandering are natural consequences of how the attentional system works. Attention is automatically directed to salient cues in the environment and mind-wandering is a common phenomenon that will naturally occur in low external stimulation conditions. These are automatic processes that are difficult to control through willpower alone. Consequently, attempts to reduce RTS events by reprimanding train crews to avoid distraction and pay closer attention are not likely to have a substantial impact on RTS.

To summarize, the model described in Figure 18 reflects some fundamental characteristics of human cognition that can contribute to RTS. Most particularly:

- Perception is influenced by characteristics of the physical environment.
- Information in long term memory is subject to *forgetting* over time.
- Perception and understanding are driven by *expectations* resulting in potential error if expectations are violated.
- Information in working memory is subject to short-term memory lapses, particularly in situations that are mentally demanding and/or involve interruptions or distractions.

In the following sections, this study discusses the impact of these cognitive factors on RTS. In each case, researchers recommend mitigations to reduce the impact of cognitive factors on RTS.

6.1.2 Perceptual Factors

To avoid a RTS the person on the ground (either a conductor or brakeman) must determine if a switch is correctly aligned, and if it is not aligned, he or she must throw the switch to line it up for the desired move. This involves identifying the correct switch and accurately reading the switch points. If switch targets are present, the individual may also look at the position of the switch targets to determine switch position.

Analysis indicated that under some circumstances these perceptual tasks could be challenging, leading to error. For example, a conductor might incorrectly identify which switch must be thrown for the desired move and thus throw the wrong switch (e.g., because the location of the switches and switch handles make them confusable). Alternatively, the individual might identify the right switch but misread the switch points. If there are switch targets, they might rely on the switch targets to determine switch position. This might lead to an error if the switch targets have become misaligned and are thus providing erroneous information.

If the switch is not correctly aligned, the person on the head end of the train (typically a locomotive engineer or conductor) can prevent the RTS by detecting the misaligned switch and stopping the train before going through the switch. This requires the person on the head end to identify the correct switch and accurately read the switch points. If there are switch targets, the person may also look at the position of the switch targets to determine switch lineup. Analysis indicated that these perceptual tasks could be challenging, leading to delays or errors in detection a misaligned switch.

6.1.2.1 Contributors to RTS

Qualitative analysis identified a number of factors that made it challenging to identify the correct switch and its position. Factors included:

- ***Track design:*** In many cases, the track location and configuration of switches made them difficult to detect, confusable, and/or challenging to read. Examples included switches around curves where crewmembers needed to get very close to the switch before they could easily read it. This could make it difficult to stop in time if the switch was misaligned. There were also "back to back" switches that made it difficult to tell which switch needed to be thrown for a given move. Researchers were told of a case where there had been two switches close together with handles on the same side. As a result, an employee would throw the wrong switch. In response, yard managers modified the switches so the handles were on different sides. Employees described locations with complex switch layouts resulting in trailing points and facing points close together, making it confusing to identify which points related to a particular move. Employees also described closely located switches where individuals inadvertently looked past the first switch to another one nearby that resulted in reading the wrong switch. In another case, the switch handle controlled a switch some distance away, making it difficult to tell which switch it controlled.
- ***Track maintenance:*** Track maintenance contributed to perceptual challenges. Switch targets were often misaligned, resulting in misleading indications. Because switch targets were so unreliable, the railroad ordered train crews not to rely on switch targets to determine switch position.
- ***Weather and lighting conditions:*** Environmental conditions reduced the ability to see and read switch positions. This included weather conditions, such as rain and snow that impaired visibility, as well as poor lighting conditions. At the yards visited, new lighting was put in to make it easier to see switches and switch positions at night; however, researchers were told of cases in the past where poor lighting contributed to RTS.
- ***Physical design of equipment:*** Visibility depended on the physical design of the train equipment from which the train crew was looking out of. For example, researchers were told that with some locomotives with long hood forward it was not possible to read the switch position from the locomotive. The person on the head end had to either stop and get off to read the points or rely on information provided by someone else (e.g., a conductor on the ground). Switches can look very different from the equipment (e.g., the head end) than when one is on the ground. Switch position can be easier to see and read when positioned on equipment because the person is higher off the ground. The larger visual angle between the switch and the viewer's position makes switch position easier to discern. At ground level, the visual angle is smaller making reading the switch points more difficult.

Researchers examined the perceptual factors that make it a challenge for a crew to detect that they have run through a switch. In most cases, crews recognize immediately that they have run through a switch. Researchers were told that in approximately 75 percent of the cases, crews immediately stopped the train and reported that they ran through a switch. Often the person on the head end identifies that they are about to run through a switch ahead of time but are not able to stop the train in time to avoid the RTS. In addition, when a RTS occurs it produces a loud metallic sound that can be heard under relatively quiet conditions and/or when the window is open. However, the sound can be masked by the train engine or radio chatter. If someone does not hear or feel the vibration, the train crew might continue through and not realize that they experienced a RTS.

Similarly, it can be perceptually challenging to detect that the upcoming switch is gapped because it has been previously run through. In many case the points may only be slightly off making it almost impossible to detect.

6.1.2.2 Recommended Mitigations

Many of the perceptual challenges identified involved the layout of switches that made them difficult to detect and read. Understanding that redesigning switch layout may not be practical, there are a number of suggestions for preventing or mitigating the consequences of run-through switches.

- ***Consider installing indicators that provide clearer and more salient indication of switch positions.*** For example, the railroad visited explored the use of colored reflective materials that signal whether the track is lined for a particular direction. For the device shown in Figure 19, green means the switch is lined for the operator and red means it is lined against. If the device displays both green and red (not shown in the figure), the switch is misaligned.

Figure 19. Colored reflective materials make it easier to identify switch position

- ***Consider use of switches designed to accommodate trailing-point operation from unaligned track without breaking.*** Examples include spring switches, which "spring" back to the original position after the rolling stock wheels have passed through. There are also other types of switches where the wheels from rolling stock operating from the unaligned track align the switch points which then remain in that position.
- ***Revisit the process for reporting and repairing misaligned switch targets or remove them.*** This includes examining why misaligned switch targets are not fixed in a timely manner and fixing the process so that switch target positions can be relied on to indicate actual switch position. Alternatively, remove the switch targets so employees cannot erroneously rely on them. Keeping unreliable switch targets in place and requiring yard

workers to ignore them by policy is an ineffective strategy, particularly when the visual salience of the targets makes them hard to ignore.

6.1.3 Knowledge & Experience

Knowledge and experience play important roles in reducing the possibility of RTS. Researchers were not able to obtain from the railroad studied quantitative data on the relationship between experience level and RTS. However, the qualitative data collected, as well as quantitative data collected in other contexts, strongly suggested that training and experience affect the likelihood of RTS. For example, Durso et al. (2015) examined RTS at a freight railroad and reported that individuals with less than 2 years of experience were more likely to have a RTS than individuals with more experience. Further, Multer et al. (2015) reported evidence that level of experience affected other types of railroad performance problems, such as passing stop signals in passenger railroads.

Note that in considering the impact of knowledge and experience on performance, what is most relevant is the level of experience working in the particular job assignment(s) that afford the opportunity to gain the specific knowledge and skills needed to work effectively in that specific job. Thus, the kind of data normally collected by railroads, such as the amount of time working in the railroad industry, working for the particular railroad, or even working in a particular craft (e.g., conductor or locomotive engineer), is not likely to be as informative in understanding the impact of experience on RTS as the amount of time working in yards or even working in a particular yard.

Relevant knowledge and skills for yard work include:

- The ability to rapidly locate the correct switch and accurately read switch points both from the ground and from the train
- Knowledge of the yard layout and the location of the most problematic switches (e.g., switches at bottlenecks likely to be thrown against the operator; switches that are confusable; switches around curves; switches where the switch handle and points are unusually far apart)
- The ability to estimate distances in car lengths; for example, when communicating distances to the next switch during shoving moves
- Knowledge and skill in efficiently planning and executing yard moves
- Knowledge of how to efficiently and accurately communicate and coordinate within a crew (intra-crew), across crews (inter-crew) and with other railroad employees (e.g., yard master)

These types of knowledge and skills are gained through training and on-the-job experiences.

As discussed in Section 6.1.1, knowledge and skills that are learned through training and experience are gradually forgotten if they are not constantly practiced. This fact becomes particularly relevant in the case of individuals called from the extra lists to replace a regular yard employee who may be out for the day. If the individuals from the extra list have primarily worked passenger train assignments, and have not worked in that yard in an extended period of time, they may not have the needed knowledge and skill to perform yard duties even if they are technically qualified to work in that yard.

Interviews with yard workers and yardmasters indicated that regular crews have developed yard- and crew-specific knowledge that gives them an advantage over individuals brought in from extra lists. This includes:

- Greater familiarity with the yard layout, where different work is conducted, and where the bottlenecks and trouble spots are likely.
- Greater familiarity with the yard moves, since they are often similar from shift to shift.
- Greater familiarity with the voices of regular crew members, so that they are less prone to confuse who is speaking and to whom over the radio.
- Greater familiarity with the communication style of regular crew members, reducing the possibility of communication errors.

Below are some of the contributors to RTS related to lack of knowledge and experience, followed by a listing of recommended mitigations. The contributors to RTS and recommended mitigations are further discussed in the sections on selection and training and crew scheduling processes.

6.1.3.1 Contributors to RTS

Interviews and focus groups suggested a number of cases where lack of knowledge or experience contributed to RTS. Specific instances that were mentioned included:

- ***Difficulty in rapidly reading switch positions*****:** Researchers were told that some individuals were not able to rapidly determine whether a switch was lined against them.
- **Difficulty in estimating distances in car lengths:** Researchers were told that some crew members may not be good at estimating distances (e.g., they may say that a switch is 10 car lengths away but actually it is 8). One individual in a focus group said:

  "Some people maybe they don't count cars as well as they might… If they don't estimate car lengths well, they may shove too short or too long. I could say we are good for 12 cars… and I may not be able to count that distance… in reality, we're only good for 8. A lot has to do with experience."

- ***Lack of knowledge of location of switches in the yard:*** As one individual in a focus group said:

  "I think if more people spent more time out there, knowing the yard like the back of their hand, it would help to prevent RTS."

- ***Lack of skill in communicating and coordinating within a crew and with others:*** The role of communication and coordination in RTS is discussed more fully in section 6.1.6.
- ***Lack of skill in maintaining awareness of "the big picture" relative to what and where other yard work is being done***—particularly as it relates to potential interaction with one's own work. As one individual in a focus group mentioned, inexperienced individuals are less likely than more experienced crews to try and understand who else is working in the yard, where they are, and what they are doing. He indicated that:

  "Now [that I am more experienced] I would be more on the radio finding out what crews are doing."

This is discussed more fully in section 6.1.6.

- ***Lack of ability to plan or implement efficient yard moves:*** Researchers were told that planning moves for drill sheets can be particularly challenging if more than one team member is inexperienced or from the extra list. This can lead to inefficiency or error. Knowledge and skills associated with planning and implementing yard moves is discussed more fully in section 6.1.7.

6.1.3.2 Recommended Mitigations

Recommendations relating to knowledge and experience largely involved improving training and improving job assignments to ensure individuals assigned to particular work have the necessary knowledge and skills to do the job well. High-level recommendations are below and are discussed in more detail in Sections 6.2.1 and 6.2.2.

Recommended mitigations:

- ***More extensive initial training:*** Training should focus on developing the specific knowledge and skills required to perform yard work, including rapidly reading switch position, effective communication and coordination during yard moves, and efficient planning and execution of yard moves. Recommendations for training in more detail are in Section 6.2.1, below.
- ***Refresher training for individuals who have not worked in that yard in a long period of time****:* Topics include review of the location of bottlenecks and problematic switches.
- ***Avoiding assigning individuals off of extra list who have primarily worked on passenger train service:*** Recommendations for crew assignment and scheduling in more detail are in Section 6.2.2, below.

6.1.4 Expectations: Crew Lineup Does Not Match Crew Expectations

As previously discussed, a fundamental aspect of cognition is that people develop and operate on expectations. In most cases the expectations are justified and enable people to detect and respond to information quickly. However, when expectations turn out to be incorrect, people will be slower in recognizing the violated expectation and more likely to make an error. One of the qualitative findings from this study is that in many RTS cases, the individual had expected the switch would be lined for their move but it was not. In some of the cases, because the crew expected the switch to be lined correctly they failed to double-check the lineup (e.g., by having the conductor walk the line prior to sending the train through). Similarly, if the person on the head end expected the switch to be correctly lined, they were more likely to miss or be delayed in detecting that the switch was misaligned. This was particularly true when operating a locomotive with long hood forward where the person was physically unable to read the switch points from their location in the locomotive.

6.1.4.1 Contributors to RTS

Next are the types of situations that led to erroneous expectations regarding switch position:

- ***A crew member lines the wrong switch or lines it incorrectly, resulting in the person on the head end believing the switch was lined for them when it is not.*** Researchers were given a case where a conductor inadvertently looked past the switch they were supposed to line and thus threw the wrong switch.

- ***Miscommunication between members within a crew (intra-crew miscommunication):*** Researchers were told of one case where the locomotive engineer misunderstood the planned route and so did not go far enough forward (relative to the conductor's intent). As a consequence, the train went through a different switch from the one the conductor had intended and lined. This other switch was not lined for them, resulting in a RTS. In another case, the locomotive engineer went through a switch before the conductor had a chance to throw it for the lineup.
- ***The crew lines up the route, but then some other individual outside the crew changes the switch position as part of their own move, without the first crew being aware of it (inter-crew miscommunication).*** There were many examples where a crewmember expected the switch would be lined for them because they had thrown the switch earlier, but unbeknownst to them someone else changed the switch position. One individual in a focus group indicated:

  "That's one of the things that cause run through switches. We're normally making a move, right, and we're normally saying that this switch should be in this direction, so it should be with us. Then now you got a crew coming in that wants to go by that switch, you know? And they go by the switch and they leave it open. They don't turn it back to you."

  Another individual described a RTS involving a similar case of violated expectations because unbeknownst to them another crewmember changed the switch position.

  "It was just me and the conductor. We were a relatively new crew. We were bringing in trains through the wash. There were a lot of crews out. It was a seven-car set. We brought it in through the wash. There are three switches you have to watch out for. As far as I knew there were no other trains before me, and one after me. The conductor was in the back because he was supposed to push me back. The first two switches were good. The third switch is right by a signal. It was a trailing switch and it was against me. I didn't know but there was a crew drilling there while we were in the wash. They must have done their work and left, and I was focused on my first two switches. I had a clear signal and went. I missed the third switch because I was looking at signal. [Note that the misaligned switch was prior to signal. The signal wasn't protecting that switch]. I was not aware of the other yard work going on. We had a lot of work that AM so rushing was maybe an issue."

6.1.4.2 Recommended Mitigations

During interviews and focus groups with train crews, yardmasters, and train masters related strategies that experienced crews used to avoid operating on incorrect expectations. These included:

- ***Assume that a switch is lined against them and stop the train before getting to it.*** This was typically done for switches known to be a problem or were located at bottlenecks where many crews were likely to come through, increasing the chance the switch would be lined against them.

- ***The conductor walks the planned route to make sure it is correctly aligned.*** In many cases this is required by operating rules, but researchers were told that not all crews consistently did that.
- ***The conductor checks the points after he/she throws a switch to verify that they throw the proper switch and throw it correctly.*** This is something that is required by operating rules, but researchers were told that not all crews consistently did that—particularly if the location of the switch points relative to the location of the switch handle makes it difficult to accurately read the switch points from where the switch handle is located.
- ***Keep track of other crews working in the area and communicate with them when throwing a switch that may be part of their lineup.***

These strategies should be taught during initial training and reinforced during on-the-job training (OJT).

6.1.5 Memory Lapses

As discussed in Section 6.1.1, individuals are subject to *memory lapses*, particularly under high workload conditions and/or in situations where there are distractions or interruptions. In those situations, intervening events can contribute to forgetting to complete intended actions. Several types of situations where memory lapses can contribute to RTS are identified below:

6.1.5.1 Contributors to RTS

- ***Forgetting to return a switch to its previous position after changing it or failing to communicate that the switch position has been changed, causing another crew to run through the switch:*** A memory lapse contributing to a RTS can occur when a crewmember throws a switch and then forgets to throw the switch back or to communicate to the yardmaster or other crews working in the same area that the switch position has been changed. This is an example of a post-completion error, where a final step that is not on the critical path to achieving a goal is omitted due to a memory lapse (McDonald & Durso, 2015). As discussed in Section 6.1.4, leaving a switch in an unexpected position and failing to let others know can create conditions for a RTS by violating the expectations of other crews.
- ***Forgetting that a switch was thrown as part of an intervening move, resulting in the same crew running through the switch:*** Interactions between multiple moves performed by a single crew can also lead to a RTS due to memory lapses. In several instances, conductors threw switches against themselves as part of multiple planned moves and forgot or failed to recognize that the route they originally lined was no longer correctly lined, as a result of an intervening move. One conductor in a focus group told researchers:

  "We threw the switch against ourselves because we were doing a different move. I didn't put the two moves together. I forgot that we threw the switch for the other move."

McDonald & Durso (2015) reported a similar case of a mental lapse leading to a RTS in a freight environment. They wrote, "A conductor told of an instance in which he aligned a switch against himself to aid a conductor on a neighboring track, forgot he had realigned the switch, and then ran through the switch that he personally had altered 30 minutes earlier."

6.1.5.2 Recommended Mitigations

- ***Encourage job briefings that cover planned moves and how they may interact.*** This is especially important when there are multiple, potentially interacting moves, unusual conditions, or changes in the plan.
- ***Provide job aids.*** Job aids should include graphic visualizations of planned moves through the yard that highlight switches that will need to be thrown and interactions across multiple moves. A more detailed discussion on job aids is in the Task Demands section, below.
- ***Reinforce policies and procedures that require the conductor or rear brakeman to walk the route***. Walking the route can help the crewmember to identify misaligned switches.
- ***Create or enhance team training.*** In particular, create or enhance training on maintaining awareness of other teams working in the same area and inter-team communication and coordination.

6.1.6 Teamwork and Communication

As previously discussed, yard work requires effective teamwork. This includes intra-crew team processes that facilitate the work of a single crew as well as inter-crew team processes that support coordination of work across multiple crews working in the same area.

Planning and executing yard moves depends on the ability of yard crews to plan, communicate, and coordinate work as a team (intra-crew teamwork). Researchers were repeatedly told of the importance of working with crewmembers familiar with one another, who were experienced, and who could be relied on. At the same time, the team was told that effective crews did not rigidly limit themselves to formal job roles. They worked cooperatively and readily stepped in to help each other. For example, while the conductor is normally responsible for planning the moves, if the conductor was less experienced, then the rear brakeman and/or the locomotive engineer may take on a bigger role in the planning process. As one interviewee put it:

> *"Who is in charge … it should be the conductor… but it depends on who has the most experience… we would have a drill sheet and between the three of us we would have 80 or 90 % the same way but maybe one has a better way and then all agree [to do it that way]."*

Good inter-crew teamwork is also important. Experienced crews actively work to maintain awareness of other crews working in the same general area. As one conductor put it:

> *"At 10 pm at night you can have 6 or more crews, all on the radio, all talking and drilling and you have to know where everyone is, who was just there, and what did they do."*

When asked how they keep track of other crews they mentioned monitoring radio communications. Good crews also contact other crews working in the same area to ask permission to throw a switch, and find out whether the other crew would like them to return the switch to its previous position after completing their work.

Good crews also take on tasks intended to facilitate the work of other crews and generally increase overall work efficiency. These are referred to as "professional courtesies." During one visit to the yard, a conductor coordinated three crews to expedite moves and get his move completed more quickly. He stood at the switch and threw it for the other crews. Researchers were given a second example during a focus group:

> *"I stood at a switch. There was a crew who had a crossover. Those switches were locked out. I told them I'll take care of it for them since I was there any way. So, I unlocked the switch and lined them out. It was lucky for them since they had long hood forward facing east and they couldn't get down off their long hood forward.... It helps make my move quicker too when I do that, they clear out quicker for me."*

As with other cognitive skills, maintaining awareness of others working in the area and communicating effectively with them is a skill that comes with experience. Researchers were told that experienced crews are more likely to know what other crews in the area are doing and what they needed. They communicate with other crews better. As one interviewee put it:

> *"A well-oiled crew would know that there are three other crews working there. We were brand new, both me and my conductor were new. If we were more experienced we would know about what the other crews were doing. We knew what we were doing."*

Regular crews whose members regularly work together as a team communicate and coordinate more effectively than crews that include individuals from the extra list. Regular crews were able to communicate more efficiently because they were more likely to recognize each other's voices over the radio and were familiar with each other's capabilities and communication styles. Consequently, they got on and off the radio more quickly and were less prone to misidentify the crew. Teams that included individuals from the extra list may not work together as well. They don't recognize each other's voices on the radio. The individuals from the extra list were not as familiar with yard, the yard moves, and drilling. This can slow down the work, require more explicit communication over the radio, and create potential for communication errors.

6.1.6.1 Contributors to RTS

- ***Congested radio channel:*** At this yard, all crews communicated on a single radio channel. There can be six or more crews on the radio at the same time, all trying to coordinate work with their own crew members. These conditions created the following consequences: First, radio time becomes a precious resource. Crew members know that they must get on and off the radio as quickly as possible. Second, crews often step on each other's communication, creating the potential for communications errors and misunderstandings. The crew call signs can be confusing, and they don't have a specialized vocabulary to facilitate clear communications. Consequently, communications often rely on voice recognition and employees indicated that they can confuse communications intended for another crewmember as directed at them.

- ***Errors in intra-team communication:*** Section 6.1.4 provides several examples of how crewmembers misunderstand each other due to failures in communication. In one case, the locomotive engineer misunderstood which switch they were supposed to go through; in a second, the locomotive engineer ran a switch because he erroneously thought the conductor had already lined it for him. Research conducted into switching operation fatalities reported similar findings, concluding that inadequate or incomplete communication among crewmembers contributed to employee fatalities (SOFA Working Group, 1999).
- ***Errors in inter-team communication:*** In multiple instances, one employee threw a switch against another without informing them or throwing the switch back after completing their work. This problem is exacerbated by the fact that crews are not always aware of what other crews are working in the same area. One example involved two passenger trains. The conductor of the first train scheduled to go out of the yard that morning lined the switches to leave the yard. Unbeknownst to him the conductor for the train that was scheduled to go out of the yard next lined his move and in the process threw the switches against the first conductor. Neither conductor contacted the other nor was aware of the other's actions.
- ***Lack of formal requirement for inter-crew communication:*** Researchers were told that at this railroad there was no formal requirement for informing another crewmember that a switch had been thrown against them. One interviewee said:

  "It is a courtesy to inform the other crew or ask them if they need the switch lined back, but there is no protocol that you have to do it."

  This is partly because it is not always possible for a crewmember to know who else is working in the same area. The yardmaster has formal responsibility to manage coordination across crews but as is discussed in the next section, lack of effective job aids and high workloads can make this a challenge.

6.1.6.2 Recommended Mitigations

- ***Provide focused training and practice on effective teamwork practices, including communication during yard moves.*** This includes training on efficient and unambiguous radio communication during intra-crew coordination of work; training on developing and maintaining situation awareness of other crews working in the same area and what they are doing; and training on inter-crew communication.
- ***Provide more training on conducting effective job briefs.*** Job briefs should enable everyone on the crew to have a shared understanding of the sequence of yard moves that will be performed, who else will be working in the area, what they will be doing, and potential for interaction. This training should include understanding when a new job briefing is needed. In addition, it is important to provide training on conducting "mini" job briefs during work execution to get everyone back on the same page. This is particularly important when there are unexpected events, there are changes in the plan, or there is any evidence of confusion. As one focus group participant put it:

"If there is any confusion it stops. If I can't hear you on the radio, it stops."

- ***Assign the more challenging yard jobs to regular crews.*** As one focus group participant pointed out:

  "When new crews are stitched together, even with a job brief, even if they have experience, switches can get run through because the team doesn't mesh. They may not operate well together. Each person has a slightly different method of operation. Maybe neither person is wrong, even when two people have different ways of doing or counting."

- ***Conduct more extensive job briefs in cases where the crew includes individuals who are not part of the regular crew, are less familiar with the yard, and/or are less familiar with planning and executing yard moves.*** The expanded job brief should include walking the route and pointing out challenging switches prior to beginning the work as well as writing out and carefully reviewing the drill plan.
- ***Conduct crew resource management (CRM) training***. CRM training emphasizes the need for all crewmembers to work cooperatively, speak up, and provide mutual support, irrespective of their formal job roles. CRM has been used effectively in the aviation industry and was recommended by the SOFA Working Group (1999) as a training tool for yard employees to reduce fatalities. FRA offers guidance on the development of CRM programs for railroads (Morgan et al. 2007).

6.1.7 Task Demands

The work of yard crews and yardmasters is mentally challenging. In the case of yard crews the work can also be physically challenging.

Yard crews plan and execute yard moves. At the start of a shift the crew receives a drill sheet indicating the equipment to move (e.g., into or out of a maintenance shop). They also receive a yard check document that indicates where in the yard equipment is currently located. At the maintenance yard visited, the yard check and drill sheets were static printouts. The conductor uses the information from the drill sheet and yard check to create a plan detailing the order in which the crew will move the equipment and the routes for each movement (i.e., the sequence of moves and routes to be taken). Depending on the crew's preferences, this task might be conducted in a collaborative fashion with all team members contributing ideas, or it can be done by the conductor, alone, who then briefs the rest of the team on the movement plan for accomplishing the drill sheet tasks. This activity can take 30 minutes or more depending on job complexity and crew experience.

The ability to efficiently plan and execute drill moves occurs through some combination of trial-and-error and mentoring by experienced conductors. One conductor said that he has been doing this job for over 4 years. He said it took him four months before he felt comfortable generating a drill plan. For the first 6 months, he needed to write out drill plans, after which he was able to do it entirely "in his head." Planning moves for a drill sheet can be particularly challenging if both conductor and rear brakeman are inexperienced.

As the yard crew starts to execute the drill plan they will call the yardmaster to let them know what equipment has been moved and to where so that the yardmaster can update the yard check form. At this yard, communication between the yardmaster and yard crews was typically conducted either via phone or radio.

It is not uncommon for the mechanical shop to update drill sheets after the yard crew has started to execute the movement plan. In that case, the yardmaster will call the crew with updates to the drill sheet and/or the yard check.

Yardmasters manage activities in the yard. This includes monitoring and directing the activities of yard crews conducting equipment moves, road crews bringing trains in and out of the yard, and others working in the yard. The yardmaster is responsible for maintaining awareness of where the different crews are and giving permission to crews to enter each other's territory or directing crews to seek permission directly from the crews whose territory they are entering.

At any given time, yardmasters can be communicating with yard crews, passenger crews, dispatchers, the mechanical shop, and/or the engineering department by phone and radio. They are also manually updating the yard check, a tabular form displayed on a computer screen, to keep track of the location of equipment in the yard. This can create high workloads during high-tempo periods, such as at night when many yard crews may be working at the same time.

6.1.7.1 Contributors to RTS

- ***The physical demands of walking the route can sometimes contribute to a decision that walking the route is unnecessary.*** As one conductor explained:

  "We walk the route. Sometimes it's a long distance. Its good exercise. But you got to do it. Conductors are the ones that do that -- the ones that care, that don't want to get into trouble."

  Sometimes locomotive engineers were reluctant to require the conductor to walk the route if it was a long distance and they felt confident that the route was already lined for them. This opens up the possibility of missing an incorrectly lined switch (e.g., if unbeknownst to them another crew had come through and thrown the switch against them).

- ***Planning and executing moves in the yard takes significant mental resources.*** Developing, communicating, and revising an effective drill plan can be cognitively challenging. As discussed earlier, the plan can be faulty or there can be miscommunication of the plan leading to potential for RTS.

- ***During yard moves, the conductor and/or locomotive engineer may be thinking about the upcoming move while working on the current move.*** This can serve as a source of distraction relative to monitoring for misaligned switches. Mind-wandering, particularly thinking ahead to the next task, is a common characteristic of cognition (Smallwood & Schooler, 2015). Multer et al. (2015) provide a more detailed discussion of mind-wandering as it applies to railroad operations.

- ***Moves can interact, making it difficult to keep track of the state of switches.*** As discussed earlier, there have been cases of conductors throwing switches against themselves as part of a different move and forgetting or failing to recognize that their route was no longer correctly lined because of the intervening move.

- ***Changes in the plan and unusual conditions increase vulnerability for error.*** Dynamic changes to yard checks and drill sheets are a common occurrence. These are communicated over the radio or by phone and updated manually. This creates opportunities for multiple types of errors. First, audio communication is a source of interruption. It contributes to workload and adds to radio congestion. It opens up the possibility for miscommunication as well as memory lapses (e.g., forgetting to throw a switch back as was intended). Further, the new information is likely to require dynamic re-planning of the yard moves under less-than-ideal conditions. This opens up the opportunity for a planning error. It also increases the possibility of one or more crewmembers misunderstanding the new plan.
- ***Generating the drill plan and communicating it to the rest of the crew is done without external aids.*** For the most part crewmembers have to generate and dynamically revise the drill plan "in their head" and communicate the plan verbally without any visual aids. This creates the possibility of suboptimal routes, incorrect routes, failures to recognize interactions across moves, and miscommunication of the plan.
- ***Yardmasters also operate in a high-workload environment with minimal external aids.*** Yardmasters have to keep track of where everyone is and what they are doing largely "in their head" based on audio communication. During high-workload periods, they may be trying to keep track of eight or more crews while responding to phone calls and monitoring the radio. Under those conditions, they may experience attention overload, leading to memory lapses and loss of situation awareness, such as losing track of where a crew is working or forgetting to communicate to crews the whereabouts of each other. Reinach and Viale (2007) reported similar findings in their study of yardmasters and yard safety, noting that yardmasters can become overloaded because the need to monitor multiple radio channels may cause loss of focus, and lose track of details concerning what is happening in the yard.

6.1.7.2 Recommended Mitigations

- ***The training recommendations provided under teamwork and communication equally apply to addressing task demands.*** Training on how to conduct a good job brief that makes sure that everyone has a chance to contribute to and understand the planned yard moves is very important. Similarly, it is important to train when and how to conduct "mini" job briefs during work execution to get everyone back on the same page after an unexpected event, a change in plan, or evidence of confusion.
- ***If possible, stagger yard crew shifts and/or reorganize the work to minimize multiple crews working in the same area.*** Doing so will reduce the possibility of crews throwing switches against each other.
- ***Consider adding a switch tender position at bottleneck switch locations where multiple trains are constantly coming through, requiring switches to be repeatedly thrown.*** A switch tender is dedicated to lining switches for all the trains that come through.
- ***Consider adding a second yardmaster to distribute the workload during high workload periods whose sole responsibility is to manage the yard crews.***
- ***Provide better job aids for yardmasters and yard crews.*** Candidate job aids include:

- Graphic displays of crew locations and movement within the yard: The location of crews could be obtained through GPS and dynamically shown on a display. The display could be presented to the yardmaster in the tower to allow him or her to more easily keep track of where crews are and the potential for getting in each other's way. A similar display could be presented on a portable device to allow yard crews to maintain awareness of where other crews are and what they are doing. The portable unit could be worn (e.g., head-mounted, at hip, around chest) so as not to interfere with the physical work demands of the conductor's job.
- Enable yard crews to view and dynamically update yard checks and drill sheets from the field. As in the prior recommendation, yard checks and drill sheets could be presented on a portable display device. This would have the benefit of eliminating the need to communicate this information by phone or radio, reducing radio congestion, avoiding untimely interruptions, eliminating potential for communication error, and allowing for more real-time updates to the yard checks and drill sheets.
- Provide work planning aids to support yard movement planning and communication. This could take the form of a graphic display of the yard layout with the location of equipment (equivalent to a graphical yard check). It could be used to graphically enter, visualize, and communicate the movement plan. It could help crews come up with better plans, more effectively communicate the plans, refresh their memory of the plan as moves are executed in the yard, revise the plan as changes arise, and recognize interactions between moves (e.g., when one move results in switches being thrown against the next planned move). These aids would be particularly useful for less-experienced crewmembers and/or crews that include individuals from the extra list.

- ***Develop "web enabled" switch position indicators.*** In Section 6.1.2, this study described electrical switch point indicators that displayed colored lights indicating switch position. One can imagine developing technology that leverages electrical switch position indicators so as to not only display switch position locally at the switch but also transmit the switch position information to displays for the yardmaster and the yard crews.

6.2 Organizational Factors

In this section, this study discusses findings related to how railroad organizational processes can contribute to train crews running through switches and provide recommendations to mitigate these unwanted behaviors. Many of the findings in this section are reinforced by previous research on contributing factors to stop signal overruns (Multer et al, 2015). This is because the way in which the railroad organizational system functions has far-reaching consequences and affects different aspects of railroad operations. Therefore, the findings related to the types of organizational issues that contribute to run-through switches align with findings from previous research looking at contributors to stop signal overruns and, the researchers believe, can generally improve system safety throughout the entire organization as well. Many of these concepts were developed in previous work (Multer et al, 2015) and this study discusses their manifestations with regard to RTS events below.

Though this study discusses these organizational issues as individual findings, the research suggests that an event is rarely attributable to a single factor but rather that individual factors often combine and interact to increase the probability of a RTS. As a result, many of the organizational issues discussed below may have been previously introduced in Section 6.1 regarding Individual and Team Factors.

6.2.1 Training

With an entire generation of the railroad workforce retiring, the railroad industry is experiencing a shift in workforce from hiring "generational railroaders," who are individuals who come from railroad families and were therefore familiar with railroad jobs and jargon, to individuals being hired off the street, often with little or no railroad experience. Training programs, therefore, are in many cases the first encounter new employees have with railroad operations. This study's findings suggest that conductor selection and training had limited focus on skills required for yard work. This was because, with the exception of yard conductors who only work in the yard, the majority of conductors who work in passenger service focused on ticket collecting and interacting with passengers. As a result, employees told the research team the current selection process emphasized skills required for passenger service and de-emphasized perceptual and cognitive skills required for yard work. Conductors said training focused more on passenger conductor work and was not adequate for the types of tasks they were expected to complete while working in the yard. While these decisions may have been appropriate based on the fact that most conductors will work passenger service, railroads should acknowledge the impact these decisions have on yard service and, where possible, provide additional support to the conductors who primarily work in yard service.

Limitations of the current training program as it relates to yard operations and suggestions for mitigations are discussed below.

6.2.1.1 Contributors to RTS

- ***Conductor training has limited focus on skills required for yard work.*** Interviews and focus groups revealed that many employees believe the conductor training program neglected to teach important yard skills necessary for yard service. Section 6.1.3 contains examples of the types of knowledge and experience cited by crew members as lacking. Further, many conductors said training was too focused on book knowledge and theory, at the expense of practical knowledge, especially regarding yard work. Several conductors said they were tested on book knowledge they deemed useless in practice, whereas they were not sufficiently tested on more practical, important yard skills such as reading switches and estimating distances by the number of car lengths, which is best taught through OJT as opposed to classroom learning.
- ***Conductor training lacks adequate OJT for yard skills.*** In addition to limited focus on yard skills during training, conductor training also lacked sufficient OJT time. Conductors and conductor trainers all agreed that there was room for improvement regarding teaching conductors using hands-on methods about important yard work skills, in particular reading and lining switches. Employees felt OJT should provide particular focus on switches known to be frequently run through.
- ***The gap between training and working in the yard results in loss of skills.*** Because most conductors graduate from the training program and immediately begin working in passenger service, they were unable to reinforce the yard work knowledge they gained

from training. By the time they were assigned work in the yard, for example because of being called in off the extra list, much of the knowledge and skills they learned in training has deteriorated from lack of use.

6.2.1.2 Recommended Mitigations

Section 6.1.3 contains examples of the types of knowledge and experience yard crews lack that can contribute to RTS events and unsafe behavior in the yard. These skills should be emphasized in both classroom and OJT, as well as re-emphasized during refresher training. This study argues training can be enhanced by providing more OJT, simulator training, and refresher training. Recommendations include:

- ***Improve training practicing scenarios encountered in RTS events.*** All conductors agreed that conductor training lacked on-the-job experience to adequately teach crews basic yard skills and improve crew confidence in the yard. Simulator training for yard tasks will accelerate conductor knowledge of the types of challenges that can occur in the yard and provide more realistic training in how to respond effectively. In particular, simulated scenarios can give conductors experience rapidly reading switches in real time, which is one of the most important skills for a yard conductor, but one which many conductors felt was not sufficiently emphasized in training. Simulated scenarios can also include realistic physical conditions that make the job hard but are not always possible during OJT, such as nighttime/dark conditions, rain, snow, etc. Some conductors also suggested the training department should have a small-scale model of the yard to help conductors learn the yard layout and develop efficient route plans. One trainer suggested he would like the railroad to have a full-size mock-up of a switch, to allow trainees the time and space to practice throwing switches without having to be in the field. If practical, this could be a way to provide conductor trainees practice physically throwing the switch; adequate time in the yard (actual OJT) is also important to provide conductors with the hands-on experience for additional yard knowledge and confidence in the yard.
- ***Focus more on effective communication and teamwork.*** Section 6.1.6 discusses the importance of effective communication and teamwork. These skills can be taught and reinforced in training. In particular, CRM training is an established method to educate crews to the roles and responsibilities of each team member, including how team members communicate with each other (Morgan et al, 2007). This type of training can guide crews as to how and when to best communicate with team members in their crew, crews working near them, and the yardmaster.
- ***Add training requirements for regular yard jobs.*** Given that most conductor jobs are in passenger service, it may not be practical to devote sufficient time to the level of training required to produce competent yard employees for all conductors. Railroads should consider adding training requirements for conductors who take on regular yard jobs, which would entail a demonstrated competency with respect to yard work. Providing this additional training to conductors assigned to the yard will accelerate their learning and add to their experience. In addition, establishing competency standards for measurable tasks will ensure they have knowledge necessary for safe operation in the yard. These tasks include:

- Rapidly locating and reading a switch under the range of conditions in which they are likely to be encountered
- Accurately estimating car distances
- Planning and making yard moves
- Switching (at bottleneck locations or corresponding switches in particular)

Railroads should consider separating the selection, training, and job assignment processes for yard and passenger conductors in the same way that locomotive engineers and conductors are treated separately. In that way, rather than adding additional training requirements for conductors who work in the yard, each job type would receive just the right training for the tasks for which they will be responsible. (This recommendation is covered in more depth below, in Crew Assignment and Scheduling.)

- ***Provide "just in time" refresher training to employees who have not recently worked in the yard.*** As discussed in detail in Section 6.1.3, knowledge and skills can diminish over time when not in use. Conductors and rear brakemen who typically work passenger jobs and are called off the extra list for a yard job, for example, may not be practically prepared to work in the yard, though they may be officially qualified for yard work. This is because in order to keep qualifications, employees must only work in the territory (not necessarily in the yard) once per year. Researchers heard from many employees that extra list conductors and rear brakemen did not feel confident working in the yard, though they were technically qualified. Assigning an experienced yard conductor as a mentor to the inexperienced one to provide a "just in time" refresher prior to starting the work will help them re-familiarize with the knowledge and skills they were taught in training (but hadn't put to use over time) as well as the location of switches and layout of the yard. Candidate topics to cover in the refresher training include:
  - Location of challenging switches in the yard
  - Effective communication methods
  - Refresher on reading switches

  Providing conductors and rear brakemen who are called off the extra list with this type of refresher training, if requested, will help them confidently and safely work in the yard.

6.2.2 Crew Assignment and Scheduling

One organizational factor that can contribute to the likelihood of RTS events is the crew assignment and scheduling process. At the railroad visited the bidding process for job selection, which is based on seniority, occurs twice per year (spring and fall). Qualified employees are given the opportunity to select which job they want in order of seniority. A result of this system is that senior employees get the more desirable assignments, typically jobs that conform to a regular work schedule. Regular passenger jobs are desirable, as are yard jobs, according to conductors, because of the pay and the regular schedules they provide. Less desirable jobs are often more variability in schedule, including the extra list jobs. Extra list jobs require employees to be on-call to fill in for other personnel and are therefore highly variable in terms of when the employee can be called to work and where the employee will work. Some employees do prefer the extra list because of the pay.

In addition to the passenger service extra list, the railroad we visited also has a "utility list," meant to act as the extra list for yard operations and flagging operations. The utility list is similar to the extra list in that it allows on-call employees to fill in jobs where necessary; however, it differs from the extra list because to be eligible for the utility list conductors must have at least 15 years' experience at this railroad. The utility list was created so crew callers could distinguish employees by experience in the yard and opt to call them first when jobs need to be filled.

In speaking with crews, including employees on the utility list and passenger service extra list, as well as crew callers at the railroad, researchers identified several shortcomings to the crew assignment and scheduling process that resulted in inexperienced employees being assigned to yard jobs. Some of these issues were due in part to staffing shortages at the railroad. Other issues stemmed from the way the two types of extra lists (passenger and utility) were used as well as the policies put in place which do not allow employees to turn down certain extra list jobs. Recommended mitigations for crew assignment and scheduling issues contributing to RTS events are below.

6.2.2.1 Contributors to RTS

- ***Less experienced employees often work the more difficult jobs.*** At the railroad visited, the most senior (experienced) employees often chose first- and second-shift yard jobs, which occurred mostly during daylight hours and had less yard activity. More junior (and less experienced) employees more often worked the third shift, which included more complex work, high workload, and work that was more susceptible to fatigue due to the late night/early morning hours. Less experienced employees were less familiar with planning and making yard moves, rapidly reading switches, and communicating effectively with their crew and may have been more susceptible to running through switches.
- ***Utility list was too short to cover all extra yard jobs and was not reserved for only yard jobs.*** The utility list was set up so that crew callers could pick from experienced yard workers when filling jobs. The utility list was used to fill flag jobs, yard jobs, and, if necessary, passenger jobs. Due to staff shortages, the utility list was too short to cover all the available yard jobs and was often exhausted before all yard jobs were filled. Flag and passenger jobs were frequently assigned before yard jobs. Employees on the utility list were sometimes also called in to work in passenger service. As a consequence, inexperienced extra list employees were called in to work in the yard. Utility list employees often preferred flag jobs, which paid better than yard jobs. The incentive for employees to prefer flag jobs over yard jobs reduced the number of skilled yard employees available for yard operations.
- ***Employees on the passenger extra list were unprepared for working in the yard, though they were qualified and were often unable to turn down jobs.*** Because the utility list was often depleted, employees on the passenger extra list were called in to work in the yard. One employee said:

  > *"If you are on the extra list, it doesn't mean that you are knowledgeable, it just means you can fill the job."*

  Individuals called from the passenger extra list may not have worked in the yard for an extended period of time and may not have had the necessary knowledge and skills to complete yard tasks. Further, many employees said it could be difficult to decline a job on the extra list, unless it did not conform to the hours of service (HOS) law. As a result, conductors and rear brakemen who had little confidence in their ability to perform yard tasks ended up working in the yard.

- ***Extra list crews were not as efficient at communication and coordination as regular crews.*** In Section 6.1.6 this study discusses the benefits of regular crews over extra list crews, including familiarity with yard layout and yard moves as well as communication style and voices of crew members. When crews were comprised of extra list members, even if they have experience in the yard, they were not able to work as well as regular crew members. Jobs could take longer to complete, and mistakes were more likely because they were not as comfortable working together. One engineer said:

  "When new crews are stitched together, even with a job brief, even if they have experience, switches can get run through because the team doesn't mesh."

- ***Crew scheduling can contribute to fatigue.*** Multer et al. (2015) discussed the role of fatigue to stop signal overruns and the role of crew scheduling on fatigue. Many of the same findings apply here as well. Crewmembers noted fatigue as a contributor to past RTS events or near-misses they experienced. Fatigue was mentioned as a problem for employees working the extra-list or utility list. These jobs included schedules with non-routine start and stop times and jobs that included both daytime and nighttime shifts and are therefore more susceptible to fatigue (Raslear, 2014). Due to the shortage of employees at the railroad, extra list employees were called frequently. Despite technically meeting HOS regulation requirements, many employees said they could be called to work within minutes of meeting HOS, making them barely rested. Fatigue can contribute to distraction and/or judgment and decision-making errors (Anderson & Horne, 2006; Harrison & Horne, 2000), which can contribute to RTS events.

6.2.2.2 Recommended Mitigations

One way to mitigate many of the crew assignment issues discussed above is to make conductor yard jobs and passenger jobs distinct—such that each job type has distinct selection criteria for hiring, training program, and extra list. In turn, this will result in employees who are specifically selected and trained for the work, and will make it easier for crew callers to fill jobs using the extra list with only qualified employees.

Short of making yard and passenger jobs separate jobs, this study recommends the following mitigations to ensure employees working in the yard are prepared:

- ***Increase the pool of employees*** such that the utility list is long enough to cover necessary yard positions.
- ***Reserve utility list employees for yard jobs***; do not call utility list conductors for passenger jobs.
- ***Allow employees who do not feel comfortable in the yard to decline a yard job or provide them with refresher training.*** Alternatively, employees should demonstrate they have the skills and knowledge to do the work, as practiced.

- ***When extra list crews work in the yard the yardmaster should assign them less complex tasks and understand that these may take longer to complete.***
- ***Provide monetary incentives for conductors to want to work yard jobs*** so a pool of individuals with experience in yard work can be maintained to fill both regular yard work positions as well as extra-lists that are dedicated to yard work.
- ***Examine scheduling practices—***particularly extra and utility list job assignments—to evaluate the impact on fatigue and the role fatigue may play in RTS events. Consider allowing extra and utility list employees who do not feel rested to decline a job.

6.2.3 Yard Design

An important consideration in understanding why run-through switches may occur has to do with the layout and configuration of switches and tracks in the yard. In Section 6.1.2, this study discusses factors that make identifying a switch difficult; for example, switches located around curves and switches located close together. The design of the yard exacerbates these issues and creates situations where crews may need to take sub-optimal routes, e.g., traverse through sections of the yard where other crews are working or take longer, less efficient routes that may require more switching than might be otherwise necessary as well as more communication within and across crews.

At the railroad visited, researchers were told that there can be up to eight crews working in the yard at once. Typically, crews control their own section of the yard and the yardmaster can give permission for them to enter other sections. However, the ability for crews to move equipment efficiently throughout the yard was hindered by the yard layout as well as use of yard tracks for long term storage of cars. As a result, crews might need to operate through sections of the yard another crew may already be working in and/or move less efficiently through the yard, causing them to take longer routes (e.g., make more moves) and going through more switches than might otherwise be necessary. These scenarios create potential for miscommunications and/or erroneous expectations about switch position, causing RTS events. Recommended yard design mitigations are below.

6.2.3.1 Contributors to RTS

- ***Switches located at bottleneck locations have a higher probability of RTS events.*** This is because these switches are traversed more frequently, and often consist of multiple switches located close together which can be difficult to see (discussed in in Section 6.1.2). Switches at bottlenecks may be operated multiple times by the same crew and/or operated over by multiple crews. Poor inter- and intra-team communication may lead to erroneous expectations about the position of the switch. For example, a crew working in that location may not realize that a second crew came through and did not return the switch to its previous position. As a result, the first crew—thinking the switch was in the same position they had left it—may run through the switch.

  Another bottleneck was the entrance and exit to the yard. Crews talked about one yard at the case study railroad that had only one entrance. As such, cars entered and departed the yard one at a time. During times of high traffic, switches near the single entrance were traversed and thrown often and by multiple crews moving cars in multiple directions. Erroneous expectations about the state of the switch (as discussed in Section 6.1.4) and miscommunications between and among crews can create situations where these switches are run through.

- ***Some switches are located too close together.*** Yard crews also mentioned switches located close together as a contributor to RTS. Some conductors said that when switches are located close together it can be easy to miss one of the switches (e.g., by looking beyond it to the next switch), causing crews to run through it because they were not expecting it. At other locations, switches located very close together could be ambiguous in terms of which switch handle controlled the switch.
- ***Long-term storage of broken-down cars in the yard limits usable tracks.*** At the railroad visited, an additional complicating factor was the use of many yard tracks for long-term storage of broken-down cars. Of the seven sections within the yard, three of them were used for storage of broken down cars. The long-term storage of so many unusable cars within the yard minimizes the amount of usable track for train movement and results in crews taking less efficient routes. The condition also contributes to crews operating through territory within the yard already occupied by another crew and creates the potential for RTS resulting from communication errors or erroneous expectations across crews regarding crew location and/or switch position.
- ***Yard organization may not be ideal for effective work.*** Another contributor to run-through switches is the overall organization of the yard. During focus groups, yard crews discussed the placement of fueling stations and car washes, for example, saying they were not ideally located for efficient work. One yard crew said the location of refueling stations caused crews to take off every engine, couple them up, bring them for fueling, and then bring them back and put them back on the trains. These types of inefficiencies create more work for yard crews and create additional opportunity for mistakes.

6.2.3.2 Recommended Mitigations

Researchers understood that redesigning the yard may not be practical due to time and budget constraints. They recommend re-organizing the yard to make the best use of current available space in the short term. In the long term, when new yards are being designed, stakeholders should be invited to identify contributors to unsafe behavior and design the yard to avoid these pitfalls.

- ***Reorganization of the yard will facilitate efficient movement within the yard.*** At the railroad visited, relocating broken-down cars in the yard would reduce the risk of RTS because crews could take more efficient routes and reduce the need for multiple crews to operate in the same location because more tracks would be available. This would reduce communication errors and erroneous expectations, as well as potentially reduce the number of switches yard crews must throw. In general, invite stakeholders (including yard crews, yardmasters, trainmasters, and the mechanical and engineering departments) to weigh in periodically to identify contributors to inefficient movement within the yard.
- ***When designing yards, eliminate as many hazards as possible.*** Researchers understood that large scale improvements to pre-existing yards is not always possible due to cost and time constraints. It is therefore critical that when designing new yards, stakeholders are invited in to identify contributors to RTS and other unsafe behaviors as well as to provide insight into what an efficient layout for the yard might be. In designing new yards or

improving pre-existing yards, reduce the number of switches and bottlenecks in the yard, and avoid placing switches close together where possible. Design yards that can accommodate the work such that the need for multiple crews to operate in the same areas is reduced or eliminated. Finally, plan for expansion and change to the extent possible, enabling the railroad to modify the yard as the work changes or the pace of operations increase.

6.2.4 Technology

This project sought to understand the role of technology in contributing to run-through switch events. Discussions with employees and observations in the yard, including observations of locomotive and switch technology, indicate potential for new technology to improve efficiency and safety in the yard. Technological shortcomings and suggestions for technology implementation are below.

6.2.4.1 Contributors to RTS

- ***Locomotive type can contribute to run-through switch events.*** As discussed in Section 6.1.2, the physical design of the equipment affects the ability of crews to see switches. Crews said that while operating locomotives with long hood forward it was not possible to read the position of the switch points from the locomotive—the crewmember on the head end would need to stop and get off to read the points or rely on information provided by someone else (e.g., a conductor on the ground).
- ***Poor-quality radios contribute to communication inefficiencies and errors.*** Section 6.1.6 discusses the importance of teamwork and communication in yard operations. Another often-discussed factor that contributed to communication breakdowns was poor-quality radios. At the railroad visited, many employees said radios do not always work properly, causing employees to use hand signals, flashlights, and/or face-to-face communication to communicate with crewmembers. These types of communications were less effective than using radios and contributed to miscommunications among crews. Employees also said a lack of radios or defective radios contributes to time pressure, because completing tasks often take longer when using hand signals instead of radios.

6.2.4.2 Recommended Mitigations

This study identified several opportunities for technology to reduce RTS events. Some of these technologies were already in-use at other railroads, while others were still in conceptual stages. Railroads should consider opportunities for current and new technologies to increase safety and productivity in their operations.

- ***Consider switching technologies that can help reduce run-through switch events.*** These switching technologies are discussed earlier in the report, in Section 6.1.2. Switch technology exists that helps to make it easier to identify switch position, showing whether the track is lined (or not) or if the switch is gapped. A 2001 study (Wilson, Ambo & Garcia) presented earlier attempts to make switch position clear. One recent example of this type of switch is displayed in Figure 19. Other switch technology exists to accommodate trailing-point operation from unaligned track without damage to the track.

These are sometimes called “spring-loaded” switches. These switches do not reduce RTS events but do reduce derailments due to gapped switches.

In section 6.1.7 this study also recommends developing “web enabled” switch position indicators. This technology could leverage electrical switch position indicators to display switch position locally at the switch but also transmit the switch position information to displays for the yardmaster and the yard crews. This is another aid that could help to reduce RTS events by helping crews (particularly inexperienced crews) better identify switch position.

- ***Provide better job aids for yardmasters and yard crews.*** This recommendation was discussed in detail in Section 6.1.7. Job aids that improve safety in the yard include:
  - Graphic displays of crew locations and movement within the yard
  - Technology that will enable yard crews to view and dynamically update yard checks and drill sheets from the field.
  - Work planning aids to support yard movement planning and communication.

  These technologies would all need to be prototyped and piloted prior to full implementation, but if properly designed, could increase yard crew and yardmaster situation awareness, decrease communication errors, and help crews plan for efficient yard moves.

6.2.5 Production Pressure

Interviews suggested that RTS events were partly a consequence of production pressures. Production pressures in the yard result, in part, from the production pressures felt in passenger service that spills over into yard operations. Production pressures in the yard were also a result of yard workflow, which consisted of low-workload periods during the day followed by periods of high workload at night. Yardmasters said the main source of time pressure resulted from the need to get trains ready for the morning rush hour. This study discusses these production pressures below and suggests mitigations to reduce the likelihood of RTS events that can result.

6.2.5.1 Contributors to RTS

- ***Production pressures from the mainline spill over to the yard.*** Production pressures in passenger service occur for a variety of reasons (Multer et al, 2015; Naweed, 2013). Because yards receive equipment for service from passenger operations, the pressures felt on the mainline (and effects thereof) are also felt in the yard. Employees provided several examples of how the pressures felt on the mainline transferred into yard operations. One employee said:

  > *“There are instances that the yard crew has to go drill a passenger train that has to get out in a half hour. This can create time pressure to rush drill a passenger train that has to be back out….That’s definitely time pressure.”*

  Another employee likened these scenarios to a domino effect, saying:

  > *“Passenger yards don’t give us enough time, so we end up getting rushed in the yard.”*

These pressures endanger operations because crews feel rushed. Acting on these feelings may contribute to taking shortcuts that compromise safety. Several employees noted that less experienced employees (who typically work more complex jobs, as explained in Section 6.2.2) were more likely to feel this time pressure compared to experienced employees.

- ***Misalignment of mechanical and yard operations causes periods of low and high workload.*** Another source of production pressures is a result of the uneven distribution of workload in the yard. Yardmasters and yard crews said the third shift in the yard, which occurs overnight, consists of high workload while first and second shift consists of low workload. This is because the car shop, which does its work during the day, provides the yardmaster with drill sheets detailing its needs for equipment to be taken in and out of the shop at the end of their day (often around 9:00 p.m.). After providing the yardmaster with the drill sheet, yard crews begin planning their moves based on the drill sheet and the car shop "opens" for yard crews to start moving equipment in and out. As one employee explained:

  > *"The car shop opens at 10 pm and everyone goes out at 10 pm... there can be up to 6 or 7 crews at the time with everyone needing to go to the same place. Crews are in each other's way. Everyone is constantly on the radio."*

  As this employee alluded to, the third shift comprised more interactions between crews because of the need for multiple crews to work in the same area of the yard at the same time. Yardmasters also said the third shift often consisted of more junior, less experienced crewmembers as well as extra-list employees. These factors combined to increase the risk exposure for RTS events.

6.2.5.2 Recommended Mitigations

Moving equipment on time is an important part of yard operations, and production pressures may be unavoidable. Railroads should acknowledge that incentives to complete work on time is important, but that production pressures can also create conditions for unsafe work and errors. The following recommendations can help:

- ***Modify work flows in the yard to create a more even distribution of work within and across shifts.*** To the extent possible, railroads should align start and stop times between mechanical and yard operations to meet revenue service demands and reduce production pressures, such that workload is more evenly distributed across shifts. At a minimum, railroads should seek to distribute work more evenly within the third shift, for example, by aligning the workload of the mechanical and yard operations to decrease the time pressure created due to the narrow time window to complete the work.
- ***Where an even distribution of work is not possible, ensure experienced crews work high pressure, complex jobs.*** As discussed in Section 6.1.6, railroads should assign the more challenging yard jobs to regular crews who are better equipped to deal with them.

7. Discussion and Conclusions

7.1 Organizational Design and Practices Shape the Factors that Contribute to RTS Events

The ability of railroad employees to successfully switch trains and equipment from one track to another depends on the design of the railroad system and how the railroad operates that system. The design of the railroad system depends upon the integration of humans, technology, and organizational policies and practices. What seems like a simple task, detecting the position of a switch and deciding whether to move past that switch, is mediated by a multitude of factors that shape the detection and decision making behavior of railroad employees.

Figure 20 shows an example of a RTS event that captures their complexity. The inset text presents the first-person account of a RTS event annotated with the contributing factors.

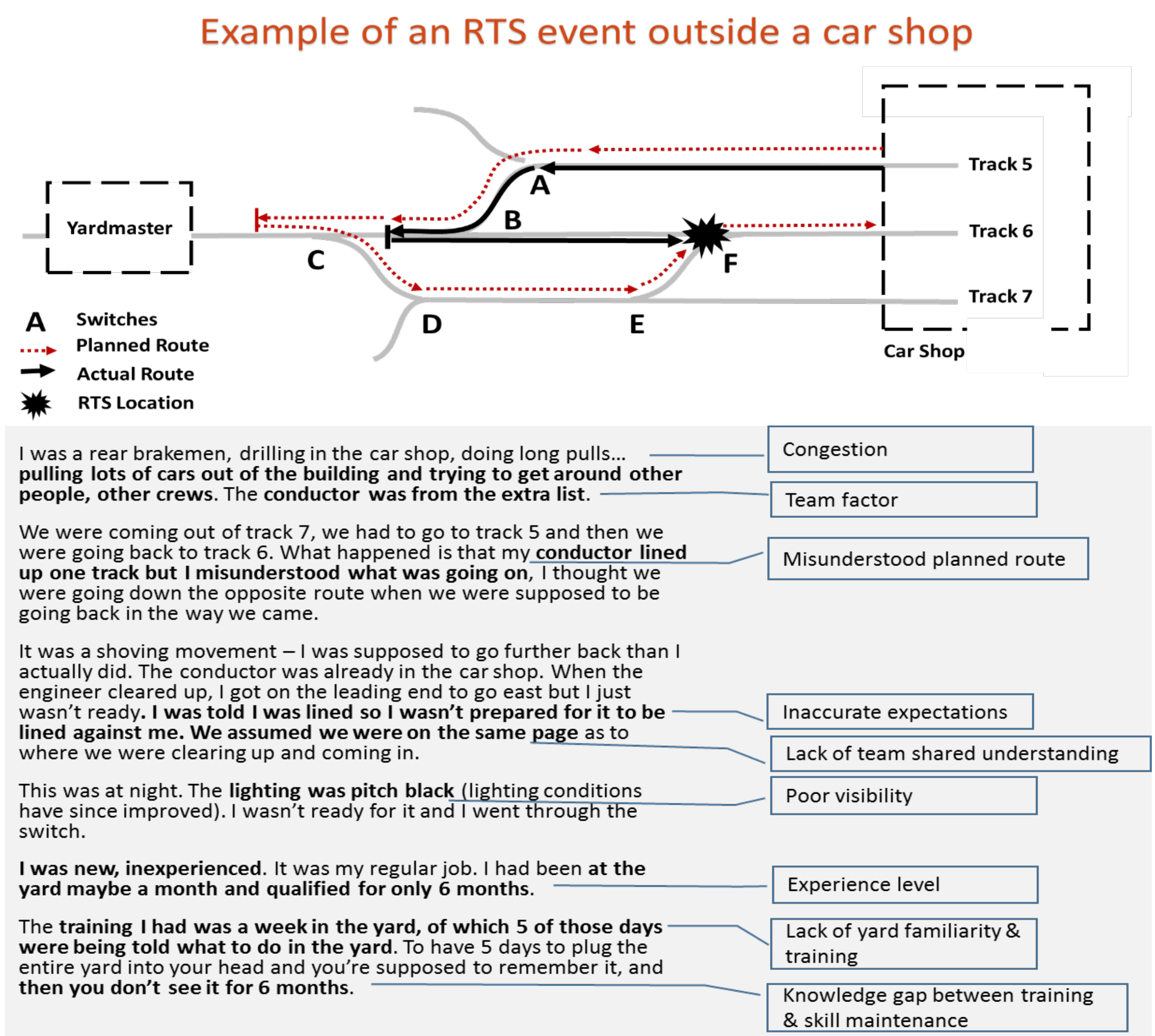


Figure 20. Example of RTS event complexity

This narrative describes a RTS event from the rear brakeman's perspective. The yard crew consisted of a locomotive engineer, rear brakeman, and a conductor. The yard crew was bringing cars from the yard into the car shop. During this event, the conductor was in the car shop and directing the locomotive engineer in cab, located in the rear, and the rear brakeman was located on the leading end of the movement. The conductor directed the engineer and rear brakeman to take the train from track 5 following the dotted red line (following points A, B, C, D, E, and F). Instead, the rear brakeman stopped the train short of the switch they were instructed to go through on track 6 that would take them onto track 7. Instead, the rear brakeman followed the path shown by the solid black line (following points A, B, and F), going through the switch lined for the other track at point F.

Based on the narrative, this study identified nine factors that, together, may have contributed to this event. What appeared to be a simple movement resulted in an unwanted outcome due to factors that were a function of the immediate context (e.g., poor visibility, misunderstanding of the route, inaccurate expectations, congestion) as well as factors that occurred over a longer time horizon (e.g., training, team factors, lack of experience, a gap between training and skill maintenance). Employees' ability to detect the correct switch position and act accordingly depends not only on their perceptual and cognitive skills. The yard crew's skills and abilities interact with the way the railroad designed its operations. These design elements include the track layout, the design of the equipment, the way it selects and trains its employees and the policies and practices for performing their jobs.

Through interviews with railroad employees, observations of switching operations, and a hazard analysis, this study identified many factors related to the design and operation of technology, work design, organizational factors and environmental factors that influenced the detection and operation of manually operated yard switches. These factors combined to produce different ways by which employees operated through an unaligned switch, resulting in damage.

Across many of the interviews, resource limitations played an important role by influencing how the railroad managed its operations. Managers and labor craft employees indicated that, over the course of several years, the budget remained stagnant while service demand grew. Increased service demands resulted in increased operations across the railroad, including in the yard as the need for maintenance increased and more trains were moving in and out of the yards. The top half of Figure 21 shows the increase in yard miles from 2006-2016. Yard miles represent a measure of yard operations. While the increase over the 11-year period was relatively modest, it was accompanied by a decrease in the number of employee hours worked for much of this 11-year period, as shown in the bottom half of Figure 21. The increased service demand accompanied by a decreasing trend in the total number of employee hours worked meant fewer employees were asked to perform the same level or increased level of work. The employees we spoke with indicated that reductions in staff at all levels of the organization made it more difficult to manage their operations. Fewer supervisors were available to manage employees, so complying with the regulatory requirements was more challenging. Training new employees was limited by the number and experience level of available trainers. With fewer experienced employees, extra lists had fewer employees available with experience working in the yard operations. While the railroad replaced some of the staff that left, the new employees were less experienced than employees who left the organization.

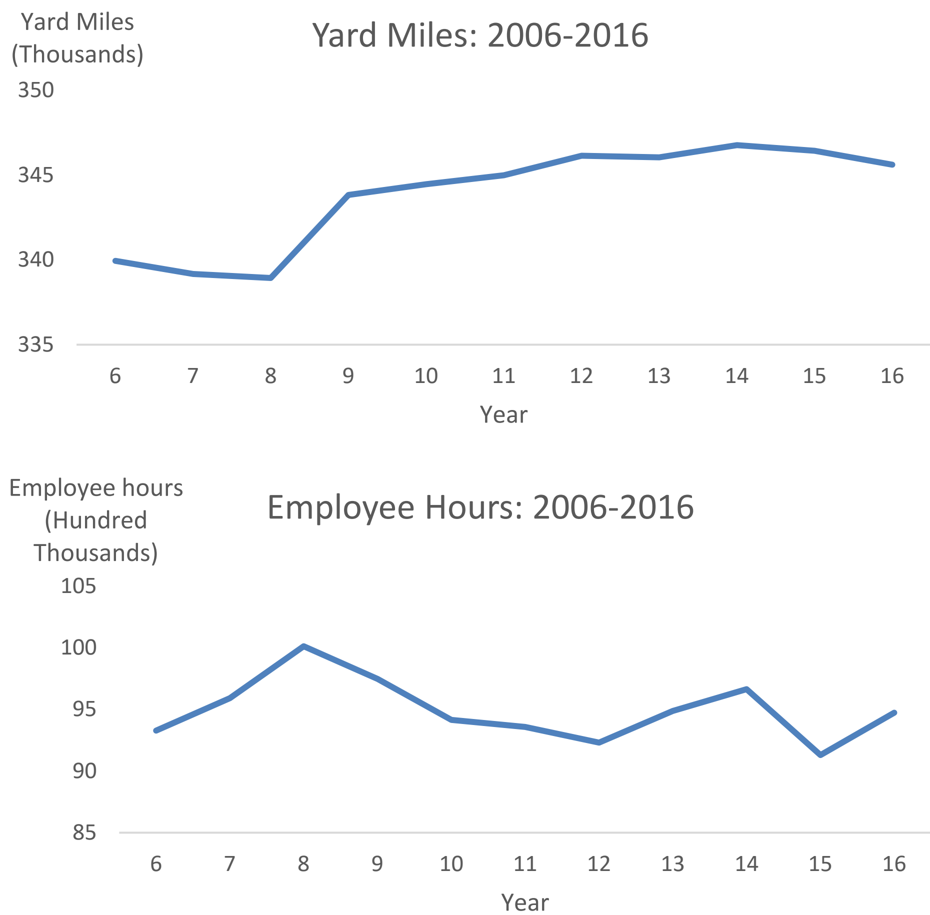


Figure 21. Number of yard miles and employee hours: 2006-2016

While there was no metric for identifying how close to the safety boundary that put railroad operations at risk of hazards like RTS events and their related derailments, many employees at this railroad were open about their feelings that the organization was increasing the risk of unsafe events like run-through switches. While all organizations are resource-constrained, an unanswered question is how to identify when resource constraints jeopardize the safety boundary in a way that calls for action. Since resource constraints exert systemic influences on an organization, it is important to identify when to take action to address these constraints. Since systemic factors influence the organization in multiple ways, it makes sense to examine how these systemic factors affect multiple safety measures. Observing changes in multiple safety-related performance measures over time can indicate how the system functions. The railroad can also identify acceptable levels of safety performance for different indicators like the target shown in Figure 22.

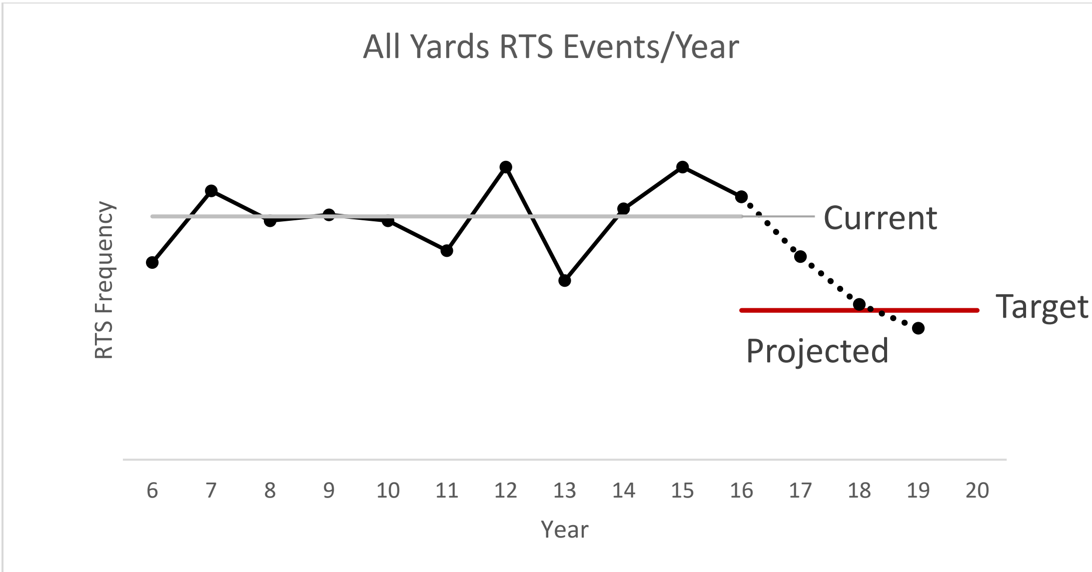


Figure 22. Setting a target level for safety performance indicators

7.2 What Does It Mean To Be Qualified?

A cross-cutting theme that emerged from discussions about how yard work is designed involved training, job design, job assignment process, incentives, and teamwork: What does it mean to be qualified to perform the duties of a conductor in yard operations? Before being eligible to work as conductors, employees must pass a test to demonstrate that they can conduct all the duties required, including yard switching operations. Passing this test indicates that they are qualified to work as conductors. Yet, there was a consensus among employees across the crafts investigated (e.g., yardmaster, trainmaster, conductors, locomotive engineers) that employees assigned to conductor and assistant conductor jobs in the yards sometimes lacked the skills and knowledge to work there safely.

The fact that the railroad offered refresher training for yard employees, that trainmasters would assign employees who were uncomfortable with working in the maintenance yard on work that would reduce their risk of running through a switch, and that yard crews would adapt by taking on greater responsibilities than usual when an inexperienced employee joined their team, speaks to the adaptability of the railroad employees to work within a system. These activities serve as compensatory mechanisms that partly mitigated the risk of run through switch events.

This compensatory behavior also suggested that there was a discrepancy between passing the qualification test and performing work safely. Interviews suggested that this discrepancy emerged from multiple factors in how the work was designed and staffed. Training practices enabled employees to learn how to read and throw switches, but the level of practice (too little to overlearn these skills), and the extended interval between when they received training and when they were called upon to work in the yard (e.g., due to how work is assigned to employees from the extra list) resulted in skill and knowledge loss. By designing the job assignment process so that newly trained conductors are more likely to work in passenger service than in yard operations, many conductors' yard performance skills will degrade over time without reinforcing what they learned through practice. Skills and knowledge tend to degrade rapidly after they are learned if they are not reinforced through practice (Hoffman et al, 2014).

Further, the lack of explicit team training for yard operations, including training planning and communicating the plan for safe and efficient equipment moves, as well as the training of non-technical skills such as CRM associated with effective communications, may result in inexperienced employees engaging in activities that put the system at risk of a RTS event. Each of these challenges resulted from the decisions that the railroad management made in organizing how railroad yard work is accomplished. Section 6 offers suggestions on how these processes (training, job design, the job bidding process, crew assignment for extra list employees) could be modified to mitigate the negative consequences for yard operations. These recommendations are also provided in list form in Appendix C.

7.3 Improvements in Investigation, Data Collection, and Analysis Needed

This study explored the factors that contribute to RTS events based primarily on interviews with a diverse set of employees discussing how yard operations take place and observations of yard operations. This study is one of the first to investigate why railroad employees in passenger operations run through switches. Additional studies are needed to confirm, expand upon, or invalidate whether the factors identified play a role in RTS events. The ability to take this information and use it effectively for decision making regarding which aspects of the operation to address and the mitigations to try depend on the quality of the information to inform decision making. Collecting data systematically on railroad operations through rigorous investigations and documentation procedures can add insight into the factors that contribute to these events and inform railroads how these factors affect the unwanted outcomes of RTS events. A rigorous investigation and document process can also inform whether mitigations implemented to reduce these unwanted outcomes are effective.

The incident data the railroad shared and was summarized in Section 3 provided little in the way of information about what factors contributed to RTS events. The railroad's investigation process, data collection procedures, and analysis left significant room for improvement. Improving these processes could contribute to a much better understanding of why these events occur and the magnitude with which individual factors operate individually and in combination to produce these events. Better information could enable the railroad to better target effective interventions to address this problem.

The challenges with the investigation process, data collection processes, IT infrastructure, and analytical capabilities are not unique to this railroad or to run-through switch events. A study of stop signal overruns (Multer et al, 2015) observed similar challenges. That study offered recommendations for addressing the weaknesses in these processes that included developing more rigorous investigation methods and documenting in greater detail their findings, using contemporary software and hardware. This would improve the quality of data collected, streamline the level of effort needed, and make the information available to decision-makers.

Improvements in the investigation and data collection process can inform the railroad's hazard analysis to identify where the risks are and where existing barriers are not operating properly or are missing. Appendix D provides an investigation template tailored to investigating RTS events. While further effort to refine and pilot this investigation template is needed, it provides a model of the kind of detailed contextual information that it is important to collect when an RTS event occurs in order to understand the factors that are contributing to RTS events.

An unanswered question from this research is, what are the barriers that create the current challenges to improving the investigation, data collection, and analysis practices for passenger railroads? The answers to this question can contribute to overcoming these barriers for passenger railroads.

7.4 Directions for the Future

This study investigated the factors that contributed to run-through switches at one passenger railroad. This railroad offered the opportunity to explore and learn how RTS events unfold and the factors that contribute to them. Further research is required to assess the generality of the findings.

An examination of similar passenger railroads shown in Figure 8 suggested the railroad in this study experienced more RTS events than other railroads. An examination of the switch technology used by other passenger railroads and how they organize their operations, design their yards, select and train their workers, and conduct switching operations can help clarify which factors have the greatest impact on running through switches. By comparing operations between passenger railroads, we can also learn which mitigations are likely to be most successful in reducing RTS events.

We also propose examining the run-through switch events at freight railroads. The work of Durso et al. (2015) suggested that run-through switches are a concern for freight railroads. More research is needed to understand the similarities and differences in how RTS events occur in passenger and freight operations. Due to the greater level of operations, the freight industry conducts more switches. What is the risk associated with running through switches in freight operations? Freight operations include a wider variety of types of switches, including remotely operated switches. Do the same factors identified in passenger operations play a role? What measures have freight railroads taken to mitigate the risk from these events? Could these equally apply to passenger operation?

Finally, we caution the reader to consider our conclusions as tentative. More evidence is needed to assess the degree to which our findings apply to passenger railroads, broadly. Further, the recommendations we offer to reduce run through switching should be pilot tested before implementing them widely to determine their efficacy and identify unintended consequences.

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Appendix A.
STPA Table of Unsafe Control Actions

Controller(s) **Control Action**	**Not Providing Causes Hazard**	**Providing Causes Hazard**	**Wrong Timing or Order**	**Stopped Too Soon or Late**
Conductor (or Brakeman) **1:** Throws switch	**UCA 1-1:** The conductor does not throw a switch when the train is approaching a switch lined for the wrong track. [H2, H3]	**UCA 1-2:** The conductor throws a switch when the train is approaching a switch which was already lined for the correct track. [H2, H3] **UCA 1-3:** The conductor throws a switch when it is part of a crossover without also ensuring that the other switch in the crossover is in a corresponding position. [H2, H3]	**UCA 1-4:** The conductor throws a switch too soon, when the switch is part of another crew's line up. [H2, H3]	**UCA 1-5:** The conductor stops too soon while throwing a switch, when switch is not fully thrown and secured. [H1, H2]
Conductor (or Brakeman) **2:** Notifies engineer switch is lined	**UCA 2-1:** The conductor does not notify the engineer that a switch is lined when the switch is correctly lined, causing delays. [H3]	**UCA 2-2:** The conductor notifies the engineer that a switch is lined when it is broken. [H1] **UCA 2-3:** The conductor notifies the engineer that a switch is lined when a switch is not lined in the desired direction. [H2, H3]	**UCA 2-4:** The conductor notifies the engineer that a switch is lined too soon when the switch has not been lined for the desired track yet. [H2, H3]	-

Controller(s) **Control Action**	**Not Providing Causes Hazard**	**Providing Causes Hazard**	**Wrong Timing or Order**	**Stopped Too Soon or Late**
Conductor (or Brakeman) **3:** Gives car counts	**UCA 3-1:** The conductor does not give car counts while the engineer reverses, causing the engineer to stop. [H3]	**UCA 3-2:** The conductor gives an inaccurate car, causing the engineer to misjudge the distance to a switch. [H2]	-	-
Engineer **4:** Moves through a switch	**UCA 4-1:** The engineer does not move through a switch when the switch is lined for the desired track and the train is currently obstructing other crews' work. [H3]	**UCA 4-2:** The engineer moves through a switch when the switch is not lined for the desired track. [H2, H3] **UCA 4-3:** The engineer moves through a switch when the switch has been "split" or broken. [H1]	-	-
Yardmaster **5:** Assigns tasks/provides drill sheets	**UCA 5-1:** The yardmaster does not assign a complete task list to the yard crew. [H3]	**UCA 5-2:** The yardmaster assigns tasks requiring many crews to work in the same area. [H2] **UCA 5-3:** The yardmaster assigns work that is too long or difficult to a particular yard crew. [H2]	-	-

Controller(s) **Control Action**	**Not Providing Causes Hazard**	**Providing Causes Hazard**	**Wrong Timing or Order**	**Stopped Too Soon or Late**
Yardmaster **6:** Grants permission for a crew to enter an area of the yard	**UCA 6-1:** The yardmaster does not grant permission for a crew to enter an area of the yard that is safe to enter. [H3]	**UCA 6-2:** The yardmaster grants permission for a crew to enter an area of the yard without notifying them of other crews or broken switches in the area. [H1, H2]	-	-
Yardmaster **7:** Informs crew of switch repair status	**UCA 7-1:** The yardmaster does not inform a crews that a switch in their area has been broken. [H1] **UCA 7-2:** The yardmaster does not inform crews that a switch in their area has been repaired. [H3]	**UCA 7-3:** The yardmaster informs a crew that a switch in their area has been repaired when it has not. [H1]	-	-

Appendix B.
STPA Table of Causal Scenarios

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
UCA 1-1: The conductor does not throw a switch when the train is approaching a switch lined for the wrong track. [H2, H3]	
1-1-1	The conductor can see the switch but does not realize it needs to be thrown. He misread the switch due to lack of experience reading switches from the cab in foggy weather. He lacks experience reading switches because he is a passenger list worker who was called to work in the yard, and has not worked a yard job since training.
1-1-2	The conductor can see the switch but does not realize it needs to be thrown. He misread the switch because he was tired and feeling time pressure near the end of his run, and glanced at it too quickly to make out the points in the lighting of the yard. The switch is part of a ladder (grouping of switches) and is nearly always lined for the main line, so he expects that to be the case and does not look closely.
1-1-3	The brakeman can see the switch but does not realize it needs to be thrown. He misread the switch because he was relying on the switch target, but it had been hit by equipment and was no longer reliable. He trusted the switch target because he was not confident reading switches, because he normally works passenger jobs and was trained in the yard a long time ago.
1-1-4	The conductor does not realize that the switch needs to be thrown because the brakeman told him it was lined. He did not verify that the brakeman's claim was accurate because he is under time pressure and believes the brakeman was adequately trained. However, the brakeman was new to working the yard and his read of the switch was inaccurate.
1-1-5	The conductor does not realize that the switch needs to be thrown because it is part of a crossover and the corresponding switch is lined correctly. She does not verify that both switches are lined because she is under time pressure. She thinks it is safe to make the assumption that both switches are lined correctly because of the rules regarding crossover switches; however a list worker on a different crew had forgotten the rule since his training and did not put both switches in corresponding positions.
1-1-6	The conductor incorrectly believes the switch the train is approaching is lined because he accidentally reads a different switch. He mixed up reading the switches because they are close together and not differentiated in a way that could be quickly identified in the yard lighting conditions.
1-1-7	The conductor knows that the switch the train is not lined and intended to throw it, but accidentally threw a different switch. He mixed up throwing the switches because the switch handles are close together and not differentiated in a way that could be quickly identified in the yard lighting conditions.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
1-1-8	The conductor does not does not realize that a switch needs to be thrown because he had already aligned it for his crew, but someone from another crew took away his lineup. He thought that the engineer would double check the switches and let him know if any of them needed to be fixed.
1-1-9	The conductor does not realize that a switch needs to be thrown because he forgot that he had thrown it against himself to assist another crew. He intended to throw it back after the other crew had passed, but became caught up in planning his future moves.
1-1-10	The brakeman does not realize the switch needs to be thrown because he incorrectly believes the conductor is lining the crew's route and has already thrown the switch. The brakeman is not a regular member of the crew and did not understand the expectations that the conductor communicated in the job briefing.
UCA 1-2: The conductor throws a switch when the train is approaching a switch which was already lined for the correct track. [H2, H3]	
1-2-1	The conductor can see the switch but incorrectly believes that it needs to be thrown. He misread the switch due to lack of experience reading switches from the cab, rather than from the ground. He lacks experience reading switches because he is a passenger list worker who was called to work in the yard, and hasn't worked a yard job since training.
1-2-2	The brakeman incorrectly believes that the switch needs to be thrown. He misread the switch because he was relying on the switch target, but it had been hit by equipment and was no longer reliable. He trusted the switch target because he was not confident reading switches, because he normally works passenger jobs and was trained in the yard a long time ago.
1-2-3	The brakeman throws the switch without verifying that it needs to be thrown because the conductor told him it needed to be thrown. He does not verify that the conductor's claim was accurate because he is under time pressure and believes the conductor is reliable; however, the conductor was fatigued from working overtime and had misread the switch from the cab.
1-2-4	The conductor incorrectly believes the switch the train is approaching is not lined because he accidentally reads a different switch. He mixed up reading the switches because they are close together and not differentiated in a way that could be quickly identified in the yard lighting conditions.
1-2-5	The conductor knows that the switch the train is lined and did not intend to throw it, but accidentally threw it when trying to line a different switch. He mixed up throwing the switches because the switch handles are close together and not differentiated in a way that could be quickly identified in the yard lighting conditions.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
UCA 1-3: The conductor throws a switch when it is part of a crossover without also ensuring that the other switch in the crossover is in a corresponding position. [H2, H3]	
1-3-1	The conductor does not throw both switches at a crossover because he does not recognize that they are part of a crossover. He aligns the switch he is using to go straight, but leaves the corresponding switch in the crossover position. He did not recognize the crossover because he is a passenger list employee and the crossover was not distinctly marked.
1-3-2	The conductor does not throw both switches at a crossover because he does not know the rules pertaining to crossover switches. He believes he does not need to align the corresponding switch since he is only going through one of the switches, and he assumes other crews will check the position of both switches before passing through them.
1-3-3	The conductor does not throw both switches at a crossover because he thinks it is not important to throw the corresponding switch if he will return the switch he is using to its original position shortly. He is under time pressure and does not want to throw the corresponding switch twice in a short time if he is not passing through it. He does not expect any other crews in the area to pass through the crossover from the other track.
1-3-4	The conductor does not throw both switches at a crossover because he thinks the brakeman will do it. However, the brakeman did not realize that the conductor wanted her to throw the corresponding switch.
1-3-5	The conductor does not throw both switches at a crossover because he is interrupted by a radio call before throwing the second switch. The yardmaster called to notify the conductor of an addition to the drill sheet.
UCA 1-4: The conductor throws a switch too soon, when the switch is part of another crew's line up. [H2, H3]	
1-4-1	The conductor did not know the switches were in use because he didn't know the first crew was in the area. The second crew had contacted the yardmaster by phone rather than radio regarding moving through that area of the yard, and the yardmaster did not notify the first crew.
1-4-2	The conductor was inexperienced and did not realize he was taking away the first conductor's lineup when he threw the switch for his own crew.
1-4-3	The conductor throws a switch that is part of another crew's line up because he thinks the other crew will not run through the switch. He notified the other crew's conductor, but the message did not make it to the engineer in time.
1-4-4	The conductor took away another crew's line up because he thought his crew could make it through the switch first, and he expected the other crew's engineer to double check switch positions before passing over them.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
UCA 1-5: The conductor stops too soon while throwing a switch, when switch is not fully thrown and secured. [H1, H2]	
1-5-1	The conductor does not finish throwing and securing a switch because he was unable to do so. There was a mechanical problem with the switch or chain that he did not notice because he was a list worker and lacked experience recognizing such issues.
1-5-2	The conductor does not finish throwing and securing a switch because he was distracted before finishing the task. He received a radio call from the yardmaster updating his drill sheet and forgot to return to secure the switch.
1-5-3	The conductor does not finish securing a switch because he thinks the train will be able to safely pass through anyway. He is under time pressure and thinks that he will be able to save time by not fully securing the switch.
UCA 2-1: The conductor does not notify the engineer that a switch is lined when the switch is correctly lined, causing delays. [H3]	
2-1-1	The conductor doesn't notify the engineer once the switch is lined because he expects the engineer to read the switch and know when it is safe to proceed. However, the engineer is not confident in his ability to read switches because he does not usually work yard jobs, and he does not intend to proceed until notified by the conductor.
2-1-2	The conductor doesn't notify the engineer once the switch is lined because he expects the engineer to read the switch and know when it is safe to proceed. However, the conductor's expectations were not communicated clearly during the job briefing and the engineer intends to wait for the conductor to notify him before moving.
2-1-3	The conductor doesn't notify the engineer once the switch is lined because he expects the brakeman to do so. However, the brakeman did not realize that he was responsible for this because the conductor did not communicate his expectations clearly during the job briefing.
2-1-4	The conductor intends to notify the engineer that the switch is lined, but does not do so in a timely manner because he is unable to contact the engineer. There is too much radio chatter to get his message through due to the number of crews working the yard using the same frequency.
2-1-5	The conductor intends to notify the engineer that the switch is lined, but only after lining a larger portion of the route. He does not realize that another crew are being held up waiting for his crew to move through the switch because of a breakdown in communication. He has moved too far from his crew for them to talk to him face-to-face and they do not want to crowd the radio.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
UCA 2-2: The conductor notifies the engineer that a switch is lined when it is broken. [H1]	
2-2-1	The conductor does not recognize that the switch is broken because he has never encountered a broken switch before. He is a list worker and does not work in the yard often. He learned about broken switches during training, but was not exposed to them on the job. Due to his inexperience recognizing broken switches, he incorrectly believes the switch is lined.
2-2-2	The conductor does not recognize that the switch is broken because he has never encountered a broken switch before. He is a new employee and has seen broken switches during the daytime from the ground, but not at night while riding in the cab. Due to his visual angle and the lighting conditions he incorrectly believes the switch is lined.
2-2-3	The conductor does not realize that a switch is broken because he is tired feeling time pressure near the end of his shift. He glanced at the switch too quickly to detect the minimal gaps and realize that it had been run through, and the switch has not been marked as broken in any way.
2-2-4	The conductor thinks that the switch could be broken, but tells engineer it is lined. He is worried about getting in trouble for causing delays if he claims the switch is broken and is incorrect. He is new to yard work and learned about broken switches during training, but is not confident recognizing them on the job.
2-2-5	The conductor thinks that the switch could be broken, but does not tell the engineer. He has forgotten his training on broken switches because he is a list worker and does not work in the yard often. He incorrectly believes that it is possible to pass through a broken switch without derailing.
UCA 2-3: The conductor notifies the engineer that a switch is lined when a switch is not lined in the desired direction. [H2, H3]	
2-3-1	The conductor incorrectly believes that the switch is lined for the desired direction because he misread the switch, threw the wrong switch, or made an incorrect assumption about the position of the switch. See scenarios for UCA 1-1 and UCA 1-2 for causal factors that would contribute to these actions.
2-3-2	The conductor notifies the engineer that the trailing switch is lined for the desired direction when he knows that it is not. He does not know that this will break the switch due to insufficient training or experience. He may incorrectly believe that these switches will not break based on past experience at another railroad that used a different type of switch.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
UCA 2-4: The conductor notifies the engineer that a switch is lined too soon when the switch has not been lined for the desired track yet. [H2, H3]	
2-4-1	The conductor notifies the engineer that a switch is lined when he hasn't lined it yet, but intends to. He incorrectly believes that he will have time to line the switch before the engineer gets to it. He told the engineer in advance because they are under time pressure and he was trying to be efficient, but he became caught up coordinating with a second crew and did not have time to line the switch.
2-4-2	The conductor notifies the engineer that a switch is lined when he believes it has been lined by the brakeman. The brakeman said it would be lined in time for the train to pass through it, but was unable to line the switch in time. He wanted to tell the engineer that it was not actually lined, but could not reach him due to radio chatter.
UCA 3-1: The conductor does not give car counts while the engineer reverses, causing the engineer to stop. [H3]	
3-1-1	The conductor forgets to give a car count because he is trying to perform other tasks at the same time. He was reviewing the drill sheets to plan out the next move and did not realize it was time to give another count. He felt the need to review the drill sheet again because he was new to working as a yard conductor, but he did not want to slow down the crew by stopping to do so because of time pressures.
3-1-2	The conductor forgets to give a car count because he is not usually the one performing this task; in his usual crew, the brakeman gives the car counts, but since his brakeman is out and his substitute is less experienced in the yard, the conductor is doing the counts. He was tired from working on his off day, so he defaulted to his typical activity--thinking about his next moves--and forgot to give the count.
UCA 3-2: The conductor gives an inaccurate car, causing the engineer to misjudge the distance to a switch. [H2]	
3-2-1	The conductor gives an incorrect car count because he knows the distance, but does not communicate it successfully to the engineer. He was tired and misspoke, or was thinking about other responsibilities and a different number intruded into his speech than the one he meant to say.
3-2-2	The conductor gives an incorrect car count because he is having difficulty judging the distance. He is not experienced at giving car counts because he does not usually work in the yard and did not receive extensive on the job training in shoving operations.
3-2-3	The conductor gives an incorrect car count because his distance estimate is off. His usual engineer knows that his car counts tend to be short and adjusts accordingly, but he just changed crews because he was displaced by a more senior employee during the bidding system.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
UCA 4-1: The engineer does not move through a switch when the switch is lined for the desired track and the train is currently obstructing other crews' work. [H3]	
4-1-1	The engineer does not move through a properly aligned switch because he is waiting for verbal confirmation from the conductor that the switch is lined. He can see the switch from the cab but isn't sure whether or not it is lined because he is new to working in the yard and lacks experience reading switches.
4-1-2	The engineer does not move through a properly aligned switch because he is waiting for verbal instruction from the conductor. He can see that the switch is lined, but thinks the conductor will tell him when to proceed. The conductor does not plan to give this go-ahead because he does not want to clutter the radio, but he did not make this clear during the job briefing, causing an unnecessary delay.
4-1-3	The engineer does not move through a properly aligned switch because he is waiting for verbal instruction from the conductor. He can see that the switch is lined, but is not sure about the status of switches that the conductor is lining further along the planned route because he has not heard from the conductor yet. The conductor is too far away to reach face-to-face and the engineer does not want to crowd the radio unnecessarily by asking for updates.
4-1-4	The engineer does not move through a properly aligned switch because he cannot see the switch position over the front of the locomotive. He is waiting for the go-ahead from the conductor, who incorrectly believed the engineer could see the switch and would know to move through it once it was aligned due to expectations that weren't clarified during the job briefing.
4-1-5	The engineer does not move through a properly aligned switch because he is waiting the conductor to align several other switches further along the route. He does not realize that he is holding up other crews who want to use the switch because he is inexperienced and was not trained in coordination with other yard crews.
UCA 4-2: The engineer moves through a switch when the switch is not lined for the desired track. [H2, H3]	
4-2-1	The engineer moves through a switch that is not lined for the desired track because he expected it to be properly aligned and did not look closely. He expected this because the conductor told him it was, but the conductor had lined it incorrectly.
4-2-2	The engineer moves through a switch that is not lined for the desired track because he expected it to be properly aligned and did not look closely. He expected this because the conductor told him it was, but another crew had taken away the line up without the crew realizing.
4-2-3	The engineer moves through a switch that is not lined for the desired track because he misread it or read the wrong switch. The conductor had told him it was correctly aligned, but someone had taken away the lineup.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
4-2-4	The engineer moves through a switch that is not lined for the desired track because he realized too late that someone had taken away the lineup. The switch was around a curve and difficult to read until it was too late to stop.
4-2-5	The engineer moves through a switch that is not lined for the desired track because he cannot see the switch from the cab due to the locomotive type. The conductor had told him the route was lined, but someone had taken away the lineup.
4-2-6	The engineer moves through a switch that is not lined for the desired track because he does not think it will break the switch. He is inexperienced and had previously worked at another railroad which uses a different type of switch.
4-2-7	The engineer moves through a switch that is not lined for the desired track because he misunderstood the instructions the conductor had given him. The conductor had wanted him to take a different path which would lead him through the switch from the other direction.
4-2-8	The engineer moves through a switch that is not lined for the desired track because he is relying on car counts from the conductor. The conductor realized that the switch was not lined and assumed the engineer would stop if he did not give an updated car count, but the engineer thought it was safe to proceed the full distance given in the previous car count and ended up running through the switch.
4-2-9	The engineer moves through a switch that is not lined for the desired track because he is relying on car counts from the conductor, who had overstated the distance remaining. The engineer was not used to working with this conductor, who was from the extra list, so he did not realize how far off his estimations would be. The conductor had trouble estimating the distance because he was not experienced in doing so.
4-2-10	The engineer moves through a switch that is not lined for the desired track because he is relying on car counts from the conductor, and did not recognize which car count was meant for him. He was working with an extra list conductor whose voice and tone he did not recognize over the radio. The extra list conductor was not practiced in giving car counts and did not use the typical intonation.
4-2-11	The engineer moves through a switch that is not lined for the desired track because he is relying on car counts from the conductor, but there was too much radio chatter for him to hear the conductor's instructions to stop.
4-2-12	The engineer moves through a switch that is not lined for the desired track because he notices too late that it is not correctly lined. The switch is around a curve so he cannot see it until he is very close and there is not enough time to stop. He was moving at the maximum speed allowed in the yard because the conductor had told him the route was fully lined for some distance ahead.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
UCA 4-3: The engineer moves through a switch when the switch has been "split" or broken. [H1]	
4-3-1	The engineer moves through a broken switch because he did not know that it was broken. He did not recognize that it was broken because he was a new employee and did not have much prior yard experience. Because of the relatively small gapping and his visual angle, the cues that the switch was broken did not look like what he had seen in training.
4-3-2	The engineer moves through a broken switch because he did not know that it was broken. The conductor did not notice the gaps and told him that the switch was properly aligned. The engineer could not see the gaps either, and was not looking closely for them since he trusted the conductor. Neither expected to encounter a broken switch because the yardmaster had not mentioned one in the area.
4-3-3	The engineer moves through a broken switch because he did not realize he had broken it. He was supposed to go through the trailing point switch to pick up a car, then reverse back through the switch. However, the switch was not properly lined when he went through in the trailing point direction, causing a run through switch. He did not notice that it had broken over the sound of the engine, so he does not know that he should not reverse through it in the facing point direction.
4-3-4	The engineer moves through a broken switch because he did not know that it was broken. The yardmaster had warned the crew that there was a broken switch but the engineer had forgotten which one it was. The switch was not marked as broken in any way and neither he nor the conductor noticed the gaps because the switch was in a poorly-lit area of the yard.
UCA 5-1: The yardmaster does not assign a complete task list to the yard crew. [H3]	
5-1-1	The yardmaster meant to inform a crew of an update to their drill list, but forgot to do so. He received notification from the mechanical department that a new move was required, but then received a phone call from a different crew informing him of a broken switch and forgot to contact the first crew about the required move.
5-1-2	The yardmaster does not realize that there is an update to a crew's drill sheet because he does not notice the call or email from the mechanical department. He is trying to coordinate six crews at once, several of which are in the same area, and is concentrating to form a mental map of the locations they are verbally describing to him over the radio.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
UCA 5-2: The yardmaster assigns tasks requiring many crews to work in the same area. [H2]	
5-2-1	The yardmaster assigns work that requires many crews to pass through the same area of the yard because each crew has a typical job and that is how the work happens to be structured when it is received from the mechanical department. He does not have the authority or the time to reassign the work so that it creates less interaction between crews' routes through the yard. He is busy responding to queries from the mechanical department, updating the yard check, and trying to prevent crews from having conflicts.
5-2-2	The yardmaster assigns multiple crews to work in the same area in order to avoid routing them through a run-through switch elsewhere in the yard. Due to the yard design, there are not many alternatives to using the currently broken switch which leads to multiple crews sharing the remaining routes. He has informed the engineering department about the broken switch but they have not had time to send someone to repair it yet.
5-2-3	The yardmaster requires multiple crews to work in the same area because he thinks they will coordinate amongst themselves to avoid conflicts. He does not notice that the latest crew he has given permission to enter that area called him on the phone, not the radio, so he forgets to notify the other crews in the area about the new crew entering.
UCA 5-3: The yardmaster assigns work that is too long or difficult to a particular yard crew. [H2]	
5-3-1	The yardmaster assigns work that is not evenly distributed, and requires some crews to do too much work for one shift. He assigns the drill sheets this way because each crew has a typical job and that is how the work happens to be structured when it is received from the mechanical department. He does not have the authority or the time to reassign the work so that it is more evenly balanced. He is busy responding to queries from the mechanical department, updating the yard check, and trying to prevent crews from having conflicts.
5-3-2	The yardmaster assigns extra work (new moves from mechanical department, moves usually performed by a crew that is out, etc.) to a crew that is overloaded. He feels like he does not have a choice because the yard is short-staffed. He thinks the employees that he is giving extra work to can handle it because they are experience. He does not realize that the crewmembers are fatigued from working overtime, but are working because they did not want to use a sick day to call out.
UCA 6-1: The yardmaster does not grant permission for a crew to enter an area of the yard that is safe to enter. [H3]	
6-1-1	The yardmaster knows that a crew is waiting on his permission to enter an area of the yard, but forgets to grant this permission because he received a phone call from another crew that interrupted his train of thought. He keeps track of crew interactions only in his head, so once his train of thought was interrupted there was

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
	nothing to remind him that the crew was still waiting. The crew did not want to call too frequently to check in because they do not wish to crowd the radio or phone line.
6-1-2	The yardmaster believes that the crew will coordinate with other crews in the area for permission to move through the yard, and do not need his permission. He told them to do so, but the conductor he was communicating with did not understand the instructions and rather than contacting the other crew, was still waiting on the go-ahead from the yardmaster. The conductor was inexperienced and had not been trained on how to request such permissions.
UCA 6-2: The yardmaster grants permission for a crew to enter an area of the yard without notifying them of other crews or broken switches in the area. [H1, H2]	
6-2-1	The yardmaster intends to warn a crew about a broken switch in the area they are about to enter but forgets to do so. He is keeping track of everything he needs to do in his head and did not realize that he had forgotten to contact the crew because another phone call came in at the same time.
6-2-2	The yardmaster does not warn a crew about a broken switch in the area they are about to enter because he is under a high workload and thinks someone else will tell them. He has told them to contact another crew in the area to coordinate, and assumes the second crew will tell them about the broken switch. However, the second yard crew thinks the yardmaster will have already warned the first crew about the broken switch.
6-2-3	The yardmaster does not warn a crew about a broken switch in the area they are about to enter because he thinks they will avoid it on their own. He believes that they will be able to recognize that the switch is broken. However, the gap between the points and the rails is not sufficient for the crew to detect unless they are experienced and know what they are looking for.
6-2-4	The yardmaster does not warn a crew about a broken switch in the area they are about to enter because he is unaware of the broken switch. The crew that ran through the switch did not realize that they had done so, and therefore did not report it. They did not recognize the sound and vibration cues that a switch had been broken because they were not trained to recognize this and the sound was masked by the engine.
6-2-5	The yardmaster does not warn a crew about a broken switch in the area they are about to enter because he is unaware of the broken switch. The crew that ran through the switch realized that they had done so, but did not report it because they were afraid of being penalized. They were inexperienced and did not realize that it could cause other crews to derail.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
6-2-6	The yardmaster does not warn a crew about a broken switch in the area they are about to enter because he is unaware of the broken switch. The crew that ran through the switch was in the process of reporting it, but had not yet called the yardmaster. They believed they had to first report it to the anonymous system that would protect them from discipline and did not realize calling the yardmaster so he could warn other crews was more time-sensitive.
6-2-7	The yardmaster does not warn a crew about a broken switch in the area they are about to enter because he incorrectly believes the switch has been repaired. He received a report from the engineering department that it would likely be repaired by a certain time, and since that time has passed, he assumes the repair is complete.
UCA 7-1: The yardmaster does not inform a crews that a switch in their area has been broken. [H1]	
7-1-1	The yardmaster plans to tell crews entering the area about the broken switch, but forgets that there is more than one crew already in the area. The crew that broke the switch knows to avoid it, but the yardmaster forgot to notify the second crew. He forgot their location because he is keeping track of the locations of all the crews in his head and he is focused on making sure the switch gets repaired.
UCA 7-2: The yardmaster does not inform crews that a switch in their area has been repaired. [H3]	
7-2-1	The yardmaster does not realize he needs to inform a crew about a repaired switch because he incorrectly believes they have already completed work in the area of the switch and will not benefit from knowing about its repair. He thought they had finished work in the area due to an unclear communication from the crew's conductor, who was from the passenger list, and their radio exchange was interrupted by another crew calling the yardmaster before he had a chance to ask for clarification.
7-2-2	The yardmaster does not realize he needs to inform a crew about a repaired switch because he incorrectly believes they will have seen the engineering crew sent to repair it and understood that it was repaired. He does not realize that they are too preoccupied with their own tasks and not within sight range of the switch to monitor its repair status, because he does not know their precise location in the yard moment-to-moment.
7-2-3	The yardmaster does not inform a crew that a switch in their work area has been repaired because he himself does not realize that it has been repaired. The engineering crew who did the repair notified their supervisor, but not the yardmaster. The supervisor did not notify the yardmaster because he believed the crew already had done so.

Unsafe Control Action	
ID	**Scenarios: Combinations of interacting causal factors that could lead to the UCA**
UCA 7-3: The yardmaster informs a crew that a switch in their area has been repaired when it has not. [H1]	
7-3-1	The yardmaster reports that a switch has been repaired when it has not been repaired yet because he received a report from the engineering department that it would likely be repaired by a certain time, and since that time has passed, he assumes the repair is complete. He does not wait for official confirmation because he is under time pressure to make sure crews complete their moves.

Appendix C. List of Recommended Mitigations

The following is a summary list of recommended mitigations to reduce RTS events. For more information on each recommendation, see Section 6.

Individual and Team

Perceptual Factors (Section 6.1.2)

- Consider installing indicators that provide clearer and more salient indication of switch positions.
- Consider use of switches designed to accommodate trailing-point operation from unaligned track without breaking.
- Revisit the process for reporting and repairing misaligned switch targets or remove them.

Knowledge & Experience (Section 6.1.3)

- Provide more extensive initial training.
- Provide refresher training for individuals who have not worked in that yard in a long period of time.
- Avoid assigning individuals off of extra list who have primarily worked on passenger train service.

Expectations (Section 6.1.4)

- Crews should assume that a switch is lined against them and stop the train before getting to it.
- Conductors should walk the planned route to make sure it is correctly aligned.
- The conductor should check the points after he/she throws a switch to verify that they throw the proper switch and throw it correctly.
- Crews should keep track of other crews working in the area and communicate with them when throwing a switch that may be part of their lineup.

Memory Lapses (Section 6.1.5)

- Encourage job briefings that cover planned moves and how they may interact.
- Provide job aids to crews and yardmasters.
- Reinforce policies and procedures that require the conductor or rear brakeman to walk the route.
- Create or enhance team training.

Teamwork & Communication (Section 6.1.6)

- Provide focused training and practice on effective teamwork practices, including communication during yard moves.
- Provide more training on conducting effective job briefs.

- Assign the more challenging yard jobs to regular crews.
- Conduct more extensive job briefs in cases where the crew includes individuals that are not part of the regular crew, are less familiar with the yard and/or are less familiar with planning and executing yard moves.
- Conduct CRM training.

Task Demands (Section 6.1.7)

- If possible, stagger yard crew shifts and/or reorganize the work to minimize multiple crews working in the same area.
- Consider adding a switch tender position at bottleneck switch locations where multiple trains are constantly coming through requiring switches to be repeatedly thrown.
- Consider adding a second yardmaster to distribute the workload during high workload periods whose sole responsibility is to manage the yard crews.
- Develop "web enabled" switch position indicators.

Organizational

Training (Section 6.2.1)

- Improve training by practicing scenarios encountered in RTS events.
- Provide more focus on effective communication and teamwork.
- Add training requirements for regular yard jobs.
- Provide "just in time" refresher training to employees who have not recently worked in the yard.

Crew Assignment & Scheduling (Section 6.2.2)

- Increase the pool of employees such that the utility list is long enough to cover necessary yard positions.
- Reserve utility list employees for yard jobs; do not call utility list conductors for passenger jobs.
- Allow employees who do not feel comfortable in the yard to decline a yard job or provide them with refresher training.
- When extra list crews work in the yard, the yardmaster should assign them less complex tasks and understand that these may take longer to complete.
- Provide monetary incentives for conductors to want to work yard jobs so that a pool of individuals with experience in yard work can be maintained to fill both regular yard work positions as well as extra lists that are dedicated to yard work.
- Examine scheduling practices – particularly extra and utility list job assignments – to evaluate the impact on fatigue and the role fatigue may play in RTS events.

Yard Design (Section 6.2.3)

- Reorganize the yard to facilitate efficient movement within the yard.

- When designing yards, eliminate as many hazards as possible.

Technology (Section 6.2.4)

- Consider switching technologies that can help reduce RTS events.
- Provide better job aids for yardmasters and yard crews.

Production Pressure (Section 6.2.5)

- Modify work flows in the yard to create a more even distribution of work within and across shifts.
- Where an even distribution of work is not possible, ensure experienced crews work high-pressure, complex jobs.

Appendix D. Example RTS Investigation Template

General Questions	Detailed Questions
Why was the switch in the wrong position?	Did the crew line the switch for the wrong track (against themselves)?
	Did the crew throw the wrong switch?
	Did someone on the ground check the switch position but misread it?
	Did a crew member walk the route to make sure the switch was in the correct position?
	Did the crew expect the switch would already be in the correct position (so did not check)?
	Did one or more crewmember have an incorrect expectation about planned route?
Why did the person on the leading end not detect that the switch was in the wrong position?	Could they see the switch points?
	Did they misread the switch?
	Did they correctly read the switch but not in time to stop?
	Did they misjudge the distance to the switch (e.g., in car lengths)?
How frequently might perceptual issues or yard design contribute to RTS?	What was the location of RTS?
	What equipment was involved in the RTS (locomotive, MU, rail cars, switch type)?
	Visibility (day, dark, dusk, dawn) at time of RTS?
	Weather at the time of RTS?
	Was the switch position around curve?
	Where were the crewmembers located at the time of the RTS event?
How frequently do RTS occur with crewmembers who are inexperienced or work extra board?	How many years in current craft do the involved employees have?
	What type of job assignment did the employees have (regular assignment, extra board)?
	What was the length of time in current assignment?
How frequently do RTS occur with crewmembers who are inexperienced or work extra board?	Was anyone on crew from the extra board?
	If yes, what extra board list?
	What were the total years of experience for each crewmember?
	Number of days worked in location in the last 30 days?
	When did you last receive training for yard skills?
	When was the last time you worked in this yard?
	When was the last time you were qualified (certified) on this yard?
How frequently might work schedule contribute to RTS?	
	Hours off duty prior to coming on duty?

General Questions	Detailed Questions
	Time reporting to duty?
	Length of time on duty before RTS occurred?
	Work schedule for previous 10 days prior to RTS?
How frequently might teamwork or communication errors contribute to RTS?	How many employees in the crew?
	Did someone outside the crew (e.g., a different crew) line the route against you after you had lined it, without letting you know?
	Were all crewmembers aware of the moves planned?
	Location of crewmembers at the time of RTS?
	Was there a miscommunication between the crew members?
	Was there a miscommunication with individuals outside the crew (Another crew, yardmaster)?
What is the impact of operations?	What operation was the crew performing (e.g., moving equipment in or out of shop; bringing equipment from/to revenue service)?
	What type of crew(s) were involved (yard crew, road crew, both)?
	Was there a delay in receiving the drill sheet?
	Was there a last minute change in the plan?

Abbreviations and Acronyms

Abbreviation or Acronym	Name
CRM	Crew Resource Management
FRA	Federal Railroad Administration
HOS	Hours of Service
OJT	On-the-Job Training
RTS	Run through switch
SCS	Safety Control Structure
STAMP	Systems-Theoretic Accident Model and Processes
STPA	Systems-Theoretic Process Analysis
UCA	Unsafe Control Action

Glossary

Term	Definition
Closure rails	Two fixed rails located between a switch point and a frog.
Crossover	A crossover is a turnout with a pair of switches that connects two parallel rail tracks, allowing a train on one track to cross over to the other.
Drill	The term drill is synonymous with the word "switch." This is a term of art used by some railroads.
Guard (check) rails	Short piece of rail placed alongside the main (stock) rail opposite the frog so that the wheels follow the appropriate track through the frog and the train does not derail.
Facing-point movement	Movement in which the switch points *point toward* the approaching equipment.
Frog	Metal casting that enables wheels to roll smoothly over the point where two rails cross.
Run-through switch event	Operating through a switch from the unaligned track.
Stock rails	Running rails immediately alongside of the switch rails against which the switch rails lay when in the closed position.
Switch	A mechanical device that guides trains and moving equipment on fixed guideways from one track to another. The terms points, switch, and turnout are often used synonymously even though they refer to different track elements.
Switch points	Movable rails which guide the wheels towards either the straight or the diverging track.
Switch rod	Metal part connected to the points that opens and closes the switch
Switch stand	Manual lever that opens and closes the switch by moving the position of the switch rod.
Switch target	A visual indicator usually constructed of 2 perpendicular metal pieces of different color, on the switch stand, that indicates the track for which the switch is lined.
Systemic factors	The combination of social, technical, and organizational factors within a system. Safety and efficiency are two examples of emergent properties that results from the interaction of multiple systemic factors.
Systems-theoretic process analysis	Systems-theoretic process analysis (STPA) is a hazard analysis technique based on systems theory.

Term	Definition
Trailing-point movement	Movement in which the switch points *point away* from the approaching equipment.
Turnout	A section of track that includes switches, frogs, guard rails, stock rails, and closure rails that enable trains and moving equipment to move from one track to another.