# Human and Organizational Factors of Positive Train Control Safety System The Application of High Reliability Organizing in Railroad

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On August 20, 1969, two Penn Central commuter trains collided head-on near Darien, Connecticut, killing four and injuring 43. That tragedy 45 years ago began the NTSB's call for development and implementation of Positive Train Control (PTC) systems. Since then, the NTSB has issued almost 50 PTC-related safety recommendations and has included PTC on its Most Wanted List every year from its inception in 1990 until enactment of the RSIA. Unfortunately, despite some progress in the four decades since that original recommendation, PTC preventable train collisions still occur. In this paper, we identify human and organizational factors that affect a successful PTC implementation and evaluate the application of High Reliability Organizing (HRO) characteristics in the implementation of this safety system.

## Introduction

An apparent rash of grave railroad accidents in the United States has not only damaged the railroad infrastructure and interrupted its operations but also endangered the safety and lives of train crewmembers and passengers. Railroads operate in high-risk, hazardous, and rapidly changing environments over long periods of time while facing the inevitable task of avoiding catastrophic events. Although train accidents are rare, they are highly visible, making the consequence of such failures disastrous. The fact that trains are major means of transportation around the world is another factor that makes these failures highly significant.

One of the accidents that had a major impact on the US railroad industry was the 2008 collision between a Metrolink commuter train and a Union Pacific freight near Chatsworth, California. The catastrophic result of the accident was the loss of 25 lives, 135 injuries, and millions of dollars in damages. Shortly after the accident, US Congress passed the Rail Safety Improvement Act that required Class I railroads to install Positive Train Control (PTC) systems on their tracks, which carry passengers or toxic-by-inhalation materials by the end of 2015. The deadline was later extended to December 31, 2018, in light of the challenges that railroad organizations had in implementing PTC systems.

High Reliability Organizing (HRO) methodology provides a systematic approach to organizational safety. This methodology creates a culture of mindfulness and can provide an extra layer of defense in railroad safety systems. To the best of our knowledge, and based on extensive research, HRO has not been implemented in railroads so much as in healthcare, nuclear, and chemical-processing industries, also there has not been a system that was designed with HRO in mind. Most studies have focused on transforming an organization into an HRO, while it would be more productive to design highly reliable organization.

In this paper, we first overview the history of railroad accidents that could have been prevented in the PTC technology was implemented and successfully working at the time of the accident. Next, we will review the HRO literature, specifically its application to the railroad industry. And finally, we provide a framework for adapting the HRO principles for a successful implementation of PTC technology.



## Railroad Accidents and PTC

On August 20, 1969, two Penn Central commuter trains collided head-on near Darien, Connecticut, killing four and injuring 43. That tragedy 45 years ago began the NTSB's call for development and implementation of Positive Train Control (PTC) systems. Since then, the NTSB has issued almost 50 PTC-related safety recommendations and has included PTC on its Most Wanted List every year from its inception in 1990 until enactment of the RSIA.

Unfortunately, despite some progress in the four decades since that original recommendation, train collisions still occur. Table 1 provides a list of railroad accidents between 1996 and 2015 that, based on NTSB investigations, could have been prevented or mitigated by the PTC technology. These accidents resulted in 84 deaths, 1,307 injuries, and millions of dollars in damages.

PTC cannot prevent all railroad failures; however, it can provide a critical redundancy in railroad safety systems that could stop train accidents. However, for PTC systems to work properly, the organizations need to develop a culture of safety. On April 3, 2016, Amtrak train 89 struck a backhoe with a worker inside while traveling 99 mph near Chester, Pennsylvania. Two Amtrak employees were killed, and 39 passengers were injured as the result of this accident (National Transportation Safety Board, 2017). PTC is designed to prevent the incursion of the train into the work zone, and that section of the track was also equipped with PTC (Laughlin, 2017). However, the accident was not prevented because the equipment used for maintenance were not detectable by the PTC system. This accident highlighted the importance of human and organizational factors in a successful implementation and performance of the PTC system.

## Positive Train Control (PTC)

In 1970, the NTSB first addressed the need to require a form of automatic train control. Since then, the NTSB has issued almost 50 PTC-related safety recommendations and has included PTC on its Most Wanted List every year from its inception in 1990 until enactment of the RSIA (NTSB, 2014). Although train accidents are rare, they are highly visible, making the consequences of such failures disastrous. The fact that trains are a major means of transportation around the world is another factor that makes these failures highly significant.

| Date | Accident | Injuries | Report |
|---|---|---|---|
| **1996 February 16** | Collision and Derailment of Maryland Rail Commuter MARC Train 286 and AMTRAK Train 29 (Silver Spring, MD) | 11 death 26 injured | (1997) |
| **1999 January 17** | Collision involving three Consolidated Rail Corporation freight trains operating in fog on a double main track near Bryan, OH | 2 death | (2001) |
| **2002 April 23** | Collision of Burlington Northern Santa Fe freight train with Metrolink passenger train (Placentia, CA) | 2 death 141 injured | (2003) |
| **2003 October 12** | Derailment of Northeast Illinois Regional Commuter Railroad Train 519 (Chicago, IL) | 2 death 117 injured | (2005) |
| **2003 November 15** | Collision of Union Pacific Railroad with a Burlington Northern Santa Fe Railway Company train (Kelso, WA) | 2 injured | (2005) |
| **2004 May 19** | Collision Between Two BNSF Railway Company Freight Trains (Gunter, TX) | 1 death 4 injured | (2006) |
| **2004 June 28** | Collision and derailment of UP Railroad train MHOTU-23 With BNSF Railway Company train MEAP-TUL-126-D (Macdona, TX) | 3 death 30 injured | (2006) |
| **2005 January 6** | Collision of Norfolk Southern Freight Train 192 With Standing Norfolk Southern Local Train P22 (Graniteville, SC) | 9 death 554 injuries | (2005) |
| **2005 July 10** | Collision of Two CN Freight Trains (Anding, MS) | 4 death | (2007) |
| **2007 November 10** | Collision of two Union Pacific Railroad freight trains (Bertram, CA) | 1 death | (2008) |
| **2007 November 30** | Collision of Amtrak Passenger Train 371 and Norfolk Southern Railway Company Freight Train 23M (Chicago, IL) | 71 injuries | (2009) |
| **2008 May 28** | Collision Between Two Massachusetts Bay Transportation Authority Green Line Trains (Newton, MA) | 5 injuries | (2009) |
| **2008 September 12** | Collision of Metrolink Train 111 with Union Pacific Freight Train LOF65-12 (Chatsworth, CA) | 25 death 135 injured | (2010) |
| **2009 July 14** | Collision of Dakota, Minnesota & Eastern Railroad Freight Train and 19 Stationary Railcars (Bettendorf, IA) | 2 deaths | (2012) |
| **2011 April 17** | Collision of BNSF Coal Train With the Rear End of Standing BNSF Maintenance-of-Way Equipment Train (Read Oaks, IA) | 2 death 2 injured | (2012) |
| **2011 May 8** | Collision of Port Authority Trans-Hudson Train with Bumping Post at Hoboken Station (Hoboken, NJ) | 37 injured | (2012) |
| **2012 January 6** | Collision between Two CSX Transportation Freight Trains (Westville, IN) | 2 injured | (2013) |
| **2012 June 24** | Collision of Two Union Pacific Railroad Freight Trains (Goodwell, OK) | 3 death 1 injured | (2013) |
| **2015 May 12** | Derailment of Amtrak Train 188 due to Over speeding (Philadelphia, PA) | 8 death 185 injured | (2017) |

**Table 1 - PTC Preventable Accidents (1996-2015)**

Shortly after the September 2008 accident between a Metrolink commuter train and a Union Pacific freight, US Congress passed the Rail Safety Improvement Act of 2008 (RSIA) on October 4. President George W. Bush signed the act into law on October 16. RSIA requires Class I railroads to install PTC systems on their tracks that carry passengers or toxic-by-inhalation (TIH) materials (Association of American Railroads, 2011). The law originally requires fully-functional PTC systems to be in place by December 31, 2015; however, in light of railroad challenges in implementing this technology, Congress extended the deadline by at least three years to December 31, 2018. There is a possibility for extension for two additional years if the organizations meet certain requirements (FRA, 2017). Approximately 70,000-80,000 miles of rail miles will be affected by the PTC mandate.

PTC is a generic term referring to a range of fully integrated technologies that overlay existing safety systems to prevent train-to-train collisions and improve worker safety. The current PTC system gives the notice of an impending penalty brake application if the train approaches a speed-limiting with full speed or if the train is traveling beyond speed restrictions. If the engineer does not take the necessary action, the system brings the train to a stop with a full-service brake application. It also prevents the train from moving beyond the speed restrictions. The conventional safety approach used signal systems with colored signs along the track, and daily bulletin reports to manage the speed of the train. If a train travels through unsignaled (dark) or automatic signal territories, movement authorities are transmitted to and confirmed with train crews over an analog voice radio system (Ditmeyer, 2011).

The PTC system consists of the wayside, office, and on-board elements. These elements are linked together through a communications network. This communications network will provide the communication links needed to transmit operational and safety critical data among the Back Office Server (BOS), the Onboard PTC package, and wayside Employee in Charge (EIC) mobile units for the movement authority.

## Application of HRO in Railroads

The fundamental characteristics of an HRO foster a culture of trust, shared values, unfettered communication, and process improvement. It nurtures, promotes, and takes advantage of distributed decision-making, "where the buck stops everywhere".

According to Weick and Sutcliffe (2001), "hallmarks of high reliability", or major characteristics of HRO while "anticipating and becoming aware of the unexpected", include 1) Preoccupation with failure, 2) Reluctance to simplify interpretations, 3) Sensitivity to operations. In addition, when the "unexpected occurs", HROs attempt to contain it by 4) Commitment to resilience and 5) Deference to expertise. Not all of these characteristics apply to all the organizational processes.

The application of HRO starts with deep knowledge of the technologies that are used in the organization, and a clear understanding of roles and responsibilities. Their organizations foster a culture that values diversity and encourages productive collaboration. The concept of complex adaptive systems enables organizational change in the system and is internalized in an HRO through systems, processes, culture, and education (Carnes E., 2010).

HROs strive to minimize the gap between "work-as-imagined" versus "work-as-done". These organizations develop detailed operation procedures, and due to their safety-sensitive nature strive to perform within the boundaries and safety limits. However, it a known fact that there are discrepancies between plans and the actual performance of the sub-systems ($\Delta W_g$). $\Delta W_g$ represents "what" is not working that puts us out of the physics-based safety basis, and it is determined using Causal Factors Analysis (CFA). The "why" in $\Delta W_g$ is determined using some of the organizational and culture investigative CFA tools. The goal is to design, implement, and manage work and processes in a way that minimizes this gap (Hartley, High Reliability Organizations and Practical Approach, 2011).

HROs aim to empower the employees, especially experts in different technical areas, and experts are not necessarily those with the greatest experience in the organization but those who have the best knowledge of the task on hand. Empowerment involves the decentralization of decision-making authority and responsibility, and it purportedly improves organizational flexibility by permitting more localized adjustments (Bigley & Roberts, 2001). In other words, when the hazardous situation happens, HROs flatten their command structure and give the person with more expertise more authority to make decisions. This way they expedite the decision-making process, which is a crucial factor to a successful emergency response.

organizational culture, and flexibility are major factors in risk mitigation of large-scale complex organizations (Grabowski & Roberts, 1996).

The main goal of organizations operating in the mass transportation industry is the safety of their passengers, and railroads are no exception. Passenger safety on railroads could be achieved by a clear definition of essential fundamentals of a safe operation and forbidding operation outside this definition (Hale & Heijer, 2006). To the best of our knowledge and based on extensive research, HRO has not been implemented in railroads so much as healthcare, nuclear, and chemical-processing industries, also there has not been a system that was designed with HRO in mind. Most studies focus on transforming an organization to an HRO, while it would be more productive to design highly reliable organizations. One of the few studies in this field divides reliability failures into two main categories of organizational vulnerability to disaster at any particular time, and the gradual degradation processes leading organizations into vulnerable states (Busby, 2006).

Failure in complex systems, include equipment failure as well as human error. Traditional risk/reliability studies assumed that the majority of system failures were due to hardware failures, but it has been found from the accident history that human error causes 20–90% of all major system failures (Verma, Ajit, & Karanki, 2010). In railroads, as an example of a complex, high-risk system, human factor related errors caused 39% of the accidents (Federal Railroad Administration, 2014), and introducing a new technology in this system would affect organizational, technical, and human elements of the system.

| Preoccupation with Failure | Reluctance to simplify | Sensitivity to operations | Commitment to resilience | Deference to expertise |
|---|---|---|---|---|
| Detect small discrepancies | Do not generalize | Identify trends and anticipate impact | Commit to resilience | Shifting the decision making to the people at the "sharp end" |
| Always look for small, emerging failures in train operations under PTC, because they could indicate a potential problem in the system. Update deliberately and often. | Treat the unexpected PTC events/failures with concern rather than rationalization that it is normal. Make fewer assumptions, notice more and ignore less. | Look for moment-to-moment changes in performance. Pay attention to what is actually happening on the track and its surrounding, regardless of intention, design and plans. | Strengthen the ability to detect and contain unplanned events and resume PTC operation. | Remember that it is the people on the front line of the operations, who have the answer to the problem at hand. |
| PTC | | | PTC Failure | |

**Table 2 - HRO adaptation to PTC**

The culture of a HRO is one that anticipates failures within its organization and sub-systems and works diligently to avoid errors and minimize their impact. This preoccupation with the possibility of failure leads to a continual state of 'mindfulness' combined with a strong desire to be a 'learning organization' (Weick, Sutcliffe, & Obstfeld, 2008). HROs communicate by paying attention to system interfaces,

### Adaptation of HRO Principles for Railroad Operations under PTC

One organization attempted to adopted HRO characteristics to petrochemical operations and translating them to their own language. Inspired by their work, we integrated the five HRO characteristics into the railroad operations under PTC (Table 2). The unexpected issue, in this case, would be the failure of the PTC system. In addition, resilience is the ability of the system to reinitiate PTC or transition to the previous safety operations. The first draft of the adaptation of HRO principles, presented in table 2, was developed based on the extensive study of HRO and PTC literature. The result was consulted with HRO and PTC experts in multiple sessions to develop an adaptation that best represents the HRO characteristics in PTC operations.

Research on organizational culture and safety has outlined developing a system of process checks to spot expected and unexpected safety problems as one of the main processes that are useful in developing HROs (Wong, Desai, Madsen, Roberts, & Ciavarelli, 2005). To integrate the HRO principle into PTC operations, we adopted Weick and Sutcliffe's book, managing the unexpected (2015), as a guide and following the steps they outlined for implementing each HRO principle. It should be mentioned that these checklists are primarily PTC oriented, and not targeted towards general organizational practices. In developing the checklists, we incorporated the findings of the interviews and site visits that conducted as part of the PTC implementation project, as well as the findings of the research studies to customize the checklist for PTC operations. Here we provide a brief summary of the checklist due to space limitations.

The first checklist is associated with preoccupation with failure. Weick and Sutcliffe define failure as a "lapse in detection". Such a lapse could happen due to a lack of anticipation of what and how things could go wrong, failure to catch deviations as soon as possible, or lack of investigation of prior unexpected events. Using this approach, questions that could help detect signs of failure in the PTC systems are as follows: 1) What does failure mean in this operation? 2) What is the organization's approach toward PTC failures once they happen? The definition of failure could change in different stages of the operation (design, implementation, etc.). The PTC system is currently at the final stages of implementation, and it is being evaluated for full operation. Therefore, failure could be defined as unsuccessful (annulled, failed, or missed-opportunity) PTC runs and delays in train operations due to PTC events (all enforcements, red fences, IT problems, and technical problems) and cascade events.

The second checklist addresses "reluctance to simplify" characteristic of HROs. Simple rules of thumb are easier to follow, therefore more appealing. However, they could result in undetected weak signs of potential failures and increase the probability of unreliable performance. This principle is about the concepts people have at hand to do the detecting and recovery. The following questions could help the organization inquire about their approach towards reluctance to simplification: 1) How do people respond to unexpected PTC events? 2) What is the organization's approach towards challenging the status quo? Are people encouraged to ask questions and express their views at all levels of the organization? 2) How do people interact with one another?

Weick and Sutcliffe define sensitivity as a "mix of awareness, alertness, and action that unfolds in real time, and that is anchored in the present" (Weick & Sutcliffe, 2015, p. 79). The two basic reliability mandates in railroad systems are 1) keep the train operations flowing and 2) protecting the system, which in this research implies the PTC system (safety feature), as well as the train operating systems. The following are examples of the qualities related to sensitivity to operations that affect how well a railroad organization can manage unexpected PTC events: a) A distracted train engineer is a danger to himself or herself, to the train's passengers, and also vehicles and people along the track. b) Even the most experienced engineer, conductor, or dispatcher can make mistakes if they are unaware of danger. c) Maintain situational awareness. Overreliance on PTC technology could affect the situational awareness of the train engineer. It is especially dangerous since the PTC system is blind to people and objects on the track.

The fourth checklist addresses the "commitment to resilience" characteristic of HROs. Interruption is a constant occurrence in HRO operations. However, they are capable of adjusting their functions prior, during, and following interruptions and bounce back to the same functions (Hollnagel, 2009). Strengthening the organization's commitment to resilience requires inquiries into learning, knowledge, and capability development. In the case of PTC implementation, the definition of normal operations changes based on the different stages of implementation. At the time that this report is drafted, if there is a problem with the PTC system that cannot be resolved in under five minutes, the PTC system is cut-out and the train operation is resumed to the Centralized Train Control (CTC) system. However, after the PTC is fully implemented and goes into operation, all trains must run under PTC at all times. Considering this issue, questions that could provide a better understanding of the resilience of the system are: 1) Is the organization concerned with improving people's knowledge and ability to respond to unexpected events? 2) What is the organization's policy regarding resource assignment for training people in their areas of expertise? 3) Do people in the organization reach out to people in other departments to solve problems?

The final checklist is focused on "deference to expertise". One of the distinct properties of HROs is migrating decision making. In other words, decisions are pushed down to the lowest levels of the organizations, when they require quick decision making (Roberts, Stouts, & Halpern, 1994). In order for these decisions to migrate to experts, the organizational hierarchy needs to be loose, identify the experts, and envision a decision-making mechanism to reach the experts in time (Weick, Sutcliffe, & Obstfeld, 1999). Deference is an activity that happens when there is an interruption in the flow of the system caused by an unexpected event. In the case of railroad operations under PTC, the dispatcher plays a vital role. They need to maintain high performance at peak times, look for potential solutions, gather and verify information from multiple sources, and maintain the reliability of the system. The following questions suggest how deference to expertise could be practiced in a railroad organization: 1) What is the organization's culture in regard to expertise? And how do people value expertise and experience over rank? 2) What is the organization's strategy in response to unexpected events and involving the most qualified people vs. rank in decision making? 3) Do people know who has the expertise in the face of an unexpected interruption in the system? And how easy it is for them to reach that person?

## Conclusion

For the foreseeable future, despite increasing levels of computerization and automation, human operators will have to remain in charge of the day-to-day control and monitoring of complex technological systems, since system designers cannot anticipate all possible scenarios of failure, and hence are not able to provide pre-planned safety measures for every unexpected event and contingency. In other words, "Operators are maintained in [complex technological] systems because they are flexible, can learn and do adapt to the peculiarities of the system, and thus they are expected to plug the holes in the designer's imagination" (Rasmussen, 1980, p. 97). Overreliance on technology could potentially hamper the reliability and resiliency of the organization.

For safety-sensitive operations, like railroads, there are always unforeseeable events that should be covered by safety systems but are not because of one or more unrecognized elements. That is why HRO acts as a safeguard against events that we cannot wholly understand. Integrating HRO principles in the system from the early stages of PTC implementation not only ensures the achievement of the key objectives of this technology but also mitigates those events that PTC is not designed to prevent. Events like grade-crossing accidents or operators' overreliance on the technology that might affect their situational awareness, hamper their performance, and eventually the overall safety and reliability of the system.

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