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Trust, Public-Private Partnerships, and Transportation Safety:

Applicability of the Aviation Model for Rail Transportation

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Executive Summary

With a continuous decline in fatal accidents since the 1950s, the aviation industry during the mid-1990s viewed aviation as an extremely safe mode of transportation. High-profile accidents by United States air carriers that occurred during 1994 to 1996 however called into question whether the aviation accident record could reliably stand as the measure of safety health and culture. As a result, the Federal Aviation Administration undertook a unique approach to collaborating with industry to promote aviation safety by developing rigorous Safety Management Systems. This effort culminated in a highly successful public-private partnership devoted to continuous improvement in aviation safety.

The Department of Transportation recognizes the success of the aviation model, wants to build on that success, and is proactively looking for opportunities to use the lessons learned from aviation in the rest of the transportation system. Given the many similarities between air and rail transportation, recent high-profile railroad accidents raise the question of whether rail transportation may benefit from using aviation's collaborative approach to safety. This paper describes the factors contributing to the success of that approach, including instilling a safety management system and culture, evolving the regulatory and legal framework, and collaboratively sharing and learning from data. Through the sponsorship of the Federal Aviation Administration, The MITRE Corporation's Center for Advanced Aviation System Development pioneered safety data sharing and analytics to identify and address proactively accident precursors.

To understand the evolution of this approach, we present the historical context of the necessary human and system elements of the aviation domain, along with an analysis of how the Federal Aviation Administration-industry trust relationship evolved into the current culture, and how MITRE evolved our role. We also draw parallels between aviation and rail transportation and describe opportunities for applying aviation's approach to rail safety.

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1 Introduction

Air and rail transportation are highly effective in providing safe, high-speed service to long-distance destinations. Beyond their obvious differences of aluminum-wing-on-air and steel-wheel-on-rail, these industries share many characteristics. In both cases, the public has been fascinated by their elegance and convenience, yet also apprehensive of the associated dangers. While every transportation fatality is indeed a tragedy, fear and a lack of tolerance for multiple fatal outcomes in commercial transportation drive the emphasis on continuing to lower the probability of aircraft or train accidents [1].

Improving safety within both of these transportation modes remains an extremely high priority, and accident rates have impressively reduced over their histories. Two decades ago, when the aviation community witnessed six major high-profile accidents in two years, a White House investigatory commission recommended how to proceed—summed up in the opening sentence: “Change.” [2] When the Federal Aviation Administration (FAA) responded by adopting a more collaborative approach to aviation safety, the trust the FAA fostered within the U.S. aviation industry facilitated a partnership that further reduced accident rates to unprecedented lows. The last fatal accident involving a scheduled U.S. commercial passenger air carrier occurred in February 2009 [2]. The last fatal accident involving a scheduled U.S. commercial freight air carrier occurred in August 2013 [3]. Low accident rates have led other transportation agencies to take note. Leadership within the National Highway Traffic Safety Administration (NHTSA) asked of FAA, “What did you do to make commercial aviation so safe? We want that safety record. We want our trend line to flat line—just like you” [4].

In comparison to highways, rail transportation is very safe [5]. So why should the rail community adopt the aviation system’s approach to safety to fix something that, by many accounts, is not broken? The rail industry continues to maintain a strong commitment to continuously improving safety by rooting out the causal factors of rail accidents. Innovative methods for the inspection of infrastructure and rolling stock can now generate vast data sets to predict failures before they happen. But no amount of inspection could have prevented the 2013 accident in Lac-Mégantic, Quebec, or the 2015 Amtrak derailment in Philadelphia, Pennsylvania [6] [7]. Even Positive Train Control (PTC) systems, which are being implemented to intervene in many cases of human error, may have directly prevented only the latter event. Because PTC is capable of generating vast amounts of operational data, it could contribute by providing valuable insights when fused with other data sources to address accidents it was not designed to prevent.

By applying lessons learned from our experiences in aviation, the MITRE Corporation’s Center for Advanced Aviation System Development (MITRE CAASD) asserts that, given the many similarities between air and rail transportation, the rail industry is poised to benefit greatly from a similar collaborative and data-driven approach to safety. We assert that this is achievable through effective application of the principles of Safety Management Systems (SMS), an understanding of aviation’s successful public-private partnership, collaborative data-sharing and analytics, all underpinned by a positive safety culture. To understand the evolution of this arrangement, we describe the historical context of the behavioral, technical, and regulatory elements. We also provide an analysis of how the industry-government trust relationship evolved into the current approach. We envision that lessons learned from aviation’s safety history could accelerate the integration of these processes into the rail domain.

2 Safety Framework in Aviation

The FAA describes SMS as "a formalized and proactive approach to system safety," as does the International Civil Aviation Organization [8]. Prescribing a framework for a manufacturer or service provider to integrate safety management into its day-to-day business activities, SMS provides the necessary components to enhance safety and to ensure regulatory compliance. SMS features processes that identify potential breakdowns before an unsafe condition can result. It promotes informed changes in an organization and a positive culture of collaboration to expose new opportunities for reliable information capture. Additionally, the scalability of SMS enables its broad use regardless of organizational size, and it can act as a vehicle for strengthening management-labor relations [9].

SMS comprises four key components [10]:

> **Safety Policy** outlines the processes required to achieve the desired safety outcomes. By establishing senior management commitment to these processes, this component establishes and promotes safety culture throughout the organization.
>
> **Safety Risk Management** (SRM) is a formalized process to assess system design by identifying and analyzing hazards as well as to establish controls to manage those risks.
>
> **Safety Assurance** requires information capture to ensure that risk controls, designed through the SRM process, achieve their intended objectives throughout the system life cycle. Safety Assurance also includes revealing hazards/controls not previously identified during the SRM process.
>
> **Safety Promotion** requires creating a positive safety culture environment to enable the achievement of safety objectives.

SMS relies on both human and machine detection to discover safety hazards within the operational system. Data from a variety of sensors can be assembled to present high-precision pictures of the system with much more accuracy than by human detection. SMS is designed to rely on these data, but also on the human ability to anticipate hazardous outcomes from perturbations in the system and expose these detections.

We illustrate safety reporting and positive culture in SMS in Figure **2-1**, depicting both human (left loop) and automated machine sensors (right loop). These two inputs comprise safety hazard data that an analysis team can use to identify hazards, precursors, root causes, and the necessary corrective actions. The success of this process often depends on the richness of the data collected from both sources. Multiple accounts of the same event yield more depth and are enriched by multiple sensor systems capturing events or by multiple witnesses submitting detailed reports.

Richness of data alone is insufficient for an effective SMS; the data must be trustworthy and reliable. Both forms of sensing—human and machine—require investment, management, and upkeep to operate reliably. Capturing reliable information from *human sensors* requires investment in training and in a positive safety culture that promotes action and trust. Following accidents, a commonly heard remark is, "I knew that was going to happen eventually." This remark indicates that individuals closest to the accident were able to identify hazards but lacked the authority, motivation, or efficacy to pursue corrective actions [11].

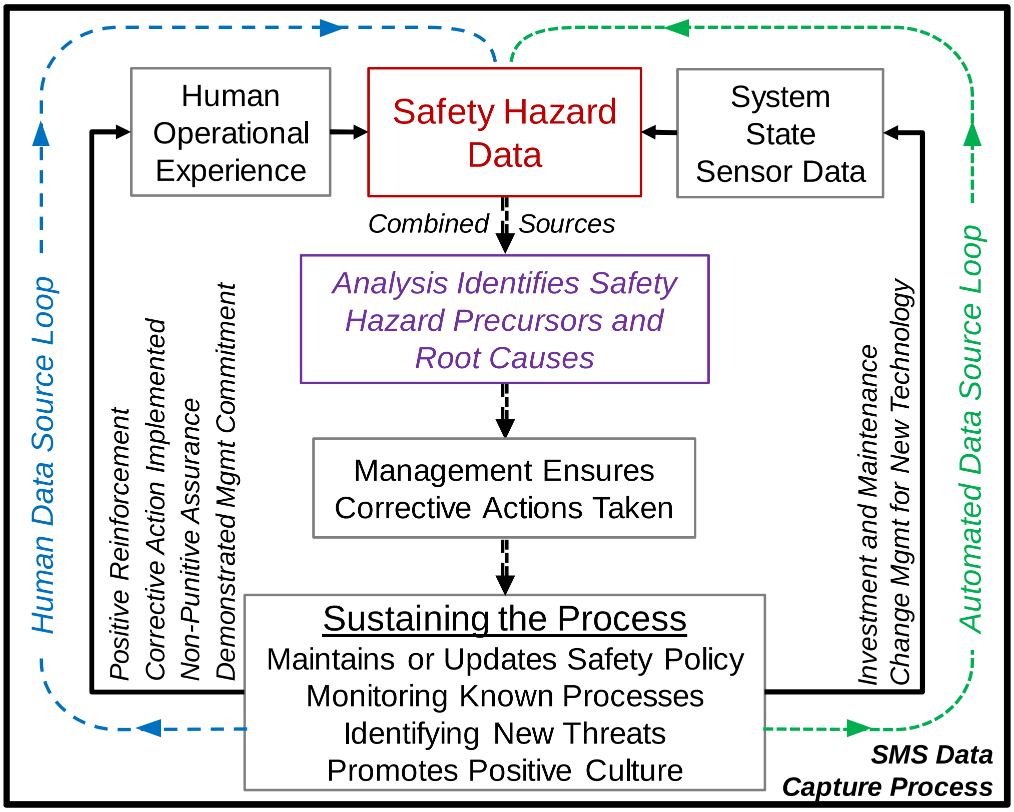

Figure 2-1. SMS Safety Data Capture Process

The four components of SMS tie to one another by a currency of trust. As Barnard (2013) describes, a natural "tension exists between the desire to obtain safety data from one of the persons most likely to be aware of a specific incident—the person who made a mistake—and the desire to penalize such persons for their mistakes." [12]. The success of an SMS program hinges on trust. Employees who are reporting on safety hazards or events must trust that they will remain free from punishment by management. And management must trust employees to provide reports, and not simply ignore safety hazards or foretell events. This type of organizational culture that actively protects those who report hazards (except in cases constituting criminal behavior or willful disregard for safety) defines "just culture" [13].

Punitive culture has roots in the Industrial Revolution, and we understand it well. The potential for punishment raises awareness in employees, and motivates care before acting. On the other hand, an employee's fear of being blamed or punished for errant actions can degrade trust, and reduce his or her willingness to report on the associated hazardous situations.

Trust and information-sharing provide the basis of a positive safety culture. When an organization places high priority on proactive safety, and values trust and information-sharing, the workforce perceives and responds to that priority eliciting a "safety climate" [14]. With an adequate level of trust and commitment, employees feel incentivized and empowered to report risks and share knowledge of risk factors without fear of reprisals (unless their actions were unlawful or reckless) [15]. Reported events become instructive, transforming the organization's knowledge and ability to gauge risk.

3 A Historical Basis for a Collaborative Safety Partnership

Early in aviation and rail history, policy-makers reacted primarily to major accidents and exhibited a blame-based safety culture. Industry introduced safety technology with trepidation, mainly when tragedy insisted on quick adoption. As the decades progressed, the government began to show progressive signs of investing in research programs to dissect safety hazards. Early examples in aviation during the 1940s were simply an experimental testing of safety concepts, such as stall warning devices and approach lighting systems.

In 1956, when a well-publicized midair collision occurred in clear and uncongested skies over the Grand Canyon (an accident that punctuated a string of sixty-five midair collisions in just over five years), it was clear that more aviation safety research was critically needed. Around that same time, railroads were changing rapidly. Mergers of large and small railroads were occurring that blended safety methods from each proponent together, with mixed results. Like the aviation field, a string of 20 high-profile rail accidents in the 1950s punctuated the need for further safety improvements.

The 1960s marked a significant shift in the safety mindset in aviation and rail. At the close of the 1950s, in response to a string of aviation accidents and public concern, the Department of Transportation Act (DOT) of 1966 set up the FAA and Federal Railroad Administration (FRA). FAA made the commitment to intensify air traffic safety methods, safety policy, and forward-thinking safety research. With the advancement of safety data collection technology such as secondary surveillance radar systems and Cockpit Voice Recorders to accompany the widespread use of aircraft Flight Data Recorders, FAA identified the need to partner with trusted independent advisory organizations to provide expert analytics. In 1961 FAA employed the help of Flight Safety Foundation to investigate the mid-air collision epidemic and compile statistical data, perform analyses, and provide recommendations. The study was based on pilot reporting and identities were protected from FAA to encourage pilot participation. This approach led to generating information regarding more than 2,500 incidents over a one-year study period. The final report recommended that FAA continues the collection of anonymized reports; however, the program did not extend beyond the study period [16].

At the end of the decade, FAA began a four-year study on the causes of near midair collisions. This study employed a non-punitive, cooperative reporting approach. To encourage participation, FAA granted limited immunity from disciplinary action to any person involved in a voluntarily reported near midair collision during the study. However, when the pilot study period terminated in 1972, so did the reporting immunity policy.

During this period, the FRA also made strong commitments to rail safety. The NTSB would later show that during this period about a third of collisions and derailments were attributed to incorrect operating practices and employee negligence [17]. By assuming the powers of the Interstate Commerce Commission’s Bureau of Railroad Safety, the FRA sought to shift the focus of rail safety regulation to people familiar with the industry [18].

Public pressure over rail accidents also prompted Congressional investigations, which concluded that the vast majority of accidents were caused by factors that were not covered under existing statutes. The result of this shift in focus was the Federal Railroad Safety Act of 1970 which gave the FRA rulemaking authority to "promote safety in all areas of railroad operations and to reduce railroad related accidents, and to reduce deaths and injuries to persons and damage to property caused by accidents involving any carrier of hazardous materials." [19] Annual safety records became a requirement for certification of railroads from the States to the Secretary of Transportation. The government listed highway-rail grade crossing incidents as the top safety task to research and address. These remain a top safety priority today. Class I railroads formed under the Regional Rail Reorganization Act of 1973 [20] required railroads to adopt safety procedures and cultures from merging railroads.

In the early 1970s, public confidence in the aviation system started to unravel, fueled mostly by the increasing number of hijackings and high-profile accidents. By the end of 1974 (aviation's worst year for fatalities), a biting congressional report and television documentary illustrated the agency's sluggishness on safety issues and further raised public concern [21] [22]. Prompted by these criticisms, in 1975, FAA established the Aviation Safety Reporting Program (ASRP) to enable pilots or controllers to identify any potentially unsafe conditions and not simply to report near midair collisions. To again encourage reporting, this broader safety program employed the same arrangement used during the midair collision program: granting immunity from disciplinary action for those reporting promptly. FAA retained the right to take appropriate punitive action in cases of gross negligence or willful disregard for safety.

Due to limited protections granted under the aviation reporting program, the aviation community still feared disciplinary consequences and employees submitted very few reports [16]. The next year, FAA transferred control of the program to a neutral third party—the National Aeronautics and Space Administration (NASA)—to handle the data, protect confidentiality, and process reports. The FAA intended to overcome fears that genuine anonymity and immunity were not being provided. The government named the program the Aviation Safety Reporting System (ASRS). This program is the aviation equivalent to rail's Confidential Close Call Reporting System (C3RS) managed by NASA [23].

In terms of technology and its role during this timeframe, the growing introduction of computers in aviation, safety-related sensing equipment, and data-recording technology rapidly expanded capabilities for weather sensing, communications, on-board collision avoidance, and flight tracking. Air Traffic Control (ATC) radar systems saw increased abilities to detect, record, and share flight data between radar facilities, and the amount of data collected by Flight Data Recorders expanded.

In rail, the FRA enacted the Rail Safety Improvement Act (RSIA) of 1988 [24]. This act mandated event recorders on the railroads, requiring rail operators to record locomotive control inputs and other safety-related data.

Building on tensions from the previous decade, aviation in the 1980s experienced growing mistrust amidst the airlines, the government regulators, and the traveling public. Labor strikes by airline pilots and air traffic controllers, significant airline merger activity, and widespread industry drug and alcohol abuse continued to stoke the discord between workforce, management, regulator, and public [25]. In other circumstances FAA "delegated" technical assessments directly to the manufacturers, relying on localized "trust-relationships" rather than directly assessing technology [26]. This behavior served to undermine the overall ability of the FAA to effectively regulate the industry.

In 1988, a Congressional report recognized a need for industry collaboration and recommended key safety management and system operating improvements considering the new order set by the Airline Deregulation Act of 1978:

> "Airlines themselves keep vital safety information, and FAA could benefit from working more closely with airline data, although ensuring the confidentiality of the air carrier data

> is crucial. FAA could encourage improved air carrier presorting of sensitive safety data, such as incidents, by guaranteeing that no penalties will result from reported information and by making *non-reporting* a violation. Additionally, access to airline computer systems, such as maintenance management systems, could enhance FAA's monitoring capabilities. One major airline already provides FAA on-line access to its computerized maintenance database." [27]

The underlying concept resembles the core of the current-day public-private partnership model, but the recommendation lacked a key ingredient – trust. By insisting that airlines grant FAA direct access to airline computer management systems and penalizing non-reporting, the recommendation revealed the government's lack of trust for the industry and its need to assert authority over the industry. The mechanism for a collaborative safety process may have been prescribed, but without an investment in building trust as a foundation, the industry maintained its status quo for nearly another decade.

As in the past, tragedy spawned action. During a period between July 1994 and July 1996, six high-profile major accidents occurred, resulting in 737 fatalities. Midway through this string of accidents, in January 1995, FAA held an industry-wide summit setting a goal of zero accidents through key areas, including safety, maintenance, and operational data collection and sharing. This decision later culminated in the Aviation Safety Action Program (ASAP). ASAP was enabled through the agreement with airlines and pilots' associations to begin the Flight Operations Quality Assurance (FOQA) program, which collects Flight Data Recorder data to analyze safety trends rather than conduct only post-incident investigations. It granted FAA access to the data, with pilot identities deleted.

Following the ValuJet crash in the Florida Everglades in May 1996 and the midair explosion of TWA Flight 800 two months later, President Clinton announced the White House Commission on Aviation Safety and Security to review the state of aviation safety. The findings of the Commission challenged the government and industry to reduce the accident rate by 80 percent over ten years [2]. A Congressional commission, the National Civil Aviation Review Commission, followed up in December of 1996 with a recommendation that FAA and industry work together to develop a comprehensive, integrated safety plan to implement existing safety recommendations [28].

These government reports recognized that the forecasted air traffic demand would exceed the limitations of existing safety strategies. The FAA responded with an approach that was a radical departure from the typical model in which the industry was regulated from a position of authority. The decision to engage in collaborative efforts to develop mitigations provided the framework for the formation of a public-private partnership for aviation safety.

4 Ingredients for a Collaborative Partnership

FAA enabled the creation of a public-private partnership by separating the internal safety improvement organization from the regulatory organization. This separation permitted the safety improvement organization within FAA to create a partnership with industry based on equality.

Formed in 1998 as the Commercial Aviation Safety Team (CAST), this unique group committed to working together to sift through large numbers of proposed safety improvements [29]. Their initial goal was to prioritize mitigations by impact, feasibility, and cost through consensus agreement. Rather than being forcibly required by regulatory compliance, implementation was voluntary. Examples include aircraft and avionics manufacturers committing to functionality improvements and airlines upgrading airframes and changing flight crew training [30].

Since its inception, participation in CAST grew to include virtually all government and industry sectors of aviation, which enabled the implementation of CAST safety enhancements to be impactful and widespread.

As stated, the original CAST goal was very aggressive: to reduce the commercial aviation fatality rate in the United States by 80 percent in 10 years. CAST tackled this challenge by developing a process to identify and prioritize top safety areas through analyses of accidents and incidents and the chain of events leading up to them. Once an underlying problem was understood, the CAST membership identified and implemented high-leverage interventions or safety enhancements to reduce the fatality rate in these areas.

This model has been extremely successful for the U.S. aviation industry. Accident data from 1998 to 2008 show that the fatal accident rate (with one or more fatalities per departure) of commercial air travel has been reduced in the U.S. by 83 percent, exceeding the original CAST goal. Since then, CAST has set new goals: to reduce the U.S. commercial aviation fatal accident rate by at least 50 percent between 2010 and 2025 and to work with international partners to reduce fatality risk in worldwide commercial aviation [31].

The analysis of commercial aviation accidents provided a solid foundation for the initial CAST focus. The CAST approach was so successful that fatal accidents became a rarity. That required an innovative approach to broadening the initial focus. The group turned their sights to more prognostic analyses using events that did not result in accidents but provided an indication of safety risk. This required operators to continually collect data through the voluntary programs enacted earlier, such as the FOQA and ASAP and its ATC analog, the Air Traffic Safety Action Program. These rich sources of information provide insight into millions of operations and help to identify potential systemic safety issues and trends. Traditionally, the sponsoring airline or FAA organizations kept these data sources. These organizations were willing to share these data sources at the national level and analyze them collectively and collaboratively to identify risks proactively.

Determining the accident precursors would require dedicated technical expertise to mine and analyze this massive and constantly growing data set. So the Aviation Safety Information Analysis and Sharing (ASIAS) program was initiated in 2007 to perform the data analytics. Learning from past experiences, FAA once again decided on employing a neutral third party—its Federally Funded Research and Development Center (FFRDC) operated by MITRE CAASD—to house, protect, and analyze the data supporting the needs of the CAST partnership.

Data sharing in the ASIAS program was entirely voluntary. Starting with seven participants, it has grown remarkably widespread. Currently, FAA and most air carriers, manufacturers, associations, and employee groups contribute data or advisory support. In fact, more than 40 airlines representing 99 percent of commercial aviation operations voluntarily contribute proprietary data. MITRE CAASD handles the data under strict confidentiality protections and uses data in aggregate analyses of systemic safety problems. MITRE CAASD mines and analyzes vast databases to track previously identified risks that require continuous monitoring, or to identify new risks or threats that have not been revealed by forensic investigations.

The ASIAS program monitors known risks, those which have been identified previously and currently controlled. ASIAS analyzes the “uneventful” flights (those that did not experience an accident or significant safety event) to monitor for these known risks, which are precursors that have shown links to accidents. These risks include a characterization of the rate of occurrence of these precursors, and conditions for these precursors to occur. ASIAS participants and CAST use the information from known risk monitoring to track the effectiveness of mitigations that were implemented to reduce these risks and to provide an alert if there is an upward trend in a known risk.

In one example, ASIAS extracted information about safety system alerts that warn pilots about terrain proximity. ASIAS metrics, based on captured flight parameters, were used to identify hotspots (areas of greatest alerts concentration). Combined with an analysis of voluntary text reports from pilots and controllers, the data sources reconstruct conditions that lead to alerts. With this information, CAST collectively developed safety enhancements for aircraft equipment upgrades and proposed route changes to reduce the frequency of proximity to terrain warnings. Once mitigations are in place, ASIAS continues to monitor these known risks to measure the effectiveness of the mitigation.

The ASIAS program also seeks to identify latent risks, which are those that may have been present for years, setting up conditions that could ultimately result in an accident. An example of a latent risk is aircraft wing flap misconfiguration (or reconfiguration) during takeoff. While the importance of correct flap configuration is well understood, ASIAS first measured the incidence of misconfiguration during takeoff using a large data set from airline operations. The new information about the rate of occurrence and the conditions associated with these events contributed to the FAA issuing an official Safety Alert for Operators and CAST efforts to develop new mitigations to reduce the incidence [32].

Finally, the ASIAS program assesses the potential for emerging risks associated with the introduction of new operations and equipment, which may inadvertently contribute to unintended effects or anomalies. ASIAS analysts identify aspects of new operations and equipment that have safety relevance so that new threats can be identified early and resolved before they contribute to an accident.

The public-private partnership has produced numerous aviation system safety benefits. CAST developed more than 100 safety enhancements, with the majority supported by detailed ASIAS analytics. By combining incident reporting with detailed data on operational activities, the identification of precursors has been much more successful via collaboration than within individual organizations alone [33].

5 Structuring the Collaborative Public-Private Partnership

We structure the collaborative public-private partnership for data sharing and safety improvement based on the CAST and ASIAS model. The public-private partnership convenes through a consensus decision-making group including representatives from both industry and regulators. These individuals work together to make consensus decisions (Figure 5-1 top-center box) on salient safety-related issues in the form of policy recommendations and voluntary corrective actions or mitigations.

In the aviation model, CAST is the public-private partnership, and the ASIAS program is the neutral third-party analytical support. The success of this model hinges on a shared trust between all of the parties involved. In this model, the ability of the neutral third party to steward data in a manner that shields it from regulatory inspection and public access granted via the Freedom of Information Act (FOIA) enables industry partners' trust. The industry agreement to provide industry perspectives and participate in consensus decisions is also a critical element of this model's success.

The contributions the parties make (also labeled in Figure 5-1) consist of the industry membership providing operational data and individuals' confidential reports. While optional for the success of the program, the CAST model enables industry partners direct access to specifically approved benchmarks (shown as the dashed line in Figure 5-1). The regulators provide government-collected data and direction in the form of safety-related research needs. Also, in this model, the regulators provide funding to the neutral third party for their analytical services, although other structures could likely be as successful. Finally, the consensus decision-making group contributes goals and requirements to the analytical third party and in return receives alerts, metrics, trends, and precursors. The neutral third party does not identify and communicate mitigations, however. Consensus decisions in the Public-Private Partnership develop the identification and communication of mitigations.

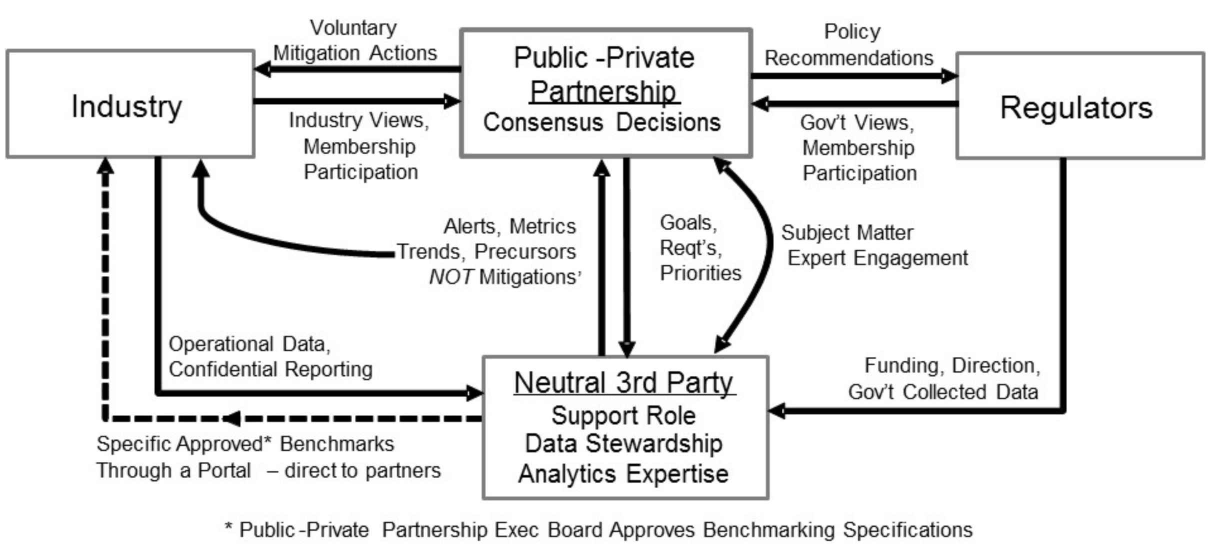

Figure 5-1. Structure for a Public-Private Partnership for Safety

Four high-level stages are necessary to enable a successful partnership, which is as follows:

Identify Barriers: Determine laws and policies that prevent non-punitive reporting of incidents (free of disciplinary actions), and get buy-in from legal and operational personnel. Decisions on how culpability is handled, are required.

Develop Policies: Develop confidential reporting procedures and structures to enable de-identification/protection from FOIA and other legal proceedings. Remove barriers to make reporting easy, determining what is mandatory, what is voluntary, whether follow-up interviews are allowed, etc.

Specify Actions: Define specific roles and responsibilities for implementing and maintaining a safety culture. Establish governance for handling sensitive data, and the design, training, and usage of reporting forms and data repository systems.

Analyze and Implement: Build data analytics and information-sharing methods. Educate stakeholders about lessons learned. Implement learning into decision-making and policy. Continue to measure safety improvements.

The development of a successful partnership requires investment by all parties within industry organizations, and by the government regulator. The efforts are not without cost, but the cost is far less than those related to fatal accidents.

In a successful partnership, each industry member:

- Implements SMS (or an analogous structured, formalized safety management process) used to identify and control risks;
- Captures safety-related data from automated sensor technology;
- Institutes a confidential safety hazard reporting system;
- Fosters a positive, non-punitive safety culture; and
- Develops capacity for data capture and transmission to enable data fusion, mining, and analytics.

In parallel, the government regulator enables an equal partnership role specifically for improving safety.

A public-private partnership features industry forums to share safety information collaboratively, form agreements on common statements of fact and implement mitigations. The underlying ingredient in the above elements is the level of trust between the regulator and the regulated, and the general industry attitude toward sharing information among industry organizations for a shared benefit. The maturity of the partnership is not developed instantaneously but rather evolves over time with trust.

6 Potential for Collaborative Partnership in the U.S. Rail Sector

Aviation and rail operating structures have many similarities due to their overall mission of providing long-distance transportation. Rail and air vehicles travel along strictly defined networks between terminal areas or transfer points while maintaining vehicle-to-vehicle separation distances for efficiency and safety. Both systems employ analogous centralized traffic control regimes communicating to vehicles operated by multi-person crews. Commercial air traffic flow is under positive control, a method that continuously tracks and collectively directs vehicle movements to ensure safe separation in three dimensions. Railroads employ a two-dimensional block-occupancy control model. Rights-of-way divide into discrete segments, and vehicle performance, track geometry, and the location of preceding trains governs train movements between blocks. The North American railroad and airline industries each have a small number of major business entities formed by a flurry of mergers and acquisitions, supported by many smaller service entities. These similarities encourage us to examine other similarities that motivate or show evidence of a collaborative partnership in the rail sector.

The rail sector, like aviation, maintains a strong commitment to safety and has experienced a steady decline in fatal accident rates despite periods of rising and falling demand. Both industries monitor and manage accident causes, and in the case of rail, derailment rates have not risen [34]. From 1975 to 2010, per capita fatality risk (i.e., the probability that any one member of society dies on the associated mode) has declined by roughly two-thirds in railroading and by four-fifths in aviation [35]. The rail industry's workplace fatality rate is equal to that of aviation, at 0.06 per 1000 workers [35]. Despite these statistics, the FRA and major representative industry organizations including the Association of American Railroads (AAR) and the American Short Line and Regional Railroad Association (ASLRRA) remain unsatisfied with the current record [36] [37] [38]. The Rail Safety Improvement Act of 2008 (RSIA [2008]) and recent accidents are large motivational forces behind improving safety.

Railroads in the United Kingdom (UK), across the European Union, in Australia, and in North America apply SMS. Because the rail networks intermix, policy-making activities across North America have strong implications for the U.S. rail sector. In Canada, the 1999 amendment to the Rail Safety Act of 1985 required railroads to implement SMS and move away from a "compliance-based" approach. The purpose of this amendment was to foster success that "depended on a partnership between industry and regulator" and that railroads would "benefit from an increased competitive advantage, … reduced regulatory oversight, and improved relationships, partnerships, and collaboration." [39]. However, a 2007 Rail Safety Act Review panel and a more recent review following the high-profile accident in 2013 in Lac-Mégantic, Quebec revealed that railroads lacked implementation consistency and expressed skepticism about the regulator's intentions [39] [40].

As with aviation, railroads have been increasingly applying technology across all aspects of the industry. Technology uptake in rail takes longer than in aviation due to much longer life cycles that enable much older rolling stock and locomotives to continue easily operating in the system. Focused research has revealed that track or wheel defects contribute greatly to accidents and derailments [34]. Currently, the major Class I railroads are investing in innovative efforts to capture safety data relating to the dynamics of infrastructure and rolling stock through an array of advanced trackside sensors [41] and via unmanned aircraft systems [42] to predict failures and causal factors. The massive development efforts involved in PTC are designed to intervene in operations to control operational risks and address human errors. With the rapid expansion of sensor technology usage, the potential for a secondary use of this inspection data and those required to support PTC implementation and operations creates an opportunity for further safety benefits. As PTC is rolled out in the system, collected data could be used to analyze not just PTC events, but also to frame the environmental conditions associated with accidents, incidents, or contributory factors. Analogous to aviation near midair collisions, PTC intervention events can provide information into what could be happening that leads up to potential derailments or collisions.

Developed in parallel to the CAST public-private partnership, the UK's Confidential Information Reporting and Analysis System (CIRAS) model borrowed from past experiences of confidential reporting in aviation. CIRAS addresses what had been identified as a lack of adequate feedback for incident reporting. Efforts to develop CIRAS began in 1995 as a result of a report regarding the under-reporting of safety-related incidents by ScotRail employees due to the "blame culture" perceived at that time [43]. Soon after CIRAS produced promising results at ScotRail, many other railways in the UK joined the program. In 1999, the decision to mandate the program nationally followed a high-profile accident in central London that shook public confidence [44].

In the U.S., following a House Transportation and Infrastructure Committee report in 2007 that revealed rail safety reporting issues [45], the FRA began a pilot program. This program involves collaborating with the DOT and NASA to develop a system, equivalent to ASRS, for railroad safety. It was entitled the C3RS, as mentioned in Section 3. Piloted by seven passenger railroads (AMTRAK and those around the Boston, New York, and Chicago metropolitan areas), the FRA demonstration project was intended to improve railroad safety by allowing railroad companies to report close calls without being penalized by FRA. By design, before inclusion into the database, reports were de-identified and then reviewed for completeness. Successful initial results indicate that the program is expanding after lessons learned are incorporated [46]. For instance, the committee found that limitations with the effectiveness of the C3RS system were often its lack of corroborating reports [47].

In the last several years, there have been mixed indications regarding the establishment of a positive safety culture in the railroad industry. News media cited court cases of freight railroads unreasonably firing workers for raising safety concerns [48] [49] or simply reporting on-the-job injuries [50]. One Class I railroad was accused of firing whistle-blowers and pressuring workers to ignore critical safety checks [51]. There were examples of a highly positive safety culture throughout the industry, with many found in passenger railroads possibly as a consequence of market demands for safe transportation [52] [15].

As recently as this year, FRA identified deficiencies in the safety culture "at the company level, the industry level, and the level of regulatory agency oversight." FRA is actively seeking to understand the problems, gaps in the industry and regulatory oversight, and the barriers to implementation of safety culture initiatives [53].

The railroads also recognize that broad changes are in order and have invested heavily in improving safety culture. Ongoing FRA-sponsored safety culture demonstrations [54] enable lessons learned to develop a better industry-wide reporting system, which requires high-quality data inputs and collaboration from the industry as a whole. The use of a neutral third party for dedicated analytics would support industry and regulator collaboration. Visualization of national trends is possible with an industry-wide data reporting system. This better focuses safety efforts and regulatory development where needed. Knowing the issues will allow for a targeted response, resulting in less over-regulation across the industry and focused mitigation options for the railroads.

Examples of successful U.S. public-private collaborations between the FRA and the rail industry currently exist. The AAR's Transportation Technology Center, Inc. operates an industry research testing facility under contract with the FRA. Similarly, the ASLRRA developed the Short Line Safety Institute, a non-profit supported by FRA and Congressional funding, to "enhance and improve safety in all respects on short line and regional railroads across North America." [36]

At the request of the FRA, a voluntary educational partnership, entitled the Switching Operations Fatality Analysis (SOFA) working group, was formed in 1998 between AAR, ASLRRA, and labor unions with the explicit goal of eliminating all switching fatalities. Their focus was similar in nature to that of early CAST efforts: to review select fatal accident cases to determine common mitigation strategies. The intention of the group was that findings and recommendations were to be used voluntarily, not in formal rulemaking processes. While SOFA has been successful as a collaborative partnership, a 2011 report found room for improvement: ideally, reductions in switching operation fatalities would be directly attributable to SOFA interventions [55].

In the last few years, both the government and industry have been demonstrating proactive safety. The FRA endorses the advancement of proactive approaches for early identification and reduction of risk, and this year it has taken action to mandate safety PTC for certain rail operations, as well as System Safety Programs for U.S. commuter and intercity passenger railroads. The FRA also issued a Notice of Proposed Rulemaking in 2015 regarding the mandate of Risk Reduction Programs for U.S. freight railroads. AAR cites on their website that with "record levels of private spending on capital improvements and maintenance over the last five years and more than $600 billion spent since 1980, America's privately owned freight railroads are at the forefront of advancing safety."

Despite this progress, some laws and regulations unique to railroading pose challenges to a successful transition to a safety culture in rail transportation. For example, the Federal Employers' Liability Act of 1908 (FELA) was long ago adopted to protect injured railroad workers but requires claimants to prove negligence by the railroad; otherwise, workers are responsible for their injuries [56] [57]. By pitting worker versus railroad, a dynamic builds that may oppose a positive safety climate. Attention is needed to changing the business environment and other barriers impacting a successful collaborative environment. Fortunately, as demonstrated throughout the history of aviation, laws can be changed.

Another challenge falls in the area of secure and effective handling of event reporting and collected data. Methods and analytics that accurately involve the *what, where* and *when* of events are critical but protecting the *who* is of utmost importance. In cases where there are mishandling of reporting, the delicate trust relationships, central to success, could easily break down. A regulator or manager seeks to penalize employee errors, secured data becomes compromised, or analyses lack sufficient quality. Learning from experiences and leading practices across both domains will be key to the successful collaborative partnership for rail safety. As with any positive, successful relationship, it requires trust and hard work.

7 Conclusions

Aviation safety has benefitted immensely from developing a trust between industry and government, enabled by the successful partnership, a strong commitment to implementing SMS, and a positive safety culture. Given the similarities between air and rail transportation, a similar approach could benefit rail safety. This paper offers lessons learned from aviation, provides examples of technology and other investments to augment causal analysis, and raises the need for shifts in culture and legal and regulatory frameworks.

SMS implementation and the adoption of a safety culture require commitment and dedication. Behavioral and technological change hinges on continued maintenance and investment in SMS implementation and safety culture commitment. Developing and nurturing trust between industry, labor, and government lead to new policies, increased reporting of safety-related incidents, insight into causal factors, and data-driven decisions on effective mitigations. There is evidence of some shifting in the rail domain, and continued evolution is needed. Finally, while evidence of working partnerships built in the rail industry has led to some success, the dynamic seems to retain the authoritative role of the regulator and the emphasis on inspection.

With the increasing adoption of high technology in railroading, an opportunity exists for rail safety to borrow from the modal similarities and lessons learned over the past 20 years in aviation safety. A significant amount of industry attention has been on PTC and its design, benefits, and challenges, with little discussion looking at the change implications and the potential for revealing new safety risks, or the value of the data generated by PTC and similar systems [56]. With the improved development and implementation of PTC, the potential to take a collaborative approach could be used to proactively determine and control the emerging risks associated with the advent of PTC. Additionally, the opportunity to tailor the system design to support advanced, collaborative safety analytics could allow railroads to realize secondary benefits of the system, beyond the current designs. Data regarding track locations, locomotive and train location and performance, signal and switch status, PTC settings and performance, and corridor scheduling could all contribute to identifying the risks for rail operations. A collaborative approach to rail safety is underway, and through targeted measures, time, and commitment this approach seems likely to achieve reduced accident rates.

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Appendix A Abbreviations and Acronyms

	Definition
AAR	Association of American Railroads
ASIAS	Aviation Safety Information Analysis and Sharing
ASLRRA	American Short Line and Regional Railroad Association
ASRP/ASRS	Aviation Safety Reporting Program/System
ATC	Air Traffic Control
ATSAP	Air Traffic Safety Action Program
C3RS	Confidential Close Call Reporting System
CAST	Commercial Aviation Safety Team
CIRAS	Confidential Information Reporting and Analysis System
DOT	Department of Transportation
FAA	Federal Aviation Administration
FELA	Federal Employers' Liability Act of 1908
FFRDC	Federally Funded Research and Development Center
FOIA	Freedom of Information Act
FOQA	Flight Operations Quality Assurance
FRA	Federal Railroad Administration
NASA	National Aeronautics and Space Administration
NHTSA	National Highway Traffic Safety Administration
PTC	Positive Train Control
RSIA	Rail Safety Improvement Act
SMS	Safety Management System
SOFA	Switching Operation Fatality Analysis
SRM	Safety Risk Management
U.S.	United States
UK	United Kingdom