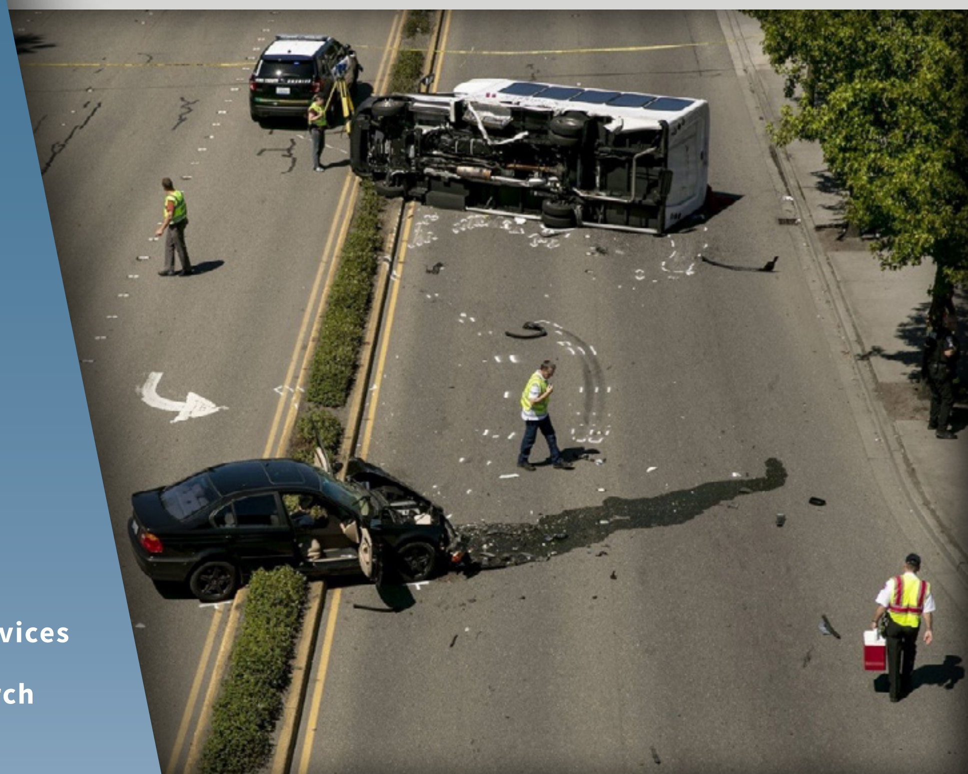
FTA Report No. 0222

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

Transit Bus Accident Investigations—Background Research



PREPARED BY
K&J Safety and Security Consulting Services

Center for Urban Transportation Research (CUTR)
University of South Florida

U.S. Department of Transportation
Federal Transit Administration

JUNE
2022

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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14. ABSTRACT
As part of FTA's effort to promote continuous safety improvement in the public transit industry, *Effective Practices in Bus Transit Accident Investigations* were developed to provide bus transit agencies leading transit industry practices for performing investigations.
This supporting document provides a comprehensive examination of each SMS element to broaden the reader's understanding of how each component complements the others. The recommended practices emphasized through the background research are not intended to be prescriptive in nature. Each public transit agency is responsible for tailoring its event investigation processes to its unique operating environment, the complexity of the operation, and the transit modes provided. These locally-developed processes should correspond to a transit agency's existing Standard Operating Procedures (SOPs) or emergency plan.

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Abstract

As part of FTA's effort to promote continuous safety improvement in the public transit industry, *Effective Practices in Performing Transit Bus Accident Investigations* were developed to provide bus transit agencies leading transit industry practices for performing investigations. This supporting document provides a comprehensive examination of each SMS element to broaden the reader's understanding of how each component complements the others. The recommended practices emphasized through the background research are not intended to be prescriptive in nature. Each public transit agency is responsible for tailoring its event investigation processes to its unique operating environment, the complexity of the operation, and the transit modes provided. These locally developed processes should correspond to a transit agency's existing Standard Operating Procedures (SOPs) or emergency plan.

Executive Summary

Introduction

The Federal Transit Administration (FTA) entered into a Cooperative Agreement with the Center for Urban Transportation Research (CUTR) at the University of South Florida to research areas of transit safety risk, identify existing standards and recommended practices to address those areas of risk, and perform a gap analysis to establish the need for additional standards, guidance, or recommended practices to support and further the safe operation of the US public transportation industry. The development of this research is one area of focus originating from the Standards Development Program (SDP) initiative. This report and the guidance provided in the accompanying *Effective Practices in Performing Transit Bus Accident Investigations* can guide public transit agency decision-making and support accident investigation procedural modifications.

Purpose

FTA's adoption of the Safety Management System (SMS) framework elevated the approach to safety in public transit, shifting the industry from a reactive one to a more proactive stance with a greater focus on the prevention of events. "SMS means a formal, top-down, organization-wide approach to managing safety risk and assuring the effectiveness of the transit agency's safety risk mitigation. SMS includes systematic procedures, practices, and policies for managing risks and hazards."[1]

Title 49 Code of Federal Regulations (CFR) Part 673 requires that each transit agency establish and implement an SMS, appropriately scaled to the size, scope, and complexity of the agency, and including the following elements:

- Safety Management Policy
- Safety Risk Management (SRM)
- Safety Assurance (SA)
- Safety Promotion

SMS brings management and labor together to build a safety culture in transit dedicated to controlling and reducing risk and detecting and correcting safety issues in their early stages. This data-driven approach aids in developing Corrective Action Plans (CAPs) to address safety concerns and establishes safety goals, safety performance targets, and safety performance indicators. These metrics are used to measure the effectiveness of risk mitigations, and CAPs are monitored to ensure the organization is achieving the intended outcomes.

[1] *Federal Register*, Vol. 83, No. 139, July 19, 2018, p. 34428; 49 CFR Part 673, Public Transportation Agency Safety Plan Final Rule, § 673.5, Definitions.

As part of FTA's effort to promote continuous safety improvement in the public transit industry, this report provides the background research in support of FTA's *Effective Practices in Transit Bus Accident Investigations*. It provides a comprehensive examination of each SMS element to broaden the understanding of how each component complements the other. The recommended practices supported by this research and reflected in the accompanying guidance document are not intended to be prescriptive in nature. Each public transit agency is responsible for tailoring its processes to its unique operating environment, the complexity of the operation, and the mode of transportation provided. This report and the accompanying guidance document occasionally make references to the responsibilities of the agency's safety department; however, it is recognized that smaller agencies may not have a formal safety department. In these instances, the existing agency personnel tasked with performing these functions are the intended audience.

The primary purpose of conducting investigations of undesirable events is to determine the cause so corrective actions can be put in place that prevent future similar events. 49 CFR § 673.27(b)(3) requires transit agencies to conduct investigations of safety events to identify causal factors as part of their safety assurance process in their Public Transportation Agency Safety Plan (PTASP).[2] An investigation evaluates the effectiveness of safety risk control methods, identifies causal factors, and may result in corrective actions to improve those control methods where gaps are identified.

Background

Accident investigation, which falls under event investigation in the SA component of SMS, is central to identifying causal or contributing factors in events. It is conducted for early detection and identification of hazards, addressing safety concerns in a permanent and effective manner, reducing the agency's exposure to risk, promoting continuous improvement, and elevating the safety of employees and the riding public. This is achieved through the development and implementation of CAPs, which are then measured and monitored to ensure they are effective and tracked to closure.

Through an agency's SA function, agency personnel will perform investigations that:

- Analyze data and information obtained through the investigation process, proactively and predictively, to identify where and when a similar event could occur.
- Identify changes to facilities, vehicles, equipment, and systems that were not effectively managed to ensure safety.

[2] 49 CFR Part 673, Effective July 19, 2018.

- Use “lessons learned” from event investigations to promote continuous improvement in safety performance.
- Enter hazards identified from data analyses during investigations into the SMS SRM Process (SMS Component 2).

Accident investigation practices, although typically used in response to an incident, may also identify and diagnosis the present state of early warning systems that allow management to harvest precursors to significant events. These early warning systems, known as non-punitive safety reporting systems, protect the reporter from retaliation and shield the identity of the person bringing forth the safety concern. Safety efficiency testing[3] is another early warning system that flags employee non-conformance to existing procedures, which can also be the precursor to more serious operational violations. Auditing is another early warning system. These components of the agency’s safety defenses can identify significant safety concerns and a systemic safety problem; however, it often requires recognition of the seriousness of the hazard by senior management for the safety issue to receive the appropriate level of resources to be adequately mitigated. Effective accident investigation promotes the organization’s capability to institute a strong response to often very indistinct stimuli to prevent a more serious event from occurring. In-depth investigations into near-miss incidents and the implementation of effective CAPs potentially can avert a future fatality.

Accident investigation activities benefit from an in-depth understanding of both technical and non-technical aspects of organizational performance and are best conducted in a holistic manner that avoids assigning individual blame for major incidents; otherwise, opportunities for system improvement may be missed and risks to the agency will not be sufficiently remediated.

Traditional non-technical organizational challenges generally stem from issues such as inadequate succession planning, ineffective recruitment and retention strategies, procurement obstacles, poor safety culture, organizational blindness to risk, failure to learn from past events, imbalance in the normal tension that exists between operations and maintenance personnel for track time allocations, inadequate funding for capital investments, or failure to maintain agency assets in a State of Good Repair (SGR).

Effective accident investigation practices often leverage the knowledge of subject matter experts (SMEs) to aid in identifying deviations from current operating or maintenance practices and identifying opportunities to make the agency more effective and efficient to reduce risk. These opportunities include:

- Improving system designs
- Modifying and improving policies and procedures

[3] Operational testing and inspections observe employees after training to ensure retention of compliance content.

- Performing quality assurance activities
- Identifying new technologies that may be used to prevent employee injuries and fatalities
- Being cognizant of and implementing best industry practices suited for the individual agency's unique environment
- Adopting and effectively using maintenance management systems to collect data that informs maintenance and investment decisions
- Making organizational improvements that support safety culture maturity

Additionally, medical expertise often is needed to evaluate human factors that can influence performance, such as the proper screening for medical conditions such as Obstructive Sleep Apnea (OSA) that can result in fatigue.

Transit agencies may find it beneficial to ensure that their frontline workforce is equipped with the required tools, training, and knowledge to diagnose and mitigate severe conditions that require immediate attention. Transit agencies will want to empower frontline employees to take the appropriate actions to safeguard their fellow employees and the riding public from harm.

This research and the corresponding *Effective Practices in Transit Bus Accident Investigations* are meant to inform and improve an investigator's critical thinking skills, which are necessary to accurately identify root causes and contributing factors, leading to short-term, intermediate, and long-range CAPs to address their key findings.

Report Organization

This report is organized by each SMS element, as follows:

- Section 1 – Safety Management Policy
- Section 2 – Safety Risk Management
- Section 3 – Safety Assurance
- Section 4 – Safety Promotion

Each section includes a description of the organizational accountabilities, recommended policies and procedures, and components of the SMS element that supports, directs, and furthers the accident investigation process. It then provides the steps and considerations that will direct an agency from the investigation process into the methods of safety assurance, promotion, and continuous improvement based on SMS principles. The research team provides case study examples presented to impart experiential knowledge.

Appendices provide supplemental support of the topics discussed in the narrative and also include resources for transit agency personnel who are assigned the responsibility of investigation and closeout activities.

Section 1

Safety Management Policy

FTA Safety Management System Framework and Safety Management Policy Directives

The Federal Transit Administration (FTA) Safety Management System (SMS) framework requires a transit agency to establish its organizational accountabilities and responsibilities and have a written statement of safety management policy that includes the agency's safety objectives. The agency should establish a process that allows employees to report safety conditions to senior management, protections for employees who report safety conditions to senior management, and a description of employee behaviors that may result in disciplinary action. At the center of an agency's SMS is the communication of the policy throughout the organization.

The transit agency must establish the necessary authorities, accountabilities, and responsibilities for the management of safety among the following individuals in its organization, as they relate to the development and management of the transit agency's SMS:

- **Accountable Executive** – The Accountable Executive should be a transit operator's chief executive; this person often is the President, Chief Executive Officer, or General Manager.[4] The Accountable Executive is accountable for ensuring that the agency's SMS is effectively implemented throughout the agency's public transportation system and that actions are taken, as necessary, to address substandard performance in the agency's SMS. They may delegate specific responsibilities, but the ultimate accountability for the transit agency's safety performance cannot be delegated and always rests with the Accountable Executive.
- **Chief Safety Officer or SMS Executive** – The Accountable Executive may designate a Chief Safety Officer (CSO) or SMS Executive who may be given authority and responsibility for the day-to-day implementation and operation of an agency's SMS. The CSO or SMS Executive should hold a direct line of reporting to the Accountable Executive. A transit agency may allow the Accountable Executive to also serve as the CSO or SMS Executive.
- **Agency leadership and executive management** – A transit agency must identify those members of its leadership or executive management, other than an Accountable Executive, Safety Officer, or SMS Executive, who have authorities or responsibilities for day-to-day implementation and operation of an agency's SMS.

[4] *Federal Register*, Vol. 83, No. 139, July 19, 2018, p. 34428; 49 CFR Part 673, Public Transportation Agency Safety Plan Final Rule.

- **Key staff** – A transit agency may designate key staff, groups of staff, or committees to support the Accountable Executive, CSO, or SMS Executive in developing, implementing, and operating the agency's SMS.

This section includes the following topics that are central to SMS and Safety Management Policy:

- Organizational Factors and Safety Culture
- Employee Safety Reporting
- Management/Labor Relations

Organizational Factors and Safety Culture

One characterization of an organization is "a unit of people that is structured and managed to meet a need or to pursue collective goals." All organizations have a management structure that determines relationships between different activities and members and subdivides and assigns roles, responsibilities, and authority to conduct various tasks. Organizations are open systems; they affect and are affected by their environment.

An organization's culture can have as significant an influence on safety outcomes as an SMS. Without directed guidance and appropriate and applicable policies, organizational culture takes on a life of its own. Understanding culture and how it aligns with the strategy of the organization is critical in the development, implementation, and maturation of an SMS. A successful culture balances people's focus on achieving results, looking both internally and externally to maximize a positive impact on all stakeholders. An ideal organizational culture is one that is stable in terms of mission and values, yet flexible enough to adapt to changes in the external and internal environments.

Organizational Risk Factors

As a part of an SMS structure, specifically the development of Safety Management Policy and associated procedures and processes, transit agencies may benefit from proactively evaluating factors that can impact organizational safety and determining the actions, if any, it will take to mitigate those risks. Organizational risk factors can include, but may not be limited to the following:

- Compliance
  - Laws and regulations
  - Cumbersome, outdated, or non-existent crisis/emergency management policies
  - Agency safety procedures and policies
- Personnel
  - Management and staff attitudes toward workplace safety

  - Staff training and preparedness
  - Succession planning
  - Recruitment and retention of qualified employees
  - Insufficient or non-existent resources to effectively monitor and address significant organizational changes
  - Staffing levels, extended shifts, and overtime requirements, and
- Procurement obstacles, including an inadequate zero-based budget (ZBB)[5]

Identifying and evaluating organizational risk factors and establishing policies and procedures to address and mitigate these factors can reduce the likelihood that an "organizational accident" will occur. In general terms, organizational accidents are those resulting from actions or inactions of companies or organizations. As James Reason stated in *Managing the Risks of Organizational Accidents*:

> Organizational accidents are the comparatively rare, but often catastrophic, events that occur within complex modern technologies such as nuclear power plants, commercial aviation, the petrochemical industry, chemical process plants, marine and rail transport, banks, and stadiums. Organizational accidents have multiple issues involving many people operating at different levels of their respective companies. By contrast, personal accidents are ones in which a specific person or group is often both the agent and the victim of the accident. Organizational accidents, on the other hand, can have devastating effects on uninvolved populations, assets, and the environment.[6]

Examples of Organizational Accidents and Incidents

The following examples of organizational accidents and incidents highlight the failures of the organizations, specifically organizational procedures and policies and the ineffectiveness of management:

- **British Petroleum (BP) Refinery Accident, Texas City, Texas.** On March 23, 2005, the BP Texas City Refinery suffered one of the worst industrial disasters in recent US history. Explosions and fires killed 15 people and injured another 180 individuals, alarmed the community, and resulted in financial losses exceeding $1.5 billion. The accident was investigated by the US Chemical Safety and Hazard Investigation Board (CSB).[7] Among several significant safety issues identified and investigated in its extensive report, the CSB noted the following:

[5] ZBB is a method of budgeting in which all expenses must be justified and approved for each new period. ZBB starts from a "zero base" at the beginning of every budget period and analyzes needs and costs of every function within an organization and allocates funds accordingly, regardless of how much money was previously budgeted to any given line item.
[6] J. Reason (1997), *Managing the Risks of Organizational Accidents*, Ashgate.
[7] For additional information, see CSB report 2005-04-I-TX, March 2007.

- BP lacked focus on controlling major hazard risks. BP management paid attention to, measured, and rewarded personal safety rather than process safety.
- BP and Texas City managers provided ineffective leadership and oversight. BP management did not implement adequate safety oversight, provide needed human and economic resources, or consistently model adherence to safety rules and procedures.
- BP and Texas City managers did not effectively evaluate the safety implications of significant organizational, personnel, and policy changes.

- **Metropolitan Transportation Authority (MTA), Results of Blue-Ribbon Panel (BRP) Report (August 27, 2014).** In August 2013, the Chairman/CEO of the MTA assembled a BRP of transportation safety officials and railroad industry leaders following mainline derailments at the Long Island Rail Road (LIRR), Metro-North Railroad (MNR), and New York City Transit (NYCT) that had track-related defects identified as either a potential cause or a contributing factor to these events. Several members of the BRP were tasked with reviewing non-technical aspects of the rail properties, such as their safety climate,[8] organizational, funding, management issues, and the overall policy setting and oversight. A specific concern that emerged focused on the need to modify the organizational structure that had existed between the safety function and the rail agency's leadership at LIRR and MNR. The panel emphasized that this relationship must assure that a clear communication channel exists between these parties and send the message throughout the organization that safety is not subsidiary to other departments. The Chairperson/CEO acted upon the finding by directing the presidents of MNR and LIRR to designate a lead safety individual at each respective agency to report directly to them and to ensure the CSO had no job responsibilities other than safety. This reporting structure had already existed at NYCT. In addition, an interim report by the BRP identified that organizational changes were needed to assure that safety groups were seen by all as "clear and effective champions" of safety with the tools and support necessary to do their job well.

Conducting an Organizational Risk Assessment (ORA)

An ORA, broadly defined, is a structured means of identifying, assessing, and rating the risks faced by an organization within the context of its financial reporting processes, operations, reputation, and compliance with laws and

[8] Safety climate refers to the perceived value given to safety considerations within an organization. It is a holistic term that includes corporate policies, management attitudes, and worker beliefs about safety in the workplace. The concept of safety climate is similar to the concept of safety culture; however, the latter refers more specifically to the individual attitudes toward safety practice that exist within an organization, whereas safety climate refers to how those attitudes are collectively understood. The two terms are sometimes contrasted as referring to an organization's "personality" (safety culture) and "mood" (safety climate). Safety climate, such as a mood, exists at a given point in time and can change significantly based on circumstances. Safety culture refers to a more durable set of beliefs and practices that may persist even as the safety climate changes.

regulations. Specifically, organizational safety can be impacted by several factors, including recruitment and retention, budget cuts/constraints, procurement obstacles, succession planning, and ZBB activities.

An ORA is designed to provide the organization with a structured means to obtain relevant information necessary to consider the implications of such risks proactively, and what actions, if any, the organization can take to mitigate those risks. General questions that can be asked when attempting to conduct an ORA include:

- Does the organization identify and define its values?
- Is there consistency between philosophy, policy, procedures, and practices?
- Do the members of a leadership team have a consistent vision for the organization's culture? Is it discussed/disseminated?
- How do employees view their current organization compared to their ideal organization?

Safety Culture

Whereas there are various definitions of what constitutes safety culture, an accepted and recognized meaning is the following:

> Safety culture is defined as how safety is managed in a workplace. It is the combination of beliefs, perceptions, and attitudes of employees toward the safety of workers and the overall safety of the work environment. Cultivating a safety culture is a crucial aspect of maintaining workplace safety.

Just as every organization has a structure, every organization has a safety culture. In a strong safety culture, safety is the top priority. At all times, across all levels of the organization, safety is placed above all other priorities. If hazardous, potentially harmful safety concerns are identified, operations affected by the hazard that poses an imminent safety risk do not continue until the safety concerns have been resolved. Competing demands such as productivity, profitability, and on-time performance are not prioritized above safety. When competing demands are prioritized over safety, a favorable, proactive safety culture suffers.

Considerable research has been conducted to identify indicators of a positive safety culture. Reason[9] identified five main components of a strong safety culture on a generic basis, and many of the guidelines in industries have been adapted from this model.

[9] Reason, *Managing the Risks of Organizational Accidents*.

- An **informed** culture is one in which "those who manage and operate the system have current knowledge about the human, technical, organizational, and environmental factors that determine the safety of the system."
- A **reporting** culture is one that allows and encourages people to report their errors and near-misses. This can often be difficult to achieve but can be helped by using a confidential reporting system, keeping a separation between those who collect information and those who would implement sanctions, providing fast and useful feedback, and making the reporting system easy to use.
- A **learning** culture is evident when an organization has the willingness and competence to learn from its safety information and will include this when implementing safety reforms.
- A **flexible** culture is a culture that can re-configure itself and respond to change and may change from a conventional hierarchical structure to a flatter one. A flexible culture also encourages people to adapt and allows people regardless of their position to have an active role in the overall organizational safety.
- A **just** culture avoids apportioning blame on an individual, which in turn facilitates a focus on systemic deficiencies rather than on individual failings. In a just culture, there will be an atmosphere of trust and a clear understanding of the difference between an error and a violation for all involved.

Determining the Effectiveness of Safety Culture in an Organization

Given that safety culture is a multi-dimensional construct encompassing psychological, behavioral, and organizational components, agencies may want to consider assessing it using multi-method measurements. Effective safety culture measurement captures all three components—psychological, behavioral, and organizational. Measurement methods include:

- Direct observations
- Interviews
- Focus groups
- Performance indicator tracking
- Surveys

Agencies may benefit from basing any investigative findings concerning safety culture on substantial evidence rather than subjective judgment. Furthermore, it may help to target any recommendations to address safety culture issues at specific areas of concern, e.g., lack of reporting or not learning from prior experience.

Additional Resources

Transit Advisory Committee for Safety (TRACs) Report on Safety Culture. FTA tasked TRACS with developing practical recommendations that detail how processes, practices, tasks, and individual employee responsibilities can support a safety culture.[10] The report represents a comprehensive review of the strategies available to FTA and transit agencies in building and improving a strong culture of safety. In addition to making specific recommendations in support of a strong safety culture, TRACS also recommended that FTA take a stronger role in implementing change and driving improvements in safety culture to support safety management principles and approaches for transit agencies.

"The Investigation of Safety Management Systems and Safety Culture: Discussion Paper"[11] This paper seeks to provide a practitioner's view on the investigation of SMS and safety culture. In doing so, it addresses questions such as:

- What are the key elements of a standard SMS that an investigator is likely to encounter?
- How could the role of these elements in the causation of an accident be investigated?
- How have SMSs been used and analyzed during real investigations?
- How could the investigator address safety culture?
- Can investigations influence the shape of SMSs?

It also addresses and provides examples of sources of evidence and analytical techniques. Case studies of accidents are also examined.

Employee Safety Reporting

An agency's SMS and its Safety Management Policy should include an employee safety reporting system. A non-punitive safety reporting system has proven to be an effective method for improving safety in the chemical process, nuclear, and transportation industries. A non-punitive safety reporting system typically uses a collaborative problem-solving approach that encompasses all stakeholders. The success of such a program requires a focus on precursor events that may lead to accidents, use of data and SMEs to determine corrective actions, allows cooperative, cross-functional problem solving, and an organizational setting capable of implementing corrective actions.

[10] For additional information, see TRACS 16-01, Final Report, 02/27/17, "Building Toward a Strong Safety Culture within the Bus and Rail Transit Industry."

[11] International Transport Forum, "The Investigation of Safety Management Systems and Safety Culture; Discussion Paper 2017-20." Prepared for the Roundtable on Safety Management Systems (23-24 March 2017, Paris); Simon French, Chief Inspector of Rail Accidents, and Tabitha Steel, Human Factors Specialist, Rail Accident Investigation Branch, United Kingdom, August 2017.

Although there are several types of reporting systems, the essential components of a non-punitive safety reporting system include the following:

- **Voluntary reporting** of incidents/safety concerns.
- **Confidential reporting** that ensures the identities of reporting individuals cannot be disclosed.
- A **non-punitive approach** that protects from disciplinary action for employees; however, the process also defines actions that are not exempt from discipline.
- **Third-party data collection and de-identification** to ensure confidentiality; most, but not all, close-call safety reporting systems employ a third-party agency to receive, process, and, in some cases, investigate the reports.
- **Analysis** that may involve a Peer Review Team (PRT), which has either staff SMEs or access to SMEs, to ensure the reported safety concern is fully understood and to assist in developing CAPs to address the problem effectively.
- Although safety concerns may be made in a confidential or anonymous manner, the organization can develop methods of providing **feedback to all employees** on the actions taken to address reported problems. This can be done by posting updates on the agency's intranet or in monthly news bulletins, discussions at various safety forums, and routine safety meetings. If the reporting employee chooses to provide their identity, then direct feedback can be provided to that individual. People are more prone to report issues if they believe that problems will be addressed in a prompt, effective manner.
- **Stakeholder involvement and empowerment** that engages personnel at all levels of the organization, i.e., frontline employees, union representatives, supervisors, and management, and allows all parties to participate in the decision-making process.

Examples of Employee Safety Reporting Programs

FRA's Confidential Close Call Reporting System (C^3RS)

An example of a non-punitive confidential close call[12] reporting system is the C^3RS, a partnership between the National Aeronautics and Space Administration (NASA) and the Federal Railroad Administration (FRA) in conjunction with participating railroad carriers and labor organizations. It is designed to improve railroad safety by collecting and analyzing reports that describe unsafe conditions or events in the railroad industry. Employees can

[12] FRA defines a "close call" as an opportunity to improve safety practices in a situation or incident that has potential for more serious consequences. It represents a situation in which an ongoing sequence of events was stopped from developing further, preventing the occurrence of potentially serious safety-related consequences. See https://railroads.dot.gov/elibrary/amtrak-imou.

report safety issues or “close calls” voluntarily and confidentially. By analyzing these events, potential lifesaving information can be obtained to help prevent more serious incidents in the future.

NASA uses the expertise it has gained from developing and managing the successful Aviation Safety Reporting System (ASRS) to administer the C³RS program. NASA has operated ASRS since 1976 and has received over one million reports from the aviation community. The system has made numerous contributions to aviation safety without violating the confidentiality of any reporter. NASA is an independent and respected research organization that does not have a regulatory or enforcement interest. It, therefore, serves as an “honest broker” that is an objective and trustworthy recipient of reports submitted by railroad professionals.

FRA and NASA collaborate with rail carriers, labor representatives, and frontline personnel to implement C³RS at participating sites and all partake in the process. A rail carrier may establish a PRT that consists of local representatives from the carrier, unions, and FRA at the carrier site. PRTs promote C³RS at the site, identify why close calls may occur, recommend corrective action, and evaluate the effectiveness of any such action that was implemented. The carrier reviews PRT recommendations and may take corrective action.

The C³RS is intended to improve rail and transit safety by studying near-miss incidents and unsafe situations, identifying their root causes, and developing preventive measures or corrective actions. It is hoped that this reporting program will help foster a safety culture without the threat of administrative discipline.

In a February 2019 paper,[13] FRA attempted to determine if close call reporting systems such as C³RS are effective in the railroad industry. The C³RS evaluation was designed to answer three major questions:

- What conditions are necessary to implement C³RS as planned in a demonstration?
- What is the impact of C³RS on safety and safety culture?
- What factors help to sustain C³RS long-term, beyond the demonstration?

To address these questions, FRA implemented a “lessons learned” evaluation over a 12-year period across four demonstration pilot sites. The report describes the final answers to the evaluation questions.

In summary, implementing C³RS as planned is possible within transportation departments in the railroad industry. Bottom-line impacts were achieved in the

[13] “Confidential Close Call Reporting System (C³RS) Lessons Learned Evaluation – Final Report,” US Department of Transportation, Federal Railroad Administration, DOT/FRA/ORD-19/01.

presence of C³RS in areas such as reduced derailments (three sites), injuries (one site), discipline hearings (two sites), and improved safety culture (four sites). C³RS can be sustainable in railroad transportation when enlisting the support of local labor, management, national labor, and FRA.

A review of FRA's web site[14] pertaining to C³RS noted the following:

- NASA acts as an independent third party.
- NASA accepts close call reports online or by mail.
- Currently, there are 9 participating carriers and 18 active PRTs.
- Over 21,000 frontline railroad employees are eligible to report safety incidents to C³RS.
- PRTs are cross-functional teams that evaluate de-identified reports and make recommendations for corrective actions.

Bureau of Transportation Statistics (BTS)

Another close call reporting program is operated by the Bureau of Transportation Statistics (BTS) under an agreement with WMATA, which allows its employees to report close call events voluntarily without the threat of disciplinary action. BTS protects data and information collected for statistical purposes under the Confidential Information Protection and Statistical Efficiency Act of 2002 (CIPSEA), which established uniform confidentiality protections over disclosure and use. BTS also has agreements with the Department of the Interior, Bureau of Safety and Environmental Enforcement for its Safe Outer Continental Shelf (SafeOCS) employee reporting program.

FTA's Employee Safety Reporting Activities

In 2012, TRACS published a report[15] that recommended that FTA pilot a close call, non-punitive reporting system for transit. The report stated:

> … The primary purpose of a close call safety reporting system is to improve overall safety by encouraging employees to report unsafe conditions or acts voluntarily that would otherwise not be known or detected by transit agency management…. There is strong potential for a confidential, non-punitive, close call safety reporting system to build trust between labor and management and to help establish a just safety culture throughout a rail transit enterprise. Establishing a robust safety culture where all stakeholders work together to improve safety continually is the ultimate goal of a confidential, non-punitive, close call safety reporting system.

[14] As of July 2019.

[15] TRACS Working Group 11-01 Report, "Establishing a Confidential, Non-Punitive, Close Call Safety Reporting System for the Rail Transit Industry," 7/16/12.

Among other topics, the report identifies and discusses elements of existing systems, funding, pilot sites, criteria for successful implementation, and examples of unsafe incidents. It includes a Model Memorandum of Understanding (MOU) for Establishment of a Confidential, Non-Punitive, Close Call Safety Reporting System for the Rail Transit Industry between a rail transit agency and its employees and proposes recommendations for the establishment of a close call reporting system in the rail transit industry.

Close call events cannot be investigated and understood if transit agencies are not aware that they occurred—hence, the importance of non-punitive safety reporting systems and systems allowing confidential reporting. A NYCT track safety taskforce survey reported that more than half of maintenance-of-way (MOW) personnel had experienced a near miss or close call, but only one-third of those who had experienced them said they reported them.[16] This hesitancy to report could be the result of a blame culture.

Transit Cooperative Research Program (TCRP) Report 149 offers the following advice on reporting systems: “A culture of blame will most certainly deter widespread safety reporting. Many reporting systems offer reporting incentives that minimize or eliminate any disciplinary action for an incident except for the most egregious violations. The nonpunitive aspect of these systems eliminates any fear of retribution.”[17]

Management/Labor Relations

An effective SMS and the supporting Safety Management Policy recognize the importance of management/labor relations. This section examines some best practices related to event investigations and implementing other safety initiatives where this cooperation can have positive safety effects. Transit agencies have had extensive experience with joint union-management safety committees and accident preventability review panels. Such efforts are common in the industry.

Although labor and management have distinct roles in an organization, both labor and management share the goals of making the enterprise safe and successful and maintaining public support for the agency’s mission. Part of attaining that goal is avoiding accidents and injuries.

Joint Safety Investigations

Management does not include union personnel as part of the investigation team for day-to-day event investigation; however, agencies may want to look for ways to maximize the resource that unionized employees and their leaders possess during the investigative process. In a Special Investigation Report examining

[16] NYTC Taskforce Report, Attachment A, p. 13.
[17] TCRP Report 149, p. 62.

roadway worker accidents (RWA),[18] the National Transportation Safety Board (NTSB) described its investigatory process that includes incorporating union personnel as part of the investigation team. The report noted that "the NTSB has experienced that organizational and employee involvement in accident investigations is instrumental in investigative fact-finding." NTSB concluded that "union representation brings operations-specific knowledge to the accident investigation team and helps facilitate the cooperation of employees."

The NTSB Special Investigation Report elaborates:

> Another key perspective can be gained through employee involvement in the investigation process. Employees are the most knowledgeable about the human, technical, and organizational factors that determine the safety of the system as a whole. This leads not only to a more thorough investigation but also to employee buy-in, resulting in a stronger overall safety culture.[19]

Some agencies convene Boards of Inquiry or other committees, which include a representative from the union on the panel, to investigate serious events. In these serious events, the investigation may require specialized groups or task forces to examine organizational culture and root causes; union representation can be helpful in such efforts. Therefore, when developing accident investigation protocols, agencies may want to consider ways to use represented employees and their union leaders as a resource to understand accident causation, to find potential links to organizational culture, and to find practical corrective actions to prevent recurrences. Some best practices are discussed below where joint union-management efforts can improve an organization's safety performance.

In April 2007, NYCT experienced two roadway worker fatal accidents in a one-week period. These accidents led the President of NYCT to convene a Joint Track Safety Taskforce[20] "to identify system, cultural, and behavioral factors that negatively affect track safety and to make recommendations to neutralize or reverse those tendencies." The taskforce included management personnel from NYCT's operations and safety departments as well as representatives from the Transport Workers Union (TWU) Local 100. The Task Force goal was not to investigate the details of the specific accidents but to dig deeper into root causes and conditions that could lead to similar events. As part of the Task Force effort, several previous Board of Inquiry reports were evaluated and determined that although in many cases rules were not followed leading to an accident, there was an absence of analysis on why the rules were not followed. The report made 63 recommendations. Of note for this document

[18] "Special Investigation Report on Railroad and Rail Transit Roadway Worker Protection," NTSB Special Investigation Report, NTSB/SIR 14-03, adopted September 24, 2014.
[19] *Ibid*., p. 46.
[20] New York City Transit, Joint Track Safety Taskforce Final Report, November 20, 2007.

are the recommendations to continue joint labor-management inspections of work areas, analysis of inspection data to monitor the effectiveness of safety protocols, and joint labor-management quarterly audits of safety procedures.

TCRP Report 149[21] on rules compliance provides a detailed description of the NYCT Joint Track Safety Taskforce and notes that since the joint audits were initiated, rules non-compliance declined. The Task Force effort is noted as an industry best practice in the TCRP report and describes two key factors in its success:

- Management support and adequate resources – The transit agency's CEO has supported this effort since its inception. His endorsement of the program plus the willingness of NYCT's managers to support the findings of the safety audits have made the program a meaningful component of the agency's overall safety program.[22]
- Joint union-management compliance audits can grow out of accident investigations and CAPs (as in the NYCT example) or be a function of safety committee work or a standalone program.

Joint Union-Management National Safety Programs

There are several national safety programs with union and management participation that issue reports and other documents that can be helpful in conducting accident investigations and in supporting other safety efforts. The TRACS Safety Committee provides information, advice, and recommendations on transit safety and other issues. TRACS comprises a diverse panel of professionals representing a variety of stakeholders and interests to address issues cooperatively.

The TRACS Committee roster[23] includes one member affiliated with the Amalgamated Transit Union (ATU). Two current TRACS Safety Focus Areas[24] are right-of-way (ROW) worker protections and accident/incident investigation.

FRA established the Fatality Analysis of Maintenance-of-Way Employees and Signalmen (FAMES) Committee in collaboration with railroad labor and management representatives to review and analyze roadway worker fatalities. FAMES is a voluntary, consensus-based committee focused on identifying risks, trends, and factors impacting roadway worker safety. FAMES periodically issues findings and recommendations based on its review of available safety data; its activities are focused on education and prevention.[25]

[21] TCRP Report 149: "Improving Safety-Related Rules Compliance in the Public Transportation Industry," Transportation Research Board, 2011.
[22] *Ibid*., p. 55.
[23] TRACS membership list, March 2019, FTA public website.
[24] TRACS list of 25 Safety Focus Areas, March 2019, FTA public website.
[25] FRA public website.

Transit agencies can support national efforts by assigning personnel but can also find ways to analyze their data at the local level using existing joint labor-management safety committees or form other labor-management groups to examine specific issues arising out of investigations.

Peer Instructors/Mentors

Many transit agencies use frontline employees to serve as peer trainers or mentors for new hires. In this role, they can be a resource to apply lessons learned from close calls, rules noncompliance, and accidents. The NYCT Joint Track Safety Taskforce Final Report includes a survey[26] taken during focus groups and telephone interviews that found that "over 4 in 10 respondents say communications (bulletins) are ineffective. The top suggestion for improving communication is to increase face-to-face interactions about rules." The NYCT survey also found that "emphasizing more on-the-job training with a mentor for new workers" would support improvements in safe work practices. Peer trainers and mentors, with union-management backing, are ideally suited to provide this face-to-face contact. Other suggestions included frequent, unannounced safety audits, more safety training, and improved review and enforcement of safety rules.

Joint Safety Inspections/Audits of Workplaces

Many accidents involve incorrect execution of existing rules. In line with root cause analysis, investigators should think beyond proximate cause (someone broke a rule) and examine what Reason[27] would describe as the "defenses" and how they failed to prevent the undesirable event. One of those defenses is compliance auditing, and joint union-management auditing can be an effective tool to improve safe work practices.

NTSB has recommended[28] that FTA require, and transit agencies conduct, management checks to ensure operating rules are followed. FTA's regulation at 49 CFR Part 673 is based on the SMS approach. A key element of SMS is Safety Assurance. 49 CFR 673.27(b)(1) requires that an agency's safety plan include provisions to monitor its system for compliance with and sufficiency of the agency's procedures for operations and maintenance.

Dr. Richard Hartley, an expert in high-reliability organization theory, noted in NTSB's investigative hearing into MNR railroad accidents that "you have a safety management system (but) you have no idea how good that's working until you understand the gaps between how people do work and how you intend them to do work."[29]

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[26] "New York City Transit Joint Track Safety Taskforce Final Report," Appendix A.
[27] Reason, *Managing the Risks of Organizational Accidents*.
[28] NTSB Recommendation R-02-18 (FTA), R-02-22(CTA), R-08-02 (WMATA).
[29] NTSB Investigative Hearing Transcript, p. 310, Docket No. DCA13MR003.

The American Public Transportation Association (APTA) published APTA-RT-OP-S-11-10, Rule-Compliance Program Requirements Standard for rail transit systems, a voluntary standard that requires, among other things, defining rules to be evaluated and operating positions affected, determining the frequency of checks, and establishing methods of verification, metrics, and validation/analysis of program effectiveness. Although not specific to transit bus, there are sections and corresponding requirements that can translate to the bus transit operating environment.

A potential downside of safety compliance monitoring is that the educational and culture-changing potential of monitoring activities can be lost because they are perceived by employees as a “gotcha” program that is heavy on discipline and light on education, coaching, and improvement. It can be a difficult balance to maintain; however, effectively training auditors on employee coaching techniques can help remove negative perceptions. Another way to improve the reception is to ensure that employees are recognized and thanked for the things they do right.

Joint union-management monitoring can help to identify the gaps in ways that monitoring conducted by managers alone may not find. In addition, with less emphasis on discipline and a greater focus on correcting unsafe work practices, negative perceptions can be overcome, and programs made more effective.

Section 2 Safety Risk Management

Safety Risk Management (SRM) is a process for identifying hazards and analyzing, assessing, and mitigating safety risk. The objective of SRM is to determine and classify system-wide safety risk to develop appropriate risk mitigation strategies.

During an investigation, it might be suspected that the existing safety risk controls or mitigations are ineffective due to a change in conditions or inappropriateness, or they are not implemented as intended. The investigation might also identify new or previously unidentified hazards. The circumstances noted above may prompt the transit agency to evaluate existing mitigations, newly identified hazards, and any resultant risk through its SRM process.

SRM Process

The SRM process defines a transit agency's approach and the implementation of an integrated system-wide safety risk mitigation process. It specifies the sources of and the mechanisms to support the ongoing identification of hazards and defines the process by which identified hazards, resulting consequences, and level of safety risk will be evaluated and prioritized. It identifies the mechanism(s) that will be used to notify and report hazards to oversight agencies and the process by which a transit agency will provide ongoing reporting of hazard identification, consequence, and risk mitigation activities. This process is illustrated in Figures 2-1.

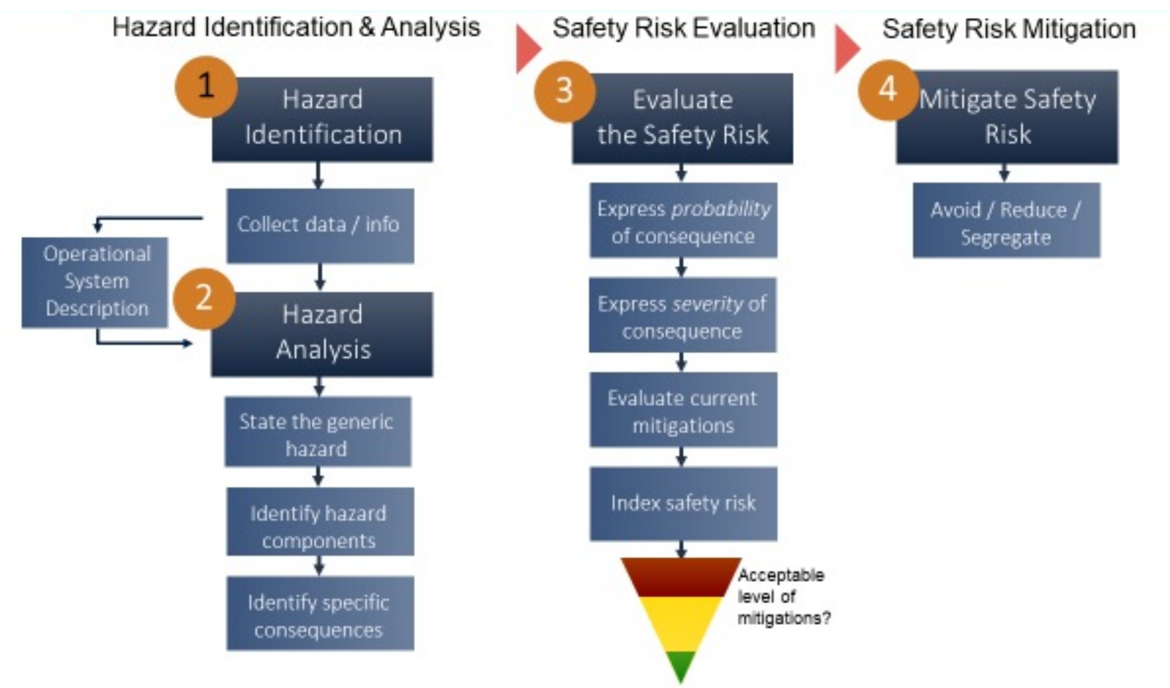

Figure 2-1 *Safety Risk Management Process*

Source: Transportation Safety Institute (TSI)

Transit agencies may find it beneficial to apply elements of the SRM process , either quantitatively or qualitatively, to the following:

- **Initial designs of systems, vehicles, equipment, material, and organization:**
  - Safety and Security Certification (SSC) is applied to projects that may be expected to pose hazards or security risks to the transit agency's passengers, employees, and emergency response personnel. SSC is conducted through a collaborative effort between the safety department and the applicable project team, which may include representatives from other transit agency departments as well as project contractors.
  - Procurement requirements including basic safety and user requirements are included in procurement specifications and coordinated with appropriate offices. As new facility, system, or equipment specifications are proposed, responding contractors can resolve hazards using the following prioritized list:
    1. Design for Minimum Hazard – The major effort during the design phase of a contract is to select appropriate safety design features (e.g., fail-safe, redundancy).
    2. Safety Devices – For hazards that cannot be eliminated through design, consider appropriate safety devices to reduce the consequences of hazards to an acceptable level.
    3. Warning Devices – When it is not possible to preclude the existence or occurrence of a hazard, employ devices for the prompt detection of the condition and the generation of an effective warning signal.
    4. Special Procedure – When it is not possible to reduce the magnitude of an existing or potential hazard through design or the use of safety and warning devices, the development of special procedures to control the hazard may be required.
- **Safety operational procedures** – Transit agency management s ensures that a safety risk assessment is conducted and used to prioritize the development, training, and compliance of rules and procedures.
- **Hazard identification** – Is addressed through safety assurance functions, such as hazards identified during accident investigations.
- **Planned changes to the operational system** – Including the introduction of new equipment, material, systems, and procedures, to identify hazards associated with those changes.

Safety Hazard Identification

A hazard is any real or potential condition that can cause injury, illness, or death; damage to or loss of facilities, equipment, rolling stock, or infrastructure of a public transportation system; damage to the environment; or reduction of ability to perform a prescribed function. For example:

- Unclear roadway signage/traffic patterns
- Worn vehicle brake assembly
- Narrow traffic lanes
- Grade crossings

Each transit agency must establish a process for safety hazard identification, including the identification of the sources (predictive, proactive, and reactive) for identifying hazards and their associated consequences (Figure 2-2):

- Consider a comprehensive list of sources.
- Ensure activities are documented.
- Training on hazard identification and reporting will improve an agency's data.
- Hazard identification is ongoing.
- If the agency receives a hazard report, act and provide feedback.

Figure 2-2 *Hazard Identification and Analysis*

Source: TSI

Hazard identification is data-driven; the use of data can facilitate hazard identification (Figure 2-3). Agencies can collect data and information from various sources (see Figure 3-5). However, it is important that the quality and integrity of the data be maintained. Inaccurate data, whether false or otherwise compromised, will not provide an accurate representation of what is occurring in the agency.

Figure 2-3 *Hazard Identification and Data Collection*
Source: TSI

Historically, an iceberg graph (Figure 2-4) has helped illustrate where the focus of hazard identification should lie (elements above the water line and hidden underneath the water surface). It presents an operational depiction of a relationship established by H. W. Heinrich in the 1930s. Heinrich was an industrial safety engineer who demonstrated that for a specific operational work situation that led to highly-damaging outcomes (an accident), there was a large number of same-type, precursor-specific work situations that led to less harmful outcomes (serious incidents), a more significant amount of same-type, precursor-specific work situations that did not lead to damaging outcomes (incidents), and (at the bottom of the iceberg) an even more significant number of "normal" work situations where the precursors to harmful outcomes (hazards) could be identified.

Figure 2-4 *Iceberg Graph – Focus of Hazard Identification*
Source: TSI

The bottom of the iceberg is where hazard identification is most effective and where practical drift can be tracked. Here, hazard identification best operates through specific activities aimed at capturing both volume and variety of data on hazards identified while monitoring service delivery operations by a transit agency. Once hazards are identified and assessed, safety risks can be evaluated, and mitigations can be proactively deployed to avoid the escalation of the potential consequences of hazards towards the accident at the tip of the iceberg. (*Note*: Practically, it might be infeasible to perform comprehensive safety risk assessments of all the precursors to damaging outcomes [hazards] at the bottom of the iceberg. Collection and analysis of “occurrence” data would assist in identifying and prioritizing hazards that could be subject to comprehensive safety risk assessment.)

Hazard identification is the responsibility of all departments, offices, branches, and individual employees, and continual management of hazards is key to an effective safety risk management program. The three methodologies for identifying hazards are:

- **Reactive** involves analysis of past outcomes or events. Hazards are identified through event investigations. Incidents and accidents are clear indicators of system deficiencies and, therefore, can be used to determine the hazards that either contributed to the event or are latent.
- **Proactive** involves analysis of existing or real-time situations, such as through an employee safety reporting program or monitoring service operations. This involves actively seeking to identify hazards in the existing processes.
- **Predictive** involves data-gathering to identify possible adverse future outcomes or events, analyzing system processes and the environment to identify potential future hazards, and initiating mitigating actions.

Hazards may be identified through many sources, as shown in Figure 2-5. Categories of hazards, hazard aspects, and descriptions are shown in Table 2-1, and details of mechanical and overexertion hazards are shown in Table 2-2.

Figure 2-5 *Sources of Hazard Identification*

Source: TSI

Table 2-1 *Hazard Categories*

Category	Hazard Aspect	Description
Is there an environment capable of producing an unwanted release of energy?		
Unwanted Energy	Fire	Potential for exposure to a chemical or substance that can ignite if exposed to an ignition source.
	Loss of power	Potential for exposure where safety-critical equipment can fail due to loss of power; unexpected loss of power can endanger people in other ways.
	Shock, short circuit, arc flash	Potential for contact with exposed conductors or device that is incorrectly grounded; potential for arc flash.
	Static	Potential for exposure where static electricity is generated by rubbing of wool, nylon, or other synthetic fibers or flowing liquids; can cause spark to ignite combustible material and spark can ignite flammables, damage electronics, or affect body's nervous system.
	Radiation – ionizing	Potential for exposure to alpha, beta, gamma, and neutron radiation.
	Radiation – nonionizing	Potential for exposure to electromagnetic fields or other light (energy) sources.
	Chemical reaction/ deflagration	Potential for incompatible materials to mix, causing an explosion or unwanted release of energy; may include explosions due to combustible dusts (e.g., brake dust).
	Over pressurization	Potential for sudden and violent release of large amount of gas or energy due to significant pressure differences such as rupture in boiler, pipe, or compressed gas cylinder.

Category	Hazard Aspect	Description
Is the workplace configured so that workers can be caught in, on, between the equipment and that employees can strike an object?		
Configuration	Caught in, on, between	Person becomes trapped in enclosure or opening or caught on protruding object; person exposed to irregularities in facilities design.
	Struck against	Person could strike exposed object.
	Design	Workplace or facility poorly designed, specifications incomplete, and or maintenance requirements not known, understood, or incomplete, which could contribute to injury or illness.
Can an employee be struck by an object or be struck by a moving mechanical object?		
Mechanical	Failure	Potential for excessive vibration or other factors, which could cause material fatigue that results in safety-critical failure (e.g., fasteners, abraded slings/ropes, weakened hoses/belts).
	Moving vehicle	Potential to be struck by or collide with moving vehicle.
	Struck/caught by	Potential for person or their clothing to be struck or grabbed by moving object.
	Transmission	Potential for signal loss, making transmission between equipment and or personnel difficult or not enabled.
Is there potential for slipping, tripping, or falling due to gravity?		
Gravity	Changing levels	Potential for exposure to a fall from elevated work area.
	Overhead	Potential for objects to fall from heights, causing injury or property damage.
	Slips & trips (walking/ working surfaces)	Potential for exposure to uneven floor or floor openings, with potential for slip or trip.
Does the presence of chemicals or substances pose a threat to the safety and health of the workers and customers?		
Chemicals/ Substances	Biological	Exposure to or contact with contaminated or pathogenic products or materials or potent compounds.
	Toxic	Potential for exposure to a chemical through inhalation, absorption, or ingestion that causes illness, disease, or death.
	Corrosive	Potential for exposure to a chemical that can cause skin and eye damage; typically, pH at 11 or more or a pH of 2 or less.
	Vegetation	Potential for adverse reactions to contact with vegetation.
Could the employee overexert from pushing, pulling, bending, twisting, repetitive motion, vibration, or lifting?		
Overexertion	Acute	Potential for exposure to non-contact injury/illness such as bodily strain or sprain from lifting, bending, twisting, pulling, pushing.
	Chronic (repetitive motion)	Potential for exposure to non-contact injury/illness such as bodily strain or sprain from repetitive motion, prolonged inactivity; potential for exposure to excessive vibration, causing nerve-ending damage (e.g., power tools, jackhammers, rock hammers, tampers).
	Vibration	Potential for exposure to excessive vibration, causing nerve-ending damage (e.g., power tools, jackhammers, rock hammers, tampers).

Category	Hazard Aspect	Description
Is the working or operating environment hazardous to safety and health?		
Environmental	Atmosphere	May include lack of oxygen or other environmental factors not direct result of substances in workplace.
	Excavation (collapse)	Potential for collapse or engulfment, e.g., in dirt from trenching or excavation as result of improper or inadequate shoring or steep edge based on soil characteristics or in confined space.
	Noise	Potential for exposure to noise levels above 85 dBA, 8-hour TWA, or 140 dBA impact noise resulting in hearing loss or interference with communication or noise at lower levels may interfere with verbal, critical communication.
	Temperature extreme (heat/ cold)	Potential for exposure to fire, burns, heat stress/exhaustion, cryogenics, hypothermia.
	Visibility	Potential for incidents or errors because of insufficient lighting or obstructed view.
	Wildlife	Potential for wildlife to encounter workers and cause injury or illness (e.g., spiders, stinging insects, ticks, mosquitos, snakes, bears).
	Weather	Changes in weather that may cause flooding, ice or snow accumulations, wind hazards, electrical hazards, arc flash.
Is the task designed to be either too complicated, too simple, or contribute to human error?		
Human Factors	Task design or complexity	Potential for system design, procedure, or system/equipment design that is error-provocative (e.g., switch must go up to turn off a device, conflicting color codes or labeling, task is monotonous); can include physical and social environment, resources, tools, incentives, equipment problems, obstacles to performance, staffing.
	Communication	Instructions required to perform a task where communication is ambiguous, vague, conflicting, and or incomplete; communications can be verbal (including over radio net) or documented.
	Experience	Includes insufficient experience, training, knowledge, proficiency, skills, experience, physical readiness, attitudes, or motives.

Source: American Society of Safety Professionals (ASSP)

Table 2-2 *Details of Mechanical and Overexertion Hazards*

Mechanical Hazards Detailed list (to be performed in addition to general hazard list. Evaluate point of operation, power transmission, other moving parts, safeguards.	
Parts or Work Pieces	Shape; relative location; mass and stability (potential energy of elements that may move under effect of gravity); mass and velocity (kinetic energy of elements in controlled or uncontrolled motion; chemical strength limitations)
Potential Energy	Elastic elements (springs); liquids and gases under pressure, vacuum effects
Other Mechanical	Crushing; shearing; cutting or severing; entanglement; drawing in or trapping; impact; stabbing or puncture; friction or abrasion; high-pressure fluid injection or ejection
Electrical	Contact with live parts; contact with parts that have become live under fault conditions; approach high voltage; arc flash; electrostatic and thermal (molten or heated particles or substances)
Thermal	Burns, scalds, or other injuries with contact of objects or materials in extremely high or low temperatures, arc flash, flames or explosions, heat source radiation

Unexpected Start-up, Overrun or Over-speed	Failure of a control system, restoration of energy after interruption, external influences on electrical equipment, other external influences (gravity, wind), errors in software, man-machine interface errors
Operational	Variations in rotation speed of tools; failure of power supply; failure of control circuit; errors of fitting; break-up during operation; falling or ejected objects or fluids; loss of stability or overturning of machine; person might slip trip or fall into a machine
Safeguards	
Safeguard Design and Construction	Pinch, shear or crush; loosening or fracturing of bolts, fasteners or of the components; loss or disturbance of external power sources; failure of electrical pneumatic or hydraulic components; hazardous energy, electromagnetic, or electrostatic interferences, shock, vibration; humidity, contaminated air, ambient noise, light, temperature, liquids; human factors, electrical shock, arc flash
Safeguard Installation	Work area layout, hazardous energy; work surfaces; housekeeping; accessibility limitations
Start-up (Safeguard)	Pinch, shear, or crush between safeguard and machine; improper mounting or positioning; power source interference, machine interface errors; machine motion; electrical shock; safeguard proximity to other tools, equipment, and materials, human factors
Safeguard Use	Set and adjustments; function; limited application; proximity to other tools, equipment and materials; housekeeping, human factors
Safeguard Maintenance	Motion, stored energy, improper testing procedures, work procedures, housekeeping, human factors.
Overexertion	
Repetition	Repeating same motion every few seconds or repeating cycle of movements involving repetition of affected body part more than twice per minute for more than two consecutive hours in a workday
Force – 25	Lifting more than 25 lbs below knees, above shoulders, or at arm's length more than 25 times per day
Force – 55	Lifting more than 55 lbs more than 10 times per day
Force – 75	Lifting more than 75 lbs at any one time
Force – Push/pull	Pushing/pulling with more than 20 lbs of initial force (e.g., equivalent to pushing 65 Force push/pull lb box across tile floor or pushing shopping cart with five 40-lb bags of dog food) for more than 2 hours per day
Grip	Gripping unsupported object weighing 10 lbs or more per hand or use of equivalent force (e.g., crushing sides of aluminum can with one hand) for more than 2 hours per day)
Pinch	Pinching unsupported object weighing 2 lbs or more per hand or using equivalent pinching force (e.g., holding small binder clip open) for more than 2 hours per day
Postures/Twisting	Repeatedly raising or working with hand(s) above head or elbow(s) above shoulder(s) for more than 2 hours total per day; kneeling or squatting for more than 2 hours total per day; working with back, neck, or wrists bent or twisted more than 200 for more than 2 hours per day; squatting or kneeling more than 4 hours per day or body bent or twisting for or 300 more than 4 hours per day
Impact	Using body part as hammer, once per minute for more than 2 hours in a day
Vibration	Local or whole-body vibration
Contact Stress	Repeated or continuous contact with hard or sharp objects such as non-rounded desk edges or unpadded, narrow tool handles, creating pressure over one area of body; can inhibit nerve function and blood flow

Source: ASSP

Practical Drift

Part of the SRM process is the evaluation of existing systems, policies, and procedures to ensure that "practical drift"[30] is not a contributor to risk. Practical drift is the slow and inconspicuous, yet steady, uncoupling between written procedures and actual practices during the provision of services (Figure 2-6). A robust data collection and analysis process may enhance practical drift identification. Figure 2-7 illustrates data needs.

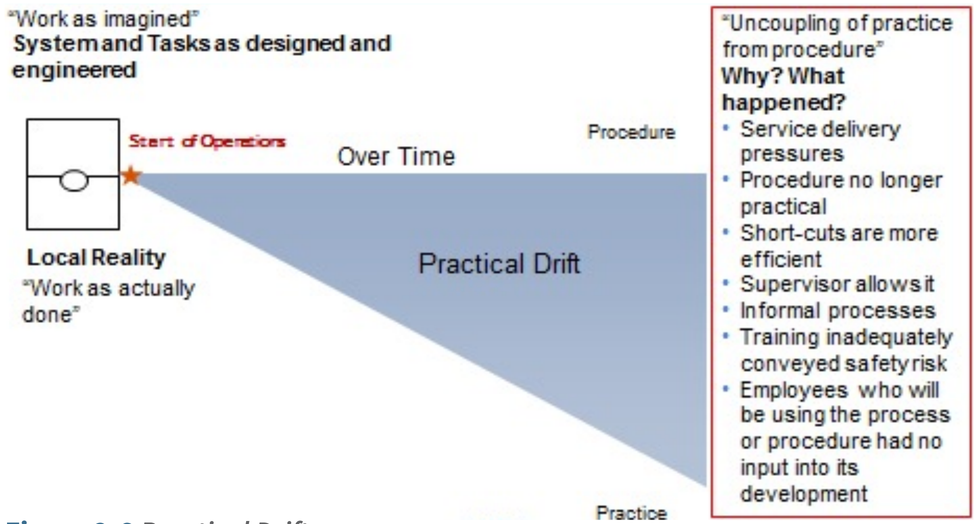

Figure 2-6 *Practical Drift*

Source: TSI

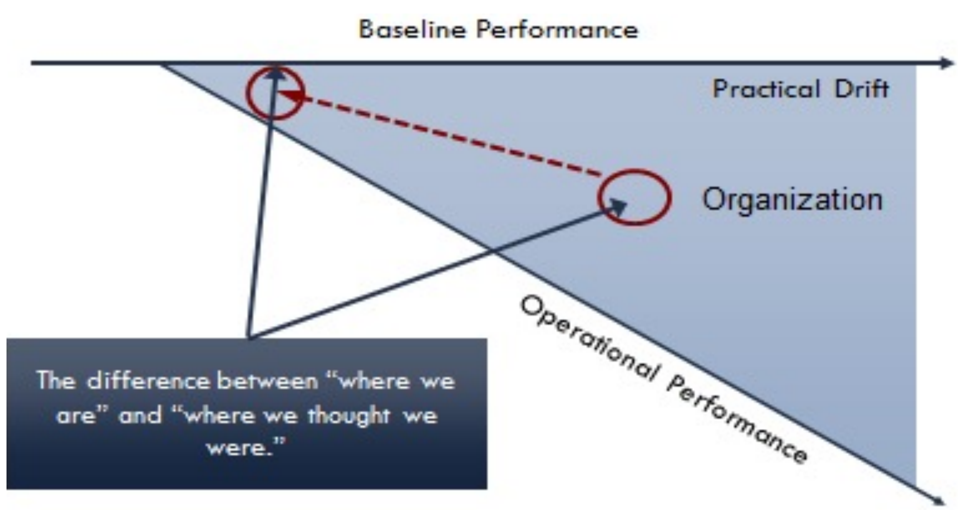

Figure 2-7 *Navigating Practical Drift – Need for Data*

Source: TSI

[30] Snook, Scott, A. *Friendly Fire: The Accidental Shootdown of U. S. Blackhawks over Northern Iraq*, Princeton University Press, Princeton, NJ, 2000; Digital Location 5234.

A practical drift from baseline performance to operational performance is unavoidable in any system's operations or maintenance functions, no matter how careful and well thought out its design planning may have been. There can be multiple reasons for practical drift, including technology that does not always operate as predicted, procedures that cannot be executed as planned because of changes in operating conditions, addition of new components to the system without an appropriate safety assessment of the problems that such components might introduce, and employee adaptations to procedures to make their job easier, improve the effectiveness of a procedure, or provide some perceived positive organizational benefit. In its simplest form, practical drift is based in human nature.

Practical drift is not always negative. The adaptation may be more productive, save time and energy, or be easier or safer. However, it potentially can put an employee, passengers, or the agency at a higher safety risk. A shortcut to a procedure or practice that seems harmless could have negative or unsafe impacts on another facet of the agency's operations. This goes back to the interconnectivity of transit systems—one small change in practice could lead to unsafe circumstances and outcomes. It is critical to know where, how, and how much drift has occurred. Data are necessary to successfully navigate practical drift. The only way to determine if drift is positive or negative is to gather information through monitoring what is happening vs. what was planned, required, or expected.

Managing Practical Drift

Managing practical drift beings with recognizing that it will occur; practical drift is human nature. The process to manage drift is as follows:

- Explore how employees come to believe that not following procedures makes more sense than systematic and principled series of activities directed to an intended completion.
- Involve knowledgeable and respected frontline employees in the development of agency policies and procedures.
- Note that, ideally, the right way to accomplish a task should also be the easiest.
- Conduct supervisory monitoring of how employees do their work; identify how tasks are being conducted rather than how they were initially designed to be conducted.
- Update procedures in line with safe, effective, current practice.

For example, a transit agency provides sufficient time for an employee to perform a comprehensive pre-trip inspection in accordance with agency policies. However, short-cuts are taken by some operators due to inclement or severe weather, fatigue, or the assumption that "everything was fine yesterday so it is good-to-go today." If the operator "gets away" with it, i.e., short-cuts, and they do not result in incidents or the operator is not noticed taking short-cuts by a supervisor, then the short-cuts continue, and perhaps, the short-cutting behavior is acquired by other operators. In the extreme, pre-trip inspections might eventually degenerate into a "pencil whipping exercise." This would be a form of practical drift.

Safety Deficiency

Identifying and defining safety deficiencies in a system is part of the Safety Risk Management process. Some organizational process-based deficiencies include those that are a result of:

- Unclear management support for the employee safety reporting system
- Insufficient documented key activities, such as hazard identification
- Shortcomings in personnel resources or training in safety-critical areas
- Incomplete certification of equipment and facilities
- Ambiguous operational procedures
- Staffing key operational positions with personnel not meeting the required qualifications
- Practical drift

Safety deficiencies could be the source of hazards or allow for the perpetuation of hazards in time.

The definition of hazard is "… any real or potential condition that can cause injury, illness, or death; damage to or loss of the facilities, equipment, rolling stock, or infrastructure of a public transportation system; or damage to the environment."[31] Hazards in the transit environment can exist due to several factors; the failure mode of the system, equipment, products, or elements exists when these components fail to perform as expected or deviate from design tolerances. Failures may present (or have the potential to present) hazardous events or harm; examples include:

- Premature operation of a system, vehicle, or equipment (e.g., unexpected activation or energy release)
- Failure to start operation (e.g., drainage pump fails to operate, and water levels rise flooding a bus garage's subterranean basement)
- Failure to stop operation (e.g., vehicle brakes release when a bus door interlocks fail)
- Failure during operation (e.g., tunnel ventilation system fails when tunnels are filling with smoke)

[31] 49 CFR § 673.5.

- Degradation or deterioration of an operation (e.g., accumulating snow or leaves, wet roadways cause slippery conditions)
- Exceeded capability or capacity of an operation (e.g., over-crowding on escalators fail to result in activation of escalator glide-stop)
- Foreseeable uses and misuses of an operation (e.g., heavy equipment transported on escalators)

A consequence is the potential outcome of the hazard. Figure 2-8 presents the transition of a hazard to a consequence. For this transition to occur, there needs to be both a form of and magnitude of energy present and a trigger event through exposure or proximity to the hazard. Energy means a property of objects that can be transferred to other objects or converted into different forms but cannot be created or destroyed. Energy gives a hazard the ability to cause harm. A trigger is a pathway of exposure to hazards:

- Direct contact with a hazard
- Indirect contact with a hazard
- Proximity to a hazard
- Duration of exposure
- Magnitude of exposure
- Concentration or dose of exposure

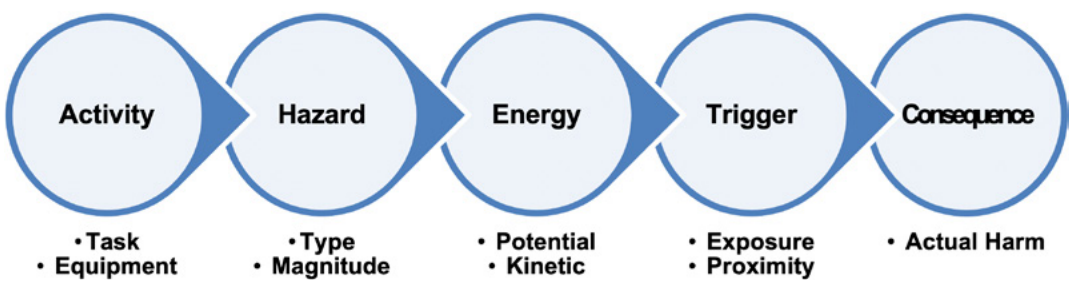

Figure 2-8 *Necessary Elements for Hazard to Result in Consequence*

Source: TSI

The following are examples of causes or triggers that could result in exposure to a hazard:

- Machinery – design, fabrication, selection, use, maintenance, SGR
- Human – actions, inactions, knowledge, skill, capability, attention, interaction, communication, practical drift
- Management – direction, supervision, instructions, inconsistencies in enforcement, communication
- Methods – design, system, process, procedure, task, consistency

- Materials – elements, constituents, selection, handling, storage, use, disposal
- Work and operating environment: design/layout, condition, external factors

It is critical to understand the difference between a hazard and a consequence. Confusing the two will limit the ability to effectively mitigate the multiple, potentially dangerous consequences of a hazard:

- Describing consequences as a hazard:
  - Disguises potential consequence(s) of hazard
  - Interferes with identifying other significant consequences
- Accurately describing hazards allows:
  - Identification of their components
  - Proper evaluation of consequence(s), including magnitude
  - Effective mitigation of consequence(s)

Examples of hazards and consequences:

- Unclear roadway signage (hazard) may lead to erratic vehicle speeds (consequence).
- Worn bolts on brake assembly (hazard) may lead to a collision (consequence).
- Narrow traffic lanes (hazard) may lead to collisions with other vehicles, pedestrians, bicyclists, or road structures (consequence).
- Grade crossings (hazard) may lead to collisions with vehicles, pedestrians, bicyclists, or grade crossing arms and other structures (consequence).

Consequences are often assessed for severity, frequency of occurrence, and cost feasibility of remedial action required to mitigate the consequences of a hazard.

Operational System Description

An operational system description can be used to examine critical operational interactions that could generate hazards and determine mitigations that may safeguard against the consequences of potential or existing hazards. The primary purpose of the operational system description is to define the contextual boundaries where hazard identification will be conducted, the components within the operational system that will be considered, and the interactions between the selected elements. A precise system description may lead to the identification of hazards, evaluation of safety risk, and identification of safety risk mitigations. The system description also encompasses the applicable regulatory and agency policy and procedure requirements under which the operations take place and any existing mitigation in place to make the system safer and more efficient.

An operational system description activity is an essential early step of an accident investigation. Documented system descriptions can serve as an ongoing record of hazard analysis and safety risk evaluation activities that provide something to return to and reference if any hazards are identified. If well-documented, they also provide one way to measure the effectiveness of the SRM process. Elements and examples sub-elements of an operational system description are presented in Figure 2-9.

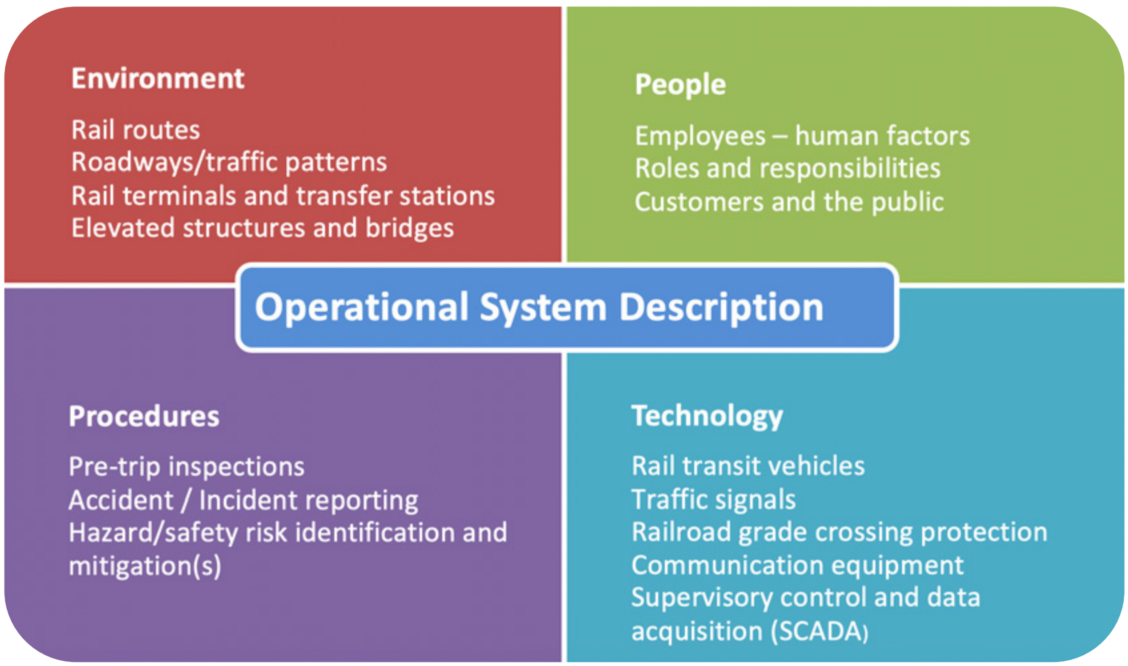

Figure 2-9 *Operational System Description*

For each described operating system, an agency may establish a team to perform the SRM analysis. Members of the safety, operating, and maintenance functions could be a part of the SRM team because functional SMEs provide accountability for safety performance under SRM. Frontline employees have excellent subject matter expertise in conducting their safety-related responsibilities and in identifying hazards inherent in those responsibilities; therefore, frontline staff and supervisors provide the necessary input and expertise.

Safety staff also play a significant role; however, the team's effectiveness often relies on input from multiple experts across the organization. The team needs to be well-rounded and inclusive of people with technical specialties and broader knowledge. It is also important to keep the size of the team in perspective and scale it to fit the area addressed. Some complex safety concerns may require more involvement and others less. Be mindful to avoid burdening the process with teams that have too many members.

Once assembled, the team can identify the operational elements for which they are responsible for the hazard(s). The team may then determine tasks performed by employees to operate and maintain the operational system for which they are responsible and identify critical elements for the successful and optimal performance of that system. The tasks might be bounded by standard operating procedures (SOP), rules, processes, and procedures. Next, the team can identify operational scenarios used to clarify interactions among service delivery elements and sub-elements. The SRM team can develop a preliminary list of potential hazards, then narrow that list to actual hazards. Finally, the team can prioritize SRM mitigation options by identifying existing and possible future mitigations to address the consequences of the hazards and ensure the safety of the operational elements and sub-elements of the various scenarios.

In less complex situations, the operational system description may require only one experienced SME, but most often it is best served by a team representing a cross-section of experienced, appropriate departmental employees such as frontline, management, and union (scalable depending on agency size) personnel. The SRM team leader's responsibilities include clarifying the role of operating and maintenance functions and determining SRM team tasks while taking accountability for the entire process. This multi-layered approach can leverage subject matter expertise across the organization and lead to a thorough and complete analysis.

Each team can submit a final report to the safety department that supplies the operational system description for their functional area of responsibility. This report may include a prioritized list of safety mitigations that are in place and those that are recommended because of the safety risk evaluation to safeguard safety success within their functional areas of responsibility. The SRM report could then be incorporated into the accident investigation report.

Hazard Identification

After hazards have been identified, they need to be analyzed for their consequences. Analyses may best be performed by SMEs from appropriate departments. These are individuals that know the technical aspects of the equipment, systems, vehicles, facilities, or the issue at hand. SMEs are experienced personnel that may have experience in addressing a similar issue. The transit agency may need to bring in outside expertise or consult with peer agencies or other transit organizations. External assistance and input can provide a new perspective on an issue.

Hazard identification is a three-step process:

1. **Identify the generic hazard.** Generic hazard is used as a term that provides focus and perspective on a safety issue and helps to simplify

the tracking and classification of many individual hazards flowing from the generic hazard.

2. **Break down the generic hazard into specific hazards or hazard components.** Each component will likely have a different and unique set of causal factors, thus making each component different and unique in nature.

3. **Link the hazard components to potentially specific consequences**, such as specific events or outcomes.

Safety-Critical Systems

Specific bus transit system systems and subsystems may be safety-critical and may present potential safety hazards:

- Vehicles and subsystems
- Infrastructure (roadway, structure, shop systems, ventilation, fire/ emergency, etc.)
- Communications (dispatch and vehicle)
- Material selections (fluids, etc.)
- Fire and emergency management systems

Hazard Identification Processes and Methods

The processes used to analyze safety-critical systems include those considered "inductive" and "deductive." An inductive analysis determines the effect of a specific event or component failure on a system; a deductive analysis examines the undesired event to determine the plausible causes of that event. Analyses that may be used to support this process include, but are not limited to:

- Operating Hazard Analysis (OHA)
- Failure Modes and Effects Analysis (FMEA)
- Fault Tree Analyses (FTA)
- Software Safety Analysis (SSA)

A description of each of these analysis methods is provided in the following section. Hazard analysis forms are included in Appendix A, and additional analytical tools are included in Appendix H.

An Operational Hazard Analysis (Figure 2-10) is used to identify and analyze hazards associated with personnel and procedures during production, installation, testing, training, operations, maintenance, and emergencies. The OHA will provide for corrective or preventive measures to be taken to minimize the possibility that any human error or procedure will result in injury or system damage. It provides inputs for recommendations for changes or improvements in design or procedures to improve operational efficiency and safety, development of manual and procedure warning and caution notes, and specialized training requirements for personnel that carry out the operation and maintenance. The OHA will result in outputs that can include but not be limited to:

- Hazardous activities in operations
- Design changes
- Safety devices
- Warnings, cautions, and special procedures
- Special procedures for the handling of hazardous materials
- Training requirements
- Security problems

The OHA analyzes hazards as described above, specifically:

- Tasks
- Human/machine interface
- Operation sequences
- Instructions
- Warnings/cautions
- Mental/physical demands
- Time requirements

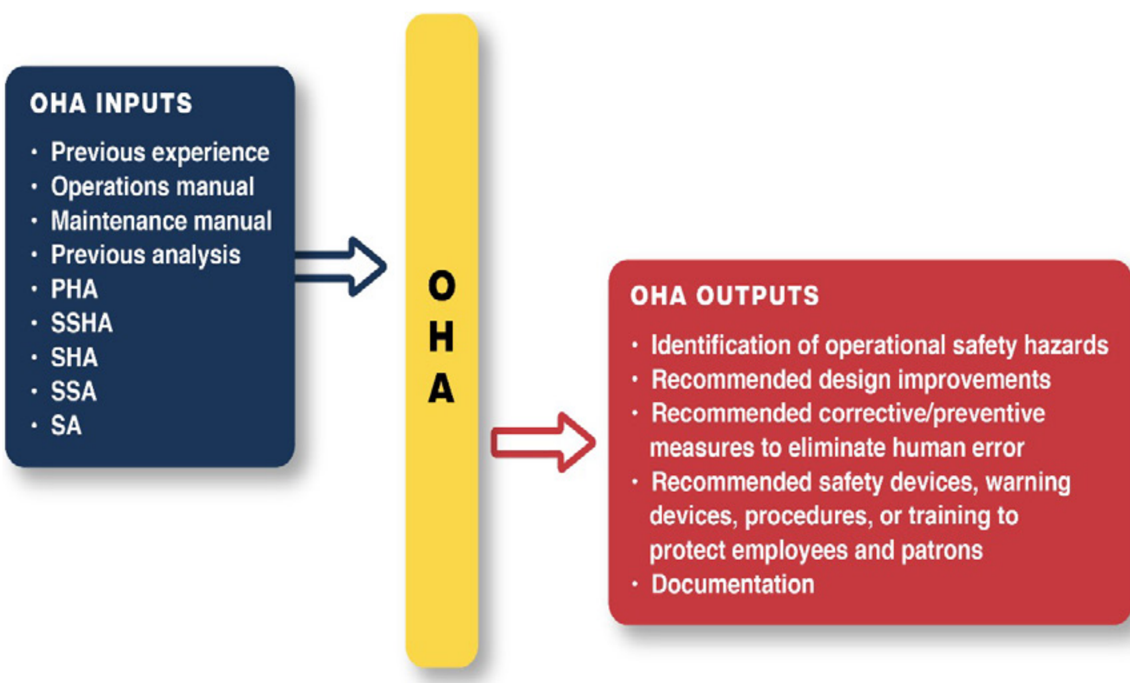

Figure 2-10 *Operational Hazard Analysis*

Source: TSI

A Failure Modes and Effects Analysis (FMEA)[32] determines the results or effects of sub-element failures on system operation and to classify each potential failure according to its severity. The FMEA is used to identify and analyze failures early in the design and major retrofit phases so that appropriate actions are taken to eliminate, minimize, or control safety. FMEA also has an application to manufacturing, construction, and the operating phases of a system.[33] The FMEA process is illustrated in Figure 2-11.

An FMEA can be used to:

- Assist in selecting effective, reliable design alternatives.
- Ensure that failure modes of system and processes and their effects on operations have been evaluated.
- Identify human error modes and effects.
- Establish a basis for planning, testing, and maintenance of systems.
- Enhance the development of procedures and processes.
- Provide both qualitative and quantitative data for analysis methods and safety risk evaluation.

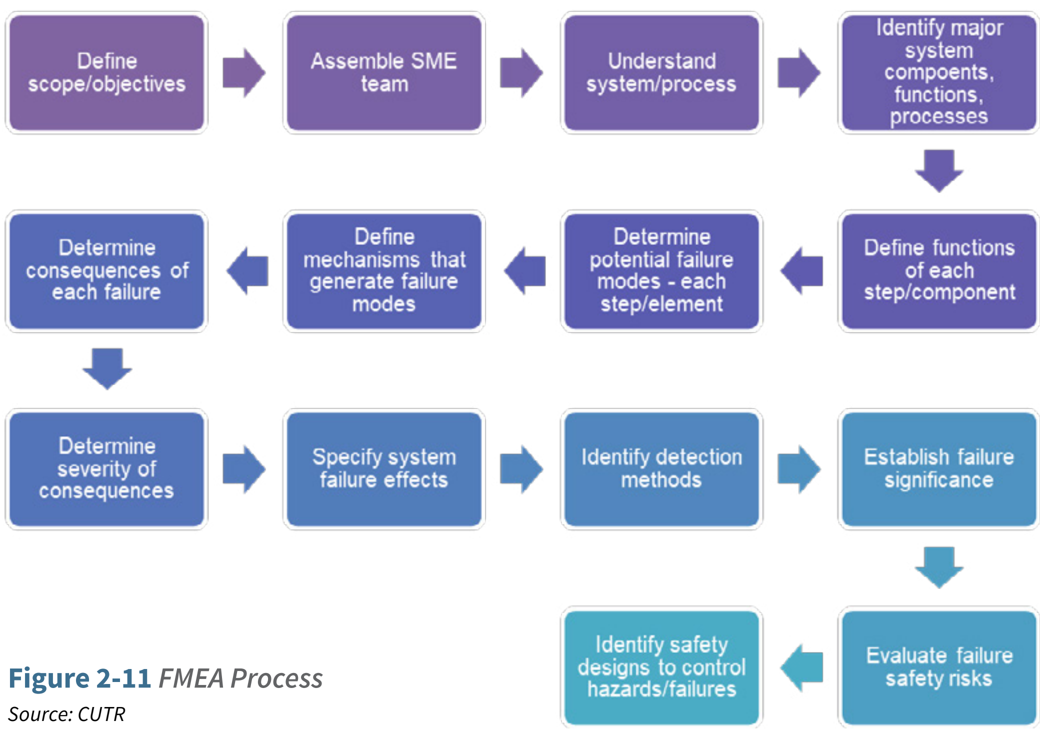

Figure 2-11 *FMEA Process*

Source: CUTR

[32] U.S. DOT, Federal Transit Administration, "Hazard Analysis Guidelines for Transit Projects," Washington, DC, January 2000.

[33] American National Standards Institute (ANSI)/American Society of Safety Professionals (ASSP), "ANSI/ASSP Z690.3-2011, Risk Assessment Techniques, » 2011, p. 56.

The output of an FMEA is a comprehensive report that contains:

- Operational system description
- Methodology
- Analytical hypothesis and conventions
- Data sources
- List of failure modes, failure mechanisms, causes, effects, and consequences, failure of each component or step of a system or process, consequences on system or process as a whole
- Test results and calculation worksheets
- Recommendations for additional analyses, mitigations, and corrective actions for each failure, if necessary

FMEA strengths include the following:

- Widely applies to the system, process, equipment, hardware, software, procedures, and human failure modes
- Identifies and organizes component failure modes, and causes and effects on the system or process
- Identifies single-point failure modes and requirements for design redundancy and mitigation via safety systems
- Identifies key features and controls that need to be evaluated in a safety assurance, safety performance monitoring plan

FMEA limitations include the following:

- Can only identify and evaluate single failure modes.
- Process is directed and focused to avoid uncontrolled expenditure of resources.
- Analysis of multi-layered, complex systems, and processes can become tedious and abstruse.

Fault Tree Analysis[34] is an analytical method to assist in determining accident causes and a hazard identification method; it provides a standardized discipline to evaluate and control hazards. The Fault Tree Analysis process is used to solve a wide variety of problems, ranging from safety to management issues. This process is further defined and presented in Appendix H. Figure 2-13 illustrates the strengths and limitations[35] of Fault Tree Analysis.

[34] USDOT, Federal Aviation Administration, *FAA System Safety Handbook*, Section 9: Analysis Techniques, December 30, 2000.
[35] ANSI/ASSP, ANSI/ASSP Z690.3-2011 : Risk Assessment Techniques, 2011. p. 62.

Fault Tree Analysis strengths include the following:

- Provides a highly systematic approach to analyze multiple factors contributing to a top event.
- Is used for analyzing systems with many interfaces and interactions.
- Graphical representation facilitates understanding of behavior of factors of the system.
- Logic Analysis is useful to follow failure pathways in a complex system.

Fault Tree Analysis limitations include the following:

- Uncertainties of probability of base events that can cause uncertainties in probability of top event.
- Is a static model; time interdependencies are not addressed and only failed, or not-failed states can be addressed.
- Human error modes can be included in a qualitative fault tree, but degree or quality of human error cannot easily be added.
- Conditional failures cannot be easily included in a fault tree.

A Software Safety Analysis can identify the hazards associated with the growing use of software to analyze, evaluate, and specify the control of system hazards. It includes software associated with bus engine controls that identifies defective systems, bus door failures, closed-circuit television (CCTV), and other systems with a computer interface. An agency (or contractor) can use Military Standard (MIL-STD)-882 E,[36] Section 4.4 and Appendix B (adapted as necessary) to perform a Software Safety Analysis. If contracted, the transit agency should require a comprehensive formal report that includes analyses, results, findings, conclusions, and recommendations that at a minimum:

- Define software hazards that will prevent hardware from operating
- Identify security-type problems that will have an operational impact on the transit system.
- Detail importance level of automated equipment failures.
- Develop items for emergency procedures to control emergencies and manual operation of equipment.

Safety Risk Assessment Process

Once a hazard has been identified and an analysis of its potential consequences has been completed, two possible scenarios exist: 1) the transit agency has enough resources to address all likely consequences or 2) the transit agency does not have enough resources to address all likely consequences. The second scenario is the critical one to be managed in SMS. The Safety Risk Assessment

[36] United States Department of Defense, Standard Practice, System Safety, MIL-STD-882E. May 2012.

process (Figure 2-12) provides the transit agency with a basis for making decisions about allocating resources to contain the damaging potential of hazard consequences.

The evaluation is performed objectively by assessing the probability of consequences occurring and the seriousness of the consequences if they do occur. This is the essential contribution of safety risk evaluation to the safety risk management process. Evaluation helps us to “put a number on” the consequences of hazards and provides a basis for making decisions about allocating resources to contain the damaging potential of hazard consequences.

Safety risk assessment provides a way to measure the potential consequence of identified hazards and includes evaluating how existing defenses mitigate the consequences of those hazards. Assessment helps determine whether certain consequences have an acceptable or unacceptable level of risk and which hazards require safety risk mitigation. Safety risk assessment within SMS is data-driven, which includes precursor data that may not lead professionals to a clear potential consequence. Data and risk analysis allow agencies to justify logical and prioritized allocation of mitigation resources.

The term “safety risk” means the composite of predicted severity and likelihood of the potential effect of a hazard. It is based both on chance that people or equipment could be harmed by the potential consequences of a hazard and how serious the harm could be. After a hazard has been identified and consequences envisioned (hazard identification step), the safety risk assessment process can begin:

- Analyze the likelihood of a consequence occurring – probability
- Evaluate the seriousness of a consequence if it does happen – severity

It is often easy to jump to the worst possible probability and severity during this assessment process, which could lead to the conclusion that the activity is too dangerous to continue. The purpose of the safety risk management is to enable agencies to continue delivering transit services but at an acceptable level of safety risk. Safety risk can be managed through the implementation of effective safety risk mitigation. Five assessment steps are included in Figure 2-13 and further described below.

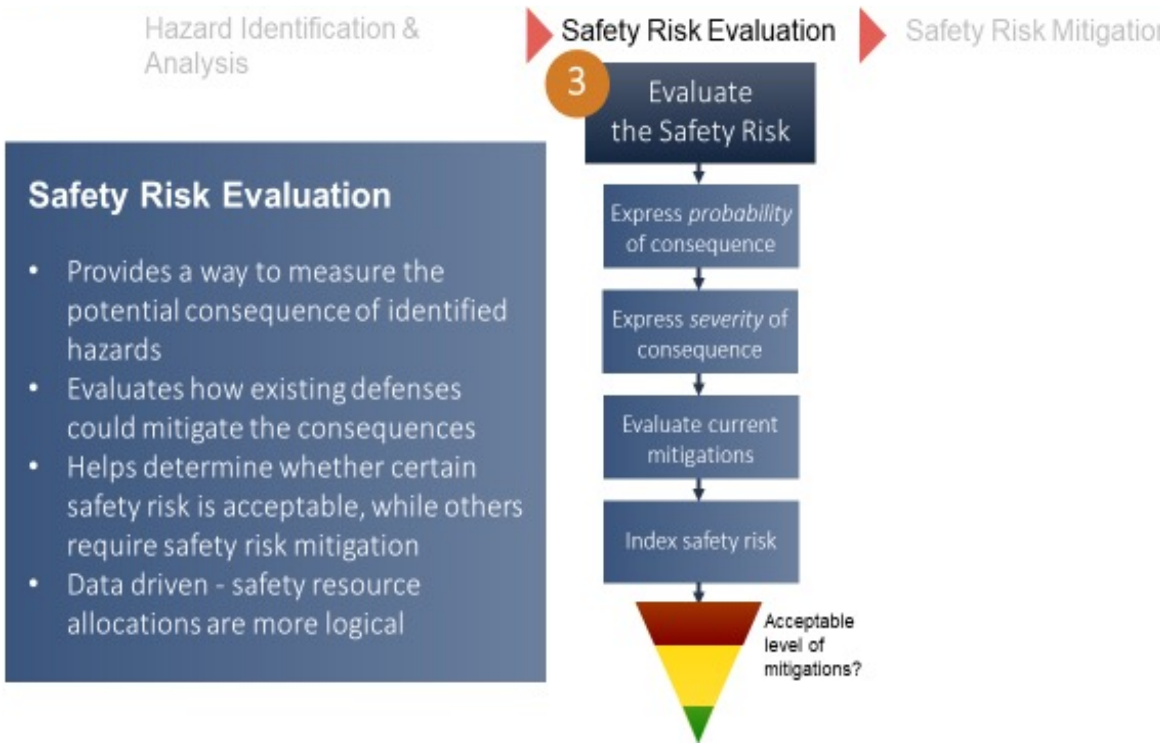

Figure 2-12 *Safety Risk Evaluation Process*
Source: TSI

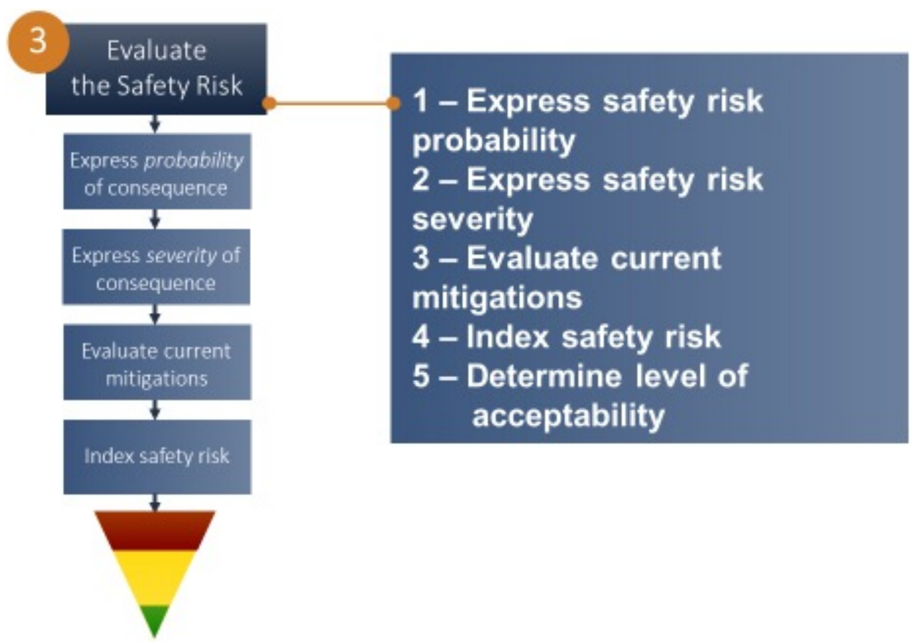

Figure 2-13 *Safety Risk Evaluation Steps*
Source: TSI

Step 1: Evaluate the hazard's consequences in terms of the probability (or likelihood) of the consequences occurring.

Step 2: Evaluate the hazard's consequences in terms of the severity of the impact of the consequences if they occur.

Step 3: Evaluate the current safety risk mitigations; determine what defenses are already in place (maybe none), and if they have been effective (SA activities may help with this question). Step 3 may be performed concurrent with the previous two—when evaluating probability and severity, the initial evaluation may be determined without considering existing mitigations, which would determine the initial safety risk. Then, the existing mitigation could be factored in, as it impacts probability and severity. The existing mitigation should reduce probability and possibly severity; however, to reduce severity, it would be necessary for the current mitigation to reduce the energy of the hazard that results in the consequence (harm). The evaluation of existing mitigations determines the existing safety risk. If the current safety risk is determined to be unacceptable, then the agency can develop and implement additional mitigations. The safety risk can then be assessed with the inclusion of the additional mitigation. This assessment would determine the residual safety risk.

Step 4: Index safety risk based on the consequence probability and severity analysis.

Step 5: Determine acceptability based on indexing of the safety risk— is it an acceptable level of safety risk to the agency?

Qualitative Safety Risk ssessment

Probability is the likelihood that something will occur—in this case, the probability that the consequence might occur. Emphasis is placed on the worst foreseeable but credible condition. The worst predictable condition might be based upon the judgment of an SME. When establishing the probability of the consequence of a hazard occurring, the more data available to determine probability, the higher the degree of confidence can be achieved. If no data exist, then a qualitative probability evaluation may need to be based on the judgment of SMEs. However, with 3–5 years of pertinent and reliable agency accident and incident data, the agency may consider using quantifiable data to determine probability. If a transit agency has reliable data that suggest the lesser likelihood of a consequence occurring, it may choose to apply such data. Reliable data may outweigh individual subjective judgment regarding the probability of occurrence.

Table 2-3 presents event probability levels. This probability table might look familiar as many transit agencies use some version of this table. The values are alphabetic and range from "A to F" with "A" being frequent or likely to occur frequently and "E" being improbable or expected that this event will never happen. The designation "F" is used when potential hazards are identified and eliminated.

Table 2-3 *Event Probability Levels*

Description	Level	Specific Individual Item	Fleet or Inventory
Frequent	A	Likely to occur often in life of item.	Continuously experience.
Probable	B	Will occur several times in life of item.	Will occur frequently.
Occasional	C	Likely to occur sometime in life of item.	Will occur several times.
Remote	D	Unlikely, but possible to occur in life of item.	Unlikely, but can reasonably be expected to occur.
Improbable	E	So unlikely, it can be assumed that occurrence may not be experienced in life of item.	Unlikely to occur, but possible.
Eliminated	F	Incapable of occurrence; level used when potential hazards identified and later eliminated.	Incapable of occurrence; level used when potential hazards identified and later eliminated.

Source: TSI

Credibility is critical and essential to Safety Risk Assessment. Credibility works in two ways—in the assessment process itself and for sustaining SMS. Whether using data or SME judgment, the condition must be credible and the data for assessment must be reliable. If circumstances demonstrate that the evaluation of the condition is either too extreme or too lax, the credibility of the SRM process will suffer. The credibility of the analysis and assessment is essential.

Assess Severity of Consequence

The next step is to assess the severity of the consequence and could leverage severity categories such as those categories provided in Table 2-4. The assessment determines how harmful a given consequence would be if it became a reality.

Table 2-4 *Event Severity Categories*

Description	Severity Category	Event Result Criteria
Catastrophic	1	Could result in one or more of following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10M.
Critical	2	Could result in one or more of following: permanent partial disability, injuries, or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1M but less than $10M.
Marginal	3	Could result in one or more of following: injury or occupational illness resulting in one or more lost workday(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $100K but less than $1M.
Negligible	4	Could result in one or more of following: injury or occupational illness not resulting in a lost workday, minimal environmental impact, or monetary loss less than $100K.

Source: TSI

Determining the severity of a given consequence may require detailed knowledge of operations and the environment. Transit agencies may benefit from examining safety risk from the perspective of what could occur if the potential consequences materialize and looking at the impacts on people/ personnel, system elements, equipment, and the operating environment.

Safety risk severity can involve an assessment of the damage potential of the consequence of the hazard under the worst foreseeable but credible condition, not the worst-case condition. The Severity of Consequence chart (Table 2-5) presents a typical safety risk severity table (MIL-STD- 882E) and includes four categories to denote the level of severity of the occurrence of a consequence, the meaning of each category, and the assignment of a value to each category using numbers.

Table 2-5 *Qualitative Severity of Consequence*

Category	Catastrophic (1)	Critical (2)	Marginal (3)		Negligible (4)
Personal Injury	Fatality	Serious injury	Non-serious injury	Minor injury	Less than minor injury
Environmental	Severe environmental damage violation, law, regulation	Reversible environmental damage violation, law, regulation	Reversible moderate environmental impact	Minor environmental impact	Superficial environmental impact
System	Severe effect—single point failure initiating catastrophic event	Serious effect—significant safeguard initiating concurrent failure event	Moderate effect—prolonged disruption initiating secondary hazard event	Minor effect—brief disruption initiating potential for secondary hazard event	Insignificant event—no impact, non-event
Emergency	Evacuation for life safety reasons	Evacuation because of event (serious non-life threatening	Fire/ smoke/ irritant	Minor fire/ smoke/ irritant	Less than minor irritant/ inhalation

Source: TSI

Evaluate Current Mitigations

A process to evaluate current mitigations is illustrated in Figure 2-14, which begins by establishing a baseline—determining the initial risk if there are no mitigations in place —then evaluating the current mitigations of a given circumstance or concern. This can be done by assessing the existing safety risk and determining the probability and severity of a consequence based on the examples above.

The SMS SA process calls for the evaluation of the effectiveness of a mitigation in correcting a deficiency or other risk and ensuring no unintended consequences. Agencies will benefit from accounting for existing defenses or mitigations when looking at probability and severity. To provide a good measure of the effectiveness of existing defenses, it may be best to consult the data received through SA activities. The consequences of the hazard can be reassessed once the mitigation(s) is developed and then continuously monitored to ensure that no unintended consequences occur due to the implemented mitigations. With properly recorded mitigation activities, the review will disclose whether the mitigation is effective or not.

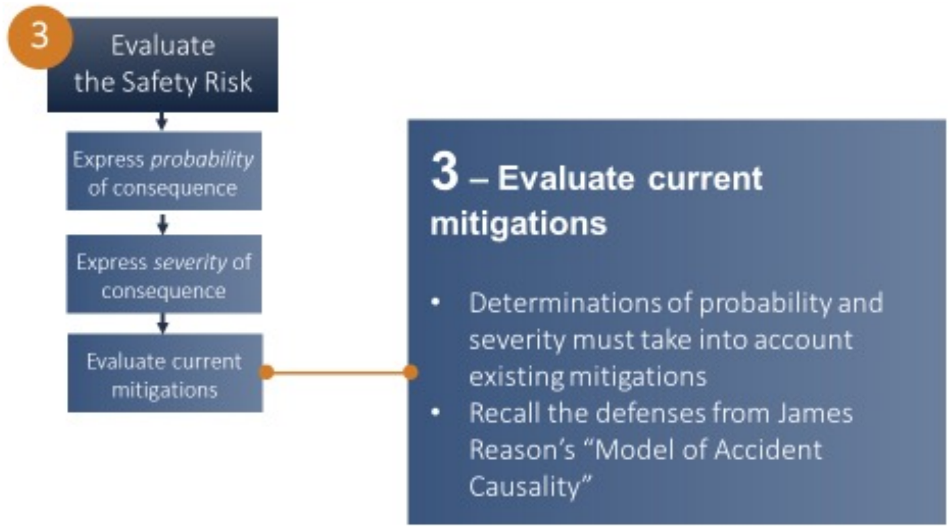

Figure 2-14 *Evaluation Process for Current Mitigations*
Source: TSI

There are different strategies for mitigating or controlling the consequences of a hazard. The first and most effective method is to eliminate the hazard at the design phase, prevent it from ever existing in the system. However, not all hazards can be designed-out of a system, and there are other ways to reduce safety risks through mitigations, such as the following:

- Installation of safety devices, equipment, and tools such as signage and interlocks
- Installation of warning systems such as guardrails and grade-crossing warning devices
- Implementation of effective administrative actions such as procedures and rules
- Proper selection and use of PPE

Administrative action is used as a quick fix in response to many incidents or safety concerns. Typically, this is the case because administrative action is the easiest and most cost-effective way to respond— send a memo, update an SOP, discipline personnel, or modify training. However, administrative action can also be effective and useful once higher-level mitigations such as engineering, or infrastructure modifications have been implemented. Administrative action often is implemented as the only mitigation when higher-level mitigation may be necessary. Over-reliance on administrative actions can lead to the appearance that something has been done, but often it does not resolve underlying contributory hazards.

Index Safety Risk

Next, agencies can combine the values of safety risk probability with the safety risk severity values given the mitigations in place. This step determines the measure or index that will be assigned to the hazard and related consequence to prioritize the safety risk (Figure 2-15). The Safety Risk Assessment Matrix in Figure 2-16 shows the platform for the comprehensive examination of the level of probability that there will be an occurrence with the level of severity of that occurrence.

Figure 2-15 *Index Safety Risk*
Source: TSI

MIL-STD-882E	Safety Risk Assessment Matrix			
Severity / Probability	Catastrophic 1	Critical 2	Marginal 3	Negligible 4
A - Frequent	1A	2A	3A	4A
B - Probable	1B	2B	3B	4B
C - Occasional	1C	2C	3C	4C
D - Remote	1D	2D	3D	4D
E - Improbable	1E	2E	3E	4E
F - Eliminated				

1A, 1B, 1C, 2A, 2B	High	**Unacceptable**
1D, 2C, 3A, 3B	Serious	**Undesirable** with management decision required
1E, 2D, 2E, 3C, 3D, 3E, 4A, 4B	Medium	**Acceptable** with review by management
4C, 4D, 4E	Low	**Acceptable** without review

Figure 2-16 *Qualitative Safety Risk Matrix*

Source: TSI

The risk assessment code (RAC) or risk index (RI) is then calculated using Probability × Severity = RAC or RI with a descriptor. Once the safety risk of a consequence has been assessed using Steps 1, 2, and 3 considering current mitigations, the fourth step is establishing a safety RI for the residual risk of the consequence. This is achieved by combining the values for residual safety risk probability and residual safety risk severity tables into a residual safety risk matrix.

If a safety risk probability has been assessed as occasional (C) and the safety risk severity has been evaluated as critical (2), the composite of probability and severity (2C) is within the serious (orange) safety risk zone. This evaluation system assigns an actual value to the hazard and consequence of concern. The color-coding in the matrix reflects the tolerability regions in the inverted safety risk tolerance triangle—red denotes unacceptable (or high), orange denotes serious, yellow denotes acceptable (or medium) with mitigation, and green denotes acceptable (or low). (*Note*: The safety risk matrix in Figure 2-16 is presented as an example. SMS is scalable, and every organization will want to perform the safety risk evaluation process in a way that works for it—what works at one organization may not work at another, but the point is to establish an evaluation system that assigns value to the consequence of a hazard so that it can be ranked and prioritized.)

A semi-quantitative risk model uses qualitative data to express risk values with numerical ratings using a formula to produce a risk score.[37] This model is intended to facilitate understanding of the effectiveness of various mitigation methods for those who are responsible for developing, implementing, and monitoring the effectiveness of mitigations to reduce safety risk. The semi-quantitative risk model adds a degree of objectivity to the more subjective qualitative safety risk analytical method. An example of these models, including sample worksheets, and scoring is provided in Appendix A.

Table 2-6, Semi-Quantitative Safety Risk Probability, assigns a numeric value to the probability of occurrence of a consequence. The probability of "Frequent" is assigned a value of 5, and the probability ranges descend to "Improbable," which is assigned a value of 1. (*Note*: Each probability level is also assigned a scientific notation value under the "Meaning" column, which would be used when reliable data is available regarding the frequency of occurrence of a consequence.)

Table 2-6 *Semi-Quantitative Safety Risk Probability*

Probability	Meaning	Value
Frequent	Likely to occur frequently ($> 10^{-1}$)	5
Probable	Likely to occur several times ($< 10^{-1}$ but $> 10^{-3}$)	4
Occasional	Likely to occur sometime ($< 10^{-3}$ but $> 10^{-6}$)	3
Remote	Very unlikely to occur ($< 10^{-6}$ but $> 10^{-8}$)	2
Improbable	Almost inconceivable that the event will occur ($< 10^{-8}$)	1

Source: TSI

Table 2-7 provides the commonly used semi-quantitative safety risk severity categories and includes four categories to denote the level of severity of the occurrence of a consequence, the meaning of each category, and the assignment of a numerical value to each category. In this table, a value of 4 is considered catastrophic, meaning possible fatalities, system loss, and equipment destroyed, and 1 is considered negligible or of little consequence with two levels in between.

[37] Lyon, B. K., and Popov, G., "Risk Management Tools for Safety Professionals," Part I, Section 3, American Society of Safety Professionals, 2018.

Table 2-7 *Semi-Quantitative Safety Risk Severity Categories*

Description	Severity Category	Event Result Criteria
Catastrophic	4	Could result in one or more of the following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10M.
Critical	3	Could result in one or more of the following: permanent partial disability, injuries, or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1M but less than $10M.
Marginal	2	Could result in one or more of the following: injury or occupational illness resulting in one or more lost workday(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $100K but less than $1M.
Negligible	1	Could result in one or more of the following: injury or occupational illness not resulting in a lost workday, minimal environmental impact, or monetary loss less than $100K.

Source: TSI

Figure 2-17 provides a comprehensive illustration of the merging of risk potential and severity, the Semi-Quantitative Safety Risk Matrix, which can be used to identify risks deemed unacceptable to and those that may be acceptable with or without management review.

Semi-Quantitative Safety Risk Assessment Matrix

Probability \ Severity	Catastrophic 4	Critical 3	Marginal 2	Negligible 1
Frequent 5	High-20	High-15	Serious-10	Medium-5
Probable 4	High-16	High-12	Serious-8	Medium-4
Occasional 3	High-12	Serious-9	Medium-6	Low-3
Remote 2	Serious-8	Medium-6	Medium-4	Low-2
Improbable 1	Medium-4	Medium-3	Medium-2	Low-1
Eliminated 0				

High (>11)	Unacceptable	High	Unacceptable
Serious (7-11)	Undesirable	Serious	Undesirable with management decision required
Medium (>3 and < 7)	Acceptable with review	Medium	Acceptable with review by management
Low (<=3)	Acceptable no review	Low	Acceptable without review

Figure 2-17 *Semi-Quantitative Safety Risk Matrix*

Source: TSI

Determining the final score or rank of the safety risk helps to prioritize items, elevating those that need immediate attention to the forefront for action. This helps the agency decide where to focus resources based on established criteria, safety risks the agency will need to act upon, and priorities for safety risk mitigation efforts.

Determining Safety Risk Tolerability

The fifth level safety risk assessment establishes agency tolerance of a given safety risk against established criteria (Figure 2-18). This step determines the safety risk level an agency will act upon and defines safety risk mitigation priorities.

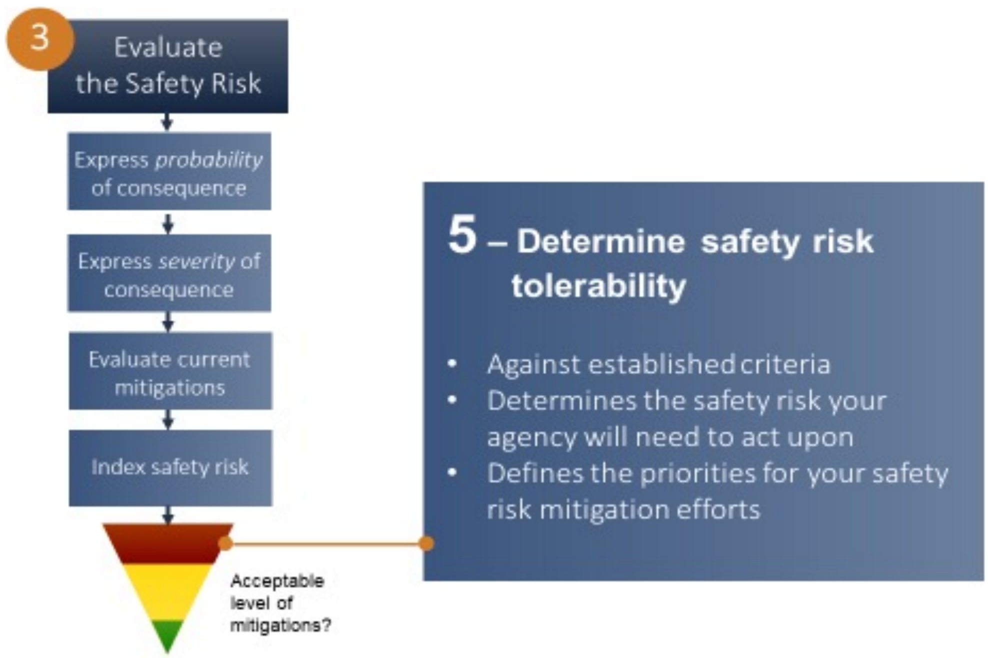

Figure 2-18 *Determining Safety Risk Tolerability*

Source: TSI

Figure 2-19 is a visual representation of safety risk in three broad categories—Acceptable, Acceptable with Mitigation, and Unacceptable. In determining what is "reasonably practicable" in the context of SRM, consider both the technical feasibility of further reducing the safety risk and the cost. Showing that the safety risk is As Low as Reasonably Practicable (ALARP) means that any further safety risk reduction is either impracticable or grossly outweighed by the cost. However, "accepting" safety risk does not mean that the potential consequences of hazards have been eliminated. Instead, it means that the possible consequences of a hazard are either low enough or have been mitigated by the transit agency so that any further effort would not be practical or beneficial. However, the effectiveness of the mitigations must be continually monitored through SA activities. The inverted triangle of Figure 2-19 suggests that the transit industry (such as any other mass transportation industry) is “top-heavy” from a safety risk perspective. There could be a significant number of hazards and consequences evaluated as within the unacceptable region (red). This evaluation could change after staff better understands the process of evaluating safety risk. Nevertheless, hazards evaluated as falling in the unacceptable region are unacceptable under any circumstances. The consequences of the hazards are of such a magnitude, and the damaging potential of the hazard poses such a threat to the viability of the transit agency to deliver its services that immediate mitigation is required.

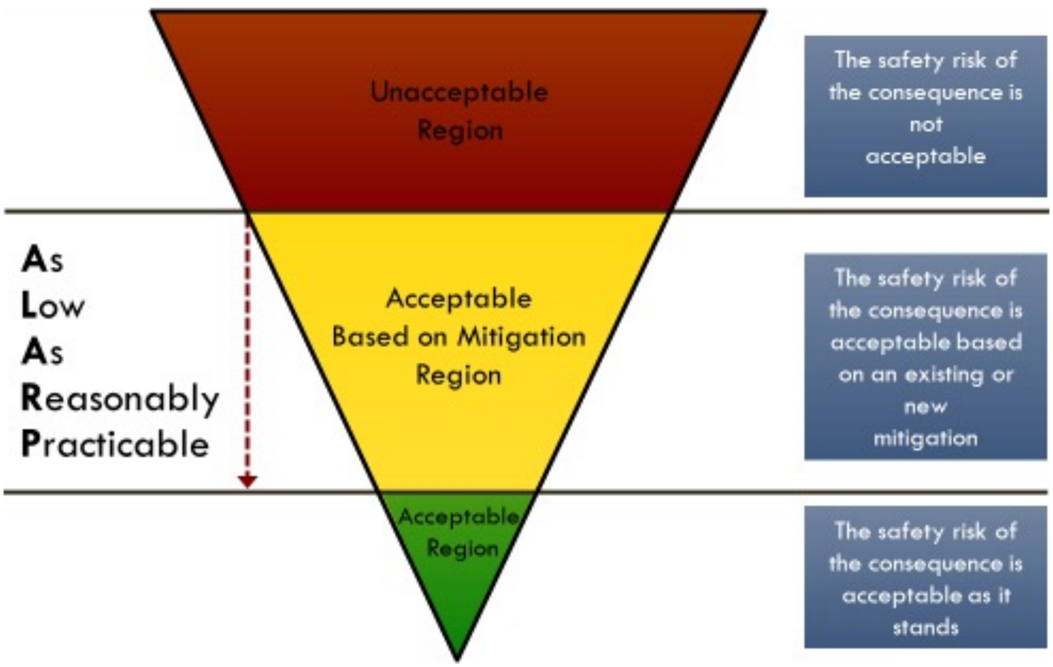

Figure 2-19 *Safety Risk Tolerability*
Source: TSI

Safety risks evaluated as falling in the “acceptable” area are acceptable provided mitigation already in place suggests that the consequences of the hazards have been effectively mitigated. The same criteria apply to safety risks evaluated initially in the unacceptable region and mitigated to the acceptable region. A safety risk initially evaluated as “unacceptable” that is mitigated and slides down to the “acceptable” area must remain “protected” by mitigation. If the safety risk is not effectively protected continuously by mitigation, it is unacceptable. Safety risks evaluated as acceptable are acceptable as they currently stand and require no action other than monitoring.

Safety Risk Mitigation

Following safety risk evaluation, safety risks ranked as “acceptable” or “acceptable with mitigation” may require management. Step 4 of SRM is Safety Risk Mitigation (Figure 2-20), a step that if effectively conducted will help address safety risk while balancing the management dilemma of protection/ safety vs. productivity/service delivery. It enables transit agencies to manage safety risk with balanced mitigation strategies that reduce risk to an acceptable level. Agencies may find it beneficial to align strategies with their safety performance objectives.

Figure 2-20 *Safety Risk Mitigation Process*
Source: TSI

Safety risk mitigation strategies (Figure 2-21) must be monitored for effectiveness and can be aligned with agency safety performance objectives. There are three common strategies of safety risk mitigation—avoid the hazard, reduce the hazard, and segregate the hazard. Safety Risk Mitigation includes initial, ongoing, and revised mitigation strategies. The SA function provides ongoing monitoring of these strategies. Transit agencies are familiar with the concept of safety risk mitigation during the building or rehabilitation of new extensions and systems. These mitigations are often tied to MIL-STD 882E and are reflected in the design, engineering, and construction of transit systems. The MIL-STD safety order of precedence includes the following:

- Eliminate hazards and consequences through system design and redesign.
- Mitigate hazards and consequences through system design and redesign.

- Incorporate safety devices.
- Provide warning systems.
- Apply administrative mitigations (work methods, rules and procedures, and training).

Figure 2-21 *Safety Risk Mitigation Strategies*
Source: TSI

Safety Risk Avoidance as a mitigation strategy is an essential safety risk management concept. It means avoiding, canceling, or delaying the operation or activity that presents the consequences of the hazard. The objective is to avoid the consequences, not the hazard (for example, rain/snow cannot be avoided). For example:

- Avoid – operational procedure modifications
  - Reducing rail speed and increasing following distance during inclement weather
  - Re-routing buses around roadway construction zones
- Cancel – defective transit vehicle removed from service and decommissioned
- Delay – transit service suspended in adverse weather, resumes only when conditions improve

Safety Risk Reduction (Figure 2-22) mitigation methods reduce the safety risk associated with the consequence of the hazard to ALARP. It allows the agency to bring the safety risks to a level acceptable to management. Safety risk reduction-related mitigation examples include:

- Reducing operating speeds
- Reducing distractions through electronic device policies

- Requiring specific certifications and protective equipment for personnel working under specific operational conditions
- Requiring additional inspections
- Highlighting information safety topics to increase employee awareness of certain safety risks; examples include signs and symptoms of heat exhaustion or cold emergencies
- Supervisors riding to monitor safe driving
- Reviewing on-board video/audio and driver behavior management systems
- Reviewing on-board event data recorder and equipment data acquisition modules
- Reviewing videos as part of safety efficiency testing
- Providing job safety briefings to provide site-specific safety advice and guidance specific to hazards in the work area; attending employees may increase their awareness and thus lower their safety risk
- Requiring a second employee for tasks such as assisting drivers when backing up buses (a "lookout" or "spotter")

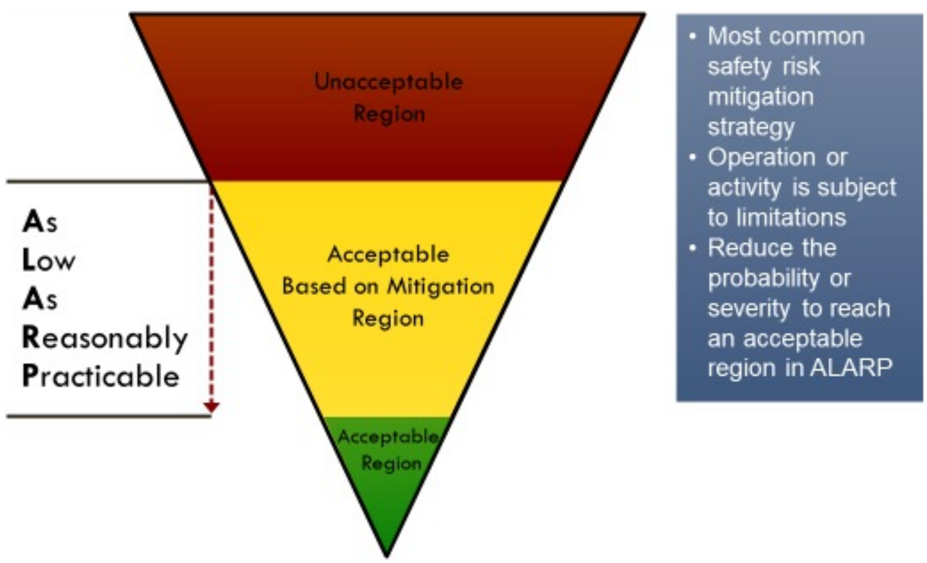

Figure 2-22 *Safety Risk Reduction*
Source: TSI

Segregation of Exposure is a mitigation strategy that involves limiting exposure to the consequences of hazards by isolating the effects of the consequences of the hazard or building in the redundancy of protection against the consequences of the hazard. Examples of segregating exposure include the following:

- Providing multiple mitigations on a transit vehicle in the event one set fails (redundancy)

- Providing cellphones programmed with restrictions to only call dispatch for radio communication dead spots within the service area (redundancy)
- Providing additional transit personnel at transfer and BRT stations during rush hour to manage crowding and passenger loading
- Limiting access to separated busway to only those who meet established levels of training

Categories of Mitigations

Mitigations can be grouped into two broad categories—Engineering and Personnel. Engineering mitigations either eliminate a hazard or its potential or adjust the operation to reduce the consequence(s) of the hazard to a manageable level; they are considered "hard" mitigations because they do not rely on flawless human performance. Personnel mitigations rely on personnel interventions to cope with the consequence(s) of the hazard—for example, by adding warnings, revised checklists, standard operating procedures, and training. Personnel mitigations are considered "soft actions" because they require flawless human performance. An example of a hard defense is an automated blocking device that operates under specified operational conditions without the need for human intervention. An example of a soft defense is a reminder to (or training of) an operator to be careful under the same specified operational conditions.

The most effective mitigations are hard mitigations, such as engineering modifications or technologies such as autonomous braking systems. Because hard mitigations are often expensive, soft mitigations such as training are more commonly proposed. In the case of soft mitigations, safety staff often work with the operating and maintenance functions to ensure that the organization is taking responsibility for SRM-developed mitigations and continue to monitor frontline employee performance.

Not all mitigation strategies have the same potential safety effect. The effectiveness of each alternative needs to be evaluated before a mitigation decision can be made. Safety and operational SMEs could be involved in this evaluation. There might be multiple alternative mitigation strategies, and some may be determined to be more effective than others. This evaluation of alternative strategies is an essential step in the mitigation process because only after this is done can final decisions be made about the safety risk mitigation strategies that will be implemented. Operations and maintenance managers are given ownership because they will implement and track the safety risk mitigation strategies and be held accountable. The Safety Department has ownership for monitoring the effectiveness of safety risk mitigation strategies through the Safety Assurance function. Everyone involved in interacting with the safety risk mitigation strategies once they are implemented has ownership.

Mitigations, Recommendations, and Corrective Action Plans

Safety risk mitigations established through event investigation activities and corresponding recommendations are tracked through the Safety Assurance process and drive corrective actions. Guidance is provided in the Safety Assurance section of this document under Accident Investigation procedures and further delineated in *Effective Practices in Performing Transit Bus Accident Investigations*.

Section 3

Safety Assurance

Transit agencies must develop and implement a Safety Assurance process that includes safety performance monitoring and measurement activities. This section focuses on the following elements of Safety Assurance:

- Safety objectives, safety performance targets, and safety performance indicators
- Event investigations
- Continuous Improvement
- SGR and Transit Asset Management (TAM)

A transit agency must perform the following activities in support of its safety assurance process:

- Monitor its system for compliance with, and sufficiency of, its procedures for operations and maintenance.
- Monitor its operations to identify any safety risk mitigations that may be ineffective or inappropriate or were not implemented as intended.
- Investigate safety events to identify causal factors.
- Monitor information reported through any internal safety reporting programs.

Included within SA is Management of Change. Some transit agencies must establish a process for identifying and assessing changes that may introduce new hazards or impact the transit agency's safety performance. If it is determined that a change may impact its safety performance, the agency must evaluate the proposed change through the SRM process.

Continuous Improvement is central to SA. Some transit agencies must establish a process to assess their safety performance. If a transit agency identifies any deficiencies as part of its safety performance assessment, it must develop and carry out, under the direction of the Accountable Executive, a plan to address the identified safety deficiencies.

Safety Objectives, Safety Performance Targets, and Safety Performance Indicators

SMS generates data and information that the Accountable Executive and other senior management need for establishing safety objectives, safety performance targets, and safety performance indicators, and provides a mechanism to evaluate whether implemented safety risk mitigations are appropriate and effective. Safety performance monitoring does not focus on monitoring individuals but on the safety performance of the transit agency itself through routine monitoring of operations and maintenance activities. FTA provides full details of the practices described below in its Transportation Safety Institute (TSI) training programs.[38]

The safety performance monitoring and measurement subcomponent of SA details activities a transit agency must establish include:

- Monitoring its system for compliance with and sufficiency of its procedures for operations and maintenance
- Monitoring its operations to identify any safety risk mitigations that may be ineffective or inappropriate or were not implemented as intended
- Investigating safety events to identify casual factors
- Monitoring information reported through any internal safety reporting programs

Three key terms for establishing performance measurement criteria are:

- **Safety Objective** – a quantifiable statement regarding safety achievements to be accomplished by an organization regarding its safety performance
- **Safety Performance Target** – a specific, quantifiable level of performance for a given performance measure over a specified timeframe related to safety management activities
- **Safety Performance Indicator** – a data-driven, quantifiable parameter used for monitoring and assessing safety performance

Once established, the safety objectives must be formally communicated throughout the agency. Transit agencies will benefit from the periodic review and update (as appropriate) of safety performance indicators and targets and may use them to inform the allocation of resources.

Noting that establishing safety performance targets and safety performance indicators is good, Andrew Hopkins provided some cautionary comments regarding performance indicators that may be manipulated, especially when financial incentives are involved:

> When deciding on the performance indicators to be included in pay schemes, it is essential to recognize that the moment there are consequences attached to performance with respect to an indicator, there is an incentive to manage the indicator itself rather than the phenomenon of which it is supposed to provide an indication. This is apparent in the case of lost-time injuries. For instance, if people are brought back to work the day after an accident and placed on alternative duties, hey presto, a potential

[38] *FTA SMS-Safety Assurance: Participant Guide*, v.12_09282018.

> lost-time injury is no longer a lost-time injury. While this can often be justified from an injury management point of view, there is plenty of anecdotal evidence of people being brought back to work purely as a means of managing the measure… The problem is so severe that a review sponsored by the New South Wales mining industry recently recommended that the industry should no longer pay bonuses based on injury outcome data, such as lost-time or medical treatment injuries.[39]

A similar position was adopted by the Occupational Safety and Health Administration (OSHA)[40] to ensure that disincentives are not created for employees to report illnesses or injuries. Reporting a work-related injury or illness is a core employee right and retaliating against a worker for reporting is a violation of Section 11c of the OSHA Act; Section 11c prohibits an employer from discriminating against an employee because the employee reports an injury or illness. Other whistleblower statutes enforced by OSHA also may protect employees who report workplace injuries. In particular, the Federal Railroad Safety Act (FRSA) prohibits railroad carriers, their contractors, and subcontractors from discriminating against employees for reporting injuries under 49 U.S.C. 20109(a)(4).

OSHA identified several workplace policies and practices that could discourage reporting and could constitute unlawful discrimination:

> Incentive programs that discourage employees from reporting their injuries are problematic.… If an employee of a firm with a safety incentive program reports an injury, the employee, or the employee's entire workgroup, will be disqualified from receiving the incentive, which could be considered unlawful discrimination. One crucial factor to consider is whether the incentive involved is of sufficient magnitude that failure to receive it "might have dissuaded reasonable workers from reporting injuries."[41]

Therefore, before implementing safety performance targets and safety performance indicators employers may find it beneficial to ensure that they do not create inappropriate financial incentives, especially for those specific to employee or contractor Lost Time Accident (LTA) rates.

Safety performance monitoring and measurement includes four essential activities that must occur:

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[39] Hopkins, A., "Failure to Learn—The BP Texas Refinery Disaster."
[40] US Department of Labor, Occupational Safety and Health Administration, Memorandum March 12, 2012, Subject: Employer Safety Incentive and Discrimination Policies and Practices.
[41] *Burlington Northern & Santa Fe Railway Co v. White*, 548 U.S. 53, 68 (2006).

- Mitigation monitoring – This verifies that mitigations are implemented, effective/appropriate and performing as intended. This helps to confirm safety risk management and verifies that new hazards have not been introduced. Mitigations can be fed into the SRM review process. Unimplemented or ineffective mitigations, along with new hazards, can be returned to the SRM function for follow-up activities.
- Monitoring for procedure compliance and sufficiency – Field observations that fall under the monitoring of regular activities area differ significantly from auditing and inspections, as they are designed to promote the collection of safety data by simply watching employees work in their normal work settings. Field observations also highlight compliance with actual agency policies and practices. Field observations are also critical to ensuring that mitigations are working as intended. Transit agencies may choose to regularly report the results of observations to management for review.
- Employee safety reporting – SMS and SA activities are heavily-dependent upon effective employee safety reporting to collect critical safety information, and employees should be encouraged to use these programs. The effectiveness of the employee reporting system should be monitored. The data can be used to identify hazards, assess the performance of safety risk mitigation, capture previously identified safety deficiencies, and confirm the effectiveness of existing safety risk mitigations and that they are performing as intended.
- Event investigations – Essential activities for effective data analysis are identifying root causes and contributing factors that lead to the events. Any hazards identified in the investigation can be fed into the SRM process for hazard analysis, safety risk assessment, and development of mitigation.

Performing these activities aids in risk-informed decision making and allows top management to prioritize organizational actions and allocations of resources more effectively. SA case studies are presented in the following section, which focus on pedal misapplication incidents.

Case Studies – Pedal Misapplication

Pedal misapplication refers to an event in which the operator of a vehicle mistakenly depresses the accelerator pedal when intending to apply the brakes. There have been many serious accidents over the years involving buses and other heavy vehicles in which pedal misapplication was determined to be a causal factor. The following case studies provide examples of good investigative techniques and how accident investigations can lead to recommendations designed to resolve larger issues involving ergonomics, human factors, vehicle design, and survival factors. Complete NTSB accident reports are available on the NTSB public website at ntsb.gov.

NTSB Highway Investigation Report on Transit Bus Pedal Misapplication – Bi-State Development[42]

On June 11, 1997, a Bi-State Development Agency transit bus being operated by a student driver with a trainer onboard accelerated from a parking bay at a transit center in Normandy, Missouri, surmounting a curb and traveling onto the platform area for about 93 ft before coming to a stop against a metal railing. Before stopping, the bus collided with two pedestrian shelters and resulted in the death of four pedestrians and injury to three others. Post-accident tests and inspections found no defective conditions that would have caused unintended acceleration. The bus was equipped with an emergency stop switch that the training instructor told investigators he had activated. The emergency stop switch functioned to deprive the diesel engine of air and cause it to shut down. The emergency stop switch was found to be disconnected; however, NTSB concluded that since it does not immediately stop the engine, it would not have prevented this accident:

- The driver trainee misapplied her foot to the accelerator pedal, thereby causing the unintended acceleration of the bus.
- The current design guidelines for saw-tooth parking by configurations commonly followed by the transit industry fail to provide adequate pedestrian safety.
- Had the positive separation barriers now installed at the agency's Normandy Station been in place at the time of the accident, the collision with the pedestrian would not have occurred.

NTSB determined the probable cause of the accident to be "the driver trainee's misapplication of the accelerator, resulting in the bus's override of the curb and travel onto the occupied pedestrian platform. Contributing to the deaths and injuries was the absence of effective positive separation between the transit facility roadway and the station's pedestrian platform." Recommendations included:

- **To the Federal Highway Administration** – Ensure, in cooperation with the Federal Transit Administration, the American Association of State Highway and Transportation Officials, the American Public Transit Association,[43] and the Community Transportation Association of America, that future transit facility designs incorporating "saw-tooth" bus parking bays, or other types of designs that direct errant vehicular traffic toward pedestrian-occupied areas include provisions for positive separation between the roadway and

[42] NTSB, "Highway Accident Summary Report, Bus Collision with Pedestrians, Normandy, Missouri, June 11, 1997," NTSB/HAR-98/01/Sum, February 19, 1998, https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR9801S.pdf.

[43] APTA changed its name to the American Public Transportation Association in January 2000.

pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area (H-98-1).

- **To the Federal Transit Administration** – Ensure, in cooperation with the Federal Highway Administration, the American Association of State Highway and Transportation Officials, the American Public Transit Association, and the Community Transportation Association of America, that future transit facility designs incorporating “saw-tooth” bus parking bays, or other types of designs that direct errant vehicular traffic toward pedestrian-occupied areas include provisions for positive separation between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area (H-98-2).
- **To the American Association of State Highway and Transportation Officials** – Ensure, in cooperation with the Federal Highway Administration, the Federal Transit Administration, the American Public Transit Association, and the Community Transportation Association of America, that future transit facility designs incorporating “saw-tooth” bus parking bays, or other types of designs that direct errant vehicular traffic toward pedestrian-occupied areas include provisions for positive separation between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area (H-98-3).
- **To the American Public Transit Association** – Ensure, in cooperation with the Federal Highway Administration, the Federal Transit Administration, the American Association of State Highway and Transportation Officials, and the Community Transportation Association of America, that future transit facility designs incorporating “saw-tooth” bus parking bays, or other types of designs that direct errant vehicular traffic toward pedestrian-occupied areas include provisions for positive separation between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area (H-98-4). Notify your members of the circumstances of the Normandy, Missouri, accident of June 11, 1997, and encourage them to retrofit any existing facilities that incorporate saw-tooth bus parking bays or other types of designs that direct errant vehicular traffic toward pedestrian-occupied areas to include provisions for positive separation between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area (H-98-5).
- **To the Community Transportation Association of America** – Ensure, in cooperation with the Federal Highway Administration, the Federal Transit Administration, the American Association of State Highway and Transportation Officials, and the American Public Transit Association,

that future transit facility designs incorporating "saw-tooth" bus parking bays, or other types of designs that direct errant vehicular traffic toward pedestrian-occupied areas include provisions for positive separation between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area (H-98-6). Notify your members of the circumstances of the Normandy, Missouri, accident of June 11, 1997, and encourage them to retrofit any existing facilities that incorporate saw-tooth bus parking bays or other types of designs that direct errant vehicular traffic toward pedestrian-occupied areas to include provisions for positive separation between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area (H-98-7).

NTSB Highway Investigation Report on Pedal Misapplication[44]

During an investigation into a school bus crash in Liberty, Missouri, investigators determined that pedal misapplication was a factor. Pedal misapplication involves depressing the accelerator pedal instead of, or in addition to, the brake pedal. Subsequently, NTSB identified four additional investigations of accidents involving pedal misapplication. NTSB investigators found that in all five accidents, the drivers either stated that there was a loss of braking or reported that there was difficulty stopping. In all events, braking systems were determined not to have failed. While the individual accidents did not involve transit buses, the same risk potential for pedal misapplication exists, and it is worth examining this report as a case study. The 5 accidents resulted in a total of 2 fatalities and 71 injuries:

- Liberty MO, 5/9/2005, collision
- Falls Township PA, 1/12/2007, collision
- Asbury Park NJ, 11/22/2006, collision
- Nanuet NY, 1/12/2007, collision
- Newtown PA, 2/11/2008, runaway bus

The first accident (Liberty, MO) involved a school bus whose driver later reported that the bus seemed to pick up speed as she stepped on the brake pedal and tried to steer the bus toward a shoulder. The driver reported that she was certain her foot was on the brake and not on the accelerator. The bus struck a light pole, several motor vehicles and finally stopped in a drainage ditch adjacent to the roadway. Two drivers of motor vehicles involved in the accident were killed. The bus driver and forty-eight children were injured. No mechanical defects were found with the bus, other than the damage sustained in the

[44] NTSB, "Pedal Misapplication in Heavy Vehicles," Special Investigation Report NTSB/SIR-09/02, September 1, 2009.

accident. A road test with a similar bus, over the same route, indicated that with both the brake and accelerator pedals simultaneously depressed, the bus could be slowed. NTSB concluded that "neither the licensing nor the training of the Liberty driver contributed to the accident, and that neither drugs nor alcohol impaired the driver's performance" and that the circumstances of the accident are "consistent with driver pedal misapplication."

The second accident (Falls Township, PA) involved a school bus whose driver later reported that after releasing the parking brake and putting his foot on the brake pedal, the bus began to move, and he heard a "racing engine" behind him. The bus continued movement, struck another bus, mounted a curb striking several pedestrians, struck a guard rail, and eventually stopped after colliding with a retaining wall. Eighteen pedestrians, three bus passengers, and the driver were injured. NTSB noted that the accident bus was not the driver's usual bus and that the two bus types had different brake and accelerator configurations. No mechanical defects were found with the bus, and the NTSB concluded that "neither the licensing nor the training of the Falls Township driver was a factor in the accident, and that neither drugs nor alcohol impaired the driver's performance" and that the circumstances of the accident are "consistent with driver pedal misapplication."

The third accident (Asbury Park, NJ) involved a fire truck whose driver later reported that he started the motor and put the truck into drive. He noticed the engine revving, and when he released the parking brake with his foot on the brake pedal, the brake did not hold, and the truck crashed into the firehouse door. The driver was experienced operating fire equipment, but the accident truck had only recently been purchased. No one was injured and no mechanical defects were noted in the post-accident inspection of the fire truck.

The fourth accident (Nanuet, NY) involved a school bus whose driver later reported that the vehicle's brakes had failed. The driver continued through an intersection and crashed into a bridge railing. No passengers were on the bus; however, the driver was seriously injured. The trip was the driver's first time driving the bus on a scheduled run and the pedal configuration was different from the bus she usually drove. Post-accident inspection revealed no defects that would have affected the control or handling of the vehicle.

The fifth accident (Newtown, PA) also involved a school bus, whose driver later reported that the bus suddenly accelerated upon placing the bus in gear and releasing the parking brake. The bus traveled across a parking lot and over a grassy area before the driver shifted into reverse and was able to stop the bus. There were no injuries. Post-accident inspection revealed no evidence of defective conditions, and testing demonstrated that the bus could be brought to a full stop from 45 mph with full brake and accelerator pedal application. The NTSB report concluded that the origins of unintended acceleration are found in human error—specifically, pedal misapplication. Although the exact mechanism of the error is not completely understood, researchers believe that the movement of the leg and foot, the position of the body, visual cues, previous experience, and the brain's response to stress all play a role. Regardless of the mechanism, pedal misapplication remains the most likely reason for unintended acceleration events where no mechanical cause can be found. Recommendations included:

- **To the National Highway Traffic Safety Administration** – Require the installation of brake transmission shift interlock systems or equivalent in newly manufactured heavy vehicles with automatic transmissions and other transmissions susceptible to unintended acceleration associated with pedal misapplication when starting from a parked position (H-09-11). Analyze pedal configurations in heavy vehicles, including innovative designs, to determine the effect of pedal design on the driving task, examining—among other things—pedal error, reaction time, driver acceptance, and driver adaptation (H-09-12). Once the analysis of pedal configurations requested in Safety Recommendation H-09-12 is complete, publish pedal design guidelines for designers and manufacturers (H-09-13).
- **To the National Association of State Directors of Pupil Transportation Services and the National Association for Pupil Transportation** – Advise your members—through your newsletters, websites, and conferences—of the following safety issues: (1) the risk of pedal misapplication and the need to educate school bus drivers about such incidents, and the need to develop and implement plans to ensure that school bus drivers undergo annual refamiliarization training on all bus types that they might drive; and (2) the risk of unintended acceleration during loading and unloading activities, as exemplified by the Falls Township, Pennsylvania, accident on January 12, 2007; and suggest possible mitigation strategies, such as installing bollards or starting buses only after loading is complete (H-09-14).

These NTSB investigation reports, and the resultant findings and recommendations speak to the criticality of robust, comprehensive accident investigations. A transit agency's SMS and its SA process must include an effective, procedural-based accident investigation process.

Accident Investigation

The following section presents suggested practices for performing accident investigations and the underlying SMS principles of this function.

Part 1: Investigation Perspective

The investigation of an undesirable safety event can be thought of as a focused safety audit. During a safety audit, a variety of criteria, based on programs, procedures, and practices, are compared with factual operating information.

Audit findings are noted where there is a gap between what should be and what is. Similarly, during the investigation of an undesirable safety event, a variety of factual operating information is developed around the circumstances of the event. This factual information is then compared with the programs, procedures, and practices that were in place and followed in the particular event. Investigation findings are noted where there is a gap between what should have been and what was. Gaps are analyzed to determine the probable cause and other factors contributing to the event. In the event that no gaps are identified between existing requirements and actual performance in an accident investigation, the adequacy of agency policies, procedures, and equipment must be assessed. In both a safety audit and safety investigation, findings are analyzed, and corrective actions are developed to address gaps that are identified.

Purpose of Conducting Investigations

The primary purpose of conducting investigations of events is to determine the cause so corrective actions can be put in place that prevents future similar events. Title 49 CFR §673.27 requires transit agencies to include the investigation of safety events to identify causal factors as part of their safety assurance process. An investigation evaluates the effectiveness of safety risk control methods and may result in corrective actions to improve those control methods where gaps are identified.

Safety investigations, as a part of SA, are central to an effective SMS. The investigation process and the benefits of that process include the following:

- Analysis of data and information obtained through the investigation process to proactively and predictively identify where and when a similar event could occur.
- Identification of changes to facilities, vehicles, equipment, and systems that were not effectively managed to ensure safety.
- Use of “lessons learned” from event investigations to promote continual improvement in safety performance.
- Identification and logging of hazards identified from data analyses during investigations into the SRM Process (SMS Component 2).

NTSB and APTA provide resources through investigation reports and guidance documents. NTSB “investigates(s) accidents to determine the probable cause, identify safety issues, and devise recommendations to prevent recurrence.”[45] These reports are available on NTSB’s website and can prove useful in understanding a robust investigation process.

APTA’s Standard for Accident/Incident Notification and Investigation Requirements, RT- OP-S-002-02 Rev. 3, defines investigation as “… to gather

[45] NTSB, FY 2018-2022 Strategic Plan.

and assess facts in order to determine cause(s), and to identify corrective measures to prevent recurrence. Accident/incident investigation is not intended to affix blame, or subject people to liability for their actions, or to recommend disciplinary action."

Although other functions of a transit agency may develop information to implement disciplinary action, manage claims, or defend litigation, a safety investigation should be independent of these interests and focused on developing the facts, determining the probable cause, and, most importantly, identifying corrective actions that can prevent future accidents.

Investigation Plan and Procedures

Bus transit agency investigation plans and procedures must conform to their own well-established, documented internal processes. Some States may have their own requirements. Generally, the transit agency plan must identify thresholds for accidents that require an investigation and level of investigation required depending on the severity of the event. An investigation plan may include the following:

- Format and content conforming to transit agency policy
- Policy statement with Accountable Executive approval
- Composition and organization of an agency inter-departmental investigation team
- Criteria for when use of a team investigation is required
- Investigation management procedures—who is in charge, roles and responsibilities of participating department personnel
- Notification procedures, internal and external, if the agency event investigation plan can reference standard operating procedures that address whom to notify and when that would be preferable; otherwise, the investigation plan needs to be updated every time a notification procedure is changed
- Coordination with public safety and highway agencies—the agency's emergency response plan can be referenced (this details the incident command structure and other interfaces)
- Scene management procedures, evidence collection, and preservation (plan should detail scene security)
- Procedures for working with FTA or NTSB if they perform separate investigations
- Procedures and policies on conducting the ongoing investigation and writing the report

Significant or complex investigations may require the assembly of an investigation team or committee. Typically, internal support for the investigative process includes agency expertise in specific areas that may include:

- Bus vehicle (mechanical)/vehicle maintenance
- Infrastructure (e.g., facilities, signaling, guardrails, busways, trolley wire)
- Transportation operations and operating rules, procedures, practices
- Training management personnel or instructors
- Human factors (e.g., medical, hours of service, training, distraction)
- Survival factors
- External expertise may also be required from vendors, manufacturers, or consultants

Notification

Management may want to be notified of all safety events (including "near-misses"), no matter how minor they may be perceived, so they can be investigated, assessed, and recorded in line with SMS data collection and analysis requirements. Not all events will require notification and reporting to oversight bodies outside the transit agency.

Investigators should acquaint themselves with the specific regulations and requirements for notification applicable to their operations. The following information is based on regulations and guidance in effect as of the date of publication of this document. It is not intended to substitute for a careful reading of the current applicable regulations.

FTA has established that transit agency events meeting established criteria be formally reported within specific timeframes. Generally, events meeting those criteria must be report to FTA via the National Transit Database (NTD) during the calendar month following the event.

Notification Contacts	
FTA	TOC-01@dot.gov, (202) 366-1863
NTD	http://www.ntdprogram.gov
State Safety Oversight Agency (SSOA)	As specified in transit agency's state requirements, if applicable

NTSB Investigations

NTSB originally was part of the US Department of Transportation; Congress later established it as an independent accident investigation agency. NTSB has broad investigative authority but no regulatory authority; its single focus is on gathering facts, determining causes, assisting victims, and making recommendations to improve transportation safety. Title 49 CFR 800-850 establishes how NTSB performs its responsibilities.

The NTSB Highway Division has 12–18 investigators and does not launch to most transit accidents. When an accident notification is received, it passes to an investigator/duty officer who assesses the likelihood that NTSB will investigate. The NTSB duty officer may reach out to the agency's point of contact and obtain additional information. Information is then passed up the management chain where the decision to, or not to send investigators is made.

If NTSB is going to send investigators, the agency point of contact will be informed by the duty officer or the NTSB Investigator-in-Charge (IIC). Some expectations of the agency are as follows:

- Provide telephone number of on-scene contact to NTSB IIC.
- Ensure preservation of evidence and scene in accordance with instructions and requirements of NTSB, which may supersede or supplement the transit agency’s actions to secure the scene.
- Identify and make available personnel to represent the agency on the technical (discipline-specific) investigative teams.
- Establish points of contact to discuss appropriate responsibilities and roles for scene management and evidence preservation.
- Provide name and telephone number of agency’s public information officer (PIO).
- Refer all press inquiries on the investigation to PIO for NTSB.

The seriousness and complexity of an accident will determine the size of the NTSB team, and a Board Member may or may not arrive with the team. When NTSB arrives on the scene, technical work groups will be formed to develop factual information relevant to the accident.

The NTSB on-scene investigative team for a more substantial accident typically consists of an IIC and technical specialists to lead the investigative groups. Technical groups may include:

- Mechanical (vehicles)
- Operations
- Railroad (if the event occurred at or on a grade crossing)
- Human performance
- Survival factors
- Other specialized groups may be formed as needed

NTSB leverages its limited resources using technical staff from party organizations. Typically, the transit agency will be asked to provide senior managers as the primary contact and technical specialists for the various investigative groups. Party participation is at the discretion of the NTSB IIC. Potential party organizations are those who have people, procedures, or equipment connected to the accident/event and can provide technical expertise to assist NTSB. Party participants may not make public comments on the investigation and may not distribute information outside the investigation. Parties may include:

- Transit agency
- FTA and SSOA (if applicable)
- Labor organizations
- Emergency responders
- Equipment manufacturers

Attorneys, claims agents, PIOs, and media are not permitted to participate in investigative activities.

The on-scene phase of an NTSB investigation is focused on developing facts and begins with an organization meeting at which party organizations and individual roles are established. Each following day, a progress meeting is held at which information is shared among the technical groups and work for the next day is planned. All information is shared; it cannot be withheld. At the end of the on-scene phase, a closeout meeting involves the final exchange of factual data and field notes from each technical group. Follow-on activities may include additional interviews, laboratory exams, testing or equipment teardowns. Each technical group produces a factual report, which are reviewed by group members to ensure accuracy. The Board may hold investigative hearings to develop the facts further.

NTSB staff perform the analysis and complete the full report independently. Parties can provide their analysis and suggest the probable cause and recommendations for NTSB's consideration. The final report is presented at a public meeting at which Board Members discuss it and may adopt it or make their edits.

Investigator Training

The essential knowledge, skills, and abilities for investigators include:

- Knowledge of system operations
- Knowledge of accident investigation methods and requirements
- Understanding of equipment and subsystem functionality (transportation, vehicles, infrastructure, communications)
- Ability to read and understand procedures and drawings
- Knowledge of agency rules, procedures, and processes in place to prevent accidents
- Understanding of SMS and system safety principles

- Knowledge of incident scene management and Incident Command System/ National Incident Management System (ICS/NIMS)
- Interviewing skills
- Skills related to documenting an accident scene (e.g., photography, sketching, measurement, evidence)
- People skills

Title 49 CFR 672 establishes minimum training for personnel overseeing fixed-guideway transit systems and a voluntary training curriculum recommended to bus transit agency personnel. The voluntary curriculum for bus transit system personnel with direct safety oversight responsibility and State DOTs overseeing safety programs for sub-recipients includes the following:

- SMS Awareness – e-learning delivery (all required participants)
- Safety Assurance – e-learning delivery (all required participants)
- SMS Principles for Transit (all required participants)
- Transit Safety and Security Program (TSSP) curriculum, minus Transit System Security (TSS) course (all required participants; credit provided if participant has Course Completion Certificate of previously taken TSSP courses)
- Transit Bus System Safety
- Effectively Managing Transit Emergencies
- Fundamentals of Bus Collision Investigations

Title 49 CFR 672, Appendix A provides a list of technical training plan elements for SSOA personnel who oversee transit operations. This list is also a good benchmark for internal transit agency investigator training.

In addition to the Public Transportation Safety Certification Training Program curriculum, there are several additional types of training investigators could consider. Potential courses of value to investigators include:

- Agency operating rules
- Agency maintenance training courses
- Agency bloodborne pathogens training
- Agency hazardous materials awareness
- Fatigue and Sleep Apnea Awareness (TSI on-line)
- Curbing Transit Employee Distracted Driving (TSI on-line)
- Transit Safety and Security Audit (TSI)
- Introduction to the Incident Command System, ICS 100 (Federal Emergency Management Agency (FEMA) on-line)
- Forensic photography (various commercial vendors)

- Interviewing skills (various commercial vendors)
- Root cause analysis (various commercial vendors)

Additionally, investigators may choose to take every opportunity to undertake self-directed training by spending time with agency technicians, operators, controllers, and other personnel to better understand system operations and maintenance. This also allows them to establish good interpersonal relationships with key staff.

Part 2: Accident Scene

NTSB made the following recommendation to APTA:

> Urge your members to conduct regular training exercises that use written ventilation procedures to provide ample opportunities for employees and emergency responders to practice those procedures (R-15-12, Urgent). National Fire Protection Association (NFPA) 130 9.11.3, Critiques, shall be held after the exercises, drills, and actual emergencies.

APTA also provides multimodal standards and recommended practices for emergency management.[46] The effectiveness of the response and coordination with responders is an element that should be assessed by investigators.

The agency's response to incidents should be established in advance in an existing SOP or emergency plan. Typically, the control center is responsible for notifying appropriate personnel and activate the response, including notifying investigators. This is where the agencies program of training, exercises, and debriefs with emergency responders pay dividends.

It is essential that agency responders are aware of the priorities—rescue and public safety followed by preservation of evidence. Emphasis should be placed on preserving the integrity of data recorders, camera systems, and vehicle control compartments.

In most traffic accident events; local law enforcement will control the scene and be responsible for the preservation of evidence and chain of custody. Transit agency investigators can support these events by contacting the IC and sharing any specialized knowledge (i.e., recorders or camera systems) that may assist in this effort.

Scene Safety

Investigators are on the scene to improve safety. If an investigator is injured, they will become part of the problem instead of being part of the solution. It is

[47] APTA Security and Emergency Management Standards, https://www.apta.com/research-technical-resources/standards/security/.

of use to no one if a responding investigator is involved in a traffic accident—a secondary accident complicates the situation. When responding to a call to an accident scene, remember that you are not a police officer and must still obey all traffic laws. If law enforcement has not already set up traffic control, the investigator should park their official vehicle on the roadway and in such a manner as to provide a shield between the vehicles, the injured, the investigator, and traffic. Response vehicles should be equipped with cones and triangles to warn traffic also. The recommended signage placement based upon miles per hour (mph) is as follows:

Speed Limit	First Triangle or Cone
25 mph	68 ft
35 mph	112 ft
45 mph	167 ft
55 mph	227 ft
65 mph	301 ft

The first stop for investigators should be the IC. This person will often be with the fire department or police, as noted above. For accidents entirely on agency property (such as a bus depot) and with no fire or injuries necessitating a response, the IC will be an agency employee.

Before entering the scene, investigators must perform a hazard scan and participate in a safety briefing with the IC. Among the potential hazards evaluated are fuel tanks, pressure vessels, batteries, trolley wire electrical status (if applicable), unstable equipment, movement on adjacent roadways, biohazards, and hazmat spills.

Safety investigators must model appropriate behavior and lead by example. Clothing and PPE appropriate to the accident scene and agency protocols must always be worn while on-scene. Generally, at a minimum, this means long pants, safety footwear, eye protection, hard hat, work gloves, and a reflective outer vest meeting agency requirement. Additional PPE may be required depending on the conditions at each accident scene.

News media often stage cameras to record activities at accident scenes. Investigators should be aware that the behavior and appearance of investigators and other personnel may make the news. The media might have video equipment that might not appear to be in use, such as video cameras pointed to the ground; these video cameras may still be recording audio.

Experienced investigators maintain a “go bag” with PPE and investigative tools that are routinely needed. Gauges, meters, measurement devices, and publications maintained as part of a go-bag (Appendix B) must be kept up to date and calibrated. Users must be appropriately trained and qualified.

Investigators who do not routinely use an electrical meter or similar device would benefit by having an experienced technician take the measurements while the investigator observes.

Potential for Bloodborne Pathogen Exposure

Transit accident investigators have the potential for exposure to bloodborne pathogens, including Hepatitis B Virus (HBV) and Human Immunodeficiency Virus (HIV). While on scene, investigators can assume that blood and other bodily fluids may be present and should use “universal precautions.” This means to treat blood and bodily fluids as if they are infectious for HIV, HBV, and other bloodborne pathogens and to take appropriate precautions. Bloodborne pathogen kits are a staple in an investigator’s go-bag. Transit accident investigators would benefit from initial and recurrent training on bloodborne pathogens as specified in applicable OSHA regulations. The training is required to cover information on the HBV vaccine, which employers must provide at no charge if requested. (See 29 CFR 1910.1030.)

Potential for Hazardous Material Exposure

Transit accident investigators have the potential for exposure to hazardous materials, particularly on systems that interface with highway vehicles. These materials may include automotive fluids (gasoline, diesel fuel, hydraulic fluid, antifreeze), unique transit vehicle fuels (natural gas or fuel cell, as examples), and a wide variety of chemicals transported by commercial motor carriers. Some level of hazardous materials awareness training for investigators is appropriate. For example, NTSB rail accident investigators who respond to transit, freight, and passenger train accidents complete the 40-hour Hazardous Waste Operations and Emergency Response (HAZWOPER) initial training with annual 8-hour refreshers. Some online courses are commercially available. Transit investigators must be provided with an appropriate level of hazardous materials training based on the operational characteristics and risk of exposure they may encounter. (See 29 CFR 1910.120.)

Documenting and Managing the Accident Scene

A key element of scene management is the preservation of factual evidence. However, rescue, recovery, and public safety trump the preservation of evidence during the emergency response. Transit investigators should contact the IC as soon as possible to coordinate the needs of the investigation with the needs of immediate response. The goal of preserving, securing, and documenting the history of pieces of evidence is to protect the condition and integrity of evidence collected during an investigation. In most bus transit accidents on streets and highways, law enforcement will assume this responsibility; however, transit investigators may have specialized technical knowledge that will assist in identifying unique transit specific features.

The primary considerations when documenting and managing an accident scene include:

- Chain of custody
- Evidence collection and retention
- Event recorder/data logger/Supervisory Control and Data Acquisition (SCADA)/camera system analysis
- Photographs, videos, sketches, and measurements
- Marking and measuring
- Diagramming the scene
- Tire marks, scrapes, and gouges
- Grade crossings/intersections
- Weather and environment
- Witness statements

Appendix B provides discussion and instruction on each of these considerations and the associated processes and steps that occur when documenting and managing an accident scene.

Inter-Agency Coordination/ICS

Multiple agencies may be involved in an accident response, particularly a significant mass casualty event. ICS is a standardized, on-scene, all-hazard incident management concept that allows its users to adopt an integrated organizational structure (see Figure 3-1) to match the complexities and demands of single or multiple incidents without being hindered by jurisdictional boundaries. ICS is part of NIMS with these defined purpose areas:

- Safety of responders and others
- Achievement of tactical objectives
- Efficient use of resources
- Communication and coordination between responding agencies

Responsibilities that are part of ICS include the following:

- IC – Overall responsibility for the incident; sets objectives.
- Operations – Develops tactical organization and directs all resources to carry out Incident Action Plan.
- Planning – Develops Incident Action Plan to accomplish objectives.
- Logistics – Provides resources and all other services needed to support incident.
- Finance/Administration – Monitors costs related to incident, provides overall fiscal guidance.

FEMA offers free online training on ICS. Various transit specific emergency management documents are available on FTA's website.

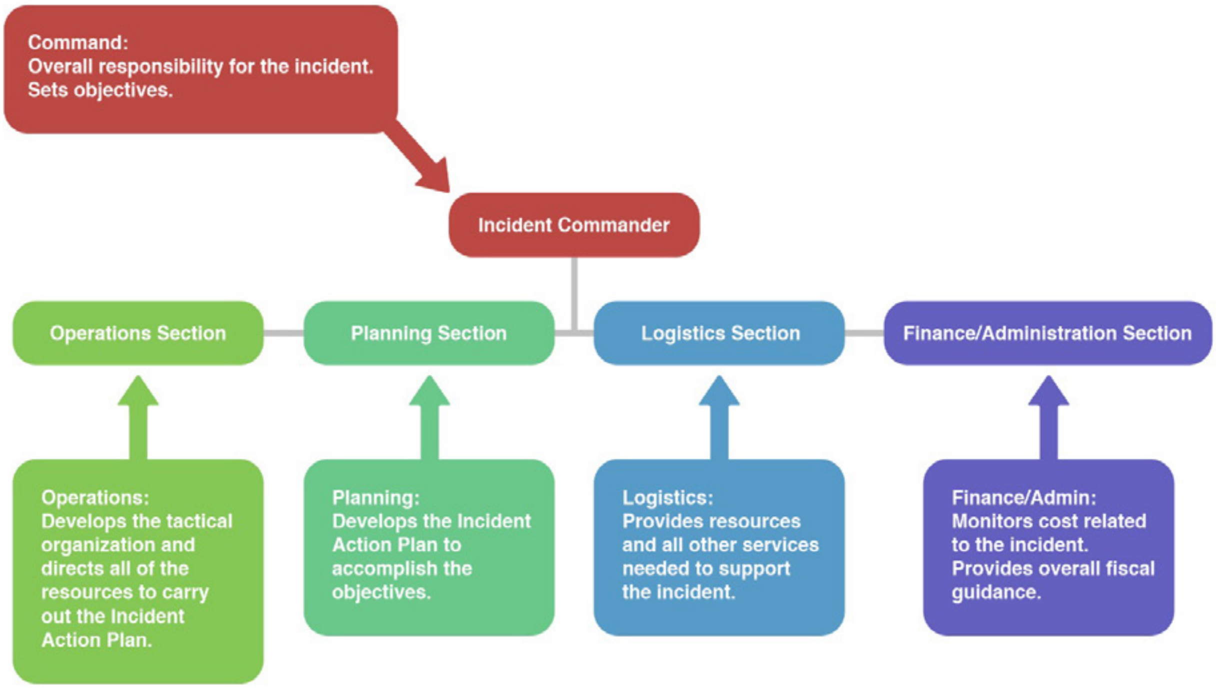


Figure 3-1 *Incident Command System Structure*

Source TSI

Typically, the first transit employee on the scene (often a bus operator) is the initial IC. The IC position may transition to a more senior agency employee until the responders arrive. When ICS is established by the response agency, the agency becomes part of the ICS and supports the IC. Once the response has concluded, agency personnel and investigators can participate in a "hot wash" immediately after the response and participate in a more in-depth debrief after the event.

Working with Law Enforcement

Local law enforcement agencies have independent authority at traffic accidents and criminal events and will be in charge of their investigation. Investigators need to forge cooperative working relationships with these local authorities, preferably in advance of the accident. Agencies with their own police department or contracting with local police for dedicated personnel often have an easier time. Relationships can be forged through meetings, training, drills, and tabletop exercises.

Law enforcement traffic investigations focus on which party broke the law—i.e., who gets the citation. In severe accidents, law enforcement may conduct a criminal investigation of agency employees, or the agency itself. In some instances, the transit operator is judged not “at fault” by law enforcement, but the agency’s operations investigation will find the accident to have been preventable. (*Note*: An accident could be determined to be non-preventable on the part of an employee by the transit agency but still have organizational implications that need to be addressed to prevent similar future accidents or that require the agency to analyze identified hazards, evaluate safety risk, and implement proactive or preventive action. The agency safety investigation is more focused on system issues and prevention than on fault.)

Points of Contact

Business cards or contact information of people from other departments and outside agencies should be obtained. An investigator will invariably have follow-up questions for them or need documentation or further information.

Other Resources

The following FRA regulations do not apply to bus transit systems but provide useful models on coordination with emergency response agencies for the PTASP:

- Title 49 CFR 239.101 (5) – establishing and maintaining a working relationship with emergency responders through training, exercises, and planning
- Title 49 CFR 239.103 – periodic full-scale simulations
- Title 49 CFR 239.105 – debriefing and critique after each actual event and large-scale simulation
- Title 49 CFR 239.105 (c), Purpose of debriefing and critique – designed to determine, at a minimum:
  - Whether on-board communications equipment functioned properly
  - How much time elapsed between occurrence of emergency or full-scale simulation and notification to emergency responders involved
  - Whether control center or emergency response communications center promptly initiated required notifications, as applicable under the plan
  - How quickly and effectively emergency responders responded after notification
  - How efficiently passengers exited from car through emergency exits, including any passengers with a disability or injury (when any such passengers are known).

These questions will also need to be explored as part of the survival factors investigation.

Part 3: Post On-Scene Investigation

Post-on-scene activities include desk reviews of documentation, follow-up interviews, tests and recreations, and analysis of factual information.

Timeline

A timeline forms the basis of laying out the accident sequence and helps to put precipitating events in order; therefore, early on, investigators should begin creating a timeline of events relevant to the accident. This starts at the beginning of the accident trip or employee shift. However, investigators should also review and include operating cautions, special or temporary orders, procedures, and instructions that might have been in effect on the day of the accident. As much detail as possible should be developed around events relevant to the accident. Inputs for the timeline include vehicle and signal system event recorder data, video recordings, interviews, SCADA data, and control center logs.

Recorder Synchronization

Recorded data are crucial for a complete timeline and for understanding the event. Synchronizing the times from multiple data recorders is an important step to ensure accuracy. Standalone cameras and data recorders have autonomous internal clocks. Over time, clocks may deviate from the original time setting, and some equipment may have had clocks initially set inaccurately or to a different time zone. Synchronizing the times to reflect the accurate and precise time can be a challenge. SCADA time is usually tied into an accurate clock, but this should be verified.

Recorded Data

Video images can provide valuable data to the survival factors investigation on where individuals were located, and the injury mechanisms involved. Forward-facing video provides valuable information on the moments leading up to the accident and the conditions of traffic, roadway, and the environment. Inward- facing (operator-facing) video is becoming more common and has been recommended to the industry by NTSB. APTA has issued Recommended Practice RT-OP-RP-024-19, Crash and Fire Protected Inward- and Outward-Facing Audio and Image Recorders in Rail Transit Operating Compartments. Inward-facing video can provide investigators with valuable information on

Effective Investigation Practice

Once a “good” time is established for an event, for example, using vehicle event recorder, forward-facing video, and/or signal system data that all show a bus entering an intersection or leaving a stop, other recorders and associated data can be synced. Investigators should plan to budget enough time for this effort.

operator actions, vigilance, and distractions that may have been factors in an accident.

SCADA system recorded data will provide information on the various systems and subsystems monitored. Potential SCADA data to review may include the bus location and speed, and mechanical conditions or any associated alarms from the bus.

Vehicle event data recorders (EDRs) are increasingly common on transit vehicles. NHTSA describes an EDR as:

> A device installed in a motor vehicle to record technical vehicle and occupant information for a brief period (seconds, not minutes) before, during, and after a crash. For instance, EDRs may record (1) pre-crash vehicle dynamics and system status, (2) driver inputs, (3) vehicle crash signature, (4) restraint usage/deployment status, and (5) post-crash data such as the activation of an automatic collision notification (ACN) system.

Some companies and agencies may have installed driving behavior management systems that monitor vehicle dynamics, inward- and forward-facing video, and record-specific parameters, which include some vehicle dynamic events such as hard braking or aggressive maneuvers, may provide immediate feedback to drivers, and provide reports to managers for follow up when problematic driving behaviors are detected.

The Federal Motor Carrier Safety Administration (FMCSA) produced a technical report[47] indicating that driving behavior management systems were associated with significant reductions in severe safety events in the two carriers studied.

Other types of recorders may capture additional electronic and video data. Transit investigators would benefit from familiarity with the types of data that are available, how to obtain it, the degree to which the data may be perishable, and how to interpret it.

In its report on a Miami, Oklahoma, truck-tractor trailer collision, NTSB recommended that FMCSA:

> Require all heavy commercial vehicles to be equipped with video event recorders that capture data in connection with the driver and the outside environment and roadway in the event of a crash or sudden deceleration event. The device can create recordings that are easily accessible for review when conducting

[48] FMCSA, “Evaluating the Safety Benefits of a Low-Cost Driving Behavior Management System in Commercial Vehicle Operations,” FMCSA-RRR-10-033, June 2010.

efficiency testing and systemwide performance-monitoring programs (H-10-10).

Require motor carriers to review and use video event recorder information in conjunction with other performance data to verify that driver actions are per company and regulatory rules and procedures essential to safety (H-10-11).

Generally, event recorders will provide time, distance traveled, and information on speed, braking, and other operational parameters. In a collision or bus off the road scenario, the last few seconds of recorded data can be corrupted or inaccurate because power interruption due to collision forces and electronic recording lag.

If recorder speed and distance data are based on wheel rotation, a tire size at the time of download may be needed for the best accuracy. The point of rest of the transit vehicle following the accident is an important measurement for calculating the location of vehicle data points approaching the accident location.

Effective Investigation Practice
Transcribed Recordings

- Word for word, no interpretation.
- Time stamps on transcript.
- Record actual language or lack of words.
- Who initiated?
- Whose words were “stepped on”?
- Who acknowledged the information provided?
- Were readbacks repeated word for word?
- Have a second set of ears verify accuracy.

Most agencies record radio and telephone communications to/from the control center. In some cases, radio communication between field units is also recorded. Review and analysis of these communications help nail down the timeline, as they may provide important information about communication flow and on decisions that were made leading up to, during, and after the accident. As with other data sources, the time stamp needs to be verified for accuracy and synchronized with other recorded data. Investigators may find it helpful to have critical communications transcribed.

Document Reviews

This can be a big task, and the documents will be selected by investigators based on the circumstances of the accident. This review is very “audit like”—what does the document say could have been done and what was done? Discrepancies or “gaps” need some analysis to determine their relevance. The focus is to document procedures and policies intended to prevent the type of accident under investigation. For example, if operating rules violations were involved, training, rules and procedures, management oversight, and compliance monitoring would be key areas of documentation to review. Figure 3-2 provides examples of documents that may be reviewed during this activity.

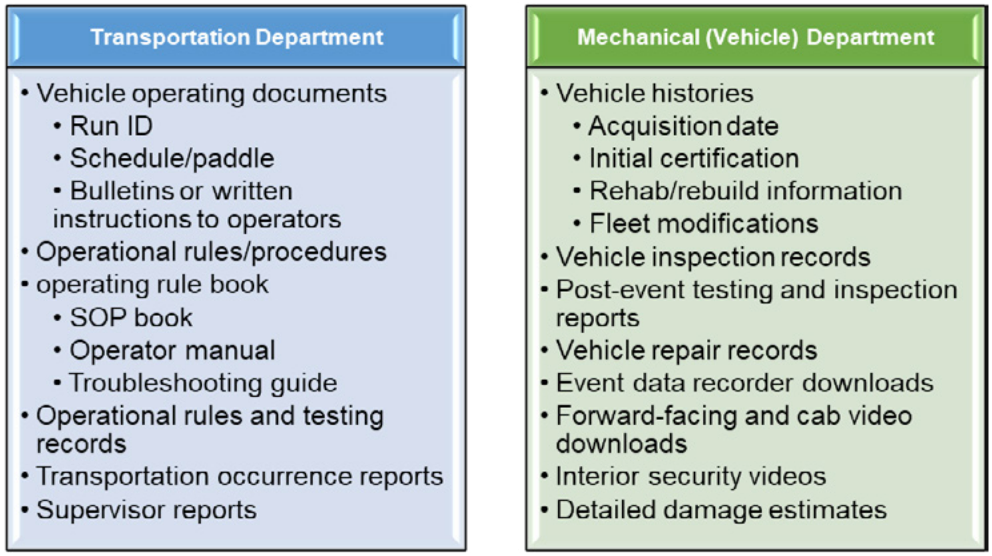


Figure 3-2 *Example Documents to Review*

Source: CUTR

If mechanical failure of system components is involved, a review of maintenance inspections, technician qualifications and training, quality control, procedures, schedule, and history would be critical areas of documentation review.

FTA produced a compendium of transit safety standards that contains potential external standards investigators can use as benchmarks.[48]

Management Oversight and Rules Compliance

Operating rules are the instructions to personnel covering bus operations and maintenance activities on vehicles. Operating rules include the agency rulebook and other associated manuals, SOPs, bulletins, and operating documents or equivalent issued to bus operators. Investigators should become familiar with the requirements in these rules and procedures.

Key points on the assessment of rules:

- Determine if established practices were followed
- If not, determine why, i.e., inadequate oversight, lack of training, cumbersome procedures promote practical drift
- If procedure/practice was followed, determine if it is effective.

Effective Investigation Practice

Document reviews should determine if the agency is complying with internal and external standards. If no, what is the relevance to the accident sequence? What obstacles need to be addressed to bring practices into conformance? If yes, are the rail agency's current practices effective in identifying and addressing latent conditions and active failures that have the potential to result in the accident?

[48] https://www.transit.dot.gov/regulations-and-guidance/safety/compendium-transit-safety-standards

It is not sufficient to have rules in place. Systems need to have quality control/assurance programs to be sure rules are understood and complied with. As Ben Franklin said, “A little neglect may breed much mischief.” Without management oversight, levels of compliance and uniform application of rules, there will be “drift.” In an SMS environment, this is called practical drift, and an agency process has to be in place to measure it, control it, and bring it back in line with the agency's expected performance standards. Rules compliance monitoring programs provide this function.

FTA requirements are general in nature. FTA regulations at 49 CFR Part 674 are based on the SMS approach. A key element of SMS is Safety Assurance, which includes rules compliance audits; 49 CFR 674.27 (b) (1) requires that an agency’s safety plan include provisions to “monitor its system for compliance with, and sufficiency of, the agency’s procedures for operations and maintenance.”

APTA published a standard on rules compliance (APTA-RT-OP-S-11-10) for rail transit systems. This voluntary APTA operational standard is rail transit-oriented, but the basic principles apply to other modes. This voluntary standard requires, among other things, defining rules to be evaluated, operating positions affected, cycles, and determining the frequency of checks, establishing methods of verification, metrics, and validation/analysis of program effectiveness.

Evaluations of the operating rules are an essential part of the investigative process. Investigators need to be familiar with the rules and determine what was required, what transpired and be able to factually document and describe any deviations or anomalies. If rules were not followed, how did that affect the event? Was the training in conformance with the current rules and the existing equipment configurations? If not, what bearing did that have on the event?

Effective Investigation Practice

Reviewing the rules compliance program data relevant to the accident under investigation, investigators should consider the following:

- Is the program guidance to managers clear on what rules to check and how to perform checks?
- Are managers performing checks themselves qualified on the rules?
- Are reports produced showing compliance data over time? Examine how managers use the data.
- Compare the agency program with the APTA Standard.
- “Red flags” in compliance checks include the following:
  - Results that are “too good,” i.e., there are never any exceptions.
  - Not spread over days and times; from an employee perspective, compliance checks should be unexpected.
  - Not spread over all locations—for example, a preponderance of checks done at reporting locations.
  - Limited to PPE, tardiness, and “easy” checks.

It is important to determine what rules were clear and were understood by those involved and whether employees had received adequate training on the rules. It is also essential to evaluate the compliance program conducted by managers. Finally, if there have been revisions to the rules involved in the event, investigators can look at the change management process, stakeholder involvement, and how rules revisions were communicated to those affected.

Interviews

Interviewees should be selected who meet the objectives of filling in the blanks or clarifying events. These may include:

- Eyewitnesses
- Operators
- Other employees
- Managers
- Passengers
- First responders
- SMEs

In addition to immediate on-scene interviews, it is often desirable to conduct follow up interviews during the post-on-scene phase of the investigation, particularly with key individuals who may have played a role in the event such as vehicle operators, controllers, and maintenance technicians.

At the scene, investigators are the least informed about the specifics of the accident. After a few days, investigators have more information that can help them ask better questions and better assess the information provided by interviewees. Additionally, information developed after the on-scene phase may identify new individuals who can shed light on the event.

One-on-one interviews may be necessary, particularly when obtaining witness statements after an event, as they may be anxious to leave the scene. An interview team of two is preferred—one person to conduct the interview and another to take notes or operate a recorder. Having a second person as a witness may also be desirable in some cases. Larger groups of interviewers can be challenging and require a leader to set clear ground rules on order of questioners, not to interrupt, and so on.

Some critical points for team interviews that may lead to greater success include having one person designated as the lead interviewer, maintaining a professional and non-judgmental demeanor, not allowing other interviewers to interrupt each other or the interviewee, and establishing a code of conduct that includes an agreement not to interrupt the questioning and establishing that each interviewer must wait their turn.

Interviews are conducted to obtain factual information to verify other information already obtained and to understand different perspectives of the same event. People involved have information not already obtained and that information is needed to develop a factual record. The interviewee's cooperation is needed; they likely do not need us. They cannot be compelled to be interviewed or helpful; establishing rapport is a key to success, and interview objectives may change.

Potential interviewees include the following:

- Operating and maintenance personnel
- Supervisors/managers
- Victims
- Bystanders
- Residents
- Persons familiar with potential participants (friends, co-workers, managers)
- Emergency crews (fire, emergency medical services, hospital staff)
- Law enforcement
- News media
- Walk-ins

NTSB Approach to Interviews

NTSB's interview approach has proven to be effective. An interview is not an interrogation; it is a structured conversation, and the interviewee is an equal partner. It is best to make an interviewee feel at ease and encouraged them to relate observations without interruption. Interviewees are allowed to have one representative with them (union representative, attorney, co-worker); an interviewee's supervisor or manager cannot be a representative, but individual agency's policies may differ.

Establishing rapport and cooperation is vital because interviewees are under no obligation to help. Although some people may be compelled to be interviewed (employees, for example), they cannot be compelled to cooperate and provide their best effort.

NTSB investigators typically record interviews, have them transcribed, and share them with the interviewee, allowing an accuracy check.

Experience has shown that an interrogation approach is not productive. Full cooperation cannot be compelled; appeal to the interviewee noting the social benefit (to fellow employees, passengers, society) of prevention of future events. The purpose of the investigation interview is to get a complete picture of the facts to prevent future occurrences rather than to attempt to identify blame or solicit a confession.

An interrogation implies that questioning is done on a formal or authoritative level, such as a lawyer/witness situation or a police officer/suspect session; questioning may be devious, shrewd, or clever, with the objective of tricking, trapping, or antagonizing the witness to get the information. An interview philosophy is desirable in the questioning of witnesses by accident investigators, wherein the witness is encouraged by the need for safety and prevention. Most people willingly recount their observations.

The interview process may include the following:

Effective Investigation Practice
NTSB Approach to Interviews

- Interview, not an interrogation; an interrogation approach is counterproductive.
- Interview should be a cooperative and informal yet structured conversation.
- Interviewee is an equal partner.
- Interviewee is encouraged to cooperate.
- Interviewee is allowed to relate observations without interruption or intimidation.
- Interviews usually conducted informally and voluntarily.
- Interviewee can have one representative present.
- Interview is recorded and transcribed; there should be no “off the record” interviews.
- Interviewee should be made aware of with the need for transportation safety and prevention; most people are in favor of these goals and want to share their observations.

- **Identify interviewees**. Who will be interviewed? When? Why? If possible, select a time and place for interviews that will put the interviewees most at ease. Set goals for the interview; identify critical areas you hope to understand better.
- **Acknowledge interviewee concerns**. Be aware of concerns the interviewee may have and be ready to discuss and address as much as possible. For example, some eyewitnesses may fear of seeing their name in media, are reluctance to get involved, or fear getting their information wrong. Direct participants may be concerned about their effect on potential participants, damage to company/organization, or personal responsibility. Potential participants may be concerned about loss of livelihood, damage to their reputation, lawsuits, or responsibility for the injury/death of innocent people.
- **Be prepared**. Do your homework—know the operating rules and method of operation involved as much as possible. Review the circumstances of the accident—rules and procedures involved, witness statements, timeline, video, event recorder, and other recorded data.

- **Identify the information to be obtained**. Determine the order in which information is to be obtained and the general questions that will elicit the information to be obtained for each topic.
- **Establish ground rules**. It is important that transit agency personnel understand the ground rules in advance of an interview and know how to manage requests for representation. It is important that interviews are not conducted alone, particularly with someone who may have been involved in the event. Ensure that notes are taken during the interview, interview only one person at a time, prohibit interviewees from observing or having knowledge of the content of other interviews, prohibit interruptions to either questions or answers, allow follow up questions, assign one person to take notes during the interview, and ensure that the participating interviewers agree to and sign the notes taken during the interviews as soon as possible.
- **Allow interviewee representatives**. In some cases, interviewees may want a representative. NTSB protocol allows an interviewee to have no more than one representative of the interviewee's choosing; unionized agencies typically provide for a union representative if requested. The representative may not answer questions for the interviewee. Try to develop a rapport with the representative.
- **Take notes or record the interview**. The interviewee should be informed if the interview will be recorded. Some agencies (including NTSB) record interviews, others do not. Recording has obvious advantages in terms of accuracy. Even with a recorder, it is important to have someone take notes, as recorders can fail, and there may be nuances that a recorder will not capture. An interviewee may object to recording. The objective is to make the interviewee comfortable. Conducting an interview without a recorder is preferable to a confrontational interview or no interview at all.
- **Set the stage**. Develop a rapport with the interviewee, even if it takes an extended amount of time. Find some common ground. This must be done before beginning the interview. Developing rapport will set the stage for the rest of the interview.

Key points and recommended processes for conducting interviews are included in Appendix E.

Reenactments and Sight Distance Evaluations

Reenactments and sight distance observations are often done to verify the conditions at the time of the accident. The goal is to come as close as possible to duplicating the accident conditions and when participants could have seen a hazard before the accident.

Tests

> **Effective Investigation Practice**
>
> Reenactments should be done as soon after the accident as possible and at the same time of day with the same lighting and weather conditions. The same equipment or the same type of equipment should be used. Transit vehicle operators used for the reenactment should be qualified on the equipment, and any observations and insights from these individuals should be noted. In measuring sight distance, investigators should document that everyone was focused on identifying the item (bus, auto, worker, pedestrian), creating an artificiality from normal operations.

Agencies typically have existing test criteria that are used on a routine basis in preventive and routine maintenance or when subsystems or components are replaced. Post-incident testing can use the same tests to verify the operating condition of vehicle braking and any other subsystem or component that may be relevant to the event under investigation. For example, if traffic signal system performance needs to be validated, it may require a simple, functional verification or complex software analysis.

Most investigators will usually need to rely on technical staff to perform many of the tests, but investigators may need to witness the test performance. It is important that a written test plan be developed and reviewed by agency technical and investigative staff for any test not already covered by an internal maintenance procedure.

Laboratory Testing

A contract laboratory may be needed for specialized tests beyond the capability of the agency—i.e., metallurgical analysis, materials testing, software testing. Investigators will need engineering support from within the agency or specialized consultants to help organize and select appropriate labs and testing protocols. The agency engineering group may already have some contracts in place.

Drug/Alcohol Testing

FTA drug-alcohol testing requirements are at 49 CFR 655, and additional DOT requirements are at 49 CFR 40. In addition to alcohol testing, FTA requires tests for marijuana, cocaine, opioids, amphetamines, and phencyclidine. Specific protocols will be spelled out in the agency's testing program. A post-accident test needs to be done within two hours. Some agencies may have testing programs that screen for additional substances. Investigators should know what the specific requirements are for their agency. (See Human Factors section). If the accident conditions triggered employee post-accident or probable cause drug/alcohol testing, results will come back negative or positive. A positive result will need some analysis to determine if it is relevant to the accident.

Before ruling out impairment as a factor following a negative test, remember that the federally-required protocols test for a limited number of substances. A negative test result on FTA test criteria does not necessarily mean impairing drugs not tested for by the FTA panel were not involved.

> **Effective Investigation Practice**
>
> For an impairment to be considered a cause or contributor to an accident following a positive test result, the investigator needs to determine that vigilance, reaction time, perception, or decision making was a factor in the accident and was influenced by the substance involved. The agency medical officer may be of help in making this determination.

Survival Factors[49]

The survival factors element of an investigation seeks to understand why some people were killed and injured while others walked away unscathed. Not every accident will need full-scale survival factor investigation; however, it is important that investigators be aware of what is involved and assess if such an evaluation is appropriate. Understanding survival factors can lead to improvements in procedures and equipment design that save lives and reduce injury severity. Past survival factors investigations have resulted in many safety improvements such as automotive seat belts, airbags, seating improvements, and emergency lighting that are now commonplace.

Survival factors investigations involve an examination of:

- Evacuation
- Operator workstation and transit vehicle interior configurations
- Vehicle operator workstation and passenger area damage
- Fatal and non-fatal crash injuries
- Emergency response
- Disaster preparedness planning and training

The output of a survival factors investigation will be a separate survival factors report or a section in the final report. (See Survivor and Witness Statements and Questions in Appendix F.)

Emergency Response Documents and Debrief

It is important that on-scene investigators attend a "hot wash" with responders to discuss what went right and what challenges were encountered.

[49] See *National Transportation Safety Board Investigator's Manual*, Volume III – Regional Investigations.

For major events, responders will often hold a more formal debrief one or two weeks after the event. Investigators should attend and participate. Valuable information for the survival factors investigation will be covered at the debriefing. Documentation produced by response agencies is valuable and should be obtained. Emergency response documentation may include:

- 911 call center logs showing time and source of initial notification and who was notified/dispatched.
- Fire department/EMS dispatch logs showing when the notification was received, when units were dispatched, and when they arrived on-scene.
- For a mass casualty event, EMS triage logs indicating how many people were triaged, color-coded tag counts, lists of names, and disposition of injured.
- IC log and notes.
- Photographs and videos from response agencies and other parties.

Challenges or problems identified in the hot wash and debrief should result in a review of the agency SOPs and emergency plan with modifications where needed. Transit agencies will have control center records, recorded transmissions, SCADA data, and any other records of the event for review. Conducting debriefs with responders is an APTA-recommended practice.

The goal of the emergency response element of the survival factors investigation is to determine if the response contributed positively or negatively to the event. A delayed or inadequate response by emergency responders, coupled with severe passenger/crew injuries, could result in additional fatalities or more severe injuries to passengers and transit personnel.

It is important that an evaluation of medical response be provided also, including a list of agencies involved in the response (transit agency, hospitals, or others), the number of individuals transported, and where they were transported.

Law enforcement response may also be assessed to include which jurisdictions responded, when and how they were notified, when they arrived on the scene, how they assisted with the evacuation, and information on crowd control and on who collected witness statements. It is important to debrief with emergency response, police, and medical staff to determine what problems were encountered while responding to the event.

Survival Examination – Interviews and Key Questions

Injured passengers and employees should be interviewed to document as much information concerning their actions before, during, and after the event. Persons who could provide information and may also be interviewed include passengers,

Effective Investigation Practice

When interviewing individuals who were on the accident vehicles, it is important to have equipment layouts, photos, and scene diagrams ready to help interviewees identify their location and the location of others on whom they may have information.

vehicle operators, other agency employees, responders, and witnesses. Additional information can be collected, such as where the passenger was sitting at the time of the event and what they noticed about what other passengers around them were doing just before, during, and after the accident.

Key questions to explore regarding the vehicle interior:

- Did seats become unsecured? Did any sharp edges show evidence of impact with car occupants?
- Did windows and doors stay secured? Was there any evidence of difficulty removing emergency egress windows or using emergency door releases?
- Were any injuries the result of passenger ejection or penetration by external objects?
- Was survivable space maintained in passenger and driver areas?
- Did doors function as intended for emergency access or passenger evacuation?
- Did the emergency lighting function?
- Was fire involved? How did interior furnishings perform?
- Was the required emergency equipment in place (ex: fire extinguishers)? Were any used?
- Were instructions provided over the vehicle public address system?

Key questions to explore regarding the vehicle exterior:

- Were emergency egress windows/door releases used? Issues?
- Did responders encounter difficulty accessing equipment? Did they have keys or know how to trigger door release mechanisms?
- If applicable, did fuel tanks leak? Was fire involved?
- Was survivable space maintained in passenger and driver areas?
- Was vehicle equipped with crash protective features such as corner posts, accident posts, or crumple zones? Did they function as designed?

Several standards, regulations, and guidelines have been developed to improve crashworthy features of transit vehicles. Investigators can use these standards as benchmarks in comparison to performance in the event under investigation. These include:

- APTA Bus Transit System Standards (Bus Safety)
- APTA Recommended Practice: Recommended Practice for Transit Bus Fire Safety Shutdown, APTA BTS-BS-RP-001-05
- APTA Recommended Practice: Recommended Practice for Transit Bus Electrical System Requirements related to Fire Safety, APTA BTS-BS-RP-002-07

- TCRP Synthesis 18, Bus Occupant Safety
- TCRP Report 25: Bus Operator Workstation Evaluation and Design Guidelines
- TCRP Report 185 Bus Operator Workstation Design for Improving Occupational Health and Safety

Injuries/Fatalities

The investigatory element can be broken down into several areas. First is creating an injury table to identify by individual and type of injury the individuals involved in the event. The development of a detailed list of employee injuries is critical, and it is important that the same type of interview process be conducted with the bus operator as was done with the injured passengers. Particular attention should be taken to extract information that can shed light on crew actions just before and just after the event. Note that NTD reporting requires reporting of "transportable" injuries, i.e., individuals requiring further transport for medical reasons. Agencies may also require reporting of all injuries per policy requirements and safety data purposes.

In a mass casualty event on a public transit system, cataloging injuries can be challenging, as uninjured passengers and "walking wounded" with minor injuries may leave to continue their journey. Even determining the number of passengers involved is difficult, as transit agencies do not maintain a passenger manifest such as some other modes of transportation do. Additionally, the Health Insurance Portability and Accountability Act (HIPAA) provides patient privacy protections and restricts medical providers from providing patient information.

Sources that investigators can use to catalog injuries and fatalities include:

- Vehicle interior video recorders
- Interior conditions that may include biological residue or impact deformations
- Claims
- Interviews
- Statements
- Triage logs
- Other emergency responder records

Based on these sources, investigators may want to prepare a grid cataloging the numbers and types of injuries. An example is shown below:

	Employees	Responders	Passengers	Total
Fatal				
Injury, Serious				
Injury, Minor				
Total				

A detailed list of all fatal injuries should also be provided, including where the individual was sitting during the event and all pathological information relating to the individual's injuries.

A detailed list of and interviews with any injured emergency responders are also of great value to the survival factors investigation. Answering questions about how and why these injuries were received may help other emergency responders avoid the same risks.

A critical element of the survival factors investigation is documenting the emergency response. Several key facts need to be documented from emergency responder records, interviews with responders, and attendance at post-event debriefs (some medical information may not be readily available due to HIPAA restrictions), including:

- How many emergency responders were on the scene?
- What agencies were represented?
- Time of notification
- Delays in arriving at site
- Time ICS established
- Responder familiarity
- Command post
- Equipment used
- Adequacy of communication protocols and equipment

Survival factors investigations look closely at the preparedness training and exercises that occurred in the past to understand how well agencies are prepared. An assessment of disaster preparedness should be performed to include a review of any training provided to operating employees, fire, police, EMS, hospitals, and any City, County, or State Office of Emergency Management (OEM). It is also suggested that a review of the City, County, and transportation authority emergency management plan be reviewed and assessed for its efficacy. Resources to assist transit agencies evaluate emergency preparedness and response include:

- APTA Recommended Practice for First Responder Familiarization of Transit Systems, APTA RP-SEM-002-08
- APTA Standard for a Continuity of Operations Plan for Transit Agencies, APTA-SS-SEM-S-001-08
- APTA Standard, Transit Incident Drills and Exercises, APTA SS-SEM-S-004-09
- TCRP Report 160, *Paratransit Emergency Preparedness and Operations Handbook*

Change Management/Configuration Management

When accidents are investigated, it is essential to understand what has changed or may have changed as it relates to the various elements associated with the system being analyzed and the undesirable event being investigated. Failure to plan for and manage change may be part of the root cause of an accident. Configuration Management (CM) is a process for establishing and maintaining consistency of a product's performance, functional and physical attributes with its requirements, design, and operational information throughout its life. CM practices were first formalized in the defense and aerospace industries, bringing related industry best practices together under a common framework.

CM is applied over the life cycle of a product and provides:

- Visibility and control of performance, functional and physical attributes
- Verification that the product performs as intended
- Documentation to sufficient detail of its projected life cycle, fabrication or production, operation, maintenance, repair, replacement, and disposal

CM applies to both hardware and software[50] components (including operating rules, procedures, and drawings). Changes to hardware and software need to be evaluated and approved by affected agency departments, documented, and evaluated to make sure they do not adversely impact safety. Most agencies have a CM or Change Control Board to monitor this process.

Types of change include:

- Climatic
- Operational
- External influences
- Personnel
- Maintenance Activities
- Technological
- System
- Budget (for agency or unit)

Climatic change includes:

- Changes in temperature – interior and exterior (heat vs. cold)
- Seasonal variations (fog, dust, snow, ice, rain, wind)
- Acts of God (cyclonic storms, flooding, earthquakes)

[51] "Software" is used in the generic sense to include written procedures, training plans, and other documents.

Investigators may want to be familiar with any special procedures triggered by temperature fluctuations. For example, in cold weather, there may be restrictions related to ice buildup on roadways.

Operational changes include:

- Increased service (closer headways) to meet growing ridership demands
- Competition between maintenance forces and transportation personnel for access to revenue equipment
- Increased turnaround of transit vehicles
- New service modes (bus rapid transit [BRT], for example) or new fuel or propulsion system (compressed natural gas [CNG], hybrid electric, or electric)
- Increased headways that result in less time to perform maintenance and inspections

Change from external factors include:

- Increased ridership
- Shifts in populations
- Land-use change (zoning, development)
- Increased urbanization
- Population/demographic changes
- Regulatory changes

Examples of external changes that may impact system operation are transfer center issues with increased patronage and trespassing in busways. Regulatory changes may include changes to state commercial driver license requirements, hours of service, traffic codes, or vehicle equipment.

Personnel changes include:

- High rate of attrition/retirement resulting in a significant loss of institutional knowledge ("brain drain")
- Lack of adequate succession planning strategies
- Recent hire inexperience
- Changes in senior management and political leadership
- Organizational structural changes
- Changes to collective bargaining agreements and impacts on things such as route or personnel scheduling

As attrition occurs, employee development is a vital component of a productive workforce; therefore, evaluating training programs is a critical part of the investigation process. Absence or inadequate programs for development of talent management to address “brain drain” can be at the root or contributory cause of an incident.

Change from maintenance activities includes:

- New power systems such as hybrids that may require new equipment and processes
- Introduction of a new product that changes maintenance procedures
- Replacement of components, resulting in disarraying of wiring, leading to potential incorrect rewiring of circuitry
- Unauthorized substitution of parts or components
- Revised procedures not fully distributed to all departments
- Maintenance work on CNG systems that may require new procedures and safeguards

Technology changes may be associated with the update of existing technologies or the testing and/or integration of new technologies and may include:

- Lane departure and back-up warning systems
- Collision warnings and automatic emergency braking
- Traffic signal preemption
- Camera-based driver monitoring/coaching systems
- Exterior camera obstacle detection and alerting systems
- Autonomous vehicle technology
- Alternative fuel, hybrid, or battery power
- AVL and route direction systems

It is important that the evaluation consider the potential unintended consequences of technology changes. Agencies may adopt new technology for a variety of reasons:

- Improve performance
- Meet increased ridership demands
- Reduce accident claims
- Address retiring legacy systems that have exceeded their useful life
- Address current system inefficiency, i.e., difficulty tracking bus locations, controlling bus connections, alternative service needs
- Replace, recondition, or retrofit with a newer version equipment that exceeds its life expectancy
- Component obsolescence

- Lack of manufacturer support for equipment, too expensive to repair and maintain it
- Change out equipment at the end-of-life cycle
- Mandates by legislation, environmental regulations, or emissions control upgrades
- Design modifications and retrofits
- Upgrade as part of SGR initiatives

System changes include:

- New BRT lines or extensions
- New bus routes
- Added transfer centers or other facilities
- Facility improvements
- New buses

Acquisition of additional buses from other manufacturers may create compatibility problems concerning operational characteristics of different fleets such as brake and acceleration rates, operator interface, customer interface, and maintenance capacity and training. The need for the system to consolidate, accept, and operate more effectively may lead the agency to operate more than one type of bus service or bus equipment on any one line. The acquisition of new vehicle equipment or the mixing of different fleets needs to be thoroughly evaluated.

Budget changes include:

- Procurement Department ordering of parts at a significant cost savings to the agency, not realizing that it is inadequate and could cause a malfunction or an incident leading to a major bus incident.
- Budget constraints that may adversely impact maintenance and inspections as well as training.
- Low bid requirements that may result in parts and materials that do not meet agency needs.
- Equipment specifications that may be rewritten to reduce costs at the risk of reducing safety and impacting warranty period performance.
- Labor costs that impacting the budget, driving the need for increased productivity and greater mechanization without corresponding training.

The system may have changed because the Purchasing Department accepted the lowest bid without fully understand the operating needs of the new equipment, systems, or service procured. Part of the problem may be that the specification used was too general and did not specify the system performance requirements. Even if the specification was sufficiently detailed and accurate, the number of bidders might have been too low due to the difficulty of the project. (*Note*: This emphasizes the importance of including safety in the procurement process. If there is an intention to change a specification or allow a procurement that does not meet the established specification, hazard analysis and safety risk evaluation would be required to ensure that the proposed change does not adversely affect the safety of the system.)

Human Factors

The objective of the human factors (HF) portion of an investigation is to understand the nature and scope of human and organizational factors as they relate to transportation accidents. The methodology for conducting the investigation involves assessing information pertaining to the circumstances and conditions of an accident, the specific operator background and performance, the various psychological and physiological sub-disciplines that can offer analytic explanations for an operator's performance (human and organizational), and the ergonomic and environmental issues affecting operator behavior.[51]

The investigator is responsible for documenting and analyzing various HF factors within the disciplines of engineering, physiology, and psychology. They determine how these factors interrelate and interact and how they influenced the perceptions, decision making, and actions of individuals involved in an accident.

Examples of human factors and their related disciplines include the following:

Human Factor	Discipline
Training	Education – adult learning
Control/equipment design	Engineering
Perception, sensation, kinesthetic	Experimental psychology
Operator/personnel communication and interactions	Social psychology
Medical conditions, toxicology	Physiology, pharmacology
Mood, mental state, habits, and life events	Clinical psychology

The following human factor-related elements may contribute to an event and the examination of these elements is crucial:

- Experience/familiarity/background
- Distraction
- Task–time relationships
- Environmental factors

[51] The term "operator" may also include but not be limited to\, dispatchers, maintenance personnel, and others whose actions or inactions are of interest to the HF investigator.

- Noise/vibration/motion
- Training
- Health factors
- Operator assaults

Experience/Familiarity/Background

The investigator can determine an operator's experience and familiarity with both the equipment and the territory. Areas of inquiry include the following:

- Was this your first time operating this type of vehicle? If not, how much experience do you have with this type of equipment?
- Was this your first time in this particular vehicle? If not, how much experience do you have with this vehicle?
- Do you ever drive a different vehicle? How often? What is the difference between the two vehicles?
- Have you operated over this route before? How often? Have you operated it under similar conditions? When was the last time you operated over this route before the accident?

Distraction

Distraction, in simple terms, is the operator's attention on something other than the operating task. As research has shown, distraction has been a factor in several accidents. The HF investigator can work to determine if the operator was distracted at or near the time of the event. Areas of inquiry include the following:

- What were you doing just before the accident?
- What were you thinking about just before the accident?
- Was there anything interesting or unusual outside the vehicle before the accident?
- Was there anything interesting or unusual inside the vehicle just before the accident?
- Did you have any special concerns about operations just before the crash?
- Did you have any particular concerns about your cargo (if applicable) just before the crash?
- Were you listening to the radio? Did you change the channel/volume before the accident?
- Does your vehicle have a CB radio, television, or any other communication device? Were you using or manipulating any device before the accident?
- Were you eating or drinking anything at the time of the accident? If so, what/when?

- Were you smoking or chewing tobacco at the time of the accident? If so, when?
- Were you adjusting any of the vehicle controls – A/C, heat, seat, windows, doors, before the accident?

Do you have a cellphone? What is the number? Were you using/on a mobile telephone before or at the time of the accident (phone call, e-mail, texting)? If yes, obtain complete details. (Note: The investigator should determine and evaluate the agency's electronic device policy.)

Task–Time Relationships

It is essential to determine what the operator was doing at the time of the crash and to determine any time pressure they may have been under and how their activities relate in time to other activities or events. Areas of inquiry include the following:

- How long had you been operating at the time of the accident? How long had you operated that day? Did you take any breaks? When and how long? When was your last break before the accident?
- Were you operating on a deadline? Did you need to be anywhere at a particular time? If so, were you on time/on schedule? What would have been the consequences of being late? Of being early?
- If the accident had not happened, when would have been your next change—i.e., making a stop or a turn? How far in distance and time were you from that change when the accident occurred?

Workload

Along with a description of the task is the operator's perception of their workload. When assessing workload, be sure to look at typical and event-specific workload. Areas of inquiry include the following:

- How would you describe your typical workload when operating the vehicle (1 to 10 scale, light/medium/heavy)?
- How would you describe your workload just before the accident (1 to 10 scale, light/medium/heavy)?
- Do you typically perform any non-operational activities? What activities, how often, for how long, and why?
- Were you performing any non-operating activities before the accident? If so, what were they, when, and why?
- Do you remember what you were thinking about just before the event (i.e., was it related to the task – possible heavy workload – or not –possible lighter workload)?

Environmental Factors

External Conditions

Questioning in this area focuses on the environmental conditions external to the vehicle. The investigator can obtain weather condition reports as an independent verification of the operator's statement. Questions to ask include the following:

- What was the weather such as at the time of the accident (cloudy, sunny, raining, windy, snowing, clear)?
- Had the weather changed recently?
- What were the surface conditions at the time (icy, wet, dry)?
- Had the road conditions changed recently?
- Had there been any changes in the type or configuration of roadway or intersection?
- Were there any other external conditions?

Internal Conditions

Questioning also can focus on the conditions inside the vehicle at the time of the accident. Questions include the following (with follow-up if needed):

- Describe any noise in the vehicle just before the accident.
- What was the temperature in the vehicle? Was the heat on? Was the A/C on?
- Were any of the windows open? Which ones? How far?
- Were any of the doors open? Which ones? How far? Why?
- Were there any audible alarms or any illuminated warning indications on the bus operator's dashboard/console?

Illumination

Questions about illumination will determine the level of illumination at the time of the accident. This will help the investigator determine how far the operator could see, what he or she could see, and if glare was a factor. Questions include the following:

- Were you operating outdoors, or in an elevated, open cut, or tunnel environment?
- If the accident occurred in a tunnel, how was the lighting/illumination, i.e., what was the condition of the tunnel lighting? Was the lighting sufficient for you to see everything?
- Did the accident occur in the daytime or the nighttime?
- Where was the sun/moon (if you know?) Did the sun/moon cause you any problems?

- Did the headlights of other vehicles, reflections, or lights from the environment cause you any problems?
- Could you see and read your instrument panel?
- How well could you see other vehicles?
- Did the visibility or illumination level change before the accident?
- Was/were your headlight(s) on?
- Were you wearing sunglasses?
- How clean was your windshield? Any problems seeing through it?
- Were any of your vehicle's interior lights on? If so, why?

Noise/Vibration/Motion

These questions will help to determine if noise may have played a part in the accident. Also, by asking about vibration and motion, the investigator may be able to determine if a mechanical failure occurred or if some feature contributed. Questions include the following:

- What did you hear just before the accident?
- Any new or unusual noises, either from the roadway or from the bus?
- Did you notice any unusual motion or vibration in the vehicle?
- Describe the vehicle's motion during the accident.

Training

Documenting bus operator training in the wake of an accident is of interest to the investigator. The following questions can initially be asked of an operator, tailored as needed and based on their level of experience, education, and familiarity with equipment, procedures, policies, and systems:

- What operator education classes or training have you had? When and where was the training, including the most recent training (before the accident); describe it. Who offered/provided the training? What was your opinion of the quality of training?
- Have you had any on the job training (OJT)? If so, provide details.
- Have you had any technical training? If so, provide details.
- Do you take any annual or recurrent training? If so, provide details.
- Have you ever been required to take re-training? If so, provide details.
- Have you ever taken any simulator training? If so, provide details.
- When did you receive your first license/certificate?
- What license/certificate do you currently hold?
- Based on your training, how confident are you in effectively and safely performing your duties?

Sources of training information may include:

- Company records and company training personnel
- Personnel records
- Operational training procedures
- Simulator records
- Licenses/certificates
- Logbooks
- Fellow operators who may know the operator's skills and abilities

Health Factors

Health factors include several subtopics—general health, sensory acuity, drug and alcohol ingestion, and fatigue.

General Health

NTSB has subpoena authority to obtain medical records; however, a transit agency investigator is restricted by HIPAA regulations, which were enacted to safeguard an individual's medical information. As such, the investigator will have difficulty determining the operator's state of general health unless the individual voluntarily provides this information. The investigator is advised to discuss this issue with their internal legal and medical personnel (if available) to ensure that they are aligned regarding the proper protocols to follow during an event to ensure HIPAA regulations are not violated. In many instances, the agency's medical staff will be relied upon to review the employee's medical work history to determine if preexisting medical conditions were known and adequately controlled.

The investigator may evaluate the transit agency's medical screening process for medically based conditions such as sleep disorders, including obstructive sleep apnea. Some transit agencies attempt to elicit this information from questionnaires, which are not always successful in identifying at-risk employees. Effective measures include such things as obtaining body mass index (BMI) or having an employee suspected of having a sleep disorder undergo a polysomnography (sleep study). Areas of inquiry include:

- How is your overall health?
- When was your last physical examination? What were the results? Any problems or issues noted?

Sensory Acuity

An operator's sensory acuity may play a vital role in an accident. Information on both vision and hearing may also be protected by HIPAA regulations; however, this information may be available for the internal medical department to assess.

Again, this information may not be available to the investigator unless the individual volunteers it. Questions to ask the operator (or his/her family) include the following:

- How is your vision, generally?
- How was your vision at the time of the accident?
- Do you have, or what you ever, had problems with your sight?
- Do you wear glasses/contacts? If yes, were you wearing them at the time of the accident?
- Do you see an optometrist/ophthalmologist?
- How is your hearing generally?
- How was your hearing at the time of the accident?
- Do you have, or have you ever had problems with your hearing?
- Do you wear a hearing aid? Were you wearing it at the time of the accident? When was the last time you had it serviced or changed the batteries? (An investigator should obtain the make/model/date of hearing aid manufacture)
- Are you under the care of an audiologist or another doctor for your hearing?

Drug/Alcohol Ingestion

A post-accident examination of drug and alcohol consumption should be compliant with FTA post-accident regulations found at 49 CFR 655.44. This regulation requires that an alcohol test must be documented within two hours, i.e., if an alcohol test required is not administered within two hours following the accident, the employer must prepare and maintain on file a record stating the reasons the alcohol test was not promptly administered. If an alcohol test required is not administered within eight hours following the accident, the employer must cease attempts to administer an alcohol test and maintain the record. Also, regulations require that a drug test must be administered within 32 hours of the accident.

Unfortunately, many over-the-counter (OTC) drugs are not currently part of standardized testing. The investigator should determine and document the applicable transit agency policy, or lack thereof, on self-reporting the use of all medications by covered employees. Also, remember to look for what drugs the operator did NOT take—regular or prescribed medications that the operator missed or chose not to take; the absence of a drug could be just as important as its presence. Areas of inquiry include the following:

- Do you drink alcohol? How much? How often?
- When was the last time you drank alcohol before the accident? How much?

- Do you use illicit drugs? Which, and how often? When was the last time you used illegal drugs before the accident?
- Do you take prescription medications? Which? How often? What doctor prescribed them (contact information needed?) What conditions do they treat?
- Did you take all of your prescribed drugs in the three days before the crash? At what times? Did you forget to take any, or miss any doses?
- Did you take any OTC drugs (aspirin, Tylenol) in the three days before the accident? When? Why did you take them?
- Did you take any herbal supplements, homeopathic remedies, or vitamins in the three days before the accident? When and why?

Fatigue

Fatigue is a significant problem across all modes of transportation. Fatigue is a subjective feeling of tiredness that has a gradual onset and can have physical or mental causes. For this document, the focus is on mental fatigue, a temporary inability to maintain optimal cognitive performance. The onset of mental fatigue during any cognitive activity is gradual and depends upon an individual's cognitive ability and other factors, such as sleep deprivation and overall health, which can reduce mental and physical functioning. Although levels of fatigue vary, causes of fatigue in a work context may include:

- Long work hours
- Split shifts or night shifts
- Long hours of physical or mental activity
- Insufficient break time between shifts
- Changes to jobs or shift rotations
- Inadequate rest
- Excessive stress
- Having multiple jobs
- Changes to home environments that impact sleep, such as a new baby, change in patterns and routines, new or changing caregiver roles.
- Changes in home relationship status such as divorce or separation
- A combination of factors

[53] This is HIPAA-protected information; however, the investigator may wish to discuss the employee's medical history with trained medical personnel while following defined protocols.

Effects of Fatigue	
Reduced decision-making ability	Increased tendency for risk-taking
Reduced ability to do complex planning	Increased forgetfulness
Reduced communications skills	Increased errors in judgment
Reduced productivity or performance	Increased sick time, absenteeism, turnover
Reduced attention and vigilance	Increased medical costs
Reduced ability to manage stress on the job	Increased incident rates
Reduced reaction time – both in speed and thought	Increased risk-taking behavior
Reduced memory/ability to recall details	Impaired judgment
Failure to respond to changes in surroundings	Lowered motivation
Unable to stay awake	Slow reaction time

Source: K&J and CUTR

The investigator can try to obtain information on both the quality and quantity of an operator's sleep, noting the time of the accident for comparison to known circadian low points. Sources of information other than the operator include work schedules, work cellphone records, and logbooks. Investigators can try to establish a baseline for on and off-duty days, as well as specifics for the 72 hours before the incident and compare the two. Specific information to obtain includes:

- Times the operator awoke/went to bed each day
- Commute distance and duration
- Times, content, and duration of meals, including snacks
- Step-by-step recounting of activities, including times and durations
- Relationship between that day's activities and their normal ones –anything missing, anything new, anything odd
- People they saw or talked to, and times
- Time, duration, and location of any naps
- Any medications that are taken, including prescription, OTC, or herbal, including time, and dose
- Time and amount of any intoxicant ingestion, including alcohol and illegal drugs

If granted an interview by a surviving operator, the most effective way to obtain this information may be to have the operator start with when they up three days before the accident and move step-by-step through the days. Again, the more detail that can be obtained, the better to determine if fatigue played a role in the accident. If an operator declines to be interviewed or does not survive, the investigator can attempt to obtain this information from family members, roommates, neighbors, co-workers, or other sources.

The goal of the 72-hour history is to obtain, in as much detail as possible, information on the operator's activities in the 72 hours before the accident. Information from this history will touch on every area of the HF investigation, making it one of the most important activities the investigator will undertake. It may be beneficial to go back slightly longer than 72 hours to the time the operator awoke. (See Seventy-Two Hour Pre-Incident History Checklist in Appendix G). Questions to ask include:

- When do you usually go to sleep and get up on your days off? How much sleep do you usually get?
- When do you usually go to sleep and get up on days you have to work? How much sleep do you typically get on those days?
- Do you usually take naps? When, for how long, and why?
- How would you describe the overall quality of your sleep?
- Can you estimate how long it usually takes you to fall asleep after you go to bed?
- Do you wake during the night? If so, how often, for how long, and how long does it take you to get back to sleep?
- Specifically, when did you go to sleep and get up the three days before the accident?
- Did you nap any of the three days before the accident? If so, when and for how long?
- Did you wake during the night any of the three days before the accident? If so, why? How long were you awake? How long did it take you to get back to sleep?
- How long did it take you to fall asleep the three days before the accident?
- Do you take any medicines to help you fall asleep or stay asleep? What medications (prescribing doctor)? Did you take them three days before the accident?
- Do you take any medicines that make it difficult to fall asleep? Did you take them in the three days before the accident?

Biomathematical models of fatigue attempt to predict the effects of various work patterns on job performance. They also consider scientific input about the relationship among working hours, sleep, and employee performance. These two models are discussed below.

- **Fatigue Audit InterDyne (FAID)** – Using formulas developed and validated by Dr. Adam Fletcher and Professor Drew Dawson at the Centre for Sleep Research at the University of South Australia can assist in identifying fatigue exposure and tracking the effects of associated risk improvements to hours of work. The statistical models in FAID estimate work-related fatigue based on four factors:

– Time of day of work and breaks
– Duration of work and breaks
– Work history in the preceding seven days
– Biological limits on recovery sleep

A FAID score indicates the sleep opportunity that a work pattern allows. As the relative sleep opportunity associated with a work pattern decreases, the FAID score increases. Scores between 80 and 100 are equivalent to the predicted level of work-related fatigue achieved after 23–24 hours of continuous sleep deprivation. Performance impairment at the same levels of sleep deprivation has been associated with a blood alcohol concentration of over 0.05%.[53]

- **Fatigue Avoidance Scheduling Tool (FAST)** – The US Air Force developed FAST in 2000–2001 to address the problem of aircrew fatigue in aircrew flight scheduling. Fatigue predictions in FAST are derived from the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model. FAST is a Windows program that allows scientists, planners, and schedulers to quantify the effects of various work-rest schedules on human performance. It provides work and sleep data entry in graphic, symbolic (grid) and text formats. The graphic input-output display shows cognitive performance effectiveness as a function of time. The goal of the planner or scheduler is to keep performance effectiveness at or above 90% by manipulating the timing and lengths of work and rest periods. A work schedule is entered as red bands on the timeline. Sleep periods are entered as blue bands across the timeline below the red bands.

APTA Standard RT-OP-S-023-17, Fatigue Management Program Requirements, provides standard requirements for rail transit systems in establishing and implementing a fatigue management program and related systems. Although the standard was developed for rail transit, most elements apply equally to transit bus operations. Specifically, it provides baseline requirements for fatigue management programs (FMP) to mitigate the impacts of fatigue on their operations and thereby improve the quality and safety of transit service. The document addresses three primary areas with accompanying elements, as follows:

- Purpose of an FMP:
  – Assemble FMP Steering Committee
  – Conduct FMP pre-implementation study
  – Develop FMP policy
  – Develop FMP roles and responsibilities

[54] Dawson, D., and Reid, K., "Fatigue, Alcohol and Performance Impairment," *Nature*, July 1997.

- Develop FMP implementation timeline
- Ongoing FMP communications
- Monitor and evaluate FMP

- Core FMP components:
  - Fatigue considerations in incident investigation
  - Personnel work schedules
  - Fatigue management education
  - Fatigue-related absences and reports
  - Rest areas
  - Sleep disorder screening and treatment
  - Data assessment metrics

NTSB Recommendations

The 2019-2020 NTSB Most Wanted List of Transportation Safety Improvements focuses on several human performance areas. These include the following with a focus on rail and transit recommendations:[54]

- **Eliminate distraction**, an increasing and life-threatening problem in all modes of transportation.
- **End alcohol and other drug impairment**. Impairment is a contributing factor in many transportation accidents across all modes. Impairment in transportation is not limited to just alcohol; it also includes impairment by other drugs, legal or illicit.
- **Reduce fatigue related incidents**. Fatigue is a pervasive problem in transportation that degrades a person's ability to stay awake, alert, and attentive to the demands of safely controlling a transit vehicle.
- **Require medical fitness-screen for and treat OSA**. Undiagnosed and untreated OSA continues to be deadly in all modes of transportation, including transit.

Employee Assistance Program (EAP)

An EAP is a voluntary, confidential program that helps employees (including management) work through various life challenges that may adversely affect job performance, health, and personal well-being to optimize an organization's success. EAP services include assessments, counseling, and referrals for additional services to employees with personal and work-related concerns, such as stress, financial issues, legal issues, family problems, office conflicts, and alcohol and substance use disorders. EAPs also often work with management and supervisors, providing advanced planning for situations,

[54] For additional information about all NTSB Most Wanted List recommendations, see www.ntsb.gov/mostwanted.

such as organizational changes, legal considerations, emergency planning, and response to unique traumatic events. The investigator should evaluate the agency's EAP programs to ensure that employees who are exposed to traumatic events receive the assistance that they need.

Operator Assaults

The TRACS report "Preventing and Mitigating Transit Worker Assaults in the Bus and Rail Transit Industry" was published on July 6, 2015. In October 2014, the FTA Administrator tasked representatives from state and local transportation agencies, labor unions, research organizations, and national transportation associations to work together to create recommendations (see below) for FTA to prevent assaults against transit workers. Specifically, the Administrator tasked TRACS to:

- Develop recommendations for FTA on the key elements that should comprise an SMS approach to preventing and mitigating transit worker assaults.
- Identify risks and impediments to a safe workplace and a process to reduce the hazards that enable these assaults.

Although there is considerable focus on addressing bus transit operator assaults, the scope of this tasking is intended to include addressing assaults for all types of transit employee categories and all modes of transit. Based on a review of available literature, TRACS developed the following summary of risk factors for assaults against transit workers:

- Direct interaction with the public, especially with passengers who may be intoxicated, have a mental illness, or be experiencing frustration due to fare increases, service reductions, or delays. Bus operators usually interact directly with passengers, and rail operators experience assault most often during rules disputes and when waking sleeping passengers.
- Working alone, in isolated or high-crime areas, during late night or early morning hours raises the risk of assault against transit operators.
- Handling and enforcing fares; most assaults against bus operators occur during fare disputes.
- Having inadequate escape routes; transit operators often lack a way to escape from passengers who threaten or begin to assault them.

These recommendations included:

- Installing protective barriers, video surveillance, AVL systems, and overt or covert alarms on bus and rail transit vehicles
- Training safety-sensitive employees about how to de-escalate potentially violent situations, the importance of reporting assaults, and the standard agency response to reports of assault

- Educating the public about reporting assaults by conducting public awareness campaigns, providing resources and incentives for passengers to report assaults, and meeting with passengers to discuss strategies for preventing assaults
- Providing support for transit workers by offering psychological support and post-incident counseling, responding to every report of assault or other serious incident, and involving transit workers in safety committees
- Enforcing transit agency policy by posting passenger codes of conduct, suspending service for assailants, posting police officers on transit vehicles and property in high-risk areas, providing legal support for transit workers who file complaints, and collaborating with other agencies and organizations to develop social safety plans and advocate for changes in state and local legislation to better address assaults against transit employees
- Collecting data regarding the number, location, times, and types of assaults as well as the number, type, and implementation times of each risk control strategy to enable the evaluation of the effectiveness of each strategy and the overall SMS in preventing transit worker assaults

FTA Notice

On May 24, 2019, FTA published a notice entitled Protecting Public Transportation Operators from the Risk of Assault in the *Federal Register*.[55] This notice alerted transit agencies to the need to address the risk of transit operator assaults when identified through the processes required under the PTASP regulation. The PTASP regulation requires transit agencies to develop and implement SMS processes, which include identifying safety hazards, assessing the related safety risks, and then establishing methods of risk mitigation.

Analysis

There is no bright line that separates the fact-gathering phase from the analysis phase of the investigation. In the on-scene and early stages of the investigation, investigators are cautioned about reaching conclusions. This is important because investigators need to keep an open mind and not close off lines of inquiry that may yield valuable information.

At some point, usually days or weeks into the investigation, it is appropriate to begin analyzing the factual information developed. This serves to focus the investigation on relevant areas. For example, investigation of an intersection collision between two buses will concentrate more on signals, braking, operational performance, and human performance than on roadway conditions on a clear dry day.

[56] *Federal Register*, Vol. 84, No. 101, May 24, 2019, Notices.

Analysis can be described as separating the significant few (facts) from the trivial many. The facts and necessary analysis will vary from event to event, but the process is the same. There are several analytical tools that may assist in determining cause, including the Ishikawa Chart, Fault Tree Analysis, the SHEL model, Root Cause Analysis and the “5 Whys.” Each of these methods is further described in Appendix H, Analytical Tools to Aid the Investigation Process.

Part 4: Report Development and Corrective Action Plans

Report Timing

Generally, agencies have internal requirements to produce a preliminary summary report on the incident along with any recommended immediate actions within 24–36 hours. The agency policy may also contain timelines for interim and final reports. Whereas developing the report promptly is essential, the quality of the investigation and analysis remain the top priority. Production of quality preliminary and interim reports can help assuage the impatience of those anxious for a final product in a complex investigation.

Report Format

The agency’s report format will likely be driven by the agency policy, unless there are state requirements. The report format in this manual uses an NTSB report format for convenience, and it is not intended to supplant what may be required by agency policy. Report headings may vary slightly based on the circumstances of the individual accident and the standard prescribed by a SSOA. Appendix I. Investigation Report Organization/Content provides recommendations for report organization and headings/content.

The Chicago Manual of Style is a useful standard for stylistic formatting (punctuation, numbering, references), unless otherwise directed by agency style manual. Reports should be written in plain English; jargon and obscure technical terms should be avoided unless they are critical to an understanding of the event, in which case they can be defined or explained. An well-written investigation report will lead the reader to specific findings and recommendations that will drive the development and content of CAPs.

Factual Information

This section is the start of the full report and provides a detailed factual account of the accident without providing an analysis. It provides an overview of the accident and focuses on those areas that are relevant to the cause of the accident and lead to the recommendations. The facts support the analysis that, in turn, supports the cause and recommendations. Think of the factual portion of the report as the foundation and the analysis, conclusion, and cause as the house; without a good foundation underpinning it, the house will be prone to problems.

The factual section does not need to address every fact developed over the course of the investigation; however, there needs to be an accurate logic chain among facts, analysis, conclusions, and cause. The accident description provides the basic facts of the accident, telling the reader the "who," "what," "where," and "when." The "why" is reserved for the analysis section. Maps or aerial images of the scene are helpful here.

Effective Investigation Practice

Typical information in the accident description section of a report includes:

- Type of accident, i.e., fire, collision, bus ran off road
- Accident date and time
- Accident location
- Name of transit line
- Location identifier (road milepost) or cross street(s)
- Equipment/staff involved
- Bus type and direction of travel
- Operator's view on approach
- Other vehicle/equipment/persons involved
- Other vehicle types, direction, makeup (if applicable)
- Fatality/Injury summary
- Total damage
- Weather conditions

Analysis

This is the area of the report where the meaning of the facts is explained. When a discrepancy is found between what policy, procedures, specifications, or regulations require with what was found in the accident, the first question to answer how this discrepancy is relevant. The Analysis section is where the significance of the facts developed are explained.

Some discrepancies may not pass the relevance test; for example, a bus traveling 3 mph over the 40 mph speed limit may not be a factor in an event, but a bus traveling at 30 mph over the speed limit likely is. Keep in mind the logic chain that must be present.

The Introduction section discusses the exclusions, potential causal areas examined and found not to be factors in the accident. For example, in a collision, the report might note that investigators inspected and tested the braking system and examined maintenance records and found no anomalies. At the end of the introduction, for example, a summary would note that the investigation concluded that the condition of the braking system was not a factor in this accident. That statement is then repeated in the conclusions section.

The report includes those specific issues identified in the accident—

Effective Investigation Practice

The logic chain to strive for:

- Facts based on observable, verified, and accurate information
- Analysis based on those facts
- Conclusions based on the analysis
- Cause and contributing factors as output of the logic chain
- Recommendations address causes and contributing factors

the factors judged to cause or contribute to the accident. For example, in a hypothetical collision, if it was found that the brakes were not applied before impact, the report would provide a detailed analysis of the factors involved. This is where the "5 Whys" described in Appendix G might come into play in examining procedures, equipment, communication between maintenance and the control center and between the control center and the bus.

At the end of each analysis discussion, conclusions are identified with an explanation of what led to those conclusions. There needs to be a distinct logic chain among the facts, analysis, and conclusion.

The report will identify the probable cause(s) and contributing factors to the event—1) primary cause (or causes), as determined by the facts and the analysis conducted by the transit agency's investigative team, and 2) contributing factors that were discovered during the analysis of the facts that without these factors, the accident may not have occurred.

Probable cause and contributing factors can be a grey area. Several NTSB reports note that probable cause may be the proximate (as opposed to root) cause with elements of the root cause noted as contributing factors. In other reports, the probable cause may be a root cause with proximate causes noted as contributing.

As the more in-depth objective of the investigation is to identify preventive measures, it is important that report writers consider which elements of the causal picture best logically link to the preventive recommendations. The primary causal and contributing factors of the accident should be clearly stated in the Conclusion section.

Accident Investigation Report Recommendations

The report can provide immediate recommendations or discuss corrective actions that were implemented as the report was being prepared, i.e., a chafing wire was identified during the post-accident investigation of a bus fire, which triggered a fleet-wide inspection.

Once the probable cause has been determined and contributing factors identified, the investigators, together with the associated agency departments, develop a realistic and practical remedy to prevent a similar accident from happening again. This may take time and money or may involve immediate changes to rules and procedures. Still, it must be fully understood what needs to be done immediately, within the short term, and what long-term solution is required to prevent future events of this nature.

The Recommendations section of a report must provide a set of actions that can be taken to prevent reoccurrences of this accident. These can be organized by time so that those requiring immediate action can be implemented, and others requiring more time and funding can be scheduled for a permanent fix for the elimination of the problems leading to this accident. Long-term recommendations may require capital budgets, re-design, or extensive system modifications, i.e., retiring legacy vehicles or upgrading them with newer components.

Recommendations are action items. Each should begin with an action verb (e.g., conduct, revise, modify) that will result in measurable action. There should be a distinct logic chain, from the facts to the analysis to the conclusions to the recommendations.

Remember that the recommendations will drive corrective actions, so they need to be worded in a way that supports the corrective action format and have identifiable and measurable outcomes. For example, a recommendation reading "improve emergency responder safety training" would not meet this test. A more focused approach is needed, such as "revise the emergency responder training program to cover the use of agency supplied keys to open vehicle doors from the outside." Recommendations will then logically link to the corrective action plans.

Effective Investigation Practice

Example of logic flow:

- Fact: Vehicle brakes were not applied before impact.
- Fact: Vehicle speed was 30 mph at impact.
- Fact: Sight distance reconstructions indicate that obstruction at the point of impact was visible from 350 feet.
- Fact: Based on speed, braking deceleration characteristics, and reaction time, the vehicle operator had approximately 8 seconds to detect the obstacle and apply brakes but did not do so.
- Fact: Witnesses and inward-facing video showed the vehicle operator looking downward and manipulating a cellphone.
- Analysis/Conclusion: Had the operator been alert and looking forward, the obstruction could have been detected, and the vehicle stopped short of the collision.
- Probable Cause: Operator distraction resulting from use of a cellphone for texting.
- Contributing factors would lay out relevant issues such as training and management oversight that were explained in the analysis.

Corrective Action Plans

Once an agency has a good understanding of the causal and contributing factors driving the agency's undesired events, it is better prepared to formulate and implement CAPs. The agency may consider establishing safety performance targets and safety performance indicators to measure and monitor the effectiveness of CAPs to ensure they are achieving their intended outcomes. Also, focusing on the effectiveness of the CAP is beneficial, as it shifts the agency's attention away from how many CAPs are "open" vs. "closed" and forces senior management to concentrate on measuring performance, i.e. is this activity improving safety? If not, then the CAP must be sent back through the SRM process and adjustments made to improve performance.

Effective corrective actions are linked to specific recommendations and developed in a way that is achievable and measurable. Such as any action plan, a CAP must explain the action being taken (what), the reason (why), the person responsible for making it happen (who), and a realistic schedule (when). Without these key elements, any action plan is likely to fail.

Key CAP Elements	
What	What are the specific actions and measurable results?
Why	Links back to accident investigation and recommendation.
Who	Who (job title) is responsible for shepherding the action to completion?
When	Identify a realistic time frame and set a date.

A CAP may be developed by the department that owns (is responsible for implementation) the CAP item in conjunction with the investigators (usually the Safety Department).

Most agencies use a CAP database or spreadsheet as a tracking tool and to provide periodic reports on CAP status. Effective systems are easy to use and allow generating reports on current status. Additionally, the CAPs can be monitored through regular status meetings, where problems can be identified and resolved. This also allows for the identification and resolution of unintended consequences.

Some agencies have found color-coding the CAP items is helpful, with green meaning satisfactory progress, yellow meaning falling behind schedule, and red meaning a risk of not meeting schedule. This can also serve as motivation for responsible managers to stay on task.

The CAP puts the action verb into an actual implementation plan—how it will be done, who will be responsible for doing it, and when it will be completed. Complex CAPS may have interim milestones and multiple tasks under the control of different personnel.

The responsible manager will report that the CAP item has been

Effective Investigation Practice

Example of Washington Metrorail Safety Commission (WMSC) required CAP elements include:

- Date CAP was generated
- Unique CAP identifier
- Source
- Description
- Hazard rating
- Estimated cost and funding strategy, if known
- Interim mitigations in place (if applicable)
- Anticipated completion date
- Responsible party/department

completed. Before closure, the CAP item's satisfactory completion must be verified, and appropriate signoffs documented.

Continuous Improvement

A transit agency may ask the following questions when examining its overall safety performance and how well its SMS is working s: Are we getting the safety performance that is outlined in our safety objectives? Is our SMS process adequate and being followed? The answers to these questions support SMS continuous improvement.

Continuous Improvement[56] is a process by which a transit agency examines safety performance to identify safety deficiencies and conducts a plan, under the direction of the Accountable Executive, to address identified safety deficiencies. Evaluating the established SMS is necessary to ensure that it effectively and efficiently allows the agency to meet safety objectives and performance targets. Continuous improvement activities may include annual reviews of overall safety performance and assist transit agencies in identifying weaknesses in SMS organizational structures, processes, and resources to promptly address.

Continuous improvement occurs from:

- Timely safety information that enables executives to make informed decisions about allocating resources
- Accountability being placed at the appropriate levels of authority
- The ability to actively identify hazards and mitigate safety risks based on the prioritized allocation of resources
- Support for system-wide communication about safety issues; up, down, and across the agency
- An improved safety culture that empowers employees and solicits information from them on safety hazards and concerns

Continuous improvement is an auditing function that allows the agency to:

- Assess the effectiveness of the SMS to determine if it was performing as intended
- Assess adherence to the agency's written and intended SMS policy, procedures, and processes
- Identify the causes of sub-standard performance
- Develop CAPs to address sub-standard performance

[56] FTA, *SMS Safety Assurance Participant Guide*, v12_09282018.

CAPs are instituted when the SMS, or any part of it, is not being performed correctly. Hazards are not being identified, or no one is doing anything once the hazard is identified, or agencies are not following through on implementation activities or even data collection. These are signs that something in the SMS is not working right.

Continuous improvement tools and activities include conducting self-assessments, audits, gap analysis, and external reviews. The results of continuous improvement activities may include identification of breakdowns and disconnects, such as practical drift and correct the process at the level where it is deficient (frontline, department level, or at the broader organizational level).

Even when fully implemented, the continuous improvement sub-component of SMS is always relevant, year after year, and always improving to meet the needs of the agency. The transit industry is never static, personnel, equipment, technology, routes, and the operating environment change constantly. Therefore, SMS will continuously change, adapt, and be refined, evolving as necessary to meet organizational changes and objectives.

This evolution of the SMS is a primary goal of continuous improvement—ensuring that formal activities and tools are in place to regularly verify efficiency, effectiveness, and ongoing improvements in the management of safety.

Transit agencies can benefit from scrutiny by external parties, such as an APTA peer review team. Performing these activities proactively identifies vulnerabilities in the agency's defenses. As such, a transit agency will want to thoroughly evaluate the recommendations provided by these entities and, if adopted, monitor as a CAP and track to closure. A case study APTA Peer Review is provided below.

Case Study: Best Practice for Continuous Improvement, APTA Peer Review

The following case study demonstrates how transit agencies can use contracted resources to develop a fuller understanding of technical issues that may play a role in an accident and help to identify root cause(s) and other contributing factors that result in incidents, as well as develop proactive measures to reduce risk.

APTA provides peer review services to its members through its owned subsidiary, North American Transit Services Association (NATSA). At the request of the agency, NATSA brings a team of industry experts to the property to review a selected area, i.e., operations, security, or safety conditions and provides the property with a written report containing observations, conclusions, and recommendations.

This case involves an APTA peer review of bus operator assaults on the WMATA system. Individual assaults are criminal events and fall under law enforcement. This case study was chosen because 1) the prevention of assaults on transit agency employees is one of the industry's highest priorities, and 2) it demonstrates how transit agencies can use a process available to them to investigate an issue of concern and leverage industry resources to improve mitigation strategies.

Peer Review

The peer review scope was to examine the best industry practices for preventing and mitigating passenger assaults of transit employees with a specific focus on bus operators and station managers. The peer-review methodology involved examining industry studies, surveys, reports, and best practices; evaluating current WMATA practices; conducting stakeholder interviews; and issuing recommendations for the agency. APTA provided an overview of the report, APTA Peer Review—Bus Operator Assaults, to the WMATA Board on January 11, 2018.

The Peer Team comprised individuals with extensive experience in transit security:

- Facilitator—Director of Security, Emergency and Risk Management, APTA \
- Assistant Director of Bus Services, Miami-Dade Transit
- Chief, King County Metro Transit Police
- Deputy General Manager Bus Administration, NJ Transit
- Director of Operations and Standards, APTA

The peer review team's activities were not intended to be an investigation into the specifics of any one event, but rather an overview of the adequacy and effectiveness of the agency's strategies to prevent and deter transit employee assaults.

The following information details some of the key activities performed by the agency, as well as the observations and recommendations from the peer review team. This discussion is not intended to present an exhaustive description of all aspects of the peer review.

General Observations

The peer-review identified several effective strategies that WMATA had initiated, including the following:

- Shields in more than one-third of the current fleet with a commitment to outfitting the entire fleet
- Video surveillance on entire bus fleet
- Installation of Drive-Cam

- CCTV monitor system on some buses now and to be installed on all new buses
- AVL
- Annunciator message quoting fare
- Silent emergency alarm system
- “Call Police” message on destination sign
- Robust training program designed to instruct de-escalation techniques
- Campaign that humanizes bus operators
- “Respect Your Ride” initiative
- Offering and encouraging employee assault victims EAP assistance
- Robust data collection and analysis to guide strategies

Selected Key Conclusions from Peer Review

- Barriers (shields) between operators and the public is an emerging best practice.
- Assigning protection-equipped buses on assault-prone routes statistically is a good practice.
- Specific assault-reduction strategies that have proved to be effective:
  - Public awareness campaigns/outreach
  - Posting laws and passenger codes of conduct
  - Police presence
  - Service suspension policies
  - Enhanced penalties

Summary of Peer Review Recommendations

- WMATA should continue to examine emerging shield technology.
- Prioritize assault reduction training to those at highest risk.
- Control center personnel should receive training on supporting employees who were assaulted.
- Develop assault response training for supervisors.
- Solicit input from unions in training development.
- Develop “scripts” for responses to specific passenger inquiries.
- Conduct a resource allocation analysis of police personnel available for deployment.
- Develop a service suspension mechanism of assault perpetrators.
- Explore expectorant collection for DNA processing to support a prosecution.
- Pilot a process for company representatives to accompany assault victims to court.

- Develop an assault response SOP.
- Hold after-action reviews of assaults with operations, police, and control center.
- Evaluate control center staffing levels when assaults occur.
- Assess current training material on the use of silent alarm and Priority Request to Talk (PRTT) features.

Transit agencies can benefit from scrutiny by external parties, such as an APTA peer review team. Performing these activities proactively identifies vulnerabilities in the agency's defenses. As such, agencies will want to thoroughly review the recommendations provided by these entities and, if adopted, monitor as a CAP and track to closure.

State of Good Repair and Transit Asset Management

SGR and TAM are both integral to SMS and are mandated through Federal transit law. The text of the Public Transportation Safety Act of 2010 was incorporated into both the TAM and safety provisions of the Moving Ahead for Progress in the 21st Century Act (MAP–21), see §3638, 111th Congress (2010). In the report accompanying that Act, Congress stated that "state of good repair directly relates to the safety of a public transportation system, as the likelihood of accidents increases as the condition of equipment and infrastructure worsens'' (§112–232 at 10 (2010)). The requirements proposed under the Act were intended to establish a ''monitoring system for the safety and condition of the nation's public transportation assets.''

Several transit rail accidents have been attributed to inadequate SGR of assets.[57] SGR is defined as the condition in which a capital asset[58] can operate at a full level of performance. When transit assets are not in an SGR, the consequences include increased safety risks, decreased system reliability, higher maintenance costs, and lower system performance.

On July 26, 2016, FTA published a final rule, codified at 49 CFR 625, Transit Asset Management, that required public transportation providers to develop and implement TAM plans and establish minimum Federal requirements for TAM. A TAM plan must include an asset inventory, condition assessments of inventoried assets, and a prioritized list of investments to improve the SGR of their capital assets. Furthermore, the final rule also established SGR standards and four SGR performance measures, further discussed below.

[57] For example, WMATA, L'Enfant Plaza Station Electrical Arcing and Smoke Accident, Washington, DC, January 12, 2015, NTSB Accident Report NTSB/RAR-16/01 PB2016-103217; Railroad Accident Brief: Angels Flight Railway Derailment, Los Angeles, CA, September 5, 2013, NTSB Accident DCA13FR011; Railroad Accident Brief: Collision of Two Chicago Transit Authority Trains, Forest Park, IL, September 30, 2013, NTSB Accident DCA13FR014.

[58] Capital assets principally include equipment, rolling stock, infrastructure, and facilities.

Specifically, TAM denotes the strategic and systematic practice of procuring, operating, inspecting, maintaining, rehabilitating, and replacing transit capital assets to manage performance, risks, and costs over their life cycles to provide safe, cost-effective, and reliable public transportation. TAM is a business model that prioritizes funding based on the condition of transit assets to achieve and maintain an SGR for the nation's public transportation assets. It establishes a framework for transit agencies to monitor and manage public transportation assets, improve safety, increase reliability and performance, and establish performance measures in order to help agencies keep their systems operating smoothly and efficiently.

Key Components of a TAM

The following comprise the performance measures of a TAM. A TAM plan is a plan that includes an inventory of capital assets, a condition assessment of inventoried assets, a decision support tool,[59] and a prioritization of investments. Specifically, a TAM plan is a tool that can aid transit providers in:

- Assessing the current condition of its capital assets
- Determining what the condition and performance of its assets should be (if they are not already in an SGR)
- Identifying the unacceptable risks, including safety risks, in continuing to use an asset that is not in an SGR
- Deciding how to best balance and prioritize anticipated funds (revenues from all sources) towards improving asset conditions and achieving a sufficient level of performance within those means

A TAM policy is a transit provider's documented commitment to achieving and maintaining an SGR for all of its capital assets. The TAM policy defines the transit provider's TAM objectives and defines and assigns roles and responsibilities for meeting those objectives. A TAM strategy is the approach a transit provider takes to conduct its policy for TAM, including its objectives and performance targets. A TAM system is a strategic and systematic process of operating, maintaining, and improving public transportation capital assets effectively throughout the life cycles of those assets.

[59] "Decision support tool" refers to an analytic process or methodology to help prioritize projects to improve and maintain the SGR of capital assets within a public transportation system, based on available condition data and objective criteria, or to assess financial needs for asset investments over time.

Section 4

Safety Promotion

Safety Promotion is the fourth component of SMS. A transit agency must establish a comprehensive safety training program for all agency employees and contractors directly responsible for the management of safety in the agency's public transit system. The training program should include refresher training, as necessary. Board member training or training for others involved in approving or overseeing the PTASP may also be considered.

Competencies and Training

In addition to specifying training requirements, transit agencies may choose to define necessary competencies, including knowledge, skills, and abilities required to perform various positions. A training needs assessment can help assist transit agencies on what employees need to succeed. A competency:

- Groups together the knowledge, skills, and abilities required to fulfill job roles effectively
- May cross various job roles and functions
- May be useful as an employee training topic
- Can be developed from a variety of sources

Transit agencies may find that SMS training is most effective when focused on the specific activities an individual must perform to manage safety. For example, frontline employee SMS training will focus on how to report safety conditions rather than just general SMS concepts.

Safety Communication

A transit agency must communicate safety and safety performance information throughout the agency's organization that, at a minimum, conveys information on hazards and safety risks relevant to employees' roles and responsibilities and informs employees of safety actions taken in response to reports submitted through an employee safety reporting program. Transit agencies may choose to consider what and how to communicate safety information. Relevant questions include, but are not limited to:

- What information does this individual need to do their job?
- How can we ensure they understand what is communicated?
- How can we ensure they understand what action they must take as a result of the information?
- How can we ensure the information is accurate and kept up to date?
- Are there any privacy or security concerns to consider when sharing information? If so, what can we do to address these concerns?

Numerous methods can be used for safety communication. For example:

- Providing contact information for facility safety committee members
- Creating and communicating a safety “topic of the month”
- Establishing employee recognition programs
- Posting SMS material on safety bulletin boards
- Posting information regarding employee reporting systems
- Posting “Safety Campaign” information
- Posting safety performance objectives, safety performance targets, and safety performance indicators

Appendix A Hazard Analysis Form

OHA Form[60]

System:			OPERATING HAZARD ANALYSIS (OHA)			Sheet	Of	
Subsystem:						Prepared by:	Date:	
Drawing No:						Reviewed by:	Date:	
OHA No:		Rev. No:				Approved by:	Date:	
General Description			Hazard Cause/Effect		Hazard Risk Index (Initial)	Corrective Action		Hazard Risk Index (Final)
Task Description	Hazard Description	Probability of Occurrence	Potential Cause	Effect on Personnel/Subsystem/System		Possible Controlling Measures and Remarks	Resolution	

Figure A-1 *Sample OHA Form*

OHA Form Instructions

- In the “Task Description” column, describe the task being performed.
- In the “Hazard Description” column, describe a human act of commission or omission, error, or fault condition that could lead to an accident involving potential injury, death, or equipment damage.
- In the “Probability of Occurrence” column, enter the probability of occurrence of the error or fault condition, measured in events per million hours of operations. Give data sources, such as experience and statistics in similar applications, human factor studies.
- In the “Potential Cause” column, enter the most likely primary and secondary causes of a hazard, including those induced by hardware, software, procedures, and the environment, which can potentially contribute to the presence of the hazard.

[62] U.S. DOT, Federal Transit Administration, *Hazard Analysis Guidelines for Transit Projects*, Washington, DC, January 2000.

- In the “Effect on Personnel/Subsystem/System” column, describe the effect that the human error or fault condition may have on personnel, patrons, the public, equipment, facilities, and the entire system, in terms of system safety and operational impact (e.g., delay, inconvenience, injury, damage, fatality)
- In the “Hazard Risk Index” column, enter a combination of the qualitative measures of the worst potential consequence resulting from the hazard, and its probability of occurrence (e.g., IA, IIB).
- In the “Possible Controlling Measures and Remarks” column, describe actions that can be taken or procedural changes that can be made to prevent the anticipated hazardous event from occurring. Enter the name(s) of related analysis and reference number(s) and which approach is being proposed: Design Change, Procedures, Special Training.
- In the “Resolution” column, describe changes made or steps taken relative to design and procedures, training, to eliminate or control the hazard.

System: TRAIN SIGNAL SYSTEM	**OPERATING HAZARD ANALYSIS (OHA)**	**Sheet**	**Of**
Subsystem: PREVENTIVE MAINTENANCE PROCEDURE Wayside Signal Equipment		**Prepared by:**	**Date:**
Drawing No:		**Reviewed by:**	**Date:**
OHA No: **Rev. No:**		**Approved by:**	**Date:**

General Description			Hazard Cause/Effect		Hazard Risk Index (Initial)	Corrective Action		Hazard Risk Index (Final)
Task Description	**Hazard Description**	**Probability of Occurrence**	**Potential Cause**	**Effect on Personnel/Subsystem/System**		**Possible Controlling Measures and Remarks**	**Resolution**	
NOTIFY OPERATIONS CONTROL CENTER (OCC) OF THE ACTIVITY TO BE PERFORMED	FAILURE TO NOTIFY MAY RESULT IN WORKER BEING STRUCK BY TRAIN	1×10^{-6}	HUMAN ERROR	POSSIBLE INJURY TO MAINTENANCE WORKER	IIIC	INSURE THAT THE MAINTENANCE PROCEDURE REQUIRES NOTIFICATION TO OCC PRIOR TO STARTING WORK ACTIVITY	PROCEDURE CORRECTED ON (10/15/2015)	IIID
INSPECT SIGNAL EQUIPMENT FOR DAMAGE, RUSTED, LOOSE, BROKEN OR MISSING COMPONENTS	SIGNAL EQUIPMENT MAY FAIL OR THE MAINTENANCE WORKER MAY BE ELECTROCUTED	1×10^{-6}	IMPROPER MAINTENANCE VANDALISM	ELECTROCUTION OF MAINTENANCE WORK FAILURE OF THE SIGNAL SYSTEM	IIIC	MODIFY PROCEDURE TO INSURE MAINTENANCE PERSONNEL UTILIZE APPROPRIATE PPE	PROCEDURE CORRECTED ON (10/15/2015)	IIID
INSPECT TWC COMMUNICATION EQUIPMENT AND HARDWARE FOR DEFECTIVE INSULATION, RUST OR DAMAGE	SIGNAL EQUIPMENT MAY FAIL OR THE MAINTENANCE WORKER MAY BE ELECTROCUTED	1×10^{-6}	IMPROPER MAINTENANCE VANDALISM	ELECTROCUTION OF MAINTENANCE WORK FAILURE OF THE SIGNAL SYSTEM	IID	MODIFY PROCEDURE TO INSURE MAINTENANCE PERSONNEL UTILIZE APPROPRIATE PPE	PROCEDURE CORRECTED ON (10/15/2015)	IIID

Figure A-2 *Sample Completed OHA Form*

FMEA Form

System: Subsystem: Drawing No. FMEA No. Rev. No.			Failure Modes and Effects Analysis (FMEA)			Sheet 1 of 1 Date: Prepared by: Reviewed by: Approved by:	
General Description			**Hazard Cause/Effect**			**Corrective Action**	
LRU No. & Description	***Failure Mode***	***Cause of Failure***	***Effect of Failure on Subsystem System***	***Probability of Occurrence***	***Severity of Occurrence***	***Possible Controlling Measures and Remarks***	***Resolution***

Figure A-3 *Sample FMEA Form*

FMEA Form Instructions[61]

- In the "Line Replaceable Units" column, enter assemblies, parts, and components addressed within each subsystem and system "No. & Description" assign a number to each Line Replaceable Unit (LRU) and briefly describe the characteristics of the LRUs.
- In the "Failure Mode" column, describe an immediate failure mode or fault condition, which could lead to an accident involving potential injury, death, or equipment damage.
- In the "Cause of Failure" column, enter the primary and secondary causes that can potentially contribute to the presence of the hazard.
- In the "Effect of Failure on Subsystem/System" column, describe the effect that the failure mode of fault condition may have on the item and the next higher level, i.e., subsystem or system element in terms of inputs and outputs, and terms of system safety and operational impact (e.g., delay, inconvenience, injury, damage, fatality).
- In the "Probability of Occurrence" column, enter the probability of occurrence of the failure mode or fault condition, measured in events per million hours of operation. Give data sources, such as experience in similar applications.
- In the "Severity of Occurrence" column, enter the potential impact of a fault condition or failure mode on system operation (catastrophic, critical to insignificant).

[61] U.S. DOT, Federal Transit Administration, *Hazard Analysis Guidelines for Transit Projects*, Washington, DC, January 2000.

- In the "Possible Controlling Measures and Remarks" column, describe actions that can be taken or procedural changes that can be made to prevent the anticipated hazardous event from occurring. Enter the name(s) of related analysis and reference number(s) and which approach is being proposed: design change, procedures, specialized training.
- In the "Resolution" column, describe changes made or steps taken relative to design and procedures, training, to eliminate, mitigate or control the hazard.

Qualitative Safety Risk Evaluation Worksheets and Exercise

The worksheets on the following pages were developed by the ASSP Risk Assessment Certification Program Committee. The tables and worksheets are presented as a guide for those who might want to use the qualitative safety risk evaluation process.

The Semi-Quantitative Safety Risk Evaluation method assigns a percent reduction of safety risk based on the order of precedence of risk reduction. These percent reductions were developed by the ASSP Risk Assessment Certification Program Committee.

Table A-1 *Hierarchy of Controls*

Protective Measure	Examples	Mitigation Reduction Factors	
(Control)		***Reduction and Risk Factor***	***Example***
Avoidance / Elimination	Design a task, step, equipment, material, or tool to be eliminated before it is put into production or use.	Severity and exposure reduction	
	Eliminate human interaction.	100%	Elimination (e.g., human interaction) may also eliminate exposure; re-do the Risk Assessment based on the new task.
	Replace/eliminate a reaction step.		
	Eliminate pinch points (increase clearance).		
Substitution (Severity)	Automated materials handling (robots, conveyors) to reduce significantly human interaction.	Severity reduction only	
	Replace with a less toxic compound.	90% Substitution with little or no hazard	E.g., replace oil with water, replace lifting 75 lbs with 5 lbs.
	Significantly reduce speed, noise, weight (energy).		
		80% Substitution with something that still has some hazards	E.g., replace flammable with no-combustible, replace lifting 75 lbs. with 20 lbs. Automation: e.g., automated material handling where humans have been removed except for upset conditions.

[62] See www.assp.org.

Protective Measure	Examples	Mitigation Reduction Factors	
(Control)		*Reduction and Risk Factor*	*Example*
Engineering (Severity Only)	Barriers	Likelihood reduction only	
	Interlocks	70% Isolation and or guards with interlocks	E.g., engineering controls such as guards that also have interlocks
	Presence Sensing Devices (light curtains, safety mats)		
	Fixed machine guards, Emergency stops.	60% = engineering control redundancy or multiple engineering controls	E.g., two-hand controls plus light curtains
	Pressure relief valves, energy isolation valves		
	Non-skid floor coatings	50% = single engineering control	E.g., two-hand control, light curtain, physical barrier
	Local exhaust ventilation, containerization.		
	Two-hand controls	40% = engineering controls that require admin intervention to initiate	E.g., LOTO, where a physical device such as a lock requires human intervention to initiate.
Administrative (Training, Procedures, Warnings and Awareness Means) Likelihood only	Safe work procedures	Likelihood reduction only	
	Safety inspections		
	Training	30% = Training, plus warnings, signs, plus inspections/ observations	E.g., training, plus inspection to verify that controls are being practiced, plus at least one other
	Lights, beacons, and strobes		
	Computer warnings	20% = Training, plus warnings, signs	E.g., if there is a warning light, operators need to be trained to be aware of what it means.
	Worker rotation		
	Alarms (gas meter, fire)		
	Barrier tape, tags, floor markings		
	Signs and Labels		
	Beepers, horns, and sirens		
	Buddy systems, attendants, observers, supervision, schedule limits.		
Personal Protective Equipment (PPE)	Earplugs, gloves, respirators.	Likelihood reduction only	
	Safety glasses, face shields.	10% = Multiple PPE	Multiple PPE must be for the same hazard. e.g., gloves and arm guards
		5% = Single PPE	Must be specific to the hazard

From ANSI B11.0 2010

Subject: Servicing Bus Tires and Wheels

From the information on the worksheet (Figure A-4)—Operation, Job/Task Assessed, and Job/Task Description—three hazards from the Job/Task description were selected as an example. The worksheets have been previously completed to guide the reader.

PERFORMED BY:		**DATE:**	
SITE:	Changing Bus Tires	**OPERATION:**	Servicing bus rim wheels
JOB/TASK ASSESSED:	Veteran bus tire changers do not see the need for procedures for servicing bus rim wheels because they believe OSHA standards only apply to multi-piece rims, which are not used on buses.		
JOB/TASK DESCRIPTION: (include the basis for severity, occurrence, exposure, and existing controls)	Inexperienced employees receive on-the-job training from veteran employees who service bus tire rim wheels. Work is performed five days per week, eight hours per day. Existing Controls: None		

Figure A-4 *Job/Task Assessment Worksheet*

Table A-2 *Hazard Identification Worksheet*
(Refer to other worksheets for hazards and consequences)

Hazard Category	Hazard Aspect	Energy Source	Trigger Event(s)	Consequence Severity	
				*Actual**	*Worst Case*
Unwanted Energy	Sudden depressurization of a tire and explosive separation	Air pressure	Breaking or slipping of a tire bead	3	4
Mechanical	Propelled separated tire parts	Explosive separation of a tire	Pieces of tire propelled by explosive separation of a tire	3	4
Human Error	Communication and experience	Air pressure	Inadequate training	3	4

** If 3–5 years of reliable data are available pertaining to the severity of the consequence, the actual severity could be used rather than worst-case severity.*

The following completed worksheets (Figures A-5, A-6, A-7) are based on the hazards listed in the Hazard Identification Worksheet. For the Likelihood (b) calculation on the Risk Analysis Worksheet, occurrence (y), as agency data are collected and accumulated, the occurrence element of the likelihood will play an increasingly more significant role in the determination of likelihood Although there might be an exposure pathway, the data might indicate that a specific consequence is not occurring at the agency. Use the Hierarchy of Controls table to complete sections 2 and 4 (controls) of the Hazard Analysis worksheets.

RISK ANALYSIS WORKSHEET # 1
**Tip: use the information from Page 1 and the Hierarchy of Control, Risk Matrix, and the Risk Reduction Calculation Worksheets to complete this page.*

HAZARD #1: Sudden depressurization of a tire and explosive separation

CONSEQUENCE (a) *(severity)*	**LIKELIHOOD (b)** Likelihood = Average of Exposure (x) and Occurrence (y) For FSI, Likelihood = Highest of either x or y		**INITIAL RISK (c)** *(product of consequence (a) and Likelihood (b))*
	Exposure (x)	**Occurrence (y)**	
☒ Catastrophic (Cat) 4 ☐ Critical 3 ☐ Marginal 2 ☐ Negligible 1	☒ Frequent 5 ☐ Probable 4 ☐ Occasional 3 ☐ Remote 2 ☐ Improbable 1	☐ Frequent 5 ☒ Probable 4 ☐ Occasional 3 ☐ Remote 2 ☐ improbable 1	☒ High (>11) Unacceptable ☐ Serious (7-11) Undesirable ☐ Medium (>3 and <7) Acceptable w/review ☐ Low (<=3) Acceptable
	Likelihood Average = 5 – Fatality/Serious Injury (FSI)		Risk Number = 20

EXISTING CONTROL(S)	**DESCRIBE EXISTING CONTROL(S)**
☐ Substitution	
☐ Engineering	
☐ Administrative / Training	
☐ PPE	

(1) INITIAL RISK *(from above)*	**(2) CONTROLS** (I) Substitution	(II) Engineering	(III) Admin	(IV) PPE	**(3) EXISTING RISK** *(from Risk Reduction Calculation Worksheet)*
(a) Consequence = 4 (b) Likelihood = 5 (c) Risk = 20	☐ 90% ☐ 80%	☐ 70% ☐ 60% ☐ 50% ☐ 40%	☐ 30% ☐ 20%	☐ 10% ☐ 5%	(a) Consequence = 4 (b) Likelihood = 5 (c) Risk = 20
Is the risk acceptable?	☐ Yes ☒ No				

ADDITIONAL MITIGATING CONTROL(S) *(include any existing controls remaining)*	**DESCRIBE MITIGATION STRATEGY** *(include any existing controls remaining)*
☐ Avoidance/elimination	
☐ Substitution	
☒ Engineering	Use of a tire changing machine, a restraining device, barrier, or securely bolted on the vehicle with lug nuts fully tightened
☒ Administrative / Training	Hazard Communication Training, Development of procedures to service tires consistent with OSHA requirements and training on procedures.
☒ PPE	Eye, face, and hand protection
☐ None	

(1) INITIAL RISK *(from above)*	**(4) CONTROLS** (I) Substitution	(II) Engineering	(III) Admin	(IV) PPE	**(5) RESIDUAL RISK** *(from Risk Reduction Calculation Worksheet)*
(a) Consequence = 4 (b) Likelihood = 5 (c) Risk = 20	☐ 90% ☐ 80%	☒ 70% ☐ 60% ☐ 50% ☐ 40%	☒ 30% ☐ 20%	☒ 10% ☐ 5%	(a) Consequence =4 (b) Likelihood = 0.945 (c) Risk = 3.78
Critical to safety?	☒ Yes* ☐ No **If Yes, ensure layered controls & continuous monitoring processes are in place*				
Is the risk acceptable?	☐ Yes ☒ No** *** If No, decide on treatment priority* ***FSI: Therefore, the risk remains unacceptable. Strictly monitor implementation and effectiveness of mitigation.**				

* ***NOTE:** If the consequence is either a fatality/serious injury (FSI) and the consequence cannot be eliminated by design or substitution, then the safety risk remains unacceptable because there is a human factor in each of the applied mitigations. Strictly monitor implementation and effectiveness of mitigation.*

Figure A-5 *Risk Analysis Worksheet #1*

RISK ANALYSIS WORKSHEET # 2
**Tip: use the information from Page 1 and the Hierarchy of Control, Risk Matrix, and the Risk Reduction Calculation Worksheets to complete this page.*

HAZARD #2: Mechanical – Propelled separated tire parts

CONSEQUENCE (a) *(severity)*		**LIKELIHOOD (b)** Likelihood = Average of Exposure (x) and Occurrence (y) For FSI, Likelihood = Highest of either x or y — **Exposure (x)**		**Occurrence (y)**		**INITIAL RISK (c)** *(product of consequence (a) and Likelihood (b))*	
☒ Catastrophic (Cat)	4	☒ Frequent	5	☐ Frequent	5	☒ High (>11)	Unacceptable
☐ Critical	3	☐ Probable	4	☐ Probable	4	☐ Serious (7-11)	Undesirable
☐ Marginal	2	☐ Occasional	3	☒ Occasional	3	☐ Medium (>3 and <7)	Acceptable w/review
☐ Negligible	1	☐ Remote	2	☐ Remote	2	☐ Low (<=3)	Acceptable
		☐ Improbable	1	☐ Improbable	1		
		Likelihood Average = 5 (FSI)				Risk Number(a) X (b) = 20	

EXISTING CONTROL(S)	**DESCRIBE EXISTING CONTROL(S)**
☐ Substitution	
☐ Engineering	
☐ Administrative / Training	
☐ PPE	

(1) INITIAL RISK *(from above)*	**(2) CONTROLS** (I) Substitution	(II) Engineering	(III) Admin	(IV) PPE	**(3) EXISTING RISK** *(from Risk Reduction Calculation Worksheet)*
(a) Consequence = 4 (b) Likelihood = 5 (c) Risk = 20	☐ 90% ☐ 80%	☐ 70% ☐ 60% ☐ 50% ☐ 40%	☐ 30% ☐ 20%	☐ 10% ☐ 5%	(a) Consequence = 4 (b) Likelihood = 5 (c) Risk = 20.0
Is the risk acceptable?	☐ Yes ☒ No				

ADDITIONAL MITIGATING CONTROL(S) *(include any existing controls remaining)*	**DESCRIBE MITIGATION STRATEGY** *(include any existing controls remaining)*
☐ Avoidance/elimination	
☐ Substitution	
☒ Engineering	Use of a tire changing machine, a restraining device, barrier, or securely bolted on the vehicle with lug nuts fully tightened
☒ Administrative / Training	Hazard Communication Training, Development of procedures to service tires consistent with OSHA requirements and training on procedures.
☒ PPE	Eye, face, and hand protection
☐ None	

(1) INITIAL RISK *(from above)*	**(4) CONTROLS** (I) Substitution	(II) Engineering	(III) Admin	(IV) PPE	**(5) RESIDUAL RISK** *(from Risk Reduction Calculation Worksheet)*
(a) Consequence = 4 (b) Likelihood = 5 (c) Risk = 20	☐ 90% ☐ 80%	☒ 70% ☐ 60% ☐ 50% ☐ 40%	☒ 30% ☐ 20%	☒ 10% ☐ 5%	(a) Consequence = 4 (b) Likelihood = 0.945 (c) Risk = 3.78
Critical to safety?	☒ Yes* ☐ No **If Yes, ensure layered controls & continuous monitoring processes are in place*				
Is the risk acceptable?	☐ Yes ☒ No** *** If No, decide on treatment priority* ***FSI: Therefore, the risk remains unacceptable. Strictly monitor implementation and effectiveness of mitigation.** **** NOTE: If the consequence is either a serious injury or a fatality and the consequence cannot be eliminated by design or substitution, then the safety risk remains unacceptable because there is a human factor in each of the applied mitigations. Strictly monitor implementation and effectiveness of mitigation.***				

Figure A-6 *Risk Analysis Worksheet #2*

RISK ANALYSIS WORKSHEET # 3
**Tip: use the information from Page 1 and the Hierarchy of Control, Risk Matrix, and the Risk Reduction Calculation Worksheets to complete this page.*

HAZARD #3: Human Error

CONSEQUENCE (a) *(severity)*	**LIKELIHOOD (b)** Likelihood = Average of Exposure (x) and Occurrence (y) For FSI, Likelihood = Highest of either x or y		**INITIAL RISK (c)** *(product of consequence (a) and Likelihood (b))*	
	Exposure (x)	**Occurrence (y)**		
☒ Catastrophic (Cat) 4 ☐ Critical 3 ☐ Marginal 2 ☐ Negligible 1	☒ Frequent 5 ☐ Probable 4 ☐ Occasional 3 ☐ Remote 2 ☐ Improbable 1	☐ Frequent 5 ☐ Probable 4 ☒ Occasional 3 ☐ Remote 2 ☐ Improbable 1	☒ High (>11) ☐ Serious (7-11) ☐ Medium (>3 and <7) ☐ Low (<=3)	Unacceptable Undesirable Acceptable w/review Acceptable
	Likelihood Average = 4 (FSI) (Ignore Occurrence [Y]		Risk Number(a)X(b) = 20	

EXISTING CONTROL(S)	**DESCRIBE EXISTING CONTROL(S)**
☐ Substitution	
☐ Engineering	
☐ Administrative / Training	
☐ PPE	

(1) INITIAL RISK *(from above)*	**(2) CONTROLS** (I) Substitution	(II) Engineering	(III) Admin	(IV) PPE	**(3) EXISTING RISK** *(from Risk Reduction Calculation Worksheet)*
(a) Consequence = 4 (b) Likelihood = 5 (c) Risk = 20	☐ 90% ☐ 80%	☐ 70% ☐ 60% ☐ 50% ☐ 40%	☐ 30% ☐ 20%	☐ 10% ☐ 5%	(a) Consequence = 4 (b) Likelihood = 5 (c) Risk = 20
Is the risk acceptable?	☐ Yes ☒ No				

ADDITIONAL MITIGATING CONTROL(S) *(include any existing controls remaining)*	**DESCRIBE MITIGATION STRATEGY** *(include any existing controls remaining)*
☐ Avoidance/elimination	
☐ Substitution	
☒ Engineering	Use of a tire changing machine, a restraining device, barrier, or securely bolted on the vehicle with lug nuts fully tightened
☒ Administrative / Training	Hazard Communication Training, Development of procedures to service tires consistent with OSHA requirements and training on procedures.
☒ PPE	Eye, face, and hand protection

(1) INITIAL RISK *(from above)*	**(4) CONTROLS** (I) Substitution	(II) Engineering	(III) Admin	(IV) PPE	**(5) RESIDUAL RISK** *(from Risk Reduction Calculation Worksheet)*
(a) Consequence = 4 (b) Likelihood = 5 (c) Risk = 20	☐ 90% ☐ 80%	☒ 70% ☐ 60% ☐ 50% ☐ 40%	☒ 30% ☐ 20%	☒ 10% ☐ 5%	(a) Consequence = 4 (b) Likelihood = 0.76 (c) Risk = 3.04
Critical to safety?	☒ Yes* ☐ No **If Yes, ensure layered controls & continuous monitoring processes are in place*				
Is the risk acceptable?	☐ Yes ☒ No** *** If No, decide on treatment priority* * **FSI: Therefore, the risk remains unacceptable. Strictly monitor implementation and effectiveness of mitigation.** **** NOTE: If the consequence is either a serious injury or a fatality and the consequence cannot be eliminated by design or substitution, then the safety risk remains unacceptable because there is a human factor in each of the applied mitigations. Strictly monitor implementation and effectiveness of mitigation.***				

Figure A-7 *Risk Analysis Worksheet #3*

The following three risk hazard calculation examples are provided to demonstrate the process that an agency may use to calculate initial, existing, and residual risk hazards. When using these examples, you will want to follow these tips/guidelines:

- Work through the steps in order, 1 through 3.
- If the consequence (1a) is Catastrophic, i.e., fatal, or serious injury, apply only the highest of either exposure (x) or occurrence (y) to the likelihood (1b). This is Fatal/Serious Injury (FSI) potential.
- Always apply the more effective control first.
- Carry over the new existing likelihoods from the last box in the row above, to the first box in the row below.
- If there are no existing controls, use the initial risk (1c) to calculate the existing risk (3c).
- Fill in Risk Analysis form using the final calculations; use the corresponding labels (e.g., 1a, 2IV) as a guide.

STEP 1: Calculate Initial Risk Hazard # 1 – Unwanted Energy

(Exposure + Occurrence)/2 = Likelihood
Likelihood x Consequence = Initial Risk

5 (FSI)	(3-Ignore-FSI)		5	5	4	20
(Exposure (x) +	*Occurrence (y) /2*	=	*Likelihood (1b)*	*Likelihood (1b)* ✖	*Consequence (1a)* =	*Initial risk (1c)*

STEP 2: Calculate Existing Risk Hazard # 1

(2-I) Substitution Initial *Consequence – (Initial Consequence x Control Reduction) = New (existing) Consequence*

Initial Consequence (1a) ✖	*Control Reduction (2I)* =	*Reduction (e)*	*Initial Consequence (1a)* –	*Reduction (e)* =	*New existing consequence (3a)*

(2-II) Engineering Initial *Likelihood – (Initial Likelihood x Control Reduction) = New Likelihood*

Initial Likelihood (1b) ✖	*Control Reduction (2II)* =	*Reduction (f)*	*Initial Likelihood (1b)* –	*Reduction (f)* =	*New existing likelihood (3b)*

(2-III) Admin *New Likelihood [unless there were no entries for (2a) and (2b) then use Initial Likelihood] – (Initial Likelihood x Control Reduction) = New Likelihood*

5					5
New Likelihood (3b) ✖	*Control Reduction (2III)* =	*Reduction (g)*	*New Likelihood (3b)* –	*Reduction (g)* =	*New existing likelihood (3b)*

(2-IV) PPE *New Likelihood [unless there were no entries for (2a), (2b), and (2c) then use Initial Likelihood] – (Initial Likelihood x Control Reduction) = New Likelihood*

5					5.0
New Likelihood (3b) ✖	*Control Reduction (2IV)* =	*Reduction (h)*	*New Likelihood (3b)* –	*Reduction (h)* =	*New existing likelihood (3b)*

Existing Risk: New *existing likelihood x New existing consequence = Existing risk*

5	4	20.0
New Existing Likelihood (3b) ✖	*Consequence (3a)* =	*Existing risk (3c)*

RISK REDUCTION CALCULATION WORKSHEET

STEP 3: Calculate Residual Risk Hazard # 1 –Unwanted Energy

*Tips

- Apply from Initial risks
- Calculate Reduction from the entire set of new and existing controls remaining.

(3-I) Substitution *Initial Consequence – (Initial Consequence x Control Reduction) = New (Residual) Consequence*

Existing Consequence (3a) ✖	*Control Reduction (4I)* =	*Reduction (i)*	*Existing Consequence (3a)* –	*Reduction (i)* =	*New residual consequence (5a)*

(3-II) Engineering *Initial Likelihood – (Initial Likelihood x Control Reduction) = New (Residual) Likelihood*

5	70% (0.70)	3.5	5		3.5	1.5
Existing Likelihood ✖	*Control Reduction (2II)* =	*Reduction (j)*	*Existing Likelihood*	–	*Reduction (j)* =	*New residual likelihood*

(3-III) Admin *New residual Likelihood [unless there were no entries for (3a) and (3b) then use Existing Likelihood] – (Initial Likelihood x Control Reduction) = New (Residual) Likelihood*

1.5	30% (0.30)	0.45	1.5	0.45	1.05
New residual Likelihood ✖	*Control Reduction (2III)* =	*Reduction (k)*	*New residual Likelihood* –	*Reduction (k)* =	*New residual likelihood*

(3-IV) PPE *New residual Likelihood [unless there were no entries for (3a), (3b), and (3c), then use Existing Likelihood] – (Initial Likelihood x Control Reduction) = New (Residual) Likelihood*

1.05	10% (0.10)	0.105	1.05	0.105	0.945
New Likelihood (3b) ✖	*Control Reduction (2IV)* =	*Reduction (l)*	*New Likelihood (3b)* –	*Reduction (l)* =	*New residual likelihood (5b)*

Residual Risk- *New residual likelihood x New existing consequence = Residual risk*

0.945	4	3.78
Likelihood (3b) ✖	*Consequence (5a)* =	*Residual risk (5c)*

STEP 1: Calculate Initial Risk Hazard # 2–Mechanical

(Exposure + Occurrence)/2 – Likelihood
Likelihood x Consequence = Initial Risk

5 (FSI)	Ignore because of FSI		5	5	4	20
(Exposure (x) +	*Occurrence (y))*	=	*Likelihood (1b)*	*Likelihood (1b)* x	*Consequence (1a)* =	*Initial risk (1c)*

STEP 2: Calculate Existing Risk Hazard # 2

(2-I) Substitution Initial *Consequence – (Initial Consequence x Control Reduction) = New (existing) Consequence*

Initial Consequence (1a) x	*Control Reduction (2I)* =	*Reduction (e)*	*Initial Consequence (1a)* –	*Reduction (e)* =	*New existing consequence (3a)*

(2-II) Engineering *Initial likelihood – (Initial likelihood x Control Reduction) = New likelihood*

Initial Likelihood (1b) x	*Control Reduction (2II)* =	*Reduction (f)*	*Initial likelihood (1b)* –	*Reduction (f)* =	*New existing likelihood (3b)*

(2-III) Admin *New existing likelihood [unless there were no entries for (2a) and (2b) then use Initial likelihood] – (New Likelihood x Control Reduction) = New existing likelihood*

5					5
New Likelihood (3b) x	*Control Reduction (2III)* =	*Reduction (g)*	*New likelihood (3b)* –	*Reduction (g)* =	*New existing likelihood (3b)*

(2-IV) PPE *New existing likelihood – [unless there were no entries for (2a), (2b), and (2c), then use initial likelihood] (New likelihood x Control Reduction) = New likelihood*

5					
New existing likelihood (3b) x	*Control Reduction (2IV)* =	*Reduction (h)*	*New likelihood (3b)* –	*Reduction (h)* =	*New existing likelihood (3b)*

Existing Risk *New existing likelihood x New existing consequence = Existing risk*

5	4	20.0
Likelihood (3b) x	*Consequence (3a)* =	*Existing risk (3c)*

RISK REDUCTION CALCULATION WORKSHEET

STEP 3: Calculate Residual Risk Hazard # 2 – Mechanical

*Tips

- Apply from Initial risks
- Calculate Reduction from the entire set of new and existing controls remaining.

(3-I) Substitution Initial *Consequence – (Initial Consequence x Control Reduction) = New (Residual) Consequence*

Existing Consequence (3a) ×	*Control Reduction (4I)* =	*Reduction (i)*	*Existing Consequence (3a)* −	*Reduction (i)* =	*New residual consequence (5a)*

(3-II) Engineering Initial *Likelihood – (Initial Likelihood x Control Reduction) = New (Residual) Likelihood*

5	70% (0.70)	3.5	5	3.5	1.5
Existing Likelihood ×	*Control Reduction (2II)* =	*Reduction (j)*	*Existing Likelihood* −	*Reduction (j)* =	*New residual likelihood*

(3-III) Admin New residual *likelihood [unless there were no entries for (3a), and (3b), then use initial likelihood] – (Initial likelihood x Control Reduction) = New (residual) likelihood*

1.5	30% (0.30)	0.45	1.5	0.45	1.05
New residual Likelihood ×	*Control Reduction (2III)* =	*Reduction (k)*	*New residual Likelihood* −	*Reduction (k)* =	*New residual likelihood*

(3-IV) PPE New residual *likelihood [unless there were no entries for (3a), (3b), and (3c), then use initial likelihood] – (Initial likelihood x Control Reduction) = New residual likelihood*

1.05	10% (0.10)	0.105	1.05	0.105	0.945
New Likelihood (3b) ×	*Control Reduction (2IV)* =	*Reduction (l)*	*New Likelihood (3b)* −	*Reduction (l)* =	*New residual likelihood (5b)*

Residual Risk New *residual likelihood x New existing consequence = Residual risk*

0.945	4	3.78
Residual likelihood (3b) ×	*Consequence (5a)* =	*Residual risk (5c)*

STEP 1: Calculate Initial Risk Hazard # 3–Human Error

(Exposure + Occurrence)/2 = Likelihood
Likelihood x Consequence = Initial Risk

5 (FSI)		3		2		4	4		4		20.0
(Exposure (x)	+	*Occurrence (y))*	÷		=	*Likelihood (1b)*	*Likelihood (1b)*	×	*Consequence (1a)*	=	*Initial risk (1c)*

STEP 2: Calculate Existing Risk Hazard # 3

(2-I) Substitution Initial *Consequence – (Initial Consequence x Control Reduction) = New (existing) Consequence*

Initial Consequence (1a)	×	*Control Reduction (2I)*	=	*Reduction (e)*	*Initial Consequence (1a)*	–	*Reduction (e)*	=	*New existing consequence (3a)*

(2-II) Engineering Initial *Likelihood – (Initial Likelihood x Control Reduction) = New Likelihood*

Initial Likelihood (1b)	×	*Control Reduction (2II)*	=	*Reduction (f)*	*Initial Likelihood (1b)*	–	*Reduction (f)*	=	*New existing likelihood (3b)*

(2-III) Admin New *likelihood [unless there were no entries for (2a) and (2b) then use Initial likelihood] – (New Likelihood x Control Reduction) = New Existing Likelihood*

5									5
New Likelihood (3b)	×	*Control Reduction (2III)*	=	*Reduction (g)*	*New Likelihood (3b)*	–	*Reduction (g)*	=	*New existing likelihood (3b)*

(2-IV) PPE *New Likelihood [unless there were no entries for (2a), (2b), or 2(c), then use Initial likelihood] – (New Likelihood x Control Reduction) = New Likelihood*

5									5
New Likelihood (3b)	×	*Control Reduction (2IV)*	=	*Reduction (h)*	*New Likelihood (3b)*	–	*Reduction (h)*	=	*New existing likelihood (3b)*

Existing Risk New *existing likelihood x New existing consequence = Existing risk*

5		4		20
Likelihood (3b)	×	*Consequence (3a)*	=	*Existing risk (3c)*

RISK REDUCTION CALCULATION WORKSHEET

STEP 3: Calculate Residual Risk Hazard # 3–Human Error

*Tips
Apply from Initial risks
Calculate Reduction from the entire set of new and existing controls remaining.

(3-I) Substitution Initial *Consequence – (Initial Consequence x Control Reduction) = New (Residual) Consequence*

Existing Consequence (3a) ×	*Control Reduction (4I)* =	*Reduction (i)*	*Existing Consequence (3a)* −	*Reduction (i)* =	*New residual consequence (5a)*

(3-II) Engineering Initial *Likelihood – (Initial Likelihood x Control Reduction) = New (Residual) Likelihood*

4	70% (0.70)	2.8	4	2.8	1.2
Existing Likelihood ×	*Control Reduction (2II)* =	*Reduction (j)*	*Existing Likelihood* −	*Reduction (j)* =	*New residual likelihood*

(3-III) Admin Initial *Likelihood – (Initial Likelihood x Control Reduction) = New (Residual) Likelihood*

1.2	30% (0.30)	0.36	1.2	0.36	0.84
New residual Likelihood ×	*Control Reduction (2III)* =	*Reduction (k)*	*New residual Likelihood* −	*Reduction (k)* =	*New residual likelihood*

(3-IV) PPE Initial *Likelihood – (Initial Likelihood x Control Reduction) = New (Residual) Likelihood*

0.84	10% (0.1)	0.08	0.84	0.,08	0.76
New Likelihood (3b) ×	*Control Reduction (2IV)* =	*Reduction (l)*	*New Likelihood (3b)* −	*Reduction (l)* =	*New (Residual) likelihood (5b)*

Residual Risk: New *likelihood x existing (new, if applicable) consequence = Residual risk*

0.76	4	3.04
Likelihood (3b) ×	*Consequence (5a)* =	*Residual risk (5c)*

Appendix B

Documenting and Managing the Scene

Chain of Custody

Chain of custody documents the movement and location of evidence and the history of persons and entities who had it in their custody from the time it is obtained until its final disposition.

Evidence Collection/Retention

Investigators must have an evidence control plan along with the appropriate chain of custody forms and containers. For agencies with dedicated transit law enforcement, these resources will have established evidence control procedures and storage rooms that can be of help. Vehicles or larger components such as bus tires need to be preserved and need a secure storage location in a bus depot or other fenced facility, ideally with access control.

Event Recorder/Data Logger/Supervisory Control and Data Acquisition (SCADA)/ Camera System Analysis

Many transit systems have extensive data recording systems that provide invaluable information to the investigator. Data recorders may be installed on vehicles, traffic control devices, grade crossing warning equipment cases, and in the control center. Some transit operations use Automatic Vehicle Locator (AVL) systems that also record historical data. Most transit agencies have camera systems on vehicles, in stations, and in other locations. Private surveillance cameras may be installed at businesses and residences adjacent to the scene. Some agencies use automated driver behavior monitoring/coaching systems that produce valuable data for investigators.

Investigators need to become familiar with the various types of recorders and cameras in place on the system(s) they may be called out to investigate. If a delay in downloading data may result in data loss, the recorder should be downloaded on-scene and documented. Note the time of download against an accurate clock (such as control center time or the time on a cellphone) for later time synchronization. Agencies need to have written protocols in place for the protection, download, analysis, and retention of data generated by such systems.

Investigators need to familiarize themselves with these systems and the protocols for download and analysis. Investigators should practice obtaining information in a low-pressure, non-accident environment. Some systems will require the assistance of technicians to obtain and explain the data. Investigators should get to know these technicians in advance to facilitate analysis when needed.

Forward-facing video from same-day previous trips may be useful and should be ordered in a timely way to avoid losing data. The general rule for electronic data that is at risk of being overwritten is that it is better to have it and not need it than the other way around. Some local traffic departments collect recorded data from field devices and pole-mounted cameras. Investigators should become familiar with what is available and develop points of contact in advance.

Photographs, Videos, Sketches, and Measurements

Investigators should take many photographs and videos. Some investigators wear a "Go Pro" type device, so they are always recording on-scene. It is better to have images and not need them than vice versa. For evidence control purposes, do not delete unwanted images. Video recorders may also capture sound, so investigators should be aware of what is said during shooting.

Make a point to capture things that will change, such as debris location, tire marks, road scars, fluid spills, the operator's controls including switch and breaker positions. Start at a distance and move in closer. If documenting a vehicle, signal case, or other unique component, capture an image of the identification number (e.g., vehicle number, VIN, license plate, signal number) before and after taking the more detailed shots so you can easily link a closeup to the unique item at a later time.

Before collecting small pieces of evidence, photo document the point of rest, orientation, and location relative to the overall scene (Figure B-1). Capture unique identifiers on equipment and components such as serial numbers or model identification. Rail vehicles and maintenance equipment may have stenciling at various locations on (or under) the equipment that should be captured.

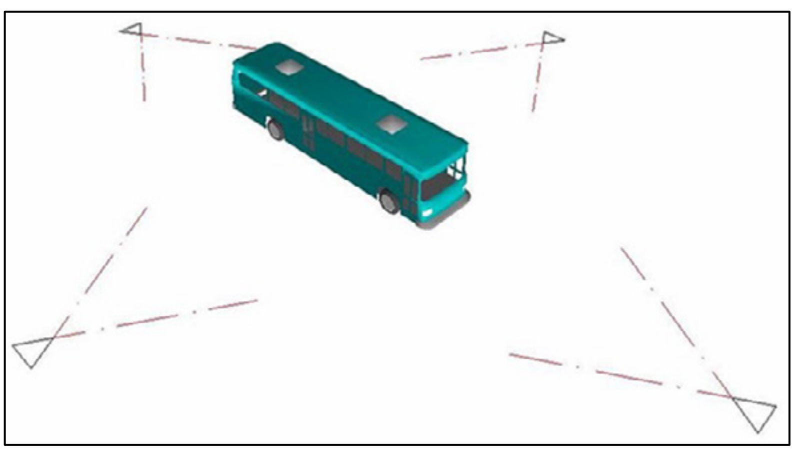


Figure B-1 *Standard Photographic Record (Four-Sided View of Vehicle Damage)*

Agencies may find it beneficial to have a drone operator/photographer on staff or under contract to record aerial images of a scene. An alternative is to ask for images from law enforcement or media who may have overflown the scene.

Mark your sketches “Not to Scale” and show a North arrow (does not have to point up). Measure from a fixed object that will not change such as the edge of a bus stop pole, curb line, hydrant, or a light pole. Vital measurements include point of impact, point of rest of each vehicle wheel, tire marks, gouges, or other accident-related marks in the roadway, fluid spills, and orientation of individual vehicles.

If multiple people are taking measurements, there are often natural discrepancies, particularly over long distances. Confer and agree on the numbers to be officially recorded, remeasuring if necessary. The goal with scene documentation is to have measurements, and relative positions accurately recorded so that the investigator could theoretically put everything back in the same place after it has been removed. In major or complex accidents, a professional survey group may need to be used. Aerial photography can also help to validate relative positions of objects at a scene.

An accident scene diagram is of the highest importance, as it assists the reader of the report in the visualization of what the scene looked like. A useful diagram helps the investigator later on if it necessary to testify in court with precision and confidence. A diagram also helps in the reconstruction of the accident if it becomes necessary at a later date.

Marking and Measuring

After the initial response, arrival, and scene management responsibilities are carried out, the next step of the investigative process is to decide what items of physical evidence must be located, marked, and documented. The following list is presented as a guide, but it is not by any means, all-inclusive:

1. Decide if measurements are necessary
2. Photograph the scene
3. Locate transient evidence
4. Locate and mark each point to be measured, including:
    - Start of the skid marks
    - Skid mark direction changes
    - Vehicle wheel positions at final rest
    - Gouges in the roadway
    - Major debris points
5. Make a field sketch of the scene

After the decision is made on what items are going to be marked and recorded in the accident diagram, the issue of how many marks or spots on the road surface must be addressed. Generally, if an accident is severe enough to warrant diagramming, then the police will place their marks. You may want to respectfully check their measurements if you feel that they mis-measured a piece of evidence. Many transit systems issue ordinary spray paint and lumber crayons to their supervisors for marking purposes.

Bright orange or yellow paint are the most common colors as they are easily visible and located for subsequent measuring. In the case of paint, less is usually best; there is no need to deface the roadway with colorful "art"—a simple paint dot to locate an item is sufficient. Paint is of little use on unpaved or dirt roads.

An alternative method on these surfaces is the use of small flags or streamers. These are small (4–6 in.) pieces of wire to which bright streamers or flags are attached. Wire coat hangers and engineering tape (found at large hardware stores) are handy materials to make these flags. They are used at every spot where the paint would ordinarily be used and are easy to locate later, particularly across rough or uneven fields.

Investigators must remember that a discussion on marking tools and devices is academic if they are not carried in the vehicle at the time they are needed. It is the responsibility of each investigator to ensure that all necessary supplies are in the vehicle at the beginning of each shift. A professional transit investigator always knows what equipment he/she has at all times. After deciding what the investigator is going to want to measure, a decision has to be made on how many marks or spots are going to be used for each item. For vehicles, bodies, long tire marks, or large debris areas, one mark is insufficient. For example, Figure B-2 shows how one mark will not locate a vehicle's specific location and heading as it can be facing in any direction if a single mark is used. If you measure something large with only one mark, you do not know which way it is oriented.

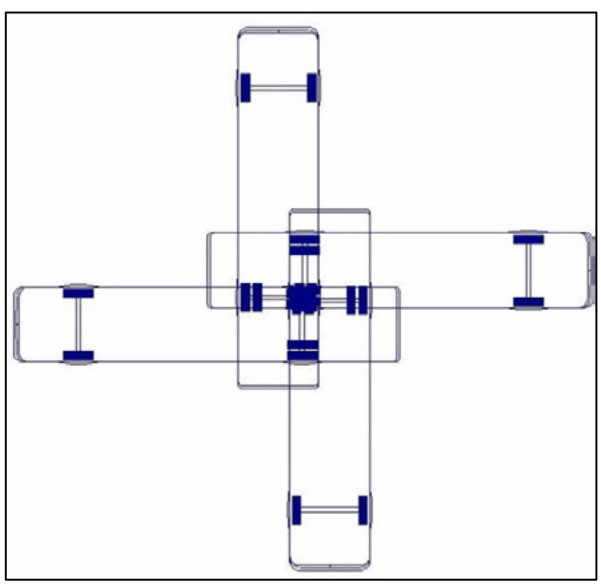


Figure B-2
Marking Large Objects

Two or more points or marks are needed for such items as vehicles, bodies, skid or scuff marks, and large areas of debris. A marking on the front and rear tire (same side) of an automobile is usually sufficient. In the case of an articulated coach, it is marked as if it were two separate vehicles. For a person, one mark at the head of a body and one at the navel are sufficient.

Straight skid marks are marked by a single spot at each end of the skid; this is repeated for every skid mark. A two-wheel vehicle such as a bicycle or motorcycle is marked by placing a paint or crayon spot at each wheel, as shown by the arrows in Figure B-3. On small objects such as gouges, minor scuff marks, or small debris areas less than 3-ft in diameter, a single mark or spot to the center of the object is sufficient. On curved tire marks such as yaw marks, locate stations along the mark at 5-, 10-, 15-, or 20-ft intervals, depending on the length and sharpness (radius) of the mark. Large debris areas can be located by placing marks along its perimeter, 4–8 marks are usually sufficient.

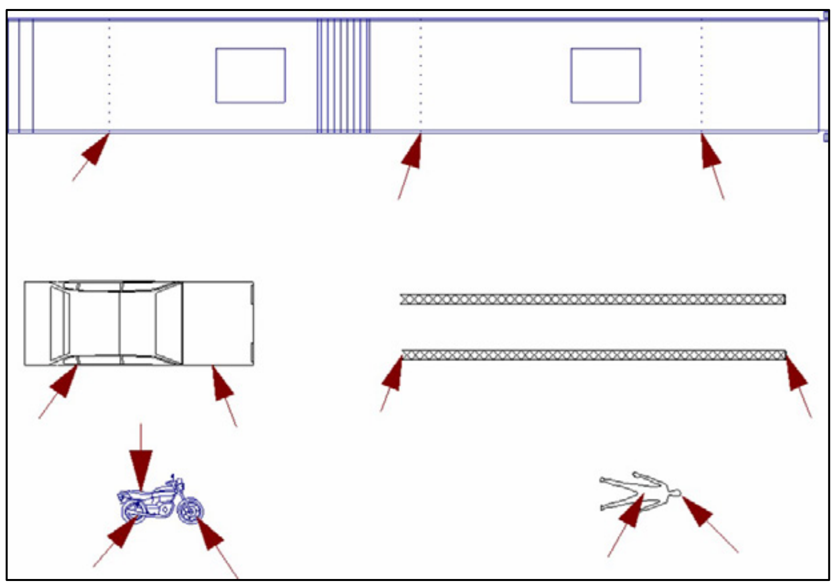


Figure B-3 *Where to Measure*

Diagramming the Scene

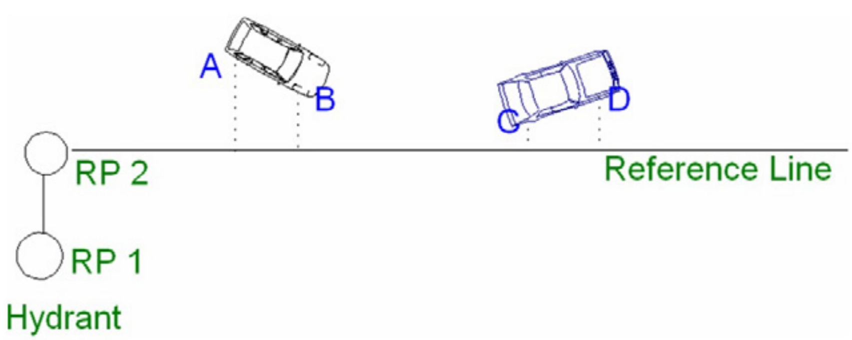
Several methods of diagramming accident scenes have been developed over the years and are in widespread use. Some are simple to learn and use, and others are somewhat complex and require considerable amounts of training. There is very little doubt that traffic accident investigation is, by its nature, a technical task. However, the majority of on-scene investigative work often is carried out by field supervision; this is particularly so in smaller transit systems. With that in mind, it is easy to see why there is a need for transit systems to teach their investigators simple yet effective accident mapping techniques. Two of these methods are the coordinate and triangulation techniques.

Coordinate Method

The coordinate system is based on locating any specific spot using distances from a fixed reference point (RP), along a reference line (RL). In using this method, a vital ingredient to accurate measurements is the selection of a good RP. If future reconstruction of the accident is necessary, the RP becomes the key from which the scene is mapped. Some examples of good RPs are highway mileposts or mile markers, utility poles, fire hydrants, culverts and bridges, intersections of roadways, and any other artificial or natural point of a permanent nature.

When selecting an RP, keep in mind that if the RP is destroyed, then surveyor plans, street maps, engineering drawings, and other resource documents should be available, which will enable the reconstructionist to "place" the RP back at its original location. Remember that the RP is the keystone from which the entire accident is measured and drawn. An incorrect RP selection would make exact reconstruction of the accident at a later date difficult, if not impossible, to the degree of accuracy required.

To use the coordinate method, as with any other technique, the accident investigator first prepares a field sketch of the scene, showing all important items. Once the field sketch is prepared, the investigator assigns each significant item a letter of the alphabet starting with "A." After this, they draw a table where all measurements will be recorded. This table can be next to the field sketch or on a separate page. The table will include a legend, and it should consist of geographical location of the accident, scene, weather, and roadway width, complete description of the RP, and the investigator's name. The date the diagram was prepared and an explanation of any non-standard symbols used can also be included here. Figure B-4 shows a simple scene sketch, including a measurement table and legend.



Point	From "0" or RP	From Ref Line	Description
A	25'6"	18'3"	Acura RR Tire
B	36'8"	14'2"	Acura RF Tire
C	45'5"	6'9"	Mercury RR Tire
D	57'9"	9'9"	Mercury RF Tire
Legend. Location: Continental Way near Storch Blvd. RP 1 Fire Hydrant. The street is 36' wide			

Figure B-4 *Coordinate Method*

On the space above or below, the legend table will show the accident measurement data are broken down in four separate columns: point, from “0” or RP, from roadway edge, and an identifying description of each item or point. The first column is simply the alphabetical listing of all significant items marked at the accident scene. After reaching the letter “Z,” the investigator may go on to 'AA,' 'BB,' and so on, or an alphanumerical system such as “A-1,” “A-2,” may be used.

The next column (from "0" or RP) will show the distance from the RP along the RL to a point abreast or perpendicular to each significant item. At each point the investigator places a mark (paint, crayon) and continues to measure up to the next point. The “0” designation is used when the RP does not lay directly on the RL, such as when using a telephone pole as the RP. This is commonly referred to as "bringing" the RP to the roadway edge by measurement. This distance is not part of the table itself, but it should be shown in the legend. It should be noted that the coordinate method should not be used when significant items are more than 35-40 ft from the roadway edge, as accuracy begins to suffer beyond this distance. In such a situation, a triangulation-based method is recommended.

After this process has been completed, the investigator then measures the distance from the roadway edge out to each significant item. This information is recorded under the "From Roadway Edge" column, next to its corresponding letter. Thus, a set of measurements, or coordinates, is established for each significant item. The last column, "Identification," is simply a short description of each item in the diagram.

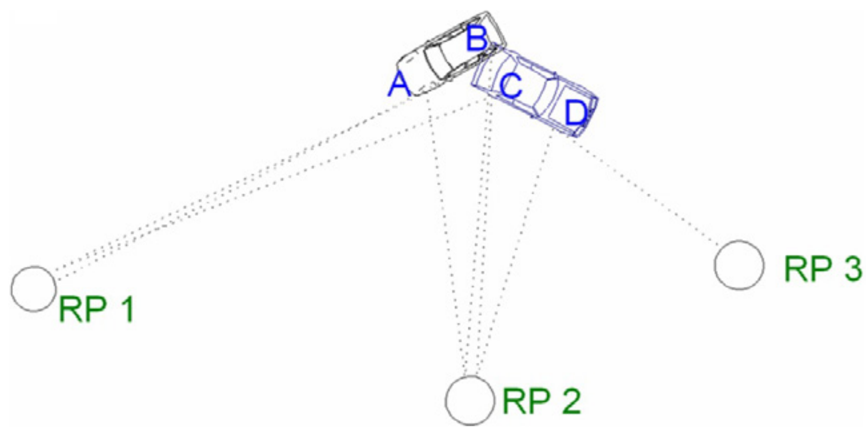
Equipped with this information, the investigator is now ready to prepare a post-accident, or final position, diagram. If the diagram is to be to scale, then he/she will need additional information such as radii of any curves.

Triangulation Method

Many times, the final resting positions of vehicles involved in accidents, particularly in rollovers, are too far from any convenient roadway edge RLs, rendering the coordinate method somewhat inaccurate when distances beyond 30-40 ft from roadway edge are involved. This is a common occurrence along county and state highways, where the high velocities involved sometimes cause the accident vehicle to arrive at its final rest at a considerable distance from the roadway. This inability to determine right angle straight lines out to an object is due to parallax error, an apparent change in position of an object when viewed from two or more positions not precisely in line with the object — the greater the distance, the more significant the margin of error.

At these times, the triangulation method (Figure B-5) presents a much more accurate alternative. When using triangulation, each significant item is located by establishing fixed distances from two RPs along a RL. In the example, point “A” is determined by (1) measuring the distance from the first RP (RP 1) to “A,” (2) measuring the distance from RP 1 to RP 2, and finally (3) measuring the distance from RP 2 to "A." The investigator can use as many RPs as necessary. The only criterion to keep in mind is to select RPs that will maintain an evenly spaced or equilateral triangle. Each of these steps is repeated for every significant item in the diagram. The table in Figure B-5 shows the recommended method of documenting these measurements. Two measurements must be obtained for each significant item.

To draw the diagram to scale, a standard compass, which has been previously adjusted to the distance required using the scale on the template, is used to draw an arc from each of the RPs. The point at which they intersect is the location of the significant item.



Point	RP 1	RP 2	RP 3	Description
A	65'7"	65'0"		Acura LF Tire
B	78'2"	71'3"		Acura LR Tire
C	78'3"	66'9"		Mercury RR Tire
D		52'1"	42'11"	Mercury RF Tire
Note: RP1 to RP2 65'4". RP 2 to RP 3 49'5"				

Figure B-5 *Triangulation Method*

These methods are simple, easy to learn, and do not require a large amount of equipment or time to use. They are accurate and will cover every accident diagramming an investigator is asked to perform, with minor modifications. The coordinate method is easier to use and can be applied to about 90% of all accident scenes, and the triangulation system is available for those few times it is required.

Drawing a Scale Diagram

The last step in the measuring and diagramming process is to prepare a scale diagram. This is a representation of the accident scene that is proportionate to the actual scene based on a given scale. Most accidents investigated by supervisors will require no more than a simple, not-to-scale diagram showing final vehicle positions and other physical evidence. Scale scene diagrams are time-consuming and not necessary for most accidents. To draw an accurate and technically acceptable scale accident diagram, the following are needed:

- Field sketch
- Field notes
- Table of measurements and legend information
- Paper and fine point pencil
- Template with 1=10 and 1=20 scales
- Compass

The first step in drawing a scale diagram is to decide what items are going to be included. It would be technically possible but extremely time-consuming to attempt to add every single item at the accident scene, such as sidewalks, poles, street signs, bushes, and other items commonly found on or near the scene. The rule to remember is to include those items in the diagram which are relevant to the accident.

All roadway evidence, such as skid marks, must be included in the drawing. The final positions of the vehicles are critical to an understanding of the accident and are also shown. The roadways involved are shown, but sidewalks and gutters are not included unless they are of relevance, i.e., in the case of a bus jumping a curb and striking a pedestrian on a sidewalk.

In drawing the diagram, a template designed for accident mapping is essential. Two templates commonly used by investigators are the Traffic Template and Calculator from Northwestern Traffic Institute and the Blue Blitz from the Institute for Police Technology and Management (IPTM). Both are plastic, have a nomograph for speed calculations, include unique cut-outs for drawing cars and trucks, and have the two most commonly used scales: 1 in. = 10 ft and 1 in. = 20 ft, or 1=10 / 1=20. These scales are printed on either edge of the template. Useful equations and traffic investigation terminology are shown in Appendix C, Equations and Terminology.

The selection of scale to be used in the diagram will determine how large the final product will be. A standard 8.5 × 11-in. piece of paper will accommodate an accident scene of approximately 160 ft × 135 ft on a 1=20 scale, and 81 ft × 68 ft on a 1=10 scale. If a larger diagram is necessary, then flip chart paper or additional sheets of paper can be taped together, or a smaller scale must be used.

In drawing the diagram (Figure B-6), it is a good idea to show North towards the top of the page; this is an accepted rule in mapmaking. To show intersection curves or other roadway curves to scale, certain measurements have to be obtained at the scene:

- Chord – straight line intersecting a curve at two points (tangent)
- Middle Ordinate (M.O.) – shortest distance from center of a chord to a point on its perimeter
- Radius –distance from center of circle to point on its perimeter

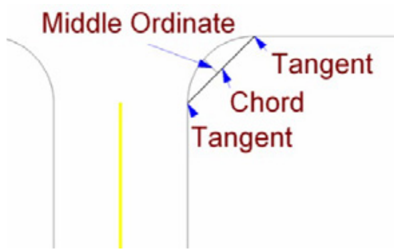


Figure B-6 *Intersection Curve Diagram – Location of Chord Line, Middle Ordinate, and Tangent Points*

The first step in calculating the radius of a curve is to measure its chord line. This is done by stretching a 100-ft tape from tangent point to tangent point. At the midpoint, the middle ordinate is then measured out to the curve. For example, if the curve chord measurement was 50 ft, then the middle ordinate measurement would be taken at the 25-ft mark.

Once the chord and middle ordinate measurements are recorded, and roadway width measurements are also taken, then all necessary information is available to go to the next step in the process. A mathematical calculation, using the radius of a curve equation, has to be completed before using a compass to draw the curve. The equation is:

$$R = \frac{C^2}{8M} + \frac{M}{2}$$

Where R = radius of curve, C = chord measurement, M = middle ordinate measurement, and 8 and 2 = are constants (in a mathematical equation, a constant is a value that never changes its value, i.e., in this equation, 8 and 2 are always used as such)

For example, the next series of steps will show how the equation is worked out, using a value of 50 ft for our hypothetical roadway curve, and 7 ft for the middle ordinate. The final result of the equation is a radius of the curve of 48.14 ft. In actuality, one-tenth of a foot is a little over one inch, which is impossible to discern in a 1=10 or 1=20 scale diagram, so you can safely round down to an even 48 ft.

$$R = \frac{50^2}{56} + \frac{7}{2}$$

$$R = \frac{2550}{56} + 3.5$$

$$R = 48.14 \text{ feet}$$

The next step in the process of drawing the curve, now that the radius is known, is accomplished using the template and an ordinary drawing compass. Start by drawing two straight, intersecting lines, as shown in Figure B-7 (Step 1). The "cross" should be on the side of the page or paper that the curve is to be. This is a trial-and-error process sometimes, and the investigator will improve with skill with practice.

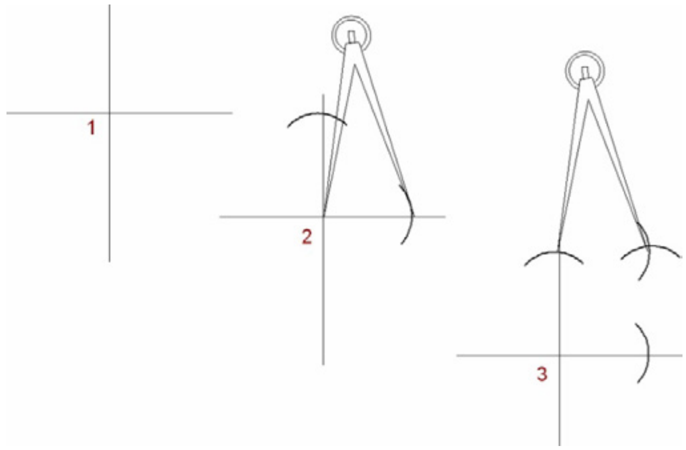


Figure B-7 *Drawing Curves to Scale – Steps 1 through 3 Used in Drawing Intersection Curves to Scale*

After deciding what scale is to be used in the diagram (1=20 for most diagrams), the compass gap is then adjusted to the distance calculated in the radius of a curve equation using the template. In this case, it would be adjusted to 48 ft. The sharp metal point of the compass is then placed at the intersection of the two lines, and two short arcs are drawn, intersecting each line as shown in Step 2.

In Step 3, the sharp point of the compass is placed at the intersection of each arc made in Step 2 above, and two additional arcs are drawn towards the side the final roadway curve will be.

Step 4 consists of placing the sharp point of the compass at the intersection of the last two arcs drawn, then drawing the curve from one side to the other (Step 5). The straight lines are now erased, leaving a perfect, to scale, roadway curve (Figure B-8).

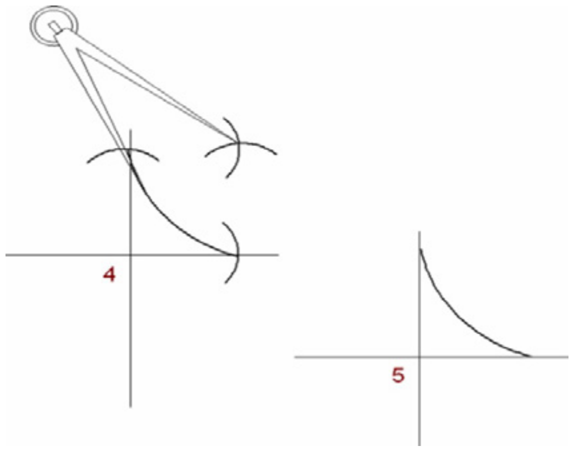


Figure B-8 *Final Steps in Curve Drawing Process (Steps 4 and 5)*

The process is completed by extending all lines and measuring the space between the lines with the template to match the roadway widths at the accident scene (Figure B-9). Once the curve drawing procedure is carried out three more times, a four-way scaled intersection is finished. The Investigator should keep in mind that, although all four curves at an intersection are generally of the same radius, this is not always so. Measure each curve to ensure accuracy.

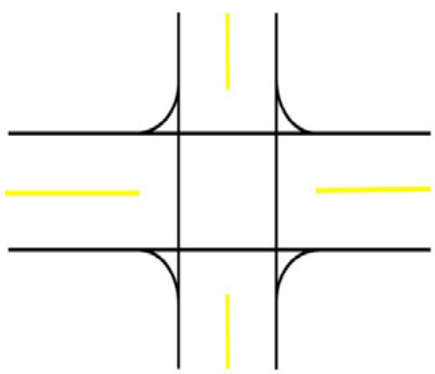


Figure B-9 *Four-way Intersection with Curves Drawn to Scale (Before Erasure of Roadway Edge Lines)*

Not all intersections are four-ways or T-bones, meaning they do not all meet at friendly, easy-to-draw 90° angles on a piece of paper without thought given to measuring actual angles. Many roadways join at acute or obtuse angles, such as the one depicted in Figure B-10. If the investigator guesses and draws freehand the intersection on the paper, it is no longer a scale diagram. The investigator must first determine the angle at which one roadway meets the other.

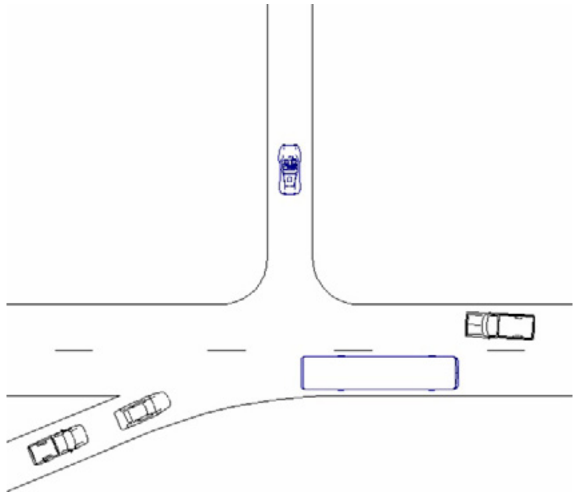


Figure B-10 *When Angles are Not 90°*

To do this, the investigator first visually extends the roadway edges and marks the point at which the two meet (apex), then an arbitrary but equal distance is measured and marked from the apex along each roadway edge (A and B in Figure B-11). The distance between A and B is recorded, along with the first distance measured.

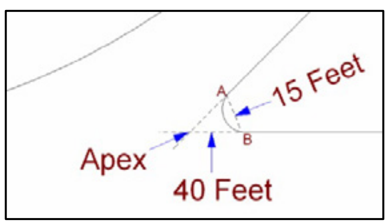


Figure B-11 *Measuring Intersection Angle*

For example, assume that the first distance was 40 ft, and the second was 15 ft. On the diagram paper, the investigator begins by drawing a straight line across the page, keeping in mind where the intersection is going to come in. Using a compass/template and adjusting the gap to the first distance (40 ft in this example), the investigator then draws an arc with the sharp point of the compass at the apex. The arc will cross the first line drawn, as shown in Figure B-12, Step 1. The compass is then removed and adjusted to the second measurement (15 ft); the sharp point is now placed at the intersection of the straight line and the arc. A second arc is now drawn intersecting the first arc (Step 2).

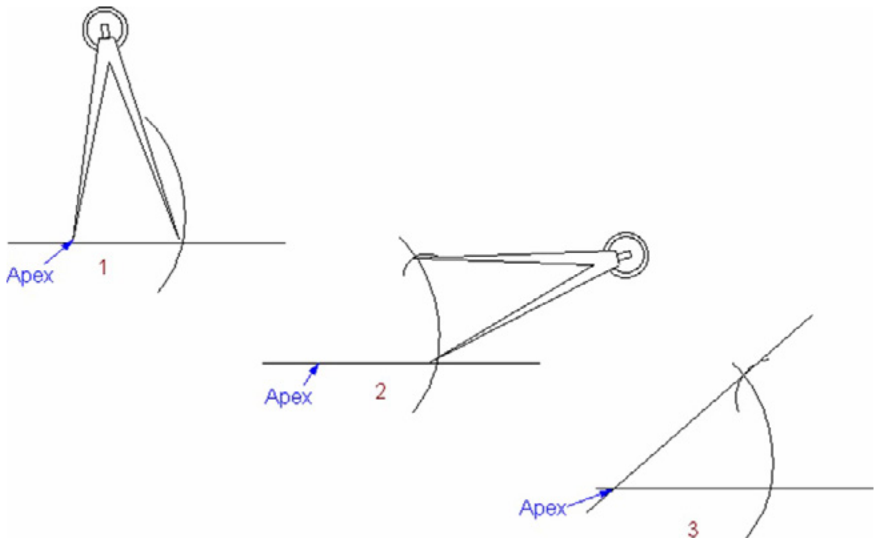


Figure B-12 *Steps to Draw Angled Intersection to Scale*

The next step is to connect the apex and the intersection of the two arcs using a straight edge; this will provide the angle of the intersection. To complete the drawing, the other two roadway edges have to be added in accordance with the actual roadway width measurements. The last step required is to draw the radius of each curve. The mathematical equation is the same one used for 90° intersections, but the process to draw the curves is slightly different.

Once the angle intersections have been drawn to scale, then the radius of each curve is added. To do this, measure two parallel lines, one on each side of the angle and to the distance of the radius obtained from the equation. Where these lines cross, place the sharp point of the compass and draw the curve.

This process is then repeated for the opposite curve, using the radius calculated for that curve. Figure B-13 shows how to complete these steps.

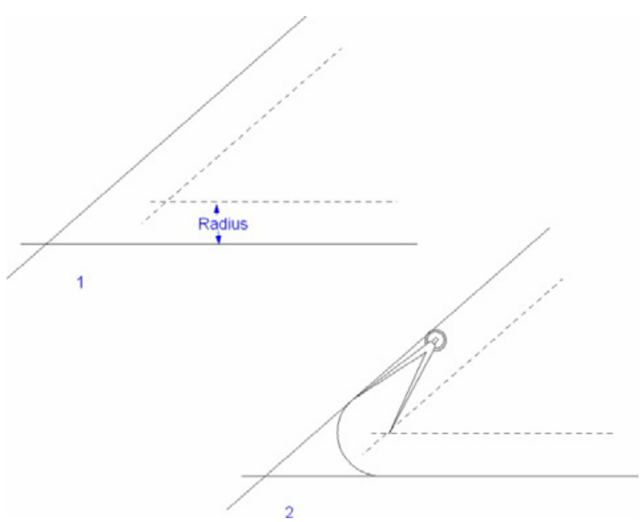


Figure B-13 *Drawing Curve Radius to Scale (Angled Intersection)*

Tire Marks, Scrapes, and Gouges

Marks on the roadway left by tires and vehicle components during the accident sequence need to be carefully measured and documented. Forensic analysis of these marks can aid specialists in reconstructing the movements of vehicles leading up to impact and provide information on vehicle speed and other operating parameters.

Tire marks fall into three categories—skids, yaws, and prints. Tire marks and roadway evidence are extremely important in determining how vehicles moved into the impact point and from impact to final resting locations. The speed of travel can be estimated using these marks (detailed equations and associated terminology are provided in Appendix C).

Before adequately analyzing tire marks, it must first be understood how they are made and the braking mechanism involved. The majority of automobiles and paratransit vehicles use standard hydraulic braking systems for their primary braking systems and mechanically activated brakes for parking brakes. Transit buses use air brake systems, which are much more effective at stopping larger vehicles.

When brakes are applied, the vehicle tends to shift forward; this results in a weight transfer from the rear wheels to the front wheels. Although every vehicle is different, there are some generally accepted guidelines. Typically, 60% of the total weight of a rear-wheel-drive automobile rests on the front wheels during braking, leaving 40% of its weight applied to the rear wheels. This ratio changes for front-wheel drive vehicles and rear-engine buses—for front-wheel drive vehicles, the ratio is 70/30 front/rear and for rear-engine buses the ratio is 40/60 front/rear. Complex weight-shift equations can provide an exact percentage of weight shift for a given vehicle; however, they are more complex and beyond the scope of this manual.

When the brakes are applied, the kinetic energy of motion (as a result of the vehicle's mass times velocity) is transformed into heat by friction. If the brakes are applied strongly enough, the tire will lock, sometimes referred to as 100% slip. The kinetic energy, or energy of motion, then dissipates between the tires and the roadway surface in the form of heat. It is this heat that dissolves or melts the tars and oils on the roadway surface, thus creating the distinctive dark smear commonly referred to as a tire mark or, in this case, a skid mark.

Skid Marks

Although some small particles of tire rubber separate from the tire itself, a skid mark is composed primarily of asphalt tar. On concrete surfaced roads, skid marks are lighter in color and are made by the rough concrete surface actually "grounding up" the tire or melting it. Sometimes, the "squeegee" effect of the tire will clean the dirty road surface, resulting in a skid mark lighter in color than the surrounding surface. When a vehicle travels with its tires locked (sliding) through a soft or loose surface, it will plow through the loose material, pushing it out to the sides and ahead of the tire.

Skid marks show evidence of:

- Location and direction of vehicle travel
- Driver's intention to stop
- Possible vehicle speed
- Area of impact by skid offsets

The skid mark shown in Figure B-14 is created by a tire that is locked, i.e., sliding, and not rolling. Skid marks tend to be straight, although they can exhibit some curvature due to asymmetrical braking (not all brake pads locking simultaneously) or due to the crown of the road. This can make the vehicle depart from a straight-ahead path. Front tire skid marks tend to be darker than rear tire marks due to weight shift, and the outside edges of the mark may be darker than the inside area due to over deflection of the tire (weight shift). Tire grooves are generally visible and easy to see in a skid mark. Rear tire skid marks tend to be even in appearance, i.e., no dark outside edges.

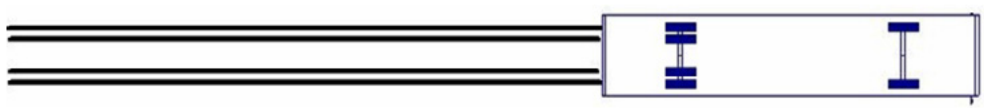


Figure B-14 *Skid Mark*

Skid marks are an extremely important piece of physical evidence to an accident investigator, as they can be used to determine the speed and establish the path of the vehicle while skidding. Unfortunately, tire mark evidence has a life span, as it is affected by weather, sunlight, and traffic, and tire marks can be obscured by the movement of other vehicles at the accident scene (very common on gravel roads). Therefore, tire marks must be located, measured, and properly documented before their disappearance.

When looking for skid marks, it is extremely important to determine the point at which the skid marks begin. This beginning point of the skid mark is a relatively faint mark compared to the rest of the dark tire mark. During initial brake application, there is a short time delay between the time the braking system/tire combination locks the wheel and the point at which the tire heats up sufficiently to begin leaving a mark. This faint beginning is called the skid mark shadow. To locate this shadow, the investigator must kneel or bend down to the roadway level, 20–30 ft ahead of the mark, and look towards the apparent beginning of the skid mark. A second person is required to assist the investigator in marking the beginning point of the shadow with a crayon or paint. The location and inclusion of this faint beginning of the skid mark are extremely important for future use in speed determination. As much as 10% of a skid mark can be in this shadow and overlooking it can underestimate the speed of the skidding vehicle considerably.

Curved skid marks indicate that the vehicle that made them was rotating while simultaneously skidding. When this happens, all four tire marks can be observed. This rotation during a skid can be initiated by the driver beginning a turning maneuver as wheels are locked in braking, and vehicle then continues in rotation. Curved skid marks can also be indicators of unequal braking. If left-side tires are braking with greater force than right-side tires, the vehicle will tend to rotate counterclockwise in the direction offering the higher resistance.

Curved skid marks can also be indicative of a half spin; this is a rotation of the vehicle 180° from its original direction of travel. This is caused by the rear tires locking up before the front wheels. A vehicle is less stable in terms of directional control when rear tires are locked up before front tires. Rear tires will then lose the necessary lateral forces, which are essential to directional control of the vehicle. When this happens, the vehicle will "switch ends."

If there is a question about the operational status of all or any brakes, every tire should be examined. . This will reveal the presence, or absence, of abraded areas at the road/tire interface, also known as skid patches.

When skid marks are not continuous but are intermittent, they may have been made by a vehicle bouncing along on the roadway (Figure B-15). In this situation, the length of the skid mark and the length of the space between them is uniform and consistent, and less than 3–4 ft apart. This condition can result when the wheel strikes a pothole, or bump on the roadway, which starts the vehicle bouncing.

Figure B-15 *Skip Skid Marks*

Measure total length of skip skids so that the gaps are included in the finished measurement; these gaps are considered to be a part of the overall skid mark. Vehicle braking is not reduced during the skip portion of the skid by virtue of the wheels being off the ground for such short distances. Although actual braking does not occur during these short intervals when the wheel leaves the ground, heavier braking occurs when it returns to the ground to compensate for the missing distance. This effect tends to average the energy lost and results in valid speed estimations from skip skids. Document and photograph skip skids, as you would any tire mark, for further evaluation of the skid mark.

Skip skids are different from the marks made by antilock brakes, although they are measured the same. Antilock brake marks show a consistent width while with skip skids, the width varies as the tire bounces.

Many times, skid marks are observed in which there is a gap between the termination of the skid marks on the roadway and a re-initiation of the skid mark some distance down the road (Figure B-16). This is the result of the driver applying the brakes and subsequent release and re-application.

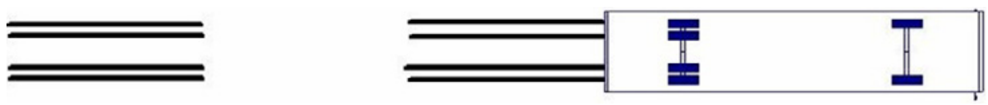


Figure B-16 *Gap Skid Marks*

Sometimes, a driver may momentarily release the brakes because they believe that the accident conflict situation ahead, in which an accident appears imminent, has passed, only to re-apply them again when they realize that the initial judgment was incorrect.

This is a typical situation in accidents with pedestrians or bicyclists, where the slower movement of the person or bicycle can change suddenly from that anticipated by the driver. For skip skids noted above, such gaps in skid marks are not included in the overall measurement of the skid mark. Gap skids are measured separately as if made by two separate vehicles. A combined speed approach is then used in calculating a speed. The discussion in the following section on speed calculations presents the mathematical approach to this situation.

Acceleration Marks

Often, tire marks that look like skid marks are acceleration marks (Figure B-17). These marks are created when a vehicle accelerates rapidly from a stopped position or when moving at a slow speed to make dark tire marks. These acceleration marks closely approximate skid marks in their appearance— they begin as heavy dark marks and slowly disappear as the rotational velocity of the tire starts to approach the linear velocity if the vehicle.

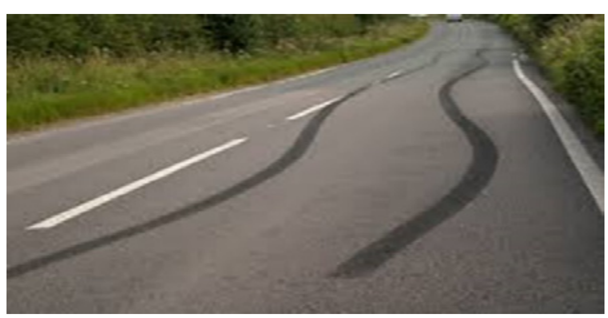


Figure B-17 *Acceleration Marks*

One characteristic common to acceleration marks is their linearity. When rapidly accelerating a vehicle under maximum forward acceleration, some steering is necessary to maintain a straight path because the torque from each wheel may not be equal at each rear tire due to road-tire interface differences. This small difference must then be corrected by steering, which results in a curved or "wavy" appearance.

Tire Tread Prints

Tire tread prints can illustrate the location and direction of vehicle travel and the driver's intention not to brake and may show the driver's intent to steer the vehicle. An imprint of the tire tread pattern indicates that the wheel was rolling (Figure B-18) and not skidding. The effect created is like an ink stamp, in which the pattern of rubber is imprinted on a flat surface without smearing. The print may be the result of loose matter picked up by the tire as it rolled on the roadway.

Figure B-18 *Tire Tread Print*

Tire prints are different from skid marks in that they convey the tire tread pattern of the tire without any of the slick or smoothly worn characteristics of a skid mark. In addition, the print pattern is uniform in contrast and noticeably similar to other print marks left by tires on other wheels of the same vehicle.

Yaw Marks

Scuff marks, also known as yaw marks or critical speed scuffs, are tire marks left on the roadway by wheels that are sliding and rolling simultaneously, as the wheel is rolling and slipping sideways at the same time (Figure B-19). Yaw marks are always curved and have very distinctive striations. As evidence, yaw marks show a vehicle traveling too fast to negotiate a curve, the vehicle's location and direction on the roadway, and the driver's intention to steer rather than to stop. Yaw marks are very accurate in determination of the speed of the vehicle.

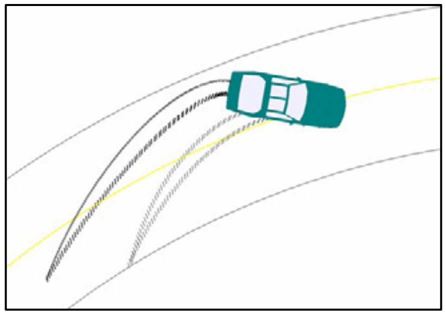


Figure B-19 *Typical Curved Scuff Mark Appearance*

When a vehicle "spins out" or "slips out" while cornering or is oriented in a direction different from its direction of travel, scuff marks will be deposited, often in the form of light parallel grooves, referred to as striations or hash marks, which run straight but are diagonal to the outline of the continuous scuff mark. They are made by the sidewall or rib of the tire.

One of the most important pieces of information obtained from scuff marks is that the vehicle was taking a turn at a critical cornering speed, the speed at which the vehicle is on the threshold of spinning out or slipping laterally. Tire scuff marks that occur under these circumstances are critical speed scuffs made by tires sliding as the vehicle traverses the curve and are made by the outside edges of the tires. The scuff mark left by the rear tire will fall outside the scuff mark made by the front tire for that side of the vehicle tending to slip off the roadway as a result of centrifugal force.

It is important to remember that scuff marks are made by steering, or slightly oversteering, as opposed to skid marks, which are made by braking. Two important characteristics to look for when examining scuff marks are their curved path and the striations (see Figure B-20).

Figure B-20 *Close-up View of Scuff Mark with Striations*

Metal Scars

When a moving vehicle is damaged in such a way that metal parts come in contact with the roadway surface, scars or scratches are left. Scars are helpful in indicating the direction of movement of the vehicle on impact. When they are correlated with the parts of the vehicle that made the scars, they can also confirm the position of the vehicle on the roadway at impact. Scars resulting from rollovers may indicate where the vehicle initiated its rollover movement. A vehicle sliding along the pavement on its side or top leaves distinctive scratches made by sharp sheet metal edges or other protruding parts. Scars may also indicate the direction of impact and the relative force of the impact. This is true when the scar can be matched with the undercarriage portion of the vehicle (engine, frame, transmission, differential, or other components) that made the scar.

There are also some instances in which scratches on pavement before impact are indicative of a failure of some vehicle components—for example, when scratches occur from the rim of a wheel, which sustained a flat tire before the accident; this can be confirmed by the distinctive pattern of a wobbly flat tire as it moves across the pavement.

Gouges may be distinguished from scratches in that they are much deeper and broader and tend to chip or chop chunks of road surface material. Examination of the undercarriage of the vehicle can indicate abraded areas that may have gouged the pavement. Deep gouges are characteristic of severe head-on accidents, where the front ends of one or both vehicles are driven down into the road surface with tremendous force; these gouges are good indicators of the point of impact or area of the accident.

Debris

Debris is not necessarily related to surface effects made by the vehicle directly in contact with the surface over which it is moving. However, as debris associated with the accident is physical evidence similar in importance to other accident evidence, it should be considered with the same careful attention. Debris includes any large or small vehicle parts or pieces separated from the vehicle as well as undercarriage dirt and mud that drops onto the roadway, rust from metal parts that is shaken loose, paint, various vehicle fluids (radiator coolant, engine oil, brake fluid, battery acid), and similar materials. Debris may also consist of portions of the roadway that are scooped up and spread in the accident area.

In severe injury-producing accidents, debris may include human fluids and other matter and portions of human bodies. Blood is perhaps the most common but may be accompanied by other human matter. Pools of blood can show where an injured person lay or crawled to or was moved to after the accident.

Material carried by the vehicle or within its passenger compartment, trunk, or cargo area is often dispersed around the accident site. This is an important consideration when attempting to interpret debris associated with only one accident vehicle. Fluids are of particular significance—when a fluid container bursts, the fluid is dispersed with the same velocity as the vehicle, resulting in fluid patterns that can help determine vehicle movement at impact.

Debris in the form of fractured parts that separate at impact is deposited in a pattern consistent with the dynamics of the accident. This can be helpful in understanding the accident, as some parts can travel great distances due to their relatively light mass and high initial velocity. In head-on accidents, for example, parts from each vehicle can be propelled forward a considerable distance from the impact point.

Other Signs of Impact

Damage to fixed objects, such as bent and broken guardrails, posts, trees, and other fixed objects, can give some idea of the speed and position of the vehicle striking them. Photographs best describe such damage; when matched with damage or marks on the vehicle, they can fix their position at a specific point in the chain of events.

Sometimes particles of paint in the scraped area will help distinguish which vehicles involved in the accident came in contact with that object. The term "fall" is used to describe a vehicle that has left the ground for a short time while falling or flipping. Signs of this are found at the beginning and particularly at the end of the fall in the shape of marks on the ground. Flips or vaults occur when the moving vehicle strikes an obstruction that suddenly stops the wheels. The vehicle then pivots upward and leaves the ground, usually landing bottom up. The signs of tire marks at the take-off and landing points should be carefully located. If the vehicle was sliding in soft material, the tires will dig a furrow; this is a distinctive spot and very easy to locate. A vault is an endwise flip.

Vehicle Fluids

Vehicle fluid patterns can be useful in determining areas of impact and post-accident movement. Examples of vehicle fluid are fuel, hydraulic fluid, radiator fluid, and windshield washer fluid. Vehicle fluid loss patterns generally take a five-step process:

1. Splashdown – fluid container is ruptured and fluid splashes onto the surface of the ground.
2. Dribble – fluid left in a trail from the area of impact to the vehicle's final rest.
3. Puddling – fluid forms in a puddle after leaking from a vehicle, generally under and around the vehicle.
4. Soak-in – fluid leaks from the vehicle and soaks into a porous surface such as soil or gravel.
5. Runoff – fluid leaks from the vehicle and runs down a grade.

Grade Crossings/Intersections

Document the position and condition of pavement markings, warning signs, and any special pedestrian enhancements (swing gates, ped gates, Z approaches) as well as the functionality of traffic signals and warning devices, if possible. During the post-on-scene phase, compare scene conditions to as-built drawings, regulatory orders, and other criteria. If conditions permit, it is helpful to record a video from a motor vehicle driver/pedestrian perspective approaching the crossing/intersection in the same manner as during the event.

Weather and Environment

The first investigators to arrive on the scene should make notes on their observations of the weather and environment at the scene:

- Do weather conditions affect visibility?
- Is it dark (after sunset or in a tunnel)?
- Is artificial lighting present? Are all lights lit?
- Is any unusual noise present (such as ventilation fans)?
- Is there anything in the environment that may have created a distraction??

Local airports often will have a weather station and data on temperature, precipitation, and wind, which can be obtained at or near the time of the event. Information on times of sunset and sunrise can also be obtained.

Witness Statements

Police or transit agency personnel should try to get as many witness statements as possible along with contact information. Passengers often are anxious to leave the scene and, at minimum, contact information for later follow-up should be obtained. Investigators may need to schedule follow-up interviews depending on the nature of the event.

Appendix C

Investigator Go-Bag Contents

Investigators typically customize their go-bags to include items they anticipate using or have found useful in the past. The following are items that investigators should consider as they develop a resource kit to have available when duty calls.

- Safety equipment:
  - Reflective vest
  - Eye protection – safety glasses, chemical splash goggles, chemical face shield
  - Hard hat
  - Gloves – vinyl/latex/nitrile examination gloves, chemical resistant gloves
  - Bloodborne pathogens protection kit
  - Cones/reflective triangles for traffic warnings
- Investigative tools:
  - Video recorder
  - Tape recorder
  - Camera (charged batteries, memory cards)
  - Flashlights/extra batteries
  - Notepads/pens/graph paper pad/memory sticks
  - Wireless electronic devices (tablet, laptop, or smart phone)
  - Templets for sketches
  - Chalk/paint pens/spray paint
  - Measuring wheel, non-metallic tape measure, or other measurement devices
  - Evidence control kit (containers/forms/tags/markers)
  - Calibrated gauges[63]
  - Drag sled
- Pre-identified and up-to-date agency manuals/documents:
  - Schematics
  - Rule books
  - Other specialized documents and plans specific to agency operations

[63] Specialized tools must be kept calibrated, and users should be trained and familiar with their use. Some agencies choose to rely on technical staff to bring tools, make measurements, and record data while the investigator observes.

Appendix D

Equations and Terminology

Equation Symbols

a = acceleration or deceleration rate, in feet per second (FT/S) per second (FT/S^2)

C = chord

D = distance

f = acceleration or deceleration factor, drag factor or coefficient of friction

g = acceleration due to gravity (32.2 feet per $second^2$)

M = middle ordinate

R = radius of a curve

S = speed, in miles per hour

t = time, in seconds

V = velocity, in feet per second

Equations

Velocity to travel a known distance in a known time:

$$v = \frac{D}{t}$$

Distance traveled at a constant velocity and a known time:

$$D = Vxt$$

Time to travel a known distance at a constant velocity:

$$t = \frac{D}{V}$$

Acceleration or deceleration factor when speed and distance are known:[64,65]

$$f = \frac{S^2}{30D}$$

Acceleration or deceleration rate when the acceleration/deceleration factor is known:

$$a = gf$$

Basic speed formula, decelerating to a stop when distance and drag factor are known:

$$S = \sqrt{30Df}$$

[64] https://www.engineeringtoolbox.com/acceleration-velocity-d_1769.html.
[65] https://www.engineeringtoolbox.com/acceleration-d_1393.html.

Combined speed:

$$S = \sqrt{S_1 + S_2 + S_3}$$

Converting speed (MPH) to velocity (FPS):

$$V = S\ x\ 1.466$$

Converting velocity (FPS) to speed (MPH):

$$S = \frac{V}{1.466}$$

Critical speed of a curve or path of the center of mass when radius and drag factor are known:

$$S = \sqrt{15}Rf$$

Distance to accelerate or decelerate to a or from a stop, when speed and acceleration/deceleration factor are known:

$$D = \frac{S^2}{30f}$$

Radius of a curve when chord and middle ordinate are known:

$$R = \frac{C^2}{8M} \times \frac{M}{2}$$

Estimating Speed from Tire Marks

Tire marks are one of the most important pieces of evidence of all physical evidence found at an accident site. They can be used to establish the pre-accident path and orientation of the vehicles, point of impact, and post-accident travel and can be of great help in estimating vehicle speed before skidding. Identifying tire marks at an accident site is fundamental to the accident investigation.

All moving bodies possess kinetic energy by virtue of their motion. The amount of kinetic energy involved is dependent on two factors: the mass of the body and its velocity. The mathematical equation for kinetic energy is:

$$K_e = \frac{1}{2}MV^2$$

Where *Ke* = kinetic energy, *M* = mass of body, and *V*= velocity.

Through formula derivation, the basic kinetic energy formula or equation above serves as the basis for the speed-from-skid formula. A moving vehicle's work energy is determined by multiplying the weight of the vehicle, times the drag factor of the road surface, times the distance it will slide over while stopping.

$$WfD = \frac{1}{2}MV^2$$

Mass is the same as the weight of an object divided by the acceleration of gravity, or W/g. If we change m to W/g and divide out W, it leaves:

$$fD = \frac{1}{2}gv^2$$

To get V^2 alone, both sides are multiplied by 2g:

$$V^2 = 2gfD$$

In the next step of the derivation process, the *g* (gravity) is changed to its actual value of 32.2 feet per second^2 and multiplied by 2, which becomes 64.4:

$$V^2 = 64.4fD$$

The next step is to change V^2 to the more conventional and familiar mph. There are 5,280 ft in a mile, and 3,600 seconds in an hour. Dividing 5280/3600, the conversion factor of 1.466 is obtained:

$$(S \times 1.466) = 64.4fD$$

Carrying out the square function of 1.466 yields 2.15, which is then divided to leave S^2 by itself:

$$\frac{S^2 \times 2.15}{2.15} = \frac{64.4fD}{2.15}$$

$$S^2 = 30fD$$

The last step is to extract the square root from both sides of the equal sign (squaring a number is the inverse of the square root):

$$S = \sqrt{30Df}$$

Where *S* = speed, *f* = drag factor 30 = constant, *D* = distance vehicle skidded, and *W* = vehicle weight.

This is the basic speed formula commonly taught and used in determining speed from skid marks. Although the accident investigator does not need to be proficient in the derivation process, it is a good idea to be able to explain or at least have an understanding of the scientific origins of the basic speed-from-skid equation.

As shown in the equation above, to determine the speed of the vehicle at the time braking was initiated, the investigator needs two pieces of information—the distance the vehicle slid and the drag factor. There are several different approaches to the drag factor—the investigator can refer to one of many published tables showing a sampling of drag factors for different surfaces (but these are traditionally unreliable) or can conduct a skid test to obtain one, use or construct a drag sled, or use an accelerometer.

Conducting a Skid Test

To obtain a drag factor from a test skid, ideally, the vehicle involved in the accident should be used. As this is highly impractical, an investigator's vehicle is an acceptable substitution. Skid testing carries a degree of risk and should be undertaken only with a well thought out safety plan. Using a drag sled (see the following section) involves little risk and likely will yield acceptable data.

The test skid should be made at or near the same location and with the same surface conditions. For maximum safety, a police officer or second transit employee should be present to monitor traffic and block the roadway while the test is being conducted. A good, safe speed for skid tests is 35 mph; speeds beyond this increase the safety risk and do not yield substantially better results.

To conduct the test, the vehicle is accelerated to 40 mph, and the driver steps off the gas pedal, allowing the vehicle to coast down to 35 mph. Upon reaching 35 mph, the driver applies the brakes hard (panic stop) until the vehicle slides to a stop. The longest skid mark should be measured and recorded, and a second test conducted. If the second test yields a distance close to or similar to the first (within 10%), then the test is valid.

If the accident occurred on a roadway that is sloped at a significant grade and the test skid was conducted on the same surface and in the same direction, then the grade is already accounted for. However, if no test skid was conducted and a drag factor table is to be used, then the percentage of grade has to be factored into the selected drag factor.

Figure D-1 shows how to obtain the road grade using an ordinary carpenter's level. One end of the level is placed on the roadway surface, and the opposite end is placed down-grade directly from the end that is on the road. Ensuring the bubble is level, a measurement is taken (in inches and tenths) from the road to the bottom edge of the level. In the example above, the run is 18 in., and the rise is 1 in. Dividing 1 by 18 yields a grade of 0.05%.

To use this grade on the selected drag factor, if the sliding vehicle was going uphill, the grade is added. For example, if the selected drag factor is 0.7 and the grade is 0.05%, then 0 .7 + 0.05 = 0.75 for drag factor. If the vehicle was sliding while traveling downhill, the grade is subtracted.

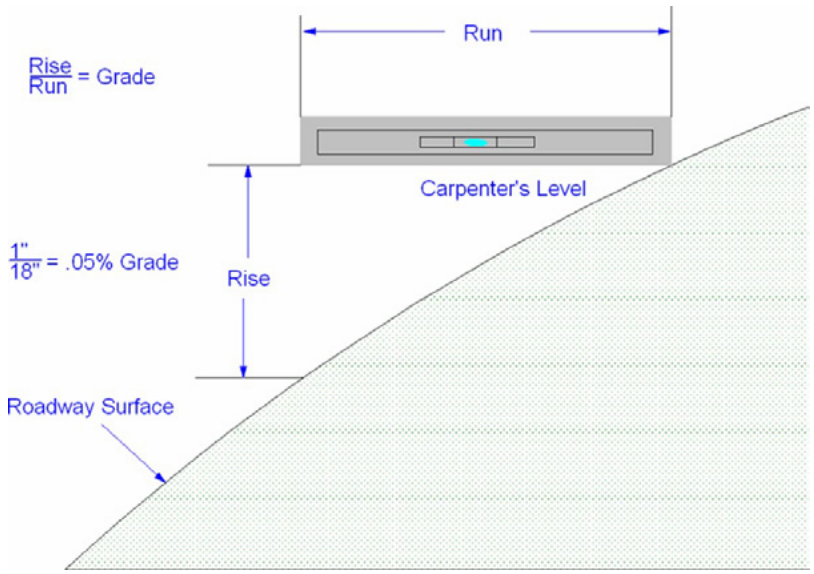


Figure D-1 *Determining Rise and Run*

Once the test skid data are obtained, this information can be used in the drag factor equation:

$$f = \frac{S^2}{30D}$$

Where *f* = drag factor, S^2 = test speed squared 30 = constant, and *D* = distance test vehicle skidded.

For example, assume that a test skid yielded a skid distance of 55 ft with a test speed of 35 mph:

$$f = \frac{35^2}{30x55}$$

$$f = \frac{1225}{1650}$$

$$f = 0.74$$

The drag factor for that surface, with all wheels locked and sliding, is 0.74; this is the value used as f in the speed formula discussed earlier. Assume that the accident vehicle skidded for 66 ft. Using the drag factor calculated above:

$$S = \sqrt{30} \times 66 \times 0.74$$
$$S = 38\ mph$$

The accident vehicle was traveling at no less than 38 mph at the beginning of the skid, as the vehicle collided with another one (or an object) before coming to rest. If it had not, the skid marks would have been longer.

It is important to remember that the speed calculated from the speed equation is the true speed of the vehicle only if it slides to a stop; that is, all energy is dissipated sliding to rest. When it is not, some energy is dissipated doing crush damage, and this energy is not accounted for in the speed equation. This is why speed from skids is referred to as a minimum speed.

If the accident vehicle was braking at less than 100% efficiency (less than all four wheels braking), an adjustment must be made to the drag factor before it is used in the speed equation; a discussion on this is beyond the scope of this manual. Investigators suspecting less than all four-tire braking should consult with someone with advanced training, preferably an accident reconstructionist, for assistance.

Drag Sleds

The drag sled offers investigators a safe and convenient method of estimating drag factors in the field (Figure D-2) and can be used on a variety of surfaces. A drag sled is constructed from materials that are commonly available to the investigator. Consideration must be given to materials used in the assembly of a drag sled. Directions for the construction of a drag sled are readily available on the internet.

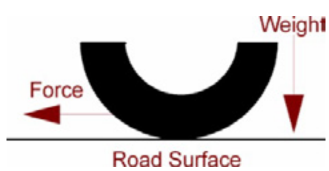


Figure D-2 *Using Drag Sled for Estimating Drag Factors*

Benefits of drag sleds are as follows:

- **Portability** – Experienced transit investigators who respond to accident scenes understand the chaos of a preliminary investigation due to too many tasks to complete at a scene. Photographs, evidence collection, drug testing, witness statements, coordinating with the police, and the media stretch priorities, and the last consideration is coordinating the skidding of a car through the pristine scene to obtain a road surface value. A drag sled carried in the trunk of an investigator's vehicle is an efficient and non-time-consuming way to obtain such a value.

- **Special Conditions** – Although accelerometers may be the most accurate way of obtaining drag factor, conditions may warrant a value obtained during the initial investigation. The portability of the drag sled affords its user the practicality to obtain a "then" and "there" value. Accelerometers also have a problem giving readings over multiple surfaces.

- **Economical** – A drag sled is a low-cost alternative to an accelerometer.
- **Safety** – Efforts must be made to properly secure the test site with enough personnel to ensure the safety of both the general public and that of the investigator(s) and personnel involved in the testing.

The primary expense is the cost of a scale from which the static weight of the drag sled and the force (pounds of pull) are measured. A drag sled should always be weighed and pulled with the same scale. The scale can be certified for accuracy, but this is not a necessity, as any inaccuracy will be the same percentage for the weight of the drag sled and the force (pounds of pull) required to move it over the test surface.

The investigator should pull the drag sled along the surface being measured at a steady pace and note the pounds of pull required to keep the drag sled moving, as displayed on the scale. The scale level in relation to the surface being measured should be kept; it is not necessary to adjust the drag factor for the surface grade or super-elevation when a drag sled is used on the actual surface in the direction the subject vehicle skidded.

To determine the drag factor by using a drag sled:

$$f = \frac{F}{w}$$

Where f = drag factor, F = force (pull) parallel to surface measured in pounds, and W = weight of object being moved.

For example, assume that the drag sled weighs 50 lbs. and requires a force of 30 lbs. to move it across a roadway at a constant speed. The drag factor would be calculated as follows:

$$f = \frac{30}{50}$$

$$f = 0.60$$

Critical Speed (Yaw) Marks

Critical speed marks, or yaw marks, are tire marks left on the roadway by wheels that are sliding and rolling at the same time. They are made by the tire sidewall and are a result of the driver over steering the vehicle.

A common occurrence in which yaw marks are found is in rollovers involving drunk drivers. The intoxicated driver falls asleep and allows the vehicle to drift off the roadway. When they suddenly awaken, they jerk the wheel to the left, launching the vehicle into a side slipping maneuver. This brings the vehicle across the opposite lane of traffic, off the shoulder, and entirely off the roadway, often flipping in the process. The telltale yaw marks can be used to estimate the vehicle speed at the beginning of the maneuver.

To calculate the speed at which the vehicle began to sideslip, the investigator must first know the drag factor (from skid test or table) and the radius of the curve followed by the vehicle. The mathematical equation used in calculating the radius has already been discussed. Figure D-3 shows how to obtain the chord and middle ordinate of the yaw mark.

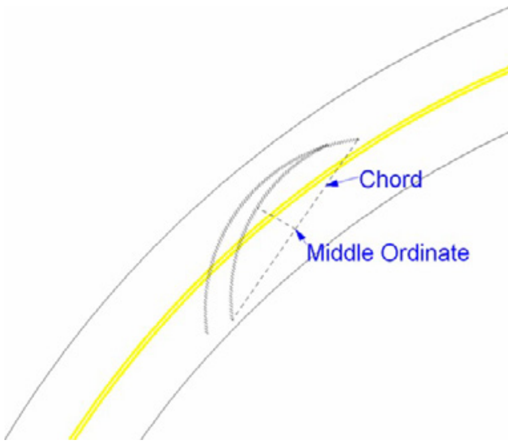


Figure D-3 *Obtaining Chord and Middle Ordinate Measurements from Yaw Mark*

When measuring the chord, the beginning of the tape measure is placed at the beginning of the yaw mark, and a chord of 100 ft is generally used. When measuring the middle ordinate, particular attention must be given to obtaining a precise measurement, as the equation is extremely sensitive to middle ordinate changes. Once the radius of the curve has been calculated, then this value can be used in the critical speed equation:

$$S = \sqrt{15R}f$$

Where *S* = speed, 15 = constant, *R* = radius, and *f* = drag factor.

For example, if a critical speed yaw mark left by a vehicle that subsequently ran off the roadway and overturned had a radius of 335 ft and the drag factor was 0.7 for that road surface:

$$S = \sqrt{15 \times 3}35 \times 0.7$$

$$S = \sqrt{35}17.5$$

$$S = 59\ mph$$

The speed of the vehicle when it began to sideslip was 59 mph.

Combined Speeds

Sometimes vehicles skid across two different surfaces before stopping or colliding with another vehicle or object. Using the same drag factor for both distances is a common approach; it is also wrong. To approach this problem, the total distance of the slide must be divided, and each segment must be calculated using the basic speed equation.

Upon completion of the step, the investigator will have two different and separate speeds. They are not added. Speed #1 and speed #2 must now be used in the combined speed equation:

$$S_c = \sqrt{S_1^2 + S_2^2}$$

Where S_c = combined speed, S_1^2 = speed #1 squared, and S_2^2 = speed #2 squared.

For example, if the two-speed calculations resulted in 40 mph for speed #1 and 60 mph for speed #2:

$$S_C = \sqrt{40^2 + 60^2}$$

$$S_C = \sqrt{1600 + 3600}$$

$$S_c = \sqrt{5200}$$

$$S_c = 72mph$$

Appendix E

Key Points on Conducting Interviews

One-on-one interviews may be necessary, particularly when obtaining witness statements after an event, as witnesses may be anxious to leave. An interview team of two is preferred—one to conduct the interview and the other to take notes or operate a recorder. Having a second person as a witness may also be desirable in some cases, as larger groups of interviewers can be challenging and require a leader to set clear ground rules about questions and the interview process.

Key points for team interviews:

- Have one person designated as the lead interviewer.
- Keep a professional and non-judgmental atmosphere – an interview is not an interrogation.
- Do not allow other interviewers to interrupt each other or the interviewee.
- Agree not to interrupt the questioning; each interviewer must wait their turn.
- Establish when follow-up questions to an interviewer's initial question will be addressed.

Interviews are used to obtain factual information to verify other data already obtained and to understand different perspectives of the same event—people involved have information that we do not have, we need that information to develop a factual record, we need the interviewee's cooperation, they likely do not need us, we can compel some people to interview, we cannot compel them to be helpful, establishing rapport is a key to success, interview objectives will change.

Potential interviewees include:

- Operating and maintenance personnel
- Supervisors/managers
- Victims
- Bystanders
- Residents

Persons familiar with potential participants include:

- Friends
- Coworkers
- Managers
- Emergency crews—fire, EMS, hospital staff, law enforcement, news media, walk-ins

Key interview points before the interview starts:

- Introduce yourself and chat with the interviewee.
- Explain the process, your role, and the identity of others who are present.
- Put them at ease as much as possible.
- Explain they can call for a break anytime.
- Identify interviewee concerns and try to address them.
- Answer any questions they may have.
- Explicitly instruct the interviewee to generate information: explain the ground rules.

Key points on question sequence:

- With two or more interviewers, follow a predetermined order of questioning; do not interrupt each other.
- Begin with open-ended questions—what happened, describe it in detail.
- Determine beforehand the order of issues to be addressed in questioning each interviewee.
- Guide the interviewee back to areas of interest where more detail is needed.
- Introduce new issues after each issue has been addressed in turn.
- Use one of two types of sequences of issues with interviewees, chronological order, or order of importance.
- Address issues that the interviewee may have raised while discussing another issue, even if it means going out of sequence.

Key points on attending to the interviewee:

- Show attention to the interviewee at all times.
- Be aware of and avoid nonverbal interviewer cues that may unwittingly be sent to the interviewee.
- Ensure that the interviewee is comfortable and that the interview location is free of distractions. Stop the interview if interviewees appear uncomfortable or begin to lose their composure; this is especially important if interviewing a victim of the event.
- Do not offer the interviewee career or personal assistance but demonstrate concern for the interviewee. Suggest a break if the interviewee becomes emotional or seems stressed.
- Have paper or whiteboard available in case the witness wants to draw a diagram. You should also have a scene sketch available so that the witness can point to what they have seen.

- Have a passenger car interior layout available to aid an interviewee in recalling locations of people or events.

Key points on follow up questions:

- Use follow-up questions when one of several interviewers has not pursued an issue that an interviewee has raised or when an interviewee has raised multiple issues in response.
- Ensure that other interviewers wait until their turn to follow up on an issue rather than disrupt other interviewers.
- Allow each interviewer at least two opportunities to ask questions, one to ask the initial questions and a second for follow up questions.

Key points on false responses:

- Rephrase or refocus the questions if there is a reason to believe that an interviewee has answered questions falsely.
- If there is contradictory factual information available, ask the interviewee to explain the discrepancy in a non-confrontational way.
- Do not express disapproval or attempt to coerce a truthful response from the interviewee.
- Do not use a prosecutorial tone in asking questions.

Key points on concluding the interview:

- Ask the interviewee if they have anything else to add or change.
- Ask if they have any questions that should have been asked.
- Ask if they have any suggestions for preventing a recurrence.
- Ask if they can think of anyone else that should be interviewed to understand what happened.
- Give interviewees a business card and ask them to contact you later if they have additional recollections or further information to provide.
- Let them know they can contact you with any questions that they may have; this will also allow you to collect any follow-up information.
- Thank interviewees for their cooperation.

Appendix F

Survivor and Witness Statements and Questions

Injured passengers and employees should be interviewed to document as much information concerning their actions just before, during, and after the event. Additional information should be collected, such as where the passenger was sitting at the time of the event and what they noticed about what other passengers around them were doing just before, during, and after the accident.

Persons who can provide information and who should be interviewed include:

- Passengers
- Agency vehicle operators
- Other agency employees
- Personal occupancy vehicle operators
- Responders
- Witnesses

Be sensitive to interviewee injuries. Request permission to tape record the interviews. If a recorder is used, the interviewer and interviewee will identify themselves as well as the date, time, and location of the interview and others present.

A technique that has been successful in interviewing survivors is to permit the interviewee to discuss their observations without interruption. The person designated as note-taker only jots down pertinent information. It is useful to have copies of seating diagrams of the vehicle type the interviewee was occupying available. Allow the interviewee to mark their location and other relevant information on the copy. At the conclusion of the interviewee's statement, specific questions noted below may be asked if they were not covered and to clarify certain areas of interest.

- What position/seat/location did you occupy?
- Describe the vehicle occupancy level.
- Were you seated or standing?
- Can you recall anything prior to the accident once you boarded the vehicle?
- Can you describe any impact forces (direction, magnitude)?
- (If injured): Can you describe your injuries and how they were sustained?
- Did you observe other passengers who were injured?
- Where were they located?
- Describe the injury mechanism if you observed.

- Can you describe your escape (method, time, difficulties, smoke, fire, egress routes)?
- Were there any difficulties during escape/rescue?
- Was there any difficulty opening doors/windows/emergency exits?
- Can you recall any observations of trapped passengers after the accident and during egress?
- Can you describe rescue/firefighting activities (location of fire, smoke)?
- Did you take any photographs/video after the accident? (if yes, ask for copies)
- Do you know how the vehicle was evacuated?
- Was any emergency equipment used, i.e., flashlights, megaphones, loudspeakers, PA?
- Did you observe any floor path emergency lights?
- Did you recall seeing/reading any safety card or other safety information?
- For passengers with disabilities: (if possible), obtain name, address, (age, weight, height), disability, mobility impairment.
- Were you using a mobility aid (walker, wheelchair)?
- What was the status of the mobility device during the evacuation and after?
- Did you notice the actions taken by POVs, pedestrians, or others just prior to the collision?
- Did you notice any other external conditions – such as weather or infrastructure malfunctions (signals, crosswalk notifications, rail crossing arms or signals, or others) that you noticed just prior to the collision?

Appendix G

72-Hour Pre-Incident History Checklist

The goal of the 72-hour pre-incident history is to obtain, in as much detail as possible, information on the operator's activities in the 72 hours before the accident. Information from this history will touch on every area of the human factor investigation, making it one of the most important activities the investigator will undertake. It may be beneficial to go back slightly longer than 72 hours, to the time the operator awoke. Initial questions to ask include, but may not be limited to, are the following:

- When do you normally go to sleep and get up on your days off?
- How much sleep do you normally get?
- When do you normally go to sleep and get up on days you have to work?
- How much sleep do you normally get on those days?
- Do you normally take naps? When, for how long, and why?
- How would you describe the general quality of your sleep?
- Can you estimate how long it normally takes you to fall asleep after you go to bed?
- Do you wake during the night? If so, how often, for how long, and how long does it take you to get back to sleep?
- Specifically, when did you go to sleep and get up the three days before the accident?
- Did you nap any of the three days before the accident? If so, when and for how long?
- Did you wake during the night any of the three days before the accident? If so, why? How long were you awake? How long did it take you to get back to sleep?
- How long did it take you to fall asleep initially the three days before the accident?
- Do you take any medications to help you fall asleep or stay asleep? What medications (contact prescribing doctors)? Did you take them three days or in the three days before the accident?
- Do you take any medications that make it difficult to fall asleep?

The human factors investigator should also try to obtain information on both the quality and quantity of an operator's sleep. Note the time of the accident for comparison to know circadian low points. Sources of information other than the operator include work schedules, cellphone records, logbooks, alarm clock settings, and hotel wake-up calls. Try to establish a baseline for on and off-duty days, as well as specifics for the 72 hours (see above) before the accident and compare the two. Specific information to obtain includes:

- Times the operator awoke/went to bed each day
- Times, content, and duration of meals, including snacks
- Step-by-step recounting of activities, including times and durations
- Relationship between that day's activities and their normal ones – anything missing, anything new, anything odd
- People they saw or talked to and times
- Time, duration, and location of any naps
- Medications taken, including prescription, OTC, or herbal, including time, and dose
- Time and amount of any intoxicant ingestion, including alcohol and illegal drugs

Appendix H

Analytical Tools to Aid Investigation Process

Fishbone Charts

Ishikawa or fishbone charts aim to help list out all possible causal factors (Figure H-1). The categories in the boxes can change as needed for the investigation. Items listed under each category can help the investigator make sure that all potential causal factors have been examined.

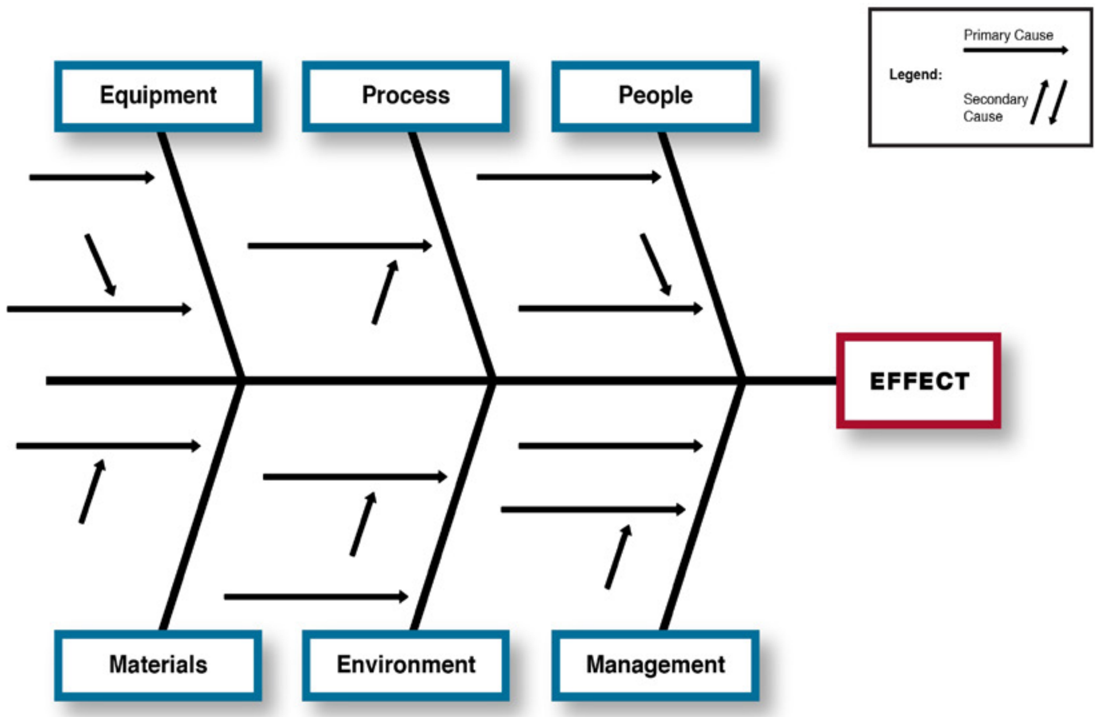


Figure H-1 *Fishbone Chart*

Source: TSI

Fault Tree Analysis

A Fault Tree Analysis is used by the professional safety and reliability community to prevent and resolve hazards and failures. Both qualitative and quantitative methods are used to identify areas in a system that are most critical to safe operation—either approach is effective. The output is a graphical presentation providing technical and administrative personnel with a map of "failure or hazard" paths. The reviewer and the analyst must develop insight into system behavior, particularly those aspects that might lead to the hazard under investigation.

Qualitative Fault Tree Analyses are cost-effective and valuable safety engineering tools. The generation of a qualitative fault tree is the first step. Quantitative approaches multiply the usefulness of the Fault Tree Analysis but are more expensive and often difficult to perform.

A Fault Tree Analysis (such as a logic diagram) is a "deductive" analytical tool used to study a specific undesired event such as "bus door relay failure." The "deductive" approach begins with a defined unwanted event, usually a postulated accident condition, and systematically considers all known events, faults, and occurrences that could cause or contribute to the occurrence of the undesired event. Top-level events may be identified through any safety analysis approach, through operational experience, or a "could it happen?" hypothesis. The procedural steps of performing a Fault Tree Analysis are the following:

- Assume a system state and identify and document the top-level undesired event(s). This is often accomplished by using a Preliminary Hazards Analysis (PHA). Alternatively, design documentation such as schematics, flow diagrams, and level B and C documentation may be reviewed.
- Develop the upper levels of the trees via a top-down process—determine the intermediate failures and combinations of failures or events that are the minimum to cause the next higher-level event to occur. The logical relationships are graphically generated, as described below, using standardized Fault Tree Analysis logic symbols.
- Continue the top-down process until the root causes for each branch are identified and until further decomposition is not considered necessary.
- Assign probabilities of failure to the lowest level event in each branch of the tree. This may be through predictions, allocations, or historical data.
- Establish a Boolean equation for the tree using Boolean logic and evaluate the probability of the undesired top-level event.
  - Start with the idea that some statement P is either true or false, it cannot be anything in between (this called the law of the excluded middle).
  - Then form other statements, which are true or false, by combining these initial statements using the fundamental operators “and,” “or,” and “not.”
- Compare to the system level requirement. If the requirement is not met, implement corrective action. Corrective actions vary from redesign to analysis refinement.

The output of the Fault Tree Analysis is a graphical logic representation of fault events that may occur to a functional system (sample provided in Figure H-2and symbols described in Figure H-3). This logical analysis must be a functional representation of the system and must include all combinations of system fault events that can cause or contribute to the undesired event. Each contributing fault event should be further analyzed to determine the logical relationships of underlying fault events that may cause them. This tree of fault events is expanded until all "input" fault events are defined in terms of primary, identifiable faults that may then be quantified for computation of probabilities if desired. When the tree has been completed, it becomes a logic gate network of fault paths, both singular and multiple, containing combinations of events and conditions that include primary, secondary, and upstream inputs that may influence or command the hazardous mode.[66]

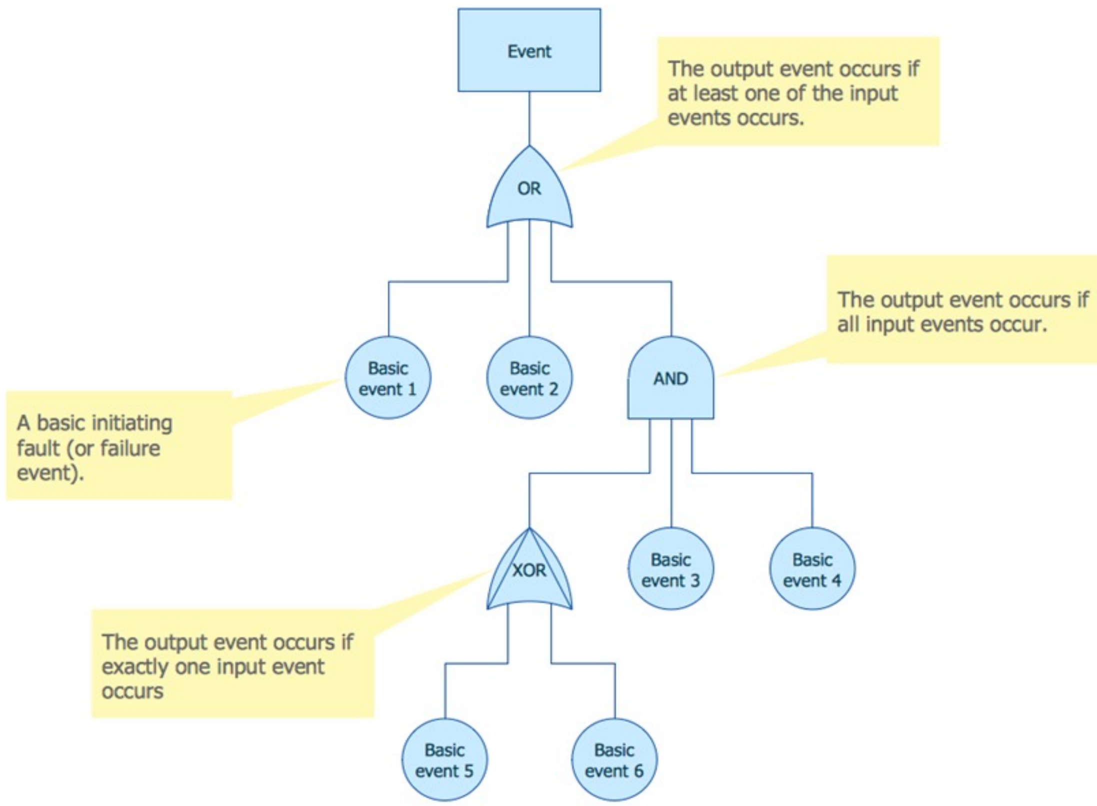


Figure H-2 *Sample Fault Tree*

[66] *Ibid*., pg. 9-5.

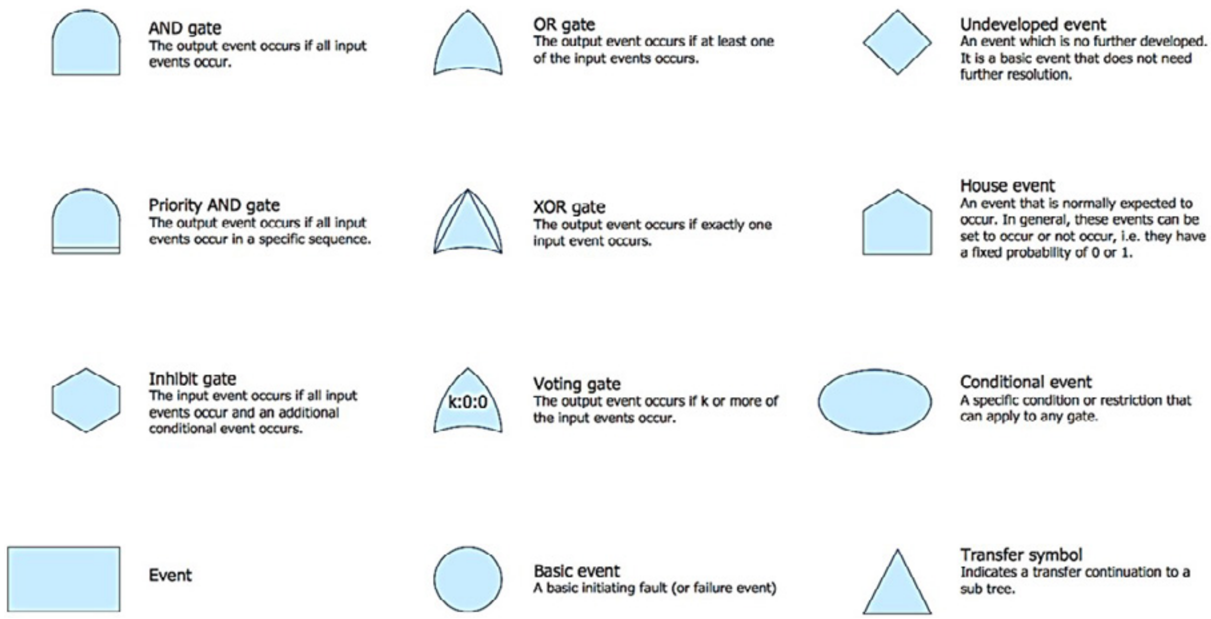


Figure H-3 *Fault Tree Symbols*

Fault tree analysis tools are designed to help the investigator dig deeper beyond proximate cause and identify more fundamental or "root" causes (Figure H-4). Fault tree analysis allows an investigator to map out possible causal scenarios in a graphic manner. Fault tree analysis imposes a logic flow that can help to support the probable cause of an event. A simplified example is shown below.

At the top of the chart is the "event"—in this case, no light in a room. Two logical explanations are provided—no natural light and no artificial light. These are proximate causes. These conditions are linked to the event box by an "and" gate, meaning both conditions must exist together. Possible causes are in circles at the bottom of the graphic. These are connected to the logical explanations by "or" gates, meaning that any one of these causes would be sufficient to result in the event.

Further analysis of factual information developed in an investigation will help to rule in or rule out the bottom level causes. For example, if the light bulb tests OK, we can rule out light bulb failure from the equation. When you get to the bottom level of a fault tree, you are at the root cause. In the above example, you can envision going deeper (see "5" whys below). For instance, if a fault in the electric circuit is verified, we would then ask why? Was there a maintenance issue, an overload issue, a training issue, a parts issue?

Several commercial vendors produce proprietary root cause analysis tools and also provide training classes. A free root cause analysis tool can be obtained from NASA at the following link: http://nsc.nasa.gov/RCAT/Software/NewRequest.

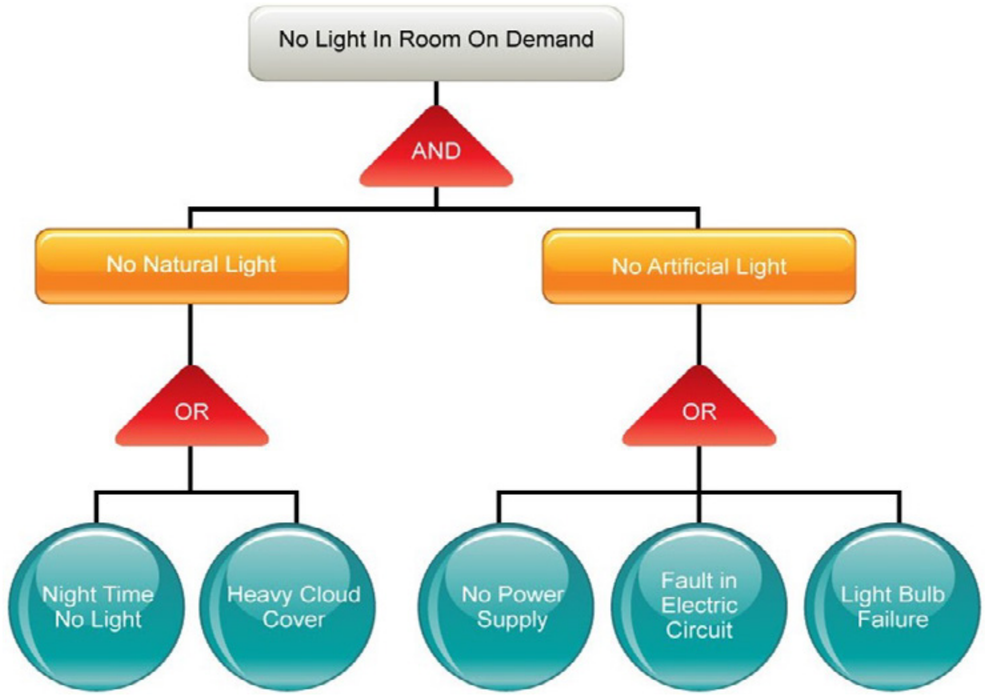


Figure H-4 *Fault Tree Analysis*
Source: TSI

SHEL Model

The International Civil Aviation Organization (ICAO) SHEL model (Figure H-5) is a conceptual tool used to analyze the interaction of multiple systems. It was first introduced by Edwards in 1972 and modified by Hawkins in 1975. According to the SHEL Model, a mismatch between the Liveware and the four other components contributes to human error. It groups factual material into groups:

- Software – documentation, procedures, symbols
- Hardware – machinery, equipment
- Environment – internal, external
- Liveware (Central) – Human element
- Liveware (Peripheral) – Other humans involved in the activity

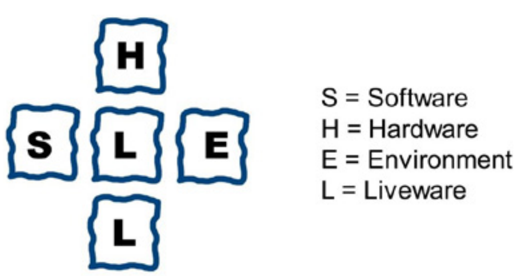


Figure H-5 *SHEL Model*
Source: ICAO 9859, Safety Management Manual

"5 Whys?"

A similar method of getting to the root cause is often referred to as the "5 Whys," a system that involves asking "why" until you reach the root cause of an event. A simplified example is as follows:

1. Why did the vehicle veer off the road? Because the left front rim and tire separated from the hub.
2. Why did the left front rim and tire separate from the hub? Because the lug nuts came loose.
3. Why did the lug nuts come loose? Because they were improperly torqued.
4. Why were they improperly torqued? Because the torque wrenches were out of calibration.
5. Why were the torque wrenches out of calibration? Because the organization lacked an effective calibration policy and procedure.

Stopping at #1 or #2 will fix only the immediate problem on the accident vehicle—the out-of-calibration torque wrench remains in service awaiting the next accident. Even stopping at #5 fixes only the individual torque wrench and does not entirely solve the problem. In this case, you could go on for a couple more "why" levels to get at a root cause related to organizational policy, procedures, management oversight, quality control, training. The idea is not to stop short so that the underlying problem can be identified and dealt with. The analysis logically links to the cause and lays the foundation for the recommendations to address the deficiencies, and which lead to CAPs. These four tools can help an investigator organize their thinking and assist in determining the critical factors in the accident scenario.

Appendix I

Investigation Report Organization/ Content

Two NTSB major accident reports were organized as follows:

- **Fatal Pedestrian Collision with Transit Bus, New York City, New York, October 4, 2016 (HWY17SH003). Adopted: September 5, 2018**
  - Crash description
  - Crash location
  - Pedestrian
  - Driver
  - Vehicle
  - MTA
  - Vehicle-based countermeasures S-1 guard, turn audible warning, collision warning alert devices, lane departure, pre-collision auto-braking
  - Applicable traffic laws
  - Roadway design
  - Probable cause
- **School Bus Run-Off-Road and Fire, Oakland, Iowa, December 12, 2017 (NTSB/HAR – 19/01)**
  - Figures and Tables
  - Acronyms and Abbreviations
  - Executive Summary
  - Section 1.0 Factual Information
    - 1.1 Run-Off-Road and Post-crash Fire Narrative
    - 1.2 Injuries
    - 1.3 School Bus Driver Information
      - 1.3.1 License, Employment, Training, and Driving History
      - 1.3.2 Medical Information
      - 1.3.3 Pre-crash Activities
    - 1.4 Motor Carrier Operations
      - 1.4.1 Riverside Community School District
      - 1.4.2 State of Iowa Requirements
      - 1.4.3 Emergency Evacuation Drills
      - 1.4.4 Federal Motor Carrier Safety Administration Requirements
    - 1.5 Vehicle
      - 1.5.1 General
      - 1.5.2 Damage
      - 1.5.3 On-Scene Evidence

    - 1.5.4 Maintenance and Inspection
    - 1.5.5 Configuration
  - 1.6 Highway Factors
  - 1.7 Weather
  - 1.8 School Bus Fire Protection
    - 1.8.1 Federal Interior Flammability Standards and Specifications
    - 1.8.2 State School Bus Interior Flammability Standards and Specifications
    - 1.8.3 Fire Suppression Systems
    - 1.8.4 Fire Demonstrations
  - 1.9 Similar Bus Fires Investigated by NTSB
    - 1.9.1 Mesquite, Texas
    - 1.9.2 Orland, California
    - 1.9.3 Wilmer, Texas
    - 1.9.4 Carrollton, Kentucky
- Section 2.0 Analysis
  - 2.1 Introduction
  - 2.2 Crash and Origin of Bus Fire
  - 2.3 School Bus Driver Fitness for Duty
    - 2.3.1 Medical Issues
    - 2.3.2 Physical Performance Tests
    - 2.3.3 Driver Oversight
    - 2.3.4 Driver Medical Referrals
    - 2.3.5 Safety Recommendations
  - 2.4 School Bus Fire Safety
    - 2.4.1 Fire Data
    - 2.4.2 Fire Suppression Systems
    - 2.4.3 Fire-Resistant Materials
    - 2.4.4 Safety Recommendations
  - 2.5 School Bus Emergency Training
    - 2.5.1 Drivers
    - 2.5.2 Passengers
    - 2.5.3 Safety Recommendations
- Section 3.0 Conclusions
  - 3.1 Findings
  - 3.2 Probable Cause

Less complicated and more minor accidents may use a more abbreviated format depending on the circumstances. NTSB uses a "brief" report format for less complicated accidents. Most NTSB brief reports include the following headings:

- Accident
- Background
- Investigation

- Safety Issues
- Post-Accident Actions
- Probable Cause (and contributing factors)
- Recommendations

Absent other direction from an agency's policy, the NTSB accident report organizational model is considered an industry best practice for accident reports. The format and report organization used by the agency may be spelled out by a SSOA in those states where SSOAs oversee bus transit operational safety.

Detailed report content descriptions and examples are provided below and are based on elements found in NTSB major incident reports.

Figures and Tables

This section is for the convenience of the reader to find figures and tables within the report.

Acronyms and Abbreviations

A general report writing convention is to spell out an acronym or abbreviation for the first use in the text and include the acronym or abbreviation in parenthesis. After that, use the acronym or abbreviation—for example, Too many acronyms (TMA). Only the acronyms and abbreviations used in the report need to be included in this section.

Executive Summary

The Executive Summary is a condensed version of the full report intended to allow readers to get acquainted with a large body of material without having to read the entire document. It is an essential section of a major report, as many readers will rely on it for a "big picture" view of the accident and may not read many other parts of the report. The Executive Summary will typically contain a brief description of the accident, pertinent background information, concise analysis, main conclusions concerning causal and contributing factors in the accident, and corrective actions already undertaken.

Factual Information

General

This section is the start of the full report and provides a detailed factual account of the accident without providing an analysis. It provides an overview of the accident and focuses on those areas that are relevant to the cause of the accident and lead to the recommendations. The facts support the analysis that, in turn, supports the cause and recommendations. The factual section does not need to address every single fact that has been developed over the course of the investigation; however, there needs to be a clear logic chain between facts, analysis, conclusions, and cause.

Accident

The accident description provides the basic facts of the accident. It tells the reader the "who," "what," "where," and "when," with the "why" reserved for the Analysis section. A map or aerial image of the scene is helpful here.

Accident Narrative

This section tells the factual story of the accident. The timeline is a significant help here. Usually, the "story" begins at the start of the trip or shift and leads up to and includes the accident sequence.

Effective Investigation Practice

Typical information in the accident description section of a report includes:

- Type of accident, i.e., fire, collision, bus ran off the road
- Accident date and time
- Accident location
  - System route name/number
  - Location identifier (road milepost or cross street)
- Equipment/staff involved
- Bus type and direction of travel
- Operator's view on approach
- Other vehicles/equipment/persons involved
- Other vehicle types, direction, makeup (if applicable)
- Injury summary
- Total damage
- Weather conditions

Factual Information – Agency Background

This section explains the organizational relationships and how the agency's safety plan ties it all together. With a single owner/operator, it is relatively straightforward, but some agencies have more complicated arrangements with multiple contractors operating transit buses and maintaining rolling stock and infrastructure.

Operations

This section lays out the operating scheme (single track, double track, signaled, non-signaled), train control system, governing operating documents, operating rule book, and any other operations manuals or guidance. Lay out factually any discrepancies between requirements and what happened during the accident sequence. For example, hypothetically, the posted speed was 25 mph. Event recorder data indicated that the accident bus was traveling at 35 mph just before the event. Based on recorder data or analysis of tire marks, factual calculations of speed and stopping distance belongs in this section. Save a discussion of the significance of these facts for the analysis section.

Oversight

This is the location to explain the SSO relationship, if there is one, when and how the event was reported, and the involvement of the SSO in the investigation. Depending on the circumstances of the accident, the agency may discuss the agency safety plan, rules compliance programs, and other relevant management programs. Any other agency that may be involved should be explained here; for example, if FTA had a role or OSHA is involved in an employee injury event.

Personnel Information

This section covers the relevant key players in the accident, which might include bus operators, maintenance technicians, controllers, or supervisors. Personnel information might consist of fitness for duty checks, training and experience, disciplinary record, and promotion history. Remember not to include any personally identifiable information such as social security numbers, phone numbers, or addresses.

Damages

Dollar damages are broken down by category (e.g., Infrastructure, Transit Agency Vehicles, Private Vehicles). A simple table format can be used.

Equipment Information

This section lays out the necessary information on the bus or other equipment involved. Describe the pre-departure inspection of the equipment and any anomalies discovered. Include factual information that is relevant to the accident, for example, weight, crashworthiness design features, rehabilitation history, or age. Describe the post-accident positions of equipment and a factual description of damage. Photos and diagrams can be helpful with this.

Survival Factors

This section focuses on issues related to the survivability of the passengers and the bus operator (or any other agency personnel) and the ability of the passengers and crew to safely evacuate. Factual information on survivable space, emergency exits, and lighting, emergency information (signs and announcements), seat securement, emergency equipment, and injury locations within equipment. The size, scope, and content of this section will vary considerably based on the circumstances of each accident. Some accidents may not need a survival factors discussion, but investigators should be alert to improvement opportunities that survival factors investigation can reveal.

Injuries

This section should include the simple injury table noted in the post-on-scene section. More detailed injury information, if available, should be used to show injury locations within equipment and other details that may support recommendations for equipment improvements. Transit agencies should consult their legal department on any health-related data to avoid sharing medical information in violation of HIPAA.[67]

Emergency Response

Explain which response agencies were involved. List the factual information regarding time notified, time of arrival, and any delays or problems with evacuation, triage, or transport of injured. A response timeline table is helpful here. Include any factual information from the debrief.

Infrastructure

Include a short description of the roadway and any specialized features, for example, on a dedicated busway. If infrastructure elements were factors in the accident, a detailed factual description of the condition, history, inspections, maintenance, and any discrepancies should be provided in sufficient detail to support any conclusions and causal statements in the analysis factually.

Traffic Control Systems

In an accident with no traffic signal connection to the cause, this section can be addressed by including a short description of the system. If the system was a factor in the accident, a detailed factual description of the condition, history, inspections, maintenance, and any discrepancies should be provided in sufficient detail to support any conclusions and causal statements in the analysis factually.

Other infrastructure

This section discusses any other infrastructure or system that may have been a factor in the accident—for example, trolley Overhead Contact System (OCS), communications, ventilation in a bus tunnel, or SCADA. Any discrepancies between requirements and performance should be laid out factually. The goal is to logically tie in the factual discussion to support the conclusions in the analysis.

Analysis

General

This is the area of the report where the meaning of the facts is explained. When there is a discrepancy between what policy, procedures, specifications, or regulation requires and what is found in the accident, the Analysis section is where the significance of the facts developed are discussed. Some

[67] For specific details on HIPAA requirements, see U.S. Department of Health & Human Services' website at www.hhs.gov.

discrepancies may not pass a "so what" test; for example, a bus traveling 3 mph over the 40-mph speed limit is not likely a factor in an event, but a bus traveling at 30 mph over the speed limit likely is. Keep in mind the logic chain that must be present.

Introduction

The introduction provides the opportunity to discuss exclusions, the potential causal areas that were examined and found not to be factors in the accident. For example, in a possible collision, the report might note that investigators inspected and tested the braking system and examined maintenance records with no anomalies found. At the end of the introduction, provide a summary noting that the investigation concluded that the condition of the braking system was not a factor in this accident. That statement is then repeated in the Conclusions section.

Specific Issues Identified in an Accident

In this section, the report discusses and analyzes the factors judged to be factors in the accident. For example, in a hypothetical collision, if it was found that the brakes were not applied before impact (or did not engage preventing impact), the report would provide a detailed analysis of the factors involved. This is where the "5 Whys" might come into play in examining procedures, equipment, communication between the bus operator and maintenance, maintenance and operations, and operations and the bus operator.

At the end of each analysis discussion, specify and explain the conclusion reached. There needs to be a clear logic chain between the facts, analysis, and conclusion.

Effective Investigation Practice

A logic chain strives for:

- Facts based on observable, verified and accurate information
- Analysis based on those facts
- Conclusions based on analysis
- Causes and contributing factors are the output of that logic chain
- Recommendations address cause and contributing factors

Human Performance

Any human performance issues such as work environment, fatigue, experience, training, impairment, distraction, or medical conditions[68] are discussed here. Refer to the Human Factors section of this report for more details.

Survival Factors

Equipment Crashworthiness

If no crashworthiness issues were developed, this section may not be needed. Crashworthiness issues such as loss of survivable space, windows that detached

[68] Ensure compliance with HIPAA requirements.

resulting in ejections, or interior amenities that broke loose resulting in injuries would be discussed here.

Emergency Response

This section evaluates the response and highlights any problems with the response. Areas that might be covered include:

- Delayed arrival/locating the scene
- Access to the scene and equipment
- Evacuations
- Agency employee performance and training
- Rescue and recovery
- Triage and transport of injured
- Communication and coordination between the transit agency and responders
- Responder training and familiarization provided by the transit agency
- Past exercises, or lack thereof

If any responders were injured during the response, a discussion is needed in this section on the nature of the injuries and the circumstances. This may lead to recommendations on training, equipment, or procedures under agency control. Any problems discussed in this section must be supported by factual information.

Conclusions – Findings

Findings are the logical outgrowth of the analysis, which is, in turn, the logical outgrowth of the facts. This section repeats the conclusions that have been developed in the text and presents them in a list format.

Probable Cause and Contributing Factors

This section is in two parts—1) the primary cause as determined by the facts and the analysis conducted by the transit agency investigator/investigative team, and 2) contributing factors discovered during the analysis of the facts that without these factors, the accident may not have occurred. In NTSB reports, sometimes the probable cause is the proximate (as opposed to root) cause with elements of the root cause listed as contributing factors. In other reports, the probable cause is a root cause with proximate causes listed as contributing. Since the more in-depth objective of the investigation is to identify preventive measures, elements of the causal picture that best logically support the preventive recommendations is needed in the report. The primary causal and contributing factors of the accident should be clearly stated in the conclusion section.

Effective Investigation Practice

Example of logic flow:

- Fact: Vehicle brakes were not applied before impact.
- Fact: Vehicle speed was 30 mph at impact.
- Fact: Sight distance reconstructions indicate that obstruction at the point of impact was visible from 350 ft.
- Fact: Vehicle operator had approximately 8 secs to detect the obstacle and apply brakes but did not do so.
- Fact: Witnesses and inward-facing video showed vehicle operator looking downward and manipulating a smartphone.
- Analysis: Conclusion – Had operator been alert and looking forward, obstruction would have been detected and vehicle stopped short of collision.
- Probable Cause: Operator distraction resulting from use of a cellphone for texting.

*The contributing factors in this hypothetical example would lay out relevant issues such as training and management oversight that were explained in the analysis.

Recommendations

The report should provide immediate recommendations and discuss corrective actions implemented as the report was being prepared, i.e., a chafing wire was identified during the post-accident investigation of a bus fire, which triggered a fleet-wide inspection.

Once the probable cause has been determined and the contributing factors identified, the investigators and the associated agency departments develop a realistic and practical remedy to prevent a similar accident from occurring again. This may take time and money or may involve immediate changes to rules and procedures, but it must be fully understood what needs to be done immediately, within the short term, and what long-term solution is required to prevent future events of this nature.

The recommendations section of a report must provide a set of actions that should be taken to prevent reoccurrences of this accident. These recommended improvements should be organized by time so those requiring immediate action can be implemented and others requiring more time and funding can be scheduled for a permanent fix for elimination of the problems leading to this accident. Long-term recommendations may require capital budgets, re-design, or extensive system modifications, i.e., retiring legacy vehicles or upgrading them with newer components or technologies.

Recommendations are action items. Each should begin with an action verb (i.e., conduct, revise, or modify) that will result in measurable action. There should be a clear logic chain from the facts to the analysis to the conclusions to the recommendations.

Recommendations will drive corrective actions, so they need to be worded in a way that supports the corrective action format and have identifiable and measurable outcomes. For example, a recommendation reading “Improve emergency responder training” would not meet this test. A more focused approach is needed, such as “Revise the emergency responder training program to cover the evacuation of passengers and personnel through transit vehicle emergency exits.” Recommendations should logically link to the corrective action plans.

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Acronyms and Abbreviations

ACN	Automatic Collision Notification
ALARP	As Low as Reasonably Practicable
APTA	American Public Transportation Association
ASRS	Aviation Safety Reporting System
ASSP	American Society of Safety Professionals
ATU	Amalgamated Transit Union
AVL	Automatic Vehicle Locator
BMI	Body Mass Index
BP	British Petroleum
BRP	Blue Ribbon Panel
BRT	Bus Rapid Transit
BTS	Bureau of Transportation Statistics
CCTV	Closed Circuit Television
C3RS	Confidential Close Call Reporting System
CAP	Corrective Action Plan
CEO	Chief Executive Officer
CFR	Code of Federal Regulations
CM	Configuration Management
CNG	Compressed Natural Gas
CSB	Chemical Safety and Hazard Investigation Board
CSO	Chief Safety Officer
CUTR	Center for Urban Transit Research
EAP	Employee Assistance Program
EDR	Event Data Recorder
EMS	Emergency Medical Services
FAID	Fatigue Audit InterDyne
FAST	Fatigue Avoidance Scheduling Tool
FD	Fire Department
FEMA	Federal Emergency Management Agency
FMCSA	Federal Motor Carrier Safety Administration
FMEA	Failure Modes and Effects Analysis
FMP	Fatigue Management Program
FRA	Federal Railroad Administration
FRSA	Federal Railroad Safety Act
FSI	Fatal/Serious Injury
FTA	Federal Transit Administration
FT/S	Feet per Second
HAZWOPER	Hazardous Waste Operations and Emergency Response
HBV/HIV	Hepatitis B Virus/Human Immunodeficiency Virus
HF	Human Factors
HIPAA	Health Insurance Portability and Accountability Act

IC	Incident Commander
ICAO	International Civil Aviation Organization
ICS/NIMS	Incident Command System/National Incident Management System
IIC	Investigator-in-Charge
IPTM	Institute for Police Technology and Management
LIRR	Long Island Railroad
LRU	Line Replaceable Units
LTA	Lost Time Accident
MAP–21	Moving Ahead for Progress in the 21st Century Act
MIL-STD	Military Standard
MNR	Metro-North Railroad
M.O.	Middle Ordinate
MOU	Memorandum of Understanding
MPH	Miles per Hour
MTA	Metropolitan Transportation Authority
NASA	National Aeronautics and Space Administration
NATSA	North American Transit Services Association
NFPA	National Fire Protection Association
NHTSA	National Highway Traffic Safety Administration
NTD	National Transit Database
NTSB	National Transportation Safety Board
NYCT	New York City Transit
OCS	Overhead Contact System
OEM	Office of Emergency Management
OHA	Operating Hazard Analysis
OJT	On-the-Job Training
ORA	Organizational Risk Assessment
OSA	Obstructive Sleep Apnea
OSHA	Occupational Safety and Health Administration
OTC	Over the Counter
PD	Police Department
PHA	Preliminary Hazard Analysis
PIO	Public Information Officer
PPE	Personal Protective Equipment
PRT	Peer Review Team
PRTT	Priority Request to Talk
PTASP	Public Transportation Agency Safety Plan
RAC	Risk Assessment Code
RI	Risk Index
RL	Reference Line
RP	Reference Point
RTA	Rail Transit Agency
SA	Safety Assurance
SAFTE	Sleep, Activity, Fatigue and Task Effectiveness

SCADA	Supervisory Control and Data Acquisition
SDP	Standards Development Program
SGR	State of Good Repair
SHA	System Hazard Analysis
SHEL	Software Hardware Environment Liveware
SME	Subject Matter Expert
SMS	Safety Management System
SOP	Standard Operating Procedure
SRM	Safety Risk Management
SSA	Software Safety Analysis
SSC	Safety and Security Certification
SSHA	Subsystem Hazard Analysis
SSO	State Safety Oversight
SSOA	State Safety Oversight Agency
TAM	Transit Asset Management
TCRP	Transit Cooperative Research Program
TRACS	Transit Advisory Committee for Safety
TSI	Transportation Safety Institute
TSSP	Transit Safety and Security Program
TWU	Transport Workers Union
U.S.	United States
WMATA	Washington Area Metropolitan Transit Authority
WMSC	Washington Metrorail Safety Commission
ZBB	Zero-based budget

Traffic Investigation Terminology

Acceleration: Time rate of change of velocity; change of velocity divided by time; a vector quantity measured in feet per second per second (fps2) or expressed as a decimal fraction of the acceleration of gravity (32.2 fps2).

Apex: Point at which two sides of an angle meet or cross.

Area of Impact: Place on the roadway or ground closest to the first contact between colliding objects.

Arc: Part of a curve, especially a part of a circle, between two points on a curve.

Berm: See Shoulder.

Braking Distance: Distance through which brakes are applied to slow a vehicle; the shortest distance in which a particular vehicle can be stopped by braking from a specified speed on a particular surface; the distance from brake application to a collision.

Braking Skid Mark: see Skid Mark.

Centrifugal Force: Force of a body in motion, which tends to keep it continuing in the same direction rather than following a curved path.

Chord: Straight line connecting the ends of an arc or two points on a curve.

Coefficient of Friction: Dimensionless number representing the resistance to sliding of two surfaces in contact; the drag factor of a vehicle or other object sliding on a roadway or other surface which is level.

Collision: Occurrence in a sequence of events that usually produces unintended death, injury, or property damage. The term 'collision' has gained wider acceptance as a more accurate term for what used to be referred to as an accident.

Contact Damage: Damage to a vehicle resulting from the direct pressure of some foreign object in a collision or rollover. It is usually indicated by striations, rub-off of material, or puncture. Compare with induced damage.

Controlled Final Position: Final position reached because of the conscious effort of some person to modify the motion of a traffic unit after a collision.

Coordinate: a method of locating a spot in an area by measurements along and at right angles to a RL or by measurements of the shortest distances to each of two intercepting RLs. Compare with triangulation.

Critical Speed: Speed at which the centrifugal force of a vehicle following a specific curve exceeds the traction force of the tires on the surface, a velocity above which a particular highway curve could not be negotiated by a vehicle without yaw.

Critical Speed Marks: See Yaw Marks.

Crook: Abrupt change of direction of a tire mark due to collision forces. See Offset.

Debris: Loose material strewn about the road as the result of a traffic collision; dirt, liquids, vehicle parts, and other materials from the involved traffic units.

Deceleration: Rate of slowing; negative acceleration. Disengagement: see the last contact.

Drag Factor: Number representing the acceleration or deceleration of a vehicle or other body as a decimal fraction of the acceleration of gravity. When a vehicle slides with all wheels locked, the drag factor is the same as the coefficient of friction.

Energy: Ability to do work or produce an effect such as damage; a unit of force operating through a unit of distance; half the mass or weight times velocity squared; measured in foot-pounds (ft-lb).

Final Position: Location of a vehicle or body when it comes to rest after a collision; final positions may be controlled or uncontrolled.

First Contact: Initial touching of objects in a collision; the place on the road or ground where this touching occurs.

First Harmful Event: First occurrence in a traffic collision that results in appreciable damage or injury.

Flip: Movement of a vehicle, without touching the ground, from a place where its forward velocity is suddenly stopped by an object such as a curb or furrow-in below its center of mass with the result that the ensuing rotation lifts the vehicle off the ground. A flip is usually sidewise, but if it is endwise, it is a vault.

Fogline: Solid white line that separates the drive lanes from the shoulder/berm area.

Furrow: Channel in loose or soft material, such as soil or dirt, made by a skidding or scuffing tire or some other part of a moving vehicle.

Gap Skid: Braking skid mark that is interrupted by release and reapplication of brakes or which terminates by the release of brakes before the collision. Compare with skip skid.

Gouge: Pavement scar deep enough to be easily felt with the fingers.

Grade: Change in elevation in the unit distance in a specified direction along the centerline of a roadway or the path of a vehicle; the difference in the level of two points divided by the level distance between the points.

Highway: Entire width between the boundary lines of every way publicly maintained when any part thereof is open to the use of the public for purposes of vehicular travel.

Imprint: Mark on the road made without sliding by a rolling tire.

Induced Damage: Damage to a vehicle other than contact damage, often indicated by bending, braking, and distortion. Compare with contact damage.

Intersection: When two or more roadways cross or connect, the area contained within the extension of curb lines, or if none, then the lateral roadway boundary lines are defined as the intersection.

Kinetic Energy: Amount of energy represented by a moving body; half of the mass times the square of the velocity.

Last Contact: Final touching of objects in a collision before separation.

Maximum Engagement: Greatest penetration of one body, such as a vehicle, by another during a collision; the moment of greatest force between objects in a collision.

Middle Ordinate: Perpendicular distance between an arc and its chord in the middle of the chord.

Nomograph: Graph on which three or more scales are arranged so that a straight line drawn through values on any two will cross the third at a corresponding value.

Radius: Distance from the center of a circle to a point on its perimeter (circumference); the distance from a point on an arc to the center of the circle of which the arc is part.

Reference Line: Line, often the edge of a roadway, from which measurements are made to locate spots, especially spots along a roadway.

Reference Point: Point from which measurements are made to locate spots in an area; sometimes, the intercept of two reference lines; RP.

Road: Part of a traffic way that includes both the roadway, which is the traveled part and any shoulder or berm along the roadway.

Roadway: Portion of the highway improved, designed, or ordinarily used for vehicular travel, exclusive of the berm and shoulder.

Rollover: Situation where the vehicle rolls at least 90 degrees. The term rollover is also sometimes used to describe a pitch over (vault).

Scrape: Broad area of a hard surface covered with many scratches or striations made by a sliding metal part without significant pressure.

Scuff Mark: Friction mark on a pavement made by a tire that is both rotating and slipping.

Shoulder: Portion of the road contiguous with the roadway for the accommodation of stopped vehicles, for emergency use, and lateral support of the roadway structure.

Skid Mark: Friction mark made on a pavement by a tire that is sliding without rotation.

Skip Skid: Braking skid mark interrupted at frequent regular intervals; the skid mark made by a bouncing wheel on which brakes keep the wheel from turning.

Traffic: Pedestrians, ridden or herded animals, vehicles, streetcars, and other conveyances either singly or together while using any highway for purposes of travel.

Trafficway: see Highway.

Triangulation: method of locating a spot in an area by measurements from two or more reference points, the locations of which are identified for future reference.

Uncontrolled Final Position: final position reached by a traffic unit after a collision without conscious human intervention.

Vault: Endwise flip.

Vehicle: Every device in, upon, or by which any person or property is or may be transported or drawn upon the highway, excepting devices moved by human power or used exclusively upon stationary rails or tracks.

Velocity: Time rate of change of position in which direction, as well as rapidity, is an element; distance divided by time if velocity is constant.

Yaw Mark: see Scuff Mark.

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