SYSTEM SAFETY PLAN FOR COMMERCIAL VEHICLES USING HYDROGEN AS AN ALTERNATIVE FUEL

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

November 2007

FOREWORD

This System Safety Plan (SSP) guidance document was the result of Task 4 of a project to help ensure overall safety of commercial vehicle fleets that implement hydrogen systems and equipment. System safety planning and management are considered important activities required to successfully implement and safely operate hydrogen systems on commercial vehicles. This guidance document is intended to serve the following purposes:

- To provide guidance on recommended elements of an SSP for commercial vehicle fleet operators that plan to implement hydrogen systems and equipment
- To establish a recommended format for an SSP
- To document the means and expertise of the commercial vehicle fleet operator for implementing a sound, effective, proactive SSP to reduce accidents related to hydrogen systems

This report provides guidance in the development of system safety programs for commercial vehicle fleet operators interested in or operating hydrogen systems and equipment. The key aspects of preparing an SSP include:

- Policies, authority, and administration
- Hazard identification and management
- Operating rules, training and procedures
- System safety reviews and audits

This report is not intended to be an in-depth specification to be used by Original Equipment Manufacturers (OEMs) or other vendors/suppliers in order to design and build hydrogen systems and equipment. The responsibility for safety design standards, including hydrogen systems and equipment, falls under the jurisdiction of the National Highway Traffic Safety Administration (NHTSA). However, once hydrogen systems and equipment are placed in service in a commercial vehicle fleet, regulatory responsibility for operations and maintenance falls under the FMCSA.

NOTICE

Technical Report Documentation Page (Form 1700.7)

1. Report No. **FMCSA-RRT-07-025**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: **System Safety Plan for Commercial Vehicles Using Hydrogen as an Alternative Fuel**		5. Report Date: **November 16, 2007**
		6. Performing Organization Code **MC-RRT**
7. Author(s): **John M. Simon, CSP, Booz Allen Hamilton Inc.** **Stephen Brady, Booz Allen Hamilton Inc.** **Dana Lowell, M. J. Bradley & Associates** **Michael Quant, Booz Allen Hamilton Inc.**		8. Performing Organization Report No.
9. Performing Organization Name and Address: **Booz Allen Hamilton Inc.** **444 S. Flower Street, Suite 1850** **Los Angeles, California 90071**		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. **GS-23F-0025K**
12. Sponsoring Agency Name and Address: **U.S. Department of Transportation** **Federal Motor Carrier Safety Administration – Technology Division (MC-RRT)** **1200 New Jersey Ave. SE** **Washington DC 20590**		13. Type of Report and Period Covered **Final Report**
		14. Sponsoring Agency Code **FMCSA**
15. Supplementary Notes: **Contracting Officer's Technical Representative:** **Quon Y. Kwan, Program Manager**		
16. Abstract: **Over the next 50 years, hydrogen use is expected to grow dramatically as an automotive and electrical power source fuel. As hydrogen becomes commercially viable, the safety concerns associated with hydrogen systems, equipment, and operation are of concern to the motor vehicle industry. This report is intended to provide guidance for the development of a System Safety Plan that would be used by a commercial vehicle fleet operator to ensure long-term safe operation of commercial vehicles utilizing hydrogen, regardless of the number of commercial vehicles in the fleet.**		
17. Key Words: **Hydrogen Safety, System Safety Plan, Hydrogen**		18. Distribution Statement **No restrictions.**

19. Security Classif. (of this report) **Unclassified**	20. Security Classif. (of this page) **Unclassified**	21. No. of Pages: **37**	22. Price

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	Acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		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
		MASS		
oz	Ounces	28.35	grams	g
lb	Pounds	0.454	kilograms	kg
T	short tons (2000 lbs)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit Temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m2	cd/m2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lbs)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	Lux	0.0929	foot-candles	fc
cd/m2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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ACRONYMS

CCIL	Critical/Catastrophic Items List
FMCSA	Federal Motor Carrier Safety Administration
FMEA	Failure Modes and Effects Analysis
GCW	Gross Combined Weight
GCWR	Gross Combined Weight Rating
GVW	Gross Vehicle Weight
GVWR	Gross Vehicle Weight Rating
HAZOP	Hazard and Operability Analysis
MIL-STD 882	Military Standard 882
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturer
OHA	Operating Hazard Analysis
PHA	Preliminary Hazard Analysis
SSP	System Safety Plan

EXECUTIVE SUMMARY

Over the next 50 years, hydrogen use is expected to grow dramatically as an automotive and electrical power source fuel. As hydrogen becomes commercially viable, the safety concerns associated with hydrogen systems, equipment, and operation are of concern to the motor vehicle industry.

As a result of the President's Hydrogen Fuel Initiative, the Federal Motor Carrier Safety Administration (FMCSA) initiated a project to facilitate the use of hydrogen as an alternative fuel in commercial vehicles with a focus on safety during vehicle operations and maintenance. As a result of that project, FMCSA developed "Guidelines for the Use of Hydrogen in Commercial Vehicle," "Recommended Changes to the Federal Motor Carrier Safety Regulations and North American Inspection Procedures to Accommodate Hydrogen as an Alternative Fuel," and this report.

This particular report, which results from Task 4 of the FMCSA project, is intended to provide guidance for the development of a System Safety Plan (SSP) that would be used by a commercial vehicle fleet operator to ensure long-term safe operation of commercial vehicles utilizing hydrogen, regardless of the number of commercial vehicles in the fleet.

Specifically, this report provides guidance in the areas of hydrogen safety planning and management, including:

- System safety planning and administration
- Hazard analysis
- Operating rules, training, and procedures
- Reviews and audits
- Emergency call-out procedures

Appendix A includes a generic outline for a System Safety Plan, which identifies all of the elements, or sections, that should be included. The remainder of this document discusses each of these elements, and is arranged in the same order as shown in Appendix A.

1. SYSTEM SAFETY PLANNING AND ADMINISTRATION

System safety is defined as "the application of engineering and management principles, criteria, and techniques to achieve acceptable mishap risk, within the constraints of operational effectiveness and suitability, time and cost, throughout all phases of the system lifecycle."[1] The fundamental principles of system safety were initially developed in the late 1960s by the United States Department of Defense in the form of Military Standard 882 (MIL-STD-882D). Preparing a written System Safety Plan defines the activities that will be conducted in order to ensure safe and reliable operation of a system.

Chapter 1 of the System Safety Plan (SSP) should describe the commercial vehicle fleet operator's organization and the roles and responsibilities of various personnel with respect to ensuring system safety. Implementing the SSP requires the support of all employees and contractors, as well as the endorsement of the fleet operator's top management. This chapter describes the contents of the SSP that are intended to provide the authority, and to delineate responsibility and accountability, for implementing hydrogen safety throughout the organization.

1.1 POLICY STATEMENT FOR SYSTEM SAFETY PLAN

The SSP should contain a policy statement endorsed by senior management. The commercial vehicle fleet operator should establish the SSP as a living, guiding document that has been prepared for and approved by the commercial vehicle fleet operator's top management. Top management approval should be indicated by signing the title page. The signature should be that of the highest level within the organization (e.g., fleet manager, facility manager, or owner-operator). Table 1 presents a sample policy statement.

[1] *MIL-STD- 882D:* Standard Practice for System Safety*, February 10, 2000.*

Table 1. Sample Policy Statement

POLICY STATEMENT It is the policy of John Doe Trucking Company to operate safely and reliably its commercial vehicle fleet incorporating hydrogen systems and equipment. This System Safety Plan (SSP) forms the foundation of this policy and is intended to promote the highest level of safety, reliability, and quality in all aspects of the John Doe Trucking Company's activities. By signing below, John Doe Trucking Company's management fully supports the System Safety Program and requires the full support, participation, and compliance of the Plan by all supervisors, operators, employees, and contractors. Sincerely, John Doe (signature) Date John Doe Trucking Company, Owner-Operator

1.2 GOALS FOR THE SYSTEM SAFETY PROGRAM

A section of the SSP should be devoted to describing the overall goals for a program of system safety by the commercial vehicle fleet operator.

A statement of goals for a SSP describing the program of system safety might include language similar to the following:

The goal of the SSP is to define system safety activities, responsibilities, management controls, and monitoring processes to ensure that:

- *Safety considerations are incorporated into the design of facilities, operations, and maintenance practices for hydrogen systems and equipment.*
- *Hazards associated with hydrogen systems and equipment are identified, analyzed, and then eliminated or minimized, to achieve an acceptable level of safety.*
- *Identified hazards will be mitigated by following accepted system safety practices, including using the following order of precedence for reducing hazards:*
  - *Design to eliminate or control the hazard*
  - *Add safety devices*
  - *Provide warning devices*
  - *Institute special procedures and training*

1.3 SCOPE

A section of the SSP should describe the scope of the hydrogen safety program.

For a fleet operator interested in implementing hydrogen systems and equipment, the scope of the SSP will include considerations for storage of hydrogen, fueling of vehicles, and storage and maintenance of vehicles with onboard hydrogen systems. During operation and maintenance, the emphasis of the System Safety Program will be to eliminate, minimize, and control hazards through design analysis, review, and equipment selection activities. The SSP will also provide the basis for developing safety-related rules, operations, and maintenance procedures, and training programs to be used during the life of the hydrogen vehicle fleet. The scope section of the SSP should also include:

- A brief description of the hydrogen systems and equipment installed on the fleet
- The number of commercial vehicles in the fleet that use hydrogen
- A description of the operations, maintenance and fueling facilities
- A brief description of safeguards that have been installed to prevent hydrogen accidents (e.g., gas monitoring equipment, fire detection system, etc.)

1.4 SYSTEM SAFETY PROGRAM MANAGEMENT

In order for a System Safety Program to be effective, specific responsibility for the system safety function must be identified in the company's organization. A section of the SSP should describe the company's organization and the reporting lines of communication. This information is usually presented in an organization chart.

In the organization chart, a single person responsible for system safety should be identified as the custodian for the SSP. Additionally, it is desirable to have the system safety staff person report to the highest level practicable within the organization in order to ensure that system safety issues are communicated to top management. In a large commercial vehicle fleet organization, a system safety manager may be identified as reporting to the Chief Executive Officer. In a single owner-operator company, the owner-operator will likely be responsible for the SSP implementation.

1.5 PLAN UPDATE PROCEDURES

A section of the SSP should discuss how and when the SSP will be updated.

Updates to the SSP must be documented to reflect changes in the fleet, changes in operations, or additional identified hazards. The person identified as the custodian of the SSP should review and update the SSP on an as-needed basis. At a minimum, the SSP should be formally reviewed and updated annually.

Updates should be tracked by annotating the revised plan with a new effective date and/or version number (i.e., SSP v.1 effective 01/01/06; SSP v.2 effective 01/01/07, etc.).

2. HAZARD ANALYSIS

Prior to implementing hydrogen systems and equipment in a fleet or vehicle, the fleet owner must perform planning activities to ensure that the hazards of hydrogen systems and equipment are managed so as to reduce the risk of potential harm to the fleet operator and the public.

This chapter discusses general safety considerations associated with hydrogen and recommended system safety activities.

2.1 THE POTENTIAL SAFETY HAZARDS OF HYDROGEN

A section of the SPP should give an overview of the potential hazards associated with hydrogen. All employees should be aware of the unique characteristics of hydrogen. In particular, hydrogen has the following properties that relate to potential hazards:

- Colorless and odorless gas—thus, a hydrogen detector may be required to locate leaks
- Nontoxic
- Very light element—1/15th the density of air; consequently, rises when released
- Broad flammability range of 4–74 percent H_2 concentration in air (as compared to narrower ranges of flammability for traditional fuels, such as gasoline, diesel, and natural gas)
- Low ignition energy—even static electricity can ignite H_2
- An almost invisible flame when ignited, and does not smoke or radiate heat like a normal flame
- Potential thermal explosion hazard when released into a confined space
- Potential for explosive container failure when stored under high pressure
- Severe frostbite hazard when stored as a cryogenic liquid
- An asphyxiant

More details on the safety hazards of hydrogen are described in a separate report.[2]

2.2 FIRE AND EXPLOSION HAZARD

The most common hydrogen hazard is the possibility of fire when leaking hydrogen is ignited. Hydrogen's high flammability and low ignition energy make it susceptible to a variety of ignition sources.[2] Flames from burning hydrogen are generally invisible in daylight, but if a hydrogen fire ignites other nearby materials, then flames and smoke from these other materials

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[2] Guidelines for the Use of Hydrogen Fuel in Commercial Vehicles, *FMCSA, Chapter 2*.

would be visible. An explosion—which is a rare event—is possible if a large enough quantity of hydrogen is trapped in a confined area and there is an ignition source.

Because you may not be able to see, hear, or smell a hydrogen fire, any facility used to fuel, store, or maintain hydrogen vehicles should be equipped with special hydrogen detection systems. These systems should be able to detect a hydrogen leak, and alert personnel to leave the building before concentrations reach one-quarter of hydrogen's lower flammability limit (1 percent in air).

2.3 MINIMAL ASPHYXIATION HAZARD

Hydrogen can also be an asphyxiant. This means that when hydrogen is present in a confined area in large concentrations, it can displace oxygen from the atmosphere. This lack of oxygen can lead to dizziness, drowsiness, nausea, loss of consciousness, or even death to exposed personnel.

While it is possible that a large hydrogen release in a vehicle maintenance bay could displace enough oxygen to achieve asphyxiation, it may be very unlikely for two reasons. First, for this situation to occur, there would have to be a failure of the hydrogen detection system. Second, because hydrogen tends to rise, it would concentrate near the ceiling. This might mean that the height of the bay would still allow sufficient oxygen, which is heavier than hydrogen, to remain at the same level as personnel on the floor.

2.4 PERMITTING PROCESS

A section of the SSP should be devoted to discussing coordination with the local fire safety and emergency responder agencies. Prior to implementing a hydrogen program, the fleet operator should review and comply with all local city, county, and state fire safety/emergency response codes and regulations. It is the responsibility of the fleet operator to inform, and obtain any necessary permits from, the city planning and emergency responder agencies relating to the use of hydrogen systems on their commercial vehicles and any indoor facilities.

As often as is practical, the local Fire Department and Police Department staff should be invited to tour the facility and discuss the facility's safety systems, procedures, and emergency plans. These meetings, as well as other contacts with city and state officials, should be documented and kept on file for at least one year.

2.5 INDOOR FACILITY REVIEWS

A section of the SSP should be devoted to procedures for review of indoor operations and maintenance facilities.

Fleet operators interested in converting from traditional automotive fuels (e.g., diesel and gasoline) to hydrogen fuel, or incorporating hydrogen systems, must consider the hazards associated with operating and maintaining hydrogen-fueled vehicles in an indoor facility, if hydrogen will not be de-fueled from the vehicles before they are brought inside. Particular attention must be paid to indoor operation and maintenance facilities, as well as fueling stations (see the next section, Section 2.4, for highlights on hazard and hazard mitigation that should be considered with regard to fueling stations).

The fundamental hazards associated with hydrogen should be considered in the facility design to ensure that the hazards of hydrogen systems and equipment are managed so as to reduce the potential risk of harm to the fleet operator and the public. It is advisable for any commercial vehicle fleet operator to seek the advice and guidance of a safety professional with hydrogen expertise to conduct an independent facility review. The facility review should identify the safety requirements for maintenance facilities and fueling stations. Appendix B of this report provides a sample checklist for review of indoor facilities.

Typical modifications to indoor facilities to accommodate hydrogen-fueled vehicles include the following:

- Incorporation of appropriate signs (e.g., "Hydrogen vehicle may be present," "No smoking," and "No use of cell phones")
- Enforcement of rules (e.g., "No smoking" and "No use of cell phones")
- Elimination of ignition sources, especially at ceiling level (e.g., prohibition of open-flame heaters and nonsealed electrical equipment)
- Upgrades to electrical utilities and equipment to make them intrinsically safe
- Isolation of high-hazard operations (e.g., welding and grinding)
- Utilization of nonsparking tools
- Modification to architectural features to eliminate potential confined spaces where leaked hydrogen could collect
- Installation of ventilation equipment
- Installation of hydrogen leak and fire detection and alarm systems

Figure 1 presents a typical facility upgraded for hydrogen use.[3]

[3] *See* Guidelines for the Use of Hydrogen Fuel in Commercial Vehicles*, FMCSA, for a detailed discussion on indoor facility recommended practices.*

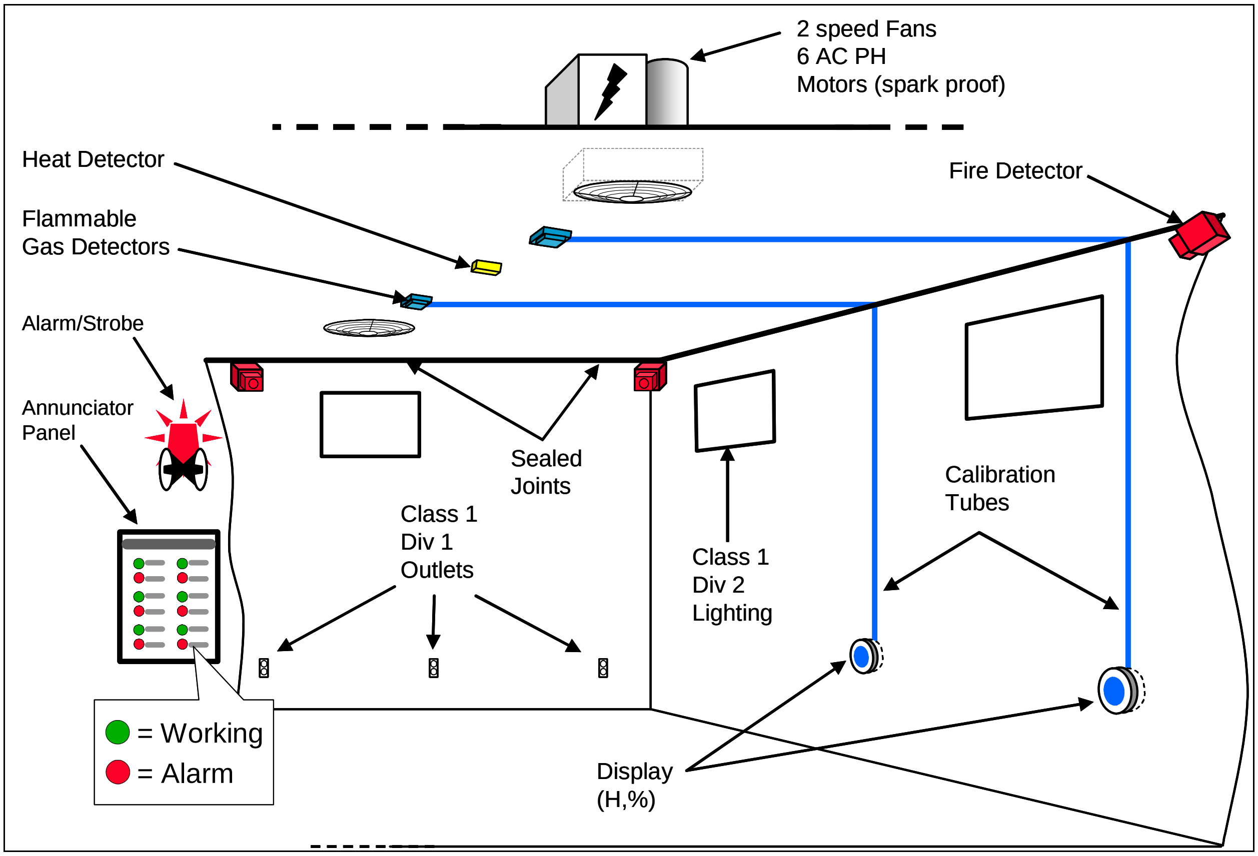

Figure 1. Typical Indoor Vehicle Maintenance and Storage Facility

2.6 FUELING STATION REVIEW

If fueling is provided at the fleet operator's facility, a section of the SSP should discuss the hydrogen fueling station, and a fueling station review should be conducted. A typical fueling facility review includes investigation of:

- Hazards associated with the type of fueling station (e.g., liquid hydrogen with vaporizers, water electrolysis, natural gas reforming, portable tube trailer, etc.)
- Property line setback requirements
- Fire detection and suppression requirements (including emergency fuel shut-off)
- Electrical considerations (including grounding and bonding to control static electricity)
- Foundation pad requirements

As noted with the indoor facility review, it is advisable for any commercial vehicle fleet operator to seek the advice and guidance of a safety professional with hydrogen expertise to conduct a fueling station review. Appendix C contains a typical checklist for a fueling station review.[4]

[4] *See* Guidelines for the Use of Hydrogen Fuel in Commercial Vehicles, *FMCSA, for a detailed discussion on fueling station reviews.*

2.7 HAZARD ANALYSIS

A section of the SSP should be devoted to defining procedures for ongoing hazard analysis and assessment.

Prior to implementing a hydrogen program, the commercial vehicle fleet operator should initiate a hazard analysis process designed to identify hazards.[5] The petrochemical and transportation industries have developed and used several types of hazard analysis tools, including:

- Preliminary Hazard Analysis (PHA), used to identify top-level system hazards
- Hazard and Operability Analysis (HAZOP), used to identify safety-critical operation activities
- Failure Modes and Effects Analysis (FMEA), used to identify the effects of failures

It is advisable for a commercial vehicle fleet operator to seek the advice and guidance of a safety professional with hydrogen expertise to conduct a formal safety analysis. An example of an FMEA hazard analysis is provided in Appendix D of this document. The goal of the hazard analysis process will be to formally:

- Provide the operator with an understanding of the hazards associated with the hydrogen systems and equipment
- Document hazards and required safeguards
- Identify safety-critical operations and maintenance activities
- Identify the need for special policies and procedures
- Identify training requirements

While the most detailed hazard analysis will be performed prior to initial implementation of a hydrogen program, it is important to recognize that the identification and analysis of hazards is an ongoing process. The SSP should delineate responsibilities and procedures to analyze proposed changes in vehicles, equipment, facilities, and procedures to determine whether they will present any new hazards not previously identified, and to identify required new mitigation strategies.

2.8 HAZARD RESOLUTION PROCESS

A section of the SSP should be devoted to resolving the hazards identified in the hazard analysis. The hazard resolution process is perhaps the most crucial aspect of any system safety program. Each fleet operator must tailor a hazard resolution program for his or her organization. It is an individual matter for each fleet operator to fit the proper process to its particular organization. The important element, which must be included in a fully developed system safety program, is the mechanism, accessible to all levels of the organization, by which hazards are identified,

5 *See* Guidelines for the Use of Hydrogen Fuel in Commercial Vehicles, *FMCSA, for a detailed discussion on hydrogen hazards.*

analyzed for potential impact on the operating system, and resolved in a manner acceptable to general management.

The most general hazard resolution process takes into account the probability and the severity of the hazard. Based on these two characteristics, the hazard must be designated as acceptable, unacceptable, or acceptable with mitigation. Safeguards designed to prevent certain hazards from becoming accidents are applied to controlling those hazards that are acceptable with mitigation. Appendix E describes a hazard resolution process that could be implemented by a fleet operator.

2.9 REPORTING A SAFETY INCIDENT

A section of the SSP should be devoted to procedures for reporting safety incidents.

Should an incident occur, a written report must be prepared that identifies the source, time, and scale of the incident, and describes the incident, any damage to the facility, fuel station, vehicles, any injuries, and other relevant details. The incident report should be provided to the safety staff within 24 hours of the incident.

The SSP should define what types of incidents must be reported, as well as delineating responsibility for completing the incident report. It may also include a standard reporting form. At a minimum, incidents that must be reported include any event that involves a hydrogen release, safety system failure, property damage, emergency shutdown of the facility, or personal injury or death.

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3. OPERATING RULES, TRAINING, AND PROCEDURES

3.1 OPERATING RULES AND PROCEDURES

A section of the SSP should be devoted to the process for developing operating and maintenance procedures. Operating procedures should be considered an important part of the system safety process, and they should be initiated only after all hazards have been resolved by elimination, minimization, or mitigation. This section should address the process to develop, review, and revise rules and procedures with safety in mind.

The SSP must contain a methodology for ensuring uniform, coordinated development and implementation of operating rules and procedures. Maintenance departments must do the same for maintenance rules and procedures. In the case of maintenance, this applies not only to rules for preventive maintenance, but also to procedures for conducting inspections of, and making repairs to, equipment.

Examples of operating rules and procedures that might be put in place to implement safety precautions when hydrogen is potentially present include:

- Never smoke in hydrogen storage areas.
- Keep all open flames away from hydrogen.
- Never tamper with relief valves.
- Never bring any vehicle with a known hydrogen leak into any building.
- Do not bring a hydrogen vehicle into any building that is not equipped with a hydrogen detection/alarm system unless the vehicle has first been de-fueled to remove all onboard hydrogen.
- Before working on any hydrogen fuel system or component, turn off the vehicle's main power switch and isolate hydrogen in the storage tank by closing manual valves. Use lock-out/tag-out procedures.
- Authorized personnel should open and close valves slowly, as a sudden change in pressure can cause a fire.
- Use only manufacturer-approved replacement parts when repairing hydrogen systems, as non-approved parts may be made from materials which are incompatible with hydrogen and subject to hydrogen embrittlement.

Manufacturer's maintenance manuals and advice should be used to develop operating and maintenance rules and procedures.

3.2 TRAINING AND CERTIFICATION

A section of the SSP should be devoted to personnel training and certification.

Persons who work with and around hydrogen must be trained on proper hydrogen handling procedures and practices, as well as the hazards of hydrogen. Each fleet operator will be responsible for training its own personnel. Proper qualification of operating and maintenance personnel is a vital part of a safe transportation environment.

The SSP should specify what hydrogen safety training is required for each category of employee (e.g., mechanics, drivers, fueling technicians, and management personnel) and how often the training will be repeated (e.g., initial training upon hire and annual/biennual refresher training).

The SSP should also specify that completion of all required training be documented in personnel files. Not only should complete and accurate certification records of operations and maintenance personnel be maintained, but the content and presentation of material and tests, including grading (i.e., pass/fail), should have clearly articulated requirements that ensure consistency, uniformity, and fairness. While the level of detail presented in the SSP for training/certification requirements is at the discretion of the fleet operator system, a training/certification policy/procedure should be in place and referenced in this section.

3.3 MAINTENANCE PROGRAM ACTIVITIES

A section of the SPP should be devoted to maintenance activities. This section should address the safety responsibilities and requirements for all employees/groups performing maintenance.

Issues such as the content, frequency, and documentation of required preventive maintenance and safety inspections should be addressed here. This can be done by referencing other documents such as maintenance plans and directives.

This section of the SSP should also address management responsibility for oversight of maintenance activities, including inspections and review and approval of repairs. Requirements to follow appropriate maintenance practices and use proper tools and test equipment are other issues to be addressed.

This section should also address required frequency and procedures for testing and recalibration of hydrogen safety equipment such as hydrogen detectors and alarm systems. Typical maintenance activities for a hydrogen facility include periodic:

- Calibration of gas-monitoring equipment
- Testing of fire detection and suppression systems and equipment
- Hydrogen-leak-sensing with hand-held detector
- Trouble indication responses

4. SYSTEM SAFETY REVIEWS AND AUDITS

A section of the SSP should be devoted to formal system safety reviews and audit.

System safety is the formal process of managing a system to ensure that all identified safety elements in a given environment are in place and are performing as designed. In a commercial vehicle fleet operational environment, it is difficult to identify any elements which are not safety-related, even if only indirectly so. The Internal Safety Management Assessment Process thus becomes extremely important in determining whether all organizational elements, equipment, procedures, and functions are performing as intended, from a system safety perspective. It requires constant attention and activity.

The commercial vehicle fleet operator should develop a checklist from the SSP that identifies each safety element. On an annual basis, an independent auditor of the fleet operator's choice should conduct an audit of each aspect of the SSP to ensure that all safety-critical functions are being performed as they should be.

The findings and recommendations of the audits should be reviewed by the top management for the commercial vehicle fleet operations and used to implement improvements to enhance the safety of the system. System safety improvements that may arise from audit findings may include:

- Developing remedies to address system weaknesses
- Budgeting for resources to implement remedies
- Implementing remedies
- Monitoring how well remedies are working

5. CONFIGURATION MANAGEMENT

A section of the SSP should be devoted to procedures and policies related to managing the configuration of the commercial vehicle fleet that uses hydrogen as an alternative fuel. There are two important features associated with configuration management: (1) drawing control and (2) change management. Each of these features is discussed below.

5.1 DRAWING CONTROL

Drawing control refers to management of technical documentation about the hydrogen systems installed on the commercial vehicle fleet, to ensure that this documentation is always up-to-date and available to operations and maintenance personnel. A complete set of manuals, parts books, drawings, and specifications for the hydrogen system(s) must be maintained by the commercial vehicle fleet operator. These drawings and manuals should be obtained from the hydrogen system manufacturer and should provide a detailed description of the onboard hydrogen system.

The SSP should address the question of how/where these documents will be stored so as to be accessible to all relevant personnel, as well as delineating specific responsibility for periodically reviewing these documents to ensure that they are complete and up-to-date.

5.2 CHANGE MANAGEMENT

Onboard hydrogen systems and equipment are designed and constructed of materials tested to be compatible with hydrogen, and they incorporate numerous intrinsic safety features and pieces of equipment that address the unique physical and chemical properties of hydrogen. Seemingly small changes to these systems could have unintended negative consequences. For this reason, modifications to hydrogen equipment should be prohibited unless a comprehensive system safety analysis is completed. Before implementing changes, any modifications identified by the fleet operator as necessary should undergo a change management process, including:

- Consultation with the hydrogen system Original Equipment Manufacturer (OEM)
- A hazard analysis as discussed in Chapter 2 of this report
- Preparation of a report that documents:
  - Description of the change
  - Discussion of applicable codes and standards
  - Approval from OEM
  - Management approval

The SSP should delineate specific responsibility for conducting the required hazard resolution process, the required steps involved, how the results must be documented (i.e., by providing a standard outline or forms), and required management approvals.

6. EMERGENCY CALL-OUT PROCEDURES

The SSP should contain a chapter on safety-critical emergency response communication procedures. In the event of an emergency, establishing quick and clear communication with local emergency responders is an important system safety activity. There should be a one-page emergency response procedure with all critical emergency response information. The call-out procedures should be clear and concise.

This emergency call-out procedure should be prominently posted in all areas where hydrogen vehicles will be fueled, stored, or maintained.

Table 2 presents a sample emergency response call-out procedure.

Table 2. Sample Emergency Call-out Procedure

EMERGENCY CALL-OUT PROCEDURE

In the event of an emergency, all employees should follow these procedures:

STEP 1. Call ext. XXXX. (This is the internal coordinator for all emergencies.)

It is important for all employees and contractors to FIRST notify the internal coordinator of all emergencies, rather than notifying any external point of contact, such as 911. The internal coordinator may be aware of any mitigating circumstances, such as maintenance, repair, or testing work that may obviate the need for an external response. Second, in the event of an emergency, the internal coordinator will arrange to have someone unlock any gates, meet the external responders, and show them the fastest way to the location where they are needed. Third, in the event of an emergency, the internal coordinator will notify and arrange for support resources, such as safety, security, plant, facilities management, and other personnel, who may be needed.

STEP 2. If the internal coordinator is not available, then call 911.

Explain to the operator the nature of emergency (medical, fire, explosion, hydrogen leak, hazardous material spill, bomb threat, other) and location of the facility:

John Doe Trucking Company
111 Main Street
Big City, CA
Major Cross Streets: Main Street and Elm Avenue

In the event of a fire, explosion, hydrogen leak, or bomb threat, advise that we are a hydrogen facility, and ask for a full response.

STEP 3. For fires, leaks, spills, or bomb threats, **evacuate all nonessential personnel.** Proceed to a predetermined safe area away from the facility.

STEP 4. If the emergency involves an **outdoor hydrogen leak without fire**, designated technical personnel should de-energize the facility and shut off all sources of hydrogen.

STEP 5. Account for all staff and visitors at the facility.

STEP 6. Assist emergency response personnel as requested.

APPENDIX A:
OUTLINE OF SYSTEM SAFETY PLAN

CHAPTER 1 SYSTEM SAFETY PLANNING AND ADMINISTRATION

1.1 Policy Statement
- Endorsed by upper management

1.2. System Safety Program Goals

1.3 Scope of System Safety Plan
- Description of facilities and equipment
- Description of hydrogen safety systems

1.4 System Safety Program Management
- Specific organizational roles and responsibilities for system safety
- Organizational lines of authority and reporting

1.5 Plan Update Procedures
- Responsibility for update
- Frequency of update

CHAPTER 2 HAZARD ANALYSIS

2.1 Safety Hazards of Hydrogen

2.2 Permitting Process
- Coordination with local agencies

2.3 Indoor Facility Review

2.4 Fuel Station Review

2.5 Hazard Analysis
- Responsibility
- Procedures

2.6 Hazard Resolution Process
- Responsibility
- Procedures

2.7 Reporting a Safety Incident
- Types of incidents which require reporting
- Specific information required for a report
- Responsibility

CHAPTER 3 OPERATING RULES, TRAINING, AND PROCEDURES

3.1 Operating Rules and Procedures

- Process to develop/review procedures with safety in mind

3.2 Training and Certification

- Required training
- Frequency of training
- Training documentation

3.3 Maintenance Program Activities

- Preventive maintenance and safety inspections
- Oversight of maintenance operations
- Testing/recalibration of hydrogen safety systems

CHAPTER 4 SYSTEM SAFETY REVIEWS AND AUDITS

CHAPTER 5 CONFIGURATION MANAGEMENT

5.1 Drawing Control

- Ensure technical documentation of hydrogen systems is complete and up-to-date

5.2 Change Management

- Process to review/approve proposed changes to hydrogen systems to ensure safety

CHAPTER 6 EMERGENCY CALL-OUT PROCEDURES

- Notification process in the event of an emergency

APPENDIX B: TYPICAL INDOOR FACILITY CHECKLIST

- Prevent the formation of ignitable concentrations of hydrogen:
  - Eliminate the possibility of hydrogen being leaked in a facility (vehicle-storage-system-dependent).
  - Incorporate capability to increase the ventilation rate to dilute any leaked hydrogen to well below its flammable limit.
- Provide hydrogen leak detection:
  - Add leak detectors and alarms.
  - Incorporate automatic responses to the presence of increased hydrogen concentrations.
- Remove all sources of ignition in the facility, particularly at ceiling level, where leaked hydrogen might collect:
  - Electrical system (remove or seal)
  - Fuel-fired heaters
  - Spark-producing operations (e.g., welding, grinding)
  - Personnel activities (e.g., prohibition against smoking and cell phone use)
- Add facility signs to remind personnel of restrictions on open flames, hot-work, smoking, cell phone use.
- Make preparations for protection from certain adverse environments (e.g., freeze protection, seismic).
- Consider structural/architectural facility features, including the following:
  - Eliminate confined spaces that may accumulate hydrogen.
  - Design flat ceiling with no traps, cavities, or deep ridges that may accumulate hydrogen.
  - Specify noncombustible roof materials.
  - Install fire-rated walls.
  - Incorporate explosion or deflagration venting.
- Install hydrogen leak detection system:
  - Use flammable gas detection system, calibrated for hydrogen.
  - Design to activate warning systems and ventilation equipment at a predetermined level of detection (e.g., 25 percent of lower explosive limit).
  - Install warning systems (e.g., audible and visual alarms).
  - Deactivate potentially hazardous systems (e.g., heating system, non-emergency electrical equipment).
  - Activate mechanical ventilation system, provided with back-up power supply.
  - Ensure fail-safe design (i.e., failure activates mechanical ventilation and deactivates other systems).

  - Ensure ease of maintenance and calibration of sensor systems.
- Consider electrical system upgrades:
  - Electrical equipment in immediate vicinity of ceiling (e.g., within 3 feet) suitable for locations similar to those of NFPA Group B, Class I, Division 2 (explosion-proof)
  - Grounding and bonding system for all hydrogen equipment on the vehicle
- Evaluate the ventilation system:
  - Passive ventilation capacity (e.g., windows, vents, etc.)
  - Ventilation system dedicated to mitigating the leak hazard, independent of the heating and air conditioning systems
  - Coordinated activation with the gas detection system
  - Circulation of only fresh make-up air (i.e., air from outside the facility)
  - Suitability of motors and other electro-mechanical equipment for locations similar to those of NFPA Group B, Class I, Division 2
  - Back-up power
  - Manual switching capability
  - Ventilation model to ensure that adequate airflow is provided for various leak scenarios

APPENDIX C:
TYPICAL FUELING FACILITY CHECKLIST

- Consider types of fueling stations and their associated hazards:
  - Liquid hydrogen with vaporizers
  - Electrolysis
  - Reformer technologies
  - Natural gas
  - Methanol gas
  - Gaseous fuel supplied from portable unit (e.g., tube trailer)
- Consider fueling operations:
  - Ability to accommodate tanker truck deliveries
  - Capability for emergency shut-off (both near dispenser and at remote location)
  - Capability to de-fuel vehicles
  - All general provisions for fire safety (e.g., fire extinguisher)
  - Facility security provisions (e.g., fencing, bollards, etc.)
  - Provide protection for storage
  - Mitigation measures for gas leaks (e.g., hand-held leak detectors)
- Consider setback requirements (property setbacks are minimum distances that must be maintained between the facility and a potentially hazardous areas). Established setbacks normally include minimum required distance from:
  - Fixed ignition sources (e.g., light poles, unclassified electrical lines)
  - Open flames and welding
  - Public roads
  - Railroads
  - Other buildings or structures
  - Places of public assembly
  - Property lines
  - Underground sewers
  - Wall openings
  - Air compressor intakes
  - Inlets for air conditioning or ventilating equipment
  - Weeds, grass, brush, trash, and other combustible materials
- Consider fire detection and suppression:
  - Hydrogen leak detection system
  - Flame detection system
  - Fire extinguishers (for secondary fires)
  - Easy access to fire hydrant

- Consider electrical requirements:
  - Electrical equipment in immediate vicinity of fueling area suitable for locations similar to those of NFPA Group B, Class I, Division 1
  - Electrical equipment in area surrounding fueling area suitable for locations similar to those of NFPA Group B, Class I, Division 2
  - Grounding and bonding system for vehicle
  - Grounding and bonding of hydrogen storage, dispensing, and defueling system
- Consider fueling station foundation:
  - A noncombustible pad to install hydrogen storage equipment
  - Weight accommodation for fully loaded commercial vehicle or hydrogen delivery tractor-trailer rig
  - Weight considerations for lifts and jacks
- Consider implementing operations requirements:
  - Training considerations
  - Management controls must be in place to ensure that personnel are trained regarding:
    - Hazard recognition (e.g., high voltage, high pressure)
    - Personal conduct (e.g., restrictions on open flames, hot-work, smoking, and cell phone use)
    - Routing considerations—for indoor garaging facilities, ensure that the area surrounding the driving route is clear of ignition sources
    - Equipment operating procedures
    - Diagnostics, alarms, and fault codes
    - Proper response to hydrogen events
    - Fueling and defueling procedures
    - Maintenance procedures
  - Ensure that staff are qualified and trained to perform maintenance on commercial vehicle
- Eliminate hazardous ignition operations:
  - Welding
  - Grinding
  - Sanding
  - Sawing
  - Smoking
  - Using nonspark-proof tools when working near hydrogen systems

APPENDIX D:
SAMPLE FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Table 3. Sample Failure Modes and Effects Analysis (FMEA): Unload and store 2,000 gal. of liquid hydrogen at 10 psig and -420° F

No	Failure Mode	Cause	Effects	Controls	F	C	Recommendation
1	Liquid trailer leak	Mechanical failure due to road vibration	Potential fire	Unloading inspection by station rep or driver Hydrogen leak detectors in area	M	L	
2	Liquid trailer leak	Vehicle impact to truck while unloading damages hydrogen piping	Potential fire/explosion	Driver puts caution cones around truck.	M	M	Establish separation distance of vehicles from unloading truck.
3	Unloading hose connection leaks	Mechanical failure or improper connection	Cryogenic burn	Unloading is continuously monitored by both driver and station rep. Driver wears a Nomex suit.	M	L	Implement a leak check prior to unloading.
4	Release from connecting hose	Hose not vented prior to disconnect—human error	Cryogenic burn	Driver training and unloading checklist, using standard established procedures for unloading cryogenics	L	M	
5	Overfill storage tank	Human error or instrument failure. Truck may contain up to 10,000 gal. or hydrogen and only 2,000 gal. might be unloaded to storage tank	Liquid hydrogen release from pressure relief valve with potential fire	Driver training and established procedure for unloading cryogenics	H	M	Review procedures for verifying tank fill level in safety plan.
6	Inner storage tank leak	Mechanical failure	Loss of vacuum between inner and outer vessel. Release from outer vessel pressure relief device set at 0 psig	PSV vents at elevated location	L	L	

Date: July 7, 2003—Process: 1. Liquid Hydrogen—Study Section: 1A. Liquid Delivery, Storage and Vaporization—Design Intent: *see table title*

APPENDIX E:
HAZARD RESOLUTION PROCESS

The Hazard Identification/Resolution Process is perhaps the heart of a program of system safety. While much has been written about the level of formality needed for this section of the program, it remains an individual matter for each fleet operator to fit the proper process to its particular organization. The important element, which must be included in a fully developed program of system safety, is the mechanism, accessible to all levels of the organization, by which hazards are identified, analyzed for potential impact on the operating system, and resolved in a manner acceptable to general management.

A Hazard Resolution Process consists of three primary components:

- Hazard identification
- Hazard categorization
- Hazard resolution

> The process offered here is taken from MIL-STD-882D. This standard offers a formal manner of addressing hazard resolution and provides a good way of ensuring that all hazards are addressed adequately, and that the resolution process is documented properly. It is emphasized, however, that this method is offered as a sample only. Each fleet operator must ensure that its safety methodologies are tailored to the unique capabilities of its organization. It should therefore not be construed that the hazard categorization methodology offered by MIL-STD-882D is a mandatory part of all programs of system safety. However, a properly functioning program of system safety must explain how the Hazard Resolution Process of the particular fleet operator is carried out and documented.

HAZARD IDENTIFICATION

In its Hazard Identification Process, a fleet operator describes the methods used for ensuring that as many hazards as possible can be identified and entered into the Hazard Resolution Process before they cause problems. While it is virtually impossible to identify every hazard, there are various formal processes, as well as the time-tested method of direct observation and input from field personnel on situations and designs which could cause accidents or injuries.

These methods may include such exercises as Preliminary Hazard Analysis (PHA), Operating Hazard Analysis (OHA), Critical/Catastrophic Items List (CCIL), Fault Tree Analysis, Subsystem Interface Analysis, and various Human Factors Analyses.

These formal Hazard Analysis Processes prove most useful in new systems, which need to analyze as completely as possible all aspects of system design. As there is no "history" to provide other means of analyzing the operation, a new system should have the necessary hazard analyses built into both design consulting and procurement contracts.

Conversely, systems in operation, especially those which have been operating for a long time, may not necessarily need to be subjected to such formal levels of hazard analysis on a regular basis. Usually, the input of operating and maintenance personnel can provide the type of data that can be used for an adequate Hazard Analysis Process. The key factor, however, is that whatever process is used, it must be as a minimum, formal enough to have been documented in a procedure, available to all units of the organization, reviewed and administered on a routine basis (usually by System Safety staff), and have high-level visibility and participation. Any formal process must have appropriate sign-offs and checks and balances built into it.

It should be noted that Hazard Identification is an ongoing process, viable throughout the system lifecycle. Accordingly, it needs to be coordinated with such other activities as Accident/Incident Investigation so that accidents and incidents which result from previously unidentified hazards are subsequently entered into the Hazard Resolution stage of the process, with all essential documentation of such situations maintained.

The following sections represent a methodology adapted from Military Standards, which can be used to develop a formal process for determining which hazards are acceptable, which are acceptable with certain conditions applied, and which are unacceptable. Once again, while other methods are available for hazard resolution, the key factors are a formal procedure with normal determination made in advance as to which types of hazards must have which type of resolution. It is also extremely important to design in advance a process for handling exceptions to the established procedure, as it is virtually impossible to anticipate every situation. Included in this section is a method for **categorization** of each and every identified hazard.

HAZARD SEVERITY

Hazard severity is defined as a subjective measure of the worst credible mishap resulting from personnel error, environmental conditions, design inadequacies, and/or procedural efficiencies for system, subsystem, or component failure or malfunction, categorized as follows:

I (Catastrophic)	Death or system loss
II (Critical)	Severe injury, severe occupational illness, or major system damage
III (Marginal)	Minor injury, minor occupational illness, or minor system damage
IV (Negligible)	Less than minor injury, occupational illness, or system damage

HAZARD PROBABILITY

Hazard probability is defined as the probability that a specific hazard will occur during the planned life expectancy of the system element, subsystem, or component. It can be described subjectively in potential occurrences per unit of time, events, population, items, or activity, categorized as follows:

A (Frequent)	Likely to occur frequently (individual); continuously experienced (fleet/inventory)
B (Probable)	Will occur several times in life of an item; will occur frequently in fleet/inventory
C (Occasional)	Likely to occur sometime in the life of an item; will occur several times in fleet/inventory
D (Remote)	Unlikely but possible to occur in life of an item; unlikely but can be expected to occur in fleet/inventory
E (Improbable)	So unlikely that it can be assumed that occurrence may not be experienced; unlikely to occur, but possible in fleet

Once a hazard is identified, an analysis of its potential severity and probability of occurrence is performed. The process for this analysis should be standardized by the fleet operator and documented by an approved procedure. This procedure must be followed as prescribed.

While it is possible to develop a qualitative methodology for this type of analysis, the most practical method for fleet operator application is simple deductive reasoning, applied on a collective or organizational basis.

The composite management staff of all key line and staff departments, administered by the safety unit, can effectively determine the severity of all but the most difficult or unusual hazards.

It is important, however, to determine in advance the exact mechanism for implementation of this process, as well as some type of administrative appeal process, should consensus on categorizing a specific hazard prove too difficult to achieve. A mechanism for outside assistance should also be provided.

Hazards identified in the course of normal operations should be entered into the formal process, the same as those identified by formal analysis techniques associated with new procurement and new system construction. All employees involved in the hazard identification process should know and understand their respective roles.

HAZARD RESOLUTION

Hazard Resolution is defined as the analysis and subsequent action taken to reduce to the lowest level practical, the risk associated with an identified hazard. Hazard Resolution is not synonymous with hazard elimination. In a fleet operator environment, there are some hazards which are impossible to eliminate and others which are highly impractical to eliminate. Reduction of risk to the lowest practical level can be accomplished in a variety of ways, from protective and warning devices to special procedures. There are, however, some hazards which present a risk which cannot be accepted because of its severity and the high probability of its occurrence; these hazards must be eliminated.

Part of the Hazard Resolution Process should be construction of a predetermined matrix prescribing which identified hazards are acceptable, which are acceptable with mitigation, and which are unacceptable. Once this matrix is defined by the fleet operator, deviation from the prescribed Resolution Process should occur only through approved, predetermined channels. A sample Hazard Resolution Matrix might look like that contained in Table 4.

In addition to the Hazard Resolution Matrix, a companion procedure must describe exactly how hazards defined as “unacceptable” and “undesirable” will be reduced to an acceptable level. In addition, any prescribed review by management staff must be predefined to ensure that the process cannot be bypassed, although provision can be made for allowing exceptions to the process in an approved manner.

It should be noted that the entire Hazard Resolution Process is nothing more than a formalized, predetermined procedure for risk acceptance by the fleet operator management staff. It allows for a systematic hazard identification process and a coordinated hazard effects minimization process. Management of the Hazard Resolution Process should reside with the safety unit of the fleet operator organization, which should be responsible for all supporting documentation and coordination.

Table 4. Hazard Resolution Matrix

Hazard Probability	Hazard Severity I	Hazard Severity II	Hazard Severity III	Hazard Severity IV
A	UN	UN	UN	AC/WR
B	UN	UN	UD	AC/WR
C	UN	UD	UD	AC
D	UD	UD	AC/WR	AC
E	AC/WR	AC/WR	AC/WR	AC
Codes: UN—Unacceptable; UD—Undesirable; AC/WR—Acceptable with review by management staff; AC—Acceptable.				

The coordination process can take on many different forms, such as Safety Committees and internal communications mechanisms; however, the key to its success still lies in the predetermined, administered process.