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The Application of Bow Ties for a Robust PSM Program

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Abstract

The fourteen elements of OSHA's Process Safety Management (PSM) program underpin so much of facility operations. PSM programs grow in complexity over time and can become increasingly disembodied from the operational elements that form their robustness. Often new PSM programs are modeled from organically grown existing programs rather than tailored to the specific risks of the operation introducing more than necessary complexity from the beginning. Barrier-based approaches can revitalize an existing PSM program or serve as a platform to build a simplified PSM program.

Bow ties reestablish direct connections to operations in a quickly visualized way transforming the perception of a PSM program from an operational albatross into an engagement tool to inspire ownership at all levels of the organization. This paper walks through each of the fourteen PSM elements highlighting the application and value of applying a barrier-based approach to the development or implementation of a PSM program.

Whether working with a robust PSM program that has become more complex over time or building a simple program based on the broad PSM concepts, bow ties can help a company focus their efforts on efficiently addressing deficiencies in their management systems and managing their most important risks.

Acronyms and Abbreviations

API RP	American Petroleum Institute Recommended Practice
BSCAT	Barrier Systematic Causation Analysis Technique
CCPS	Center for Chemical Process Safety
CFR	Code of Federal Regulations
EI	Energy Institute
HAZOP	Hazard and Operability
LOPA	Layers of Protection Analysis
MAE	Major Accident Events
OSHA	Occupation Safety and Health Administration
PHA	Process Hazards Analysis
PSI	Process Safety Information
PSM	Process Safety Management

Introduction

The fourteen elements of OSHA's Process Safety Management (PSM) program underpin so much of facility operations. PSM programs grow in complexity over time and can become increasingly disembodied from the operational elements that form their robustness. Often new PSM programs are modeled from organically grown existing programs rather than tailored to the specific risks of the operation introducing more than necessary complexity from the beginning. Barrier-based approaches can revitalize an existing PSM program or serve as a platform to build a simplified PSM program. Bow ties are commonly used to communicate the major accident hazards at an onshore or offshore facility.

Development of bow ties often follows the completion of a Process Hazards Analyses. Bow tie workshops use teams of experienced and knowledgeable people from various disciplines to develop the bow ties and select the barriers, previously identified in the PHAs, that meet the criteria for Major Accident Events (MAE) of being effective, independent, and auditable (Ref. /1/).

The focus of this paper is to show how bow ties can be used in other ways to drive success in a company's management system, regardless of where that company or facility may be in its process safety journey. This will be accomplished in the following ways:

- Lay out a process for developing or updating a relevant process safety management system for both OSHA PSM covered and non-covered facilities by engaging personnel in various levels of a company.
- Demonstrate how a bow tie can be used to develop or update a piece of the management system program associated with one of the 14 PSM elements.
- Present examples of how to tap into the additional benefits of bow ties to engage employees and improve a company's management system program. Examples are shown for some of the PSM elements.

The approach presented in this paper will include use of bow ties at the corporate level as well as at the manufacturing facility level. The principles discussed in the Center for Chemical Process Safety's (CCPS) Guidelines for Risk Based Process Safety (RBPS) are used in the development of this topic.

Using Bow Ties to Develop or Update a Management System

Bow ties can be used in developing a PSM program or updating an existing program for both OSHA PSM covered and non-covered facilities. The following benefits for using bow ties for PSM program development include:

- Illustrating the barriers associated with MAEs.
- Showing the impact of compromised degradation controls to barriers.
- Engaging employees in barrier and degradation control quality
- Encouraging employees' appreciation for their role in identifying and maintaining barriers and degradation controls.

Figure 1 shows how bow ties can be incorporated into the development or improvement of a management system program. This process is based on a company's knowledge of the three factors discussed in CCPS's Guidelines for RBPS specific to their company's business (Ref. /2/):

1. Identification of risks
2. Level demand of process safety activity work compared to resources available.
3. Existing process safety culture

The steps are discussed further in this section.

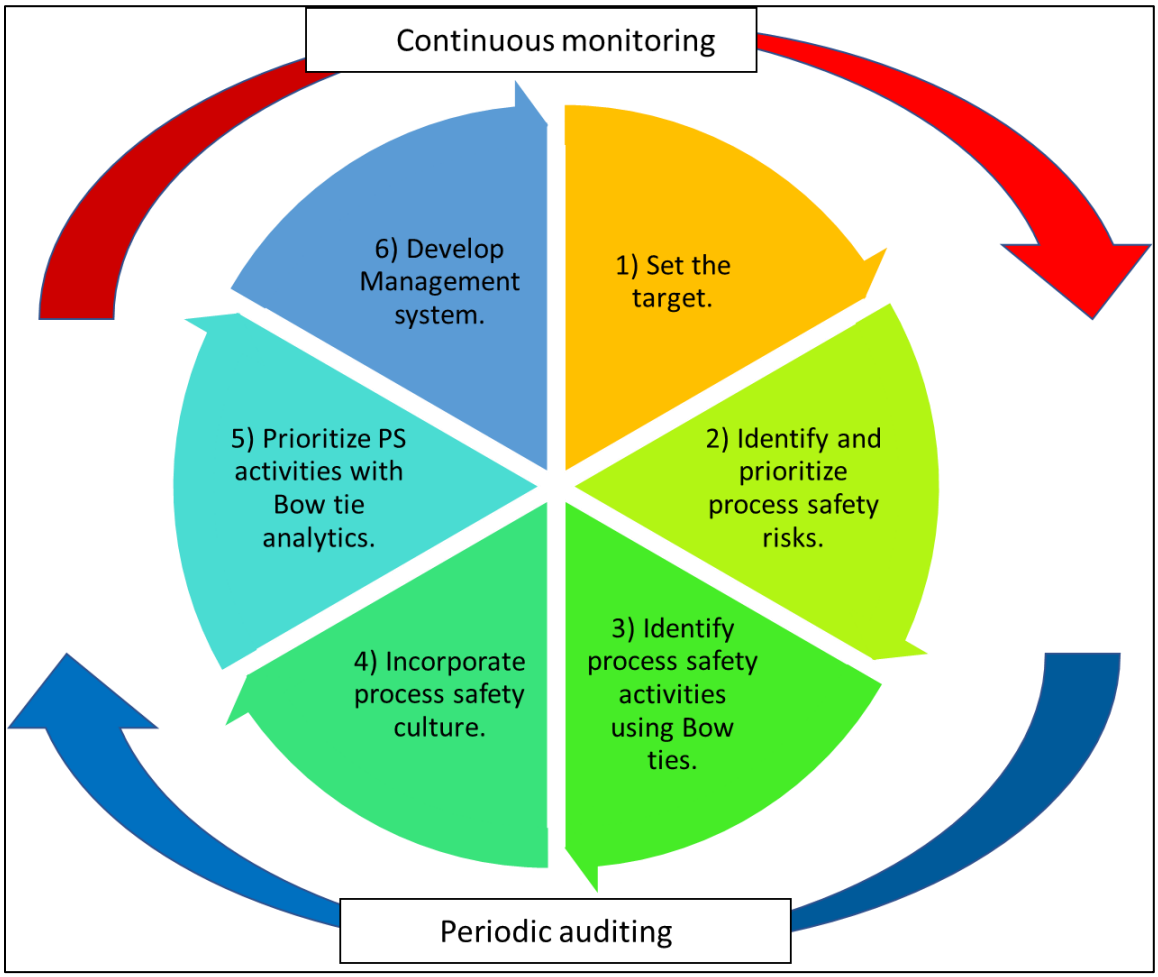

Figure 1 General Workflow for Bow Tie Application to PSM Program

Step 1: Set the target.

The target for a company's PSM program will be determined by regulatory requirements. OSHA PSM requires that companies develop program management systems that address 14 elements. A company may further decide to use Guidelines for RBPS to determine what level of rigor is needed for each element of its management system. Facilities that are not covered by OSHA PSM, still choose to have management systems as a best practice, and may use a risk-based approach to build their management system program.

Step 2: Identify and prioritize process safety risks.

The next step is to sufficiently understand the risks, which is the first factor on which process safety practices are founded (Ref. /2/). Many companies use various PHA methodologies to identify and assess risks at their facilities with Hazard and Operability (HAZOP) studies being one of the common types used. Bow ties and Layers of Protection Analyses (LOPA) are often used to identify the effective, independent, reliable and auditable barriers. Bow tie workshops go one step further in that the Bow tie workshop team members identify the degradation factors[1] and degradation controls[2] needed for the barrier be available illustrated in Figure 2. Bow tie workshops are convenient settings to engage the same people, who are assigned to the upkeep of barriers, through the activity of identifying specific degradation controls for each barrier.

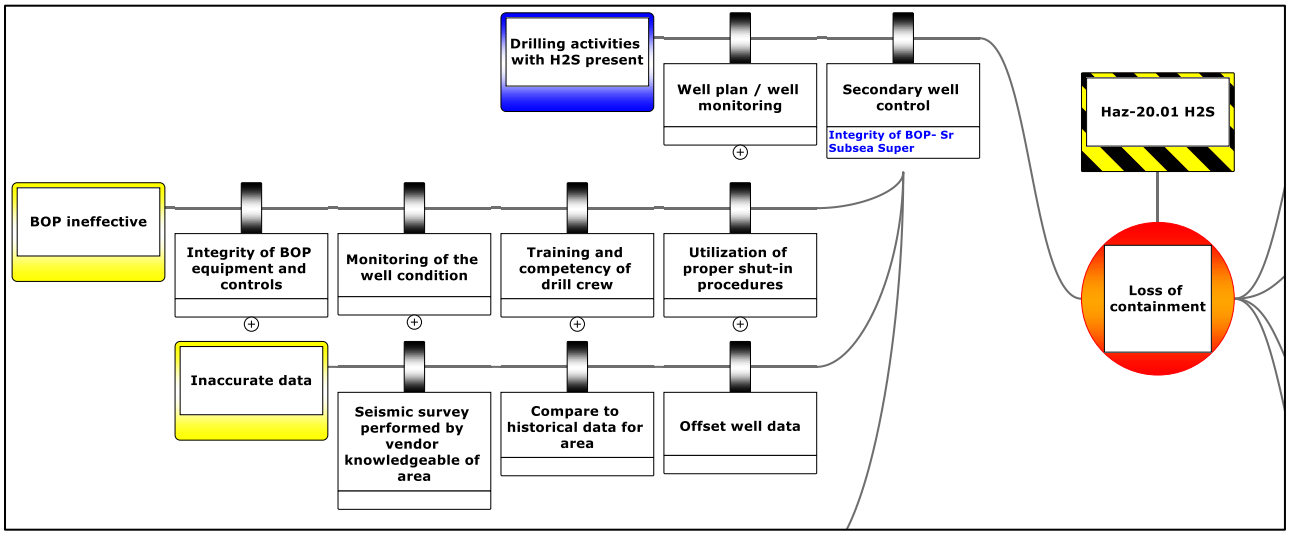

Figure 2 Bow tie Diagram Showing Barriers along with Degradation Controls

It is equally important for companies to identify process safety risks all levels of its operations including corporate and regional support levels. Bow tie diagrams can be useful for Corporate and Regional entities as well as manufacturing facilities.

Step 3: Identify process safety activities using Bow ties.

After identifying the risks and completing the bow tie workshops, the next factor to be addressed per RBPS Guidelines is the level of demand for process safety work activities needed compared to resources available (Ref. /2/). To determine the process safety activities, it is important to confirm that process safety practices associated with the degradation controls are in place. All process safety activities identified should be listed and linked to a management system element.

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[1]Degradation controls are measures which help prevent the degradation factor impairing the barrier. They lie on the pathway connecting the degradation threat to the main pathway barrier. Degradation controls may not meet the full requirements for barrier validity (Ref. /1/).

[2] Degradation factor is a situation, condition, defect, or error that compromises the function of a main pathway barrier, through either defeating it or reducing its effectiveness. If a barrier degrades then the risks from the pathway on which it lies increase or escalate, hence the alternative name of escalation factor.

This activity can be completed as part of the bow tie workshop or separately. The outcomes would include the following:

- Short-term: A list of degradation control process safety activity gaps for existing barriers (e.g., missing PSI, out of date operating procedure, no maintenance procedure) and recommendation plan to address the gaps
- Long-term: A list of process safety activities based on maintaining degradation controls
- Time estimates for completing each process safety activity

The outcome from such a workshop may look like that shown in Table 1 (following page). The information can then be used to calculate the process safety activity demand time associated with its respective management system element for all barrier degradation controls identified. Examples are shown in Figure 3, Figure 4, Figure 5, and Figure 6 (on the page following Table 1).

Figure 3 shows the process safety activity demand currently associated with each management system element for the degradation controls. Figure 4 shows the additional process safety activity time needed to ensure the barrier degradation controls are in place long-term. Figure 5 shows projected long-term process safety activity demand time for the barrier degradation controls. Long-term process safety activity time is the summation of the additional process safety activity demand time in addition to the existing process safety activity demand time. This will help a company see which management system elements need more resources long-term.

Figure 6 is the time needed to implement the actions needed for the longer-term process safety activities. It helps prioritize resources short term.

Step 4: Incorporate process safety culture findings.

In addition to determining process safety activity and resource demand, is understanding the process safety culture (Ref. /2/), which may be accomplished through process safety culture assessments and review of leading, near miss and lagging indicators such as those discussed in API RP 754 *Process Safety Performance Indicators for the Refining and Petrochemical Industries* or CCPS's Guidelines for Process Safety Metrics.

Once process safety culture is understood across the organization, it is possible to determine how to prioritize which elements of the management system to focus on first.

Table 1 Process Safety Activity Identification Outcome Worksheet

Hazard and Top Event	Threat	Barrier	Degradation control	PSM Element	In place or active	Deficiencies?	PS Activity Time (per year)	Action	Time to implement action
Loss of Containment – High Pressure Natural Gas	Overpressure	PSV-01A – Pressure Safety Valve on Natural Gas Inlet Line	Inspection procedure, FAC-01-MNT-01	Mechanical Integrity	Yes		2 hours	None	N/A
Loss of Containment – High Pressure Natural Gas	Overpressure	HIPPS-01 High-integrity Pressure Protection System on Natural Gas Inlet Line	Maintenance procedure, FAC-01-MNT-02	Mechanical Integrity	Yes	No	2 hours	None	N/A
Loss of Containment – High Pressure Natural Gas	Overpressure	HIPPS-01 High-integrity Pressure Protection System on Natural Gas Inlet Line	Training requirements, HIPPS testing training and competence	Training	Yes	Yes; 2 out of 4 I&E technicians are trained	4	Provide training to J. Smith and A. Rogers (instrument technicians) hired in Q1 2018.	16 hours
						Total	**8 hours**		**16 hours**

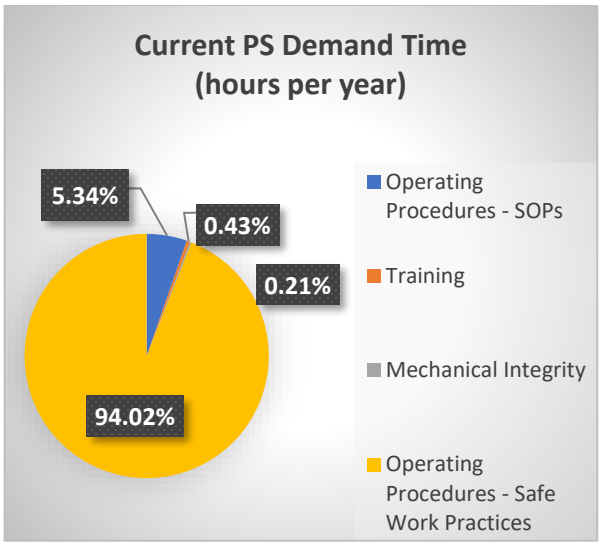

Figure 3 Current Process Safety Demand Time for Barrier Degradation Controls

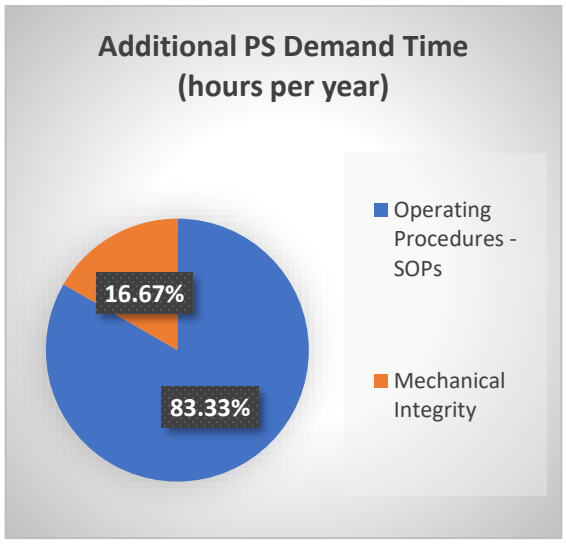

Figure 4 Additional Process Safety Demand Time for Barrier Degradation Controls

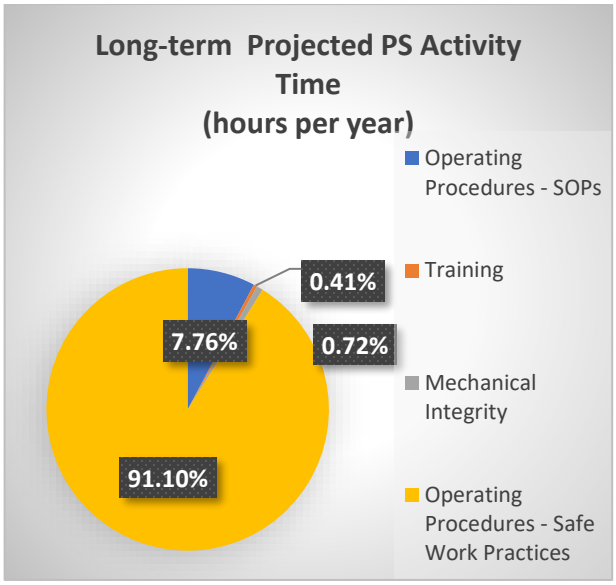

Figure 5 Long-Term Process Safety Demand Time for Barrier Degradation Controls

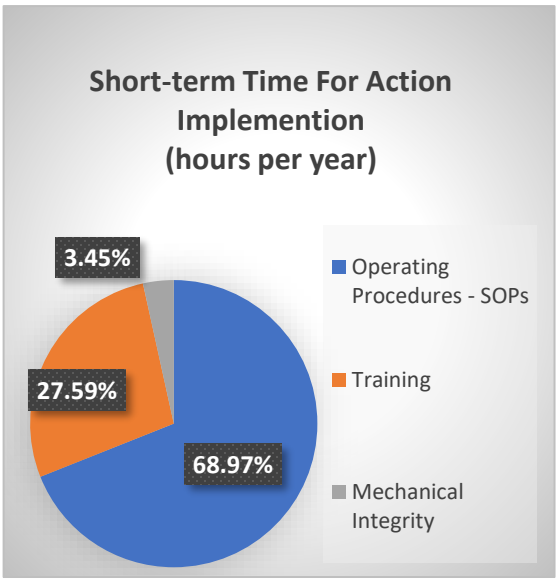

Figure 6 Short-Term Time for Action Implementation Time

The roles of the responsible resources can be assigned to each degradation control and corresponding management system. It can also be possible to see how the emphasis of a person's role can change with respect to management system elements.

How much time a person's role will change with respect to process safety activities vs. daily routine activities (if the breakdown of a resource's role in there is known). This may help a company determine if additional resources are needed or how to better prioritize the resources they have.

Step 5: Prioritize PS activities
Once the process safety activity demand and resource has been determined, the process safety culture rating can be used to help a company determine which process safety activities to focus on first with respect to their management system.

Step 6: Develop Management system
The findings from the facility level and corporate level assessments can be combined to an overall perspective of a company's management system to see company-wide, systemic patterns with current and long-term process safe activities.

Evergreen activities
Bow ties, barriers and degradation controls should be reviewed periodically to determine where process safety activities should be modified and to change the resourcing as needed. Continuously monitor barrier degradation control integrity, ensuring procedures are up-to-date, inspections on barriers or degradation controls are not overdue and maintenance activities are being performed at designated intervals. If deficiencies are noted with lagging or even leading indicators, the process safety activity demands and resourcing availability should be reviewed. When changes are made to equipment and associated barriers, bowties should be modified. If bowties are modified, this could impact the process safety activity demands associated with the barrier's degradation controls as well as the resources need to keep up the degradation controls.

Consider periodically reviewing the management system using the review of bowties, barriers and degradation controls periodically to assure that the management system is addressing the current risks with optimal resources.

Bow Ties to Design, Maintain and improve Management System Effectiveness

Bow ties can be used at a high level to develop or update a piece of the management system program associated with one of the 14 PSM elements especially at the Corporate level as mentioned in Step 2 in the previous section.

Once a company has determined the contents to be included or areas of improvement needed for the Employee Participation element of their management system, they can create a bow tie that can be reviewed periodically to determine areas of strengths and weaknesses. Figure 7 shows a bow ties that was developed using the contents of CCPS Guidelines for RBPS for Workforce Involvement (Ref. /2/). The Hazard is based on the attitude of the employees (i.e., their perception that their feedback does not matter and will not change safe work practices or safety culture). The top event is the result of the attitude which is "Lack of employee participation", which is the opposite effect of what the management system element is aiming to achieve. The threats on the left-hand side are based on a breakdown or lack of key principles needed to implement an Employee Participation Program. These key principles are discussed in CCPS's Guideline for RBPS (Ref. /2/). The preventive barriers are based on the possible work activities described for each of the key principles. To prevent breakdown of the preventive barriers, the degradation mechanisms for each barrier should be identified and controlled (Ref. /2/).

Figure 8 shows the degradation factors (i.e., Inconsistent Implementation) and degradation controls (i.e., Owner of Employee Participation Element) associated the preventive barrier of "Consistent implementation" to prevent "Lack of dependable work practice" (Ref. /2/). It is worth

noting that a bow tie like this can be created to assess the effectiveness of any company's management system elements using the information in Guidelines for RBPS. In a workshop setting, senior management and workers validate the existence of the barriers, assess the effectiveness of those barriers, review selected metrics, and develop recommendations to improve the existing Employee Participation program.

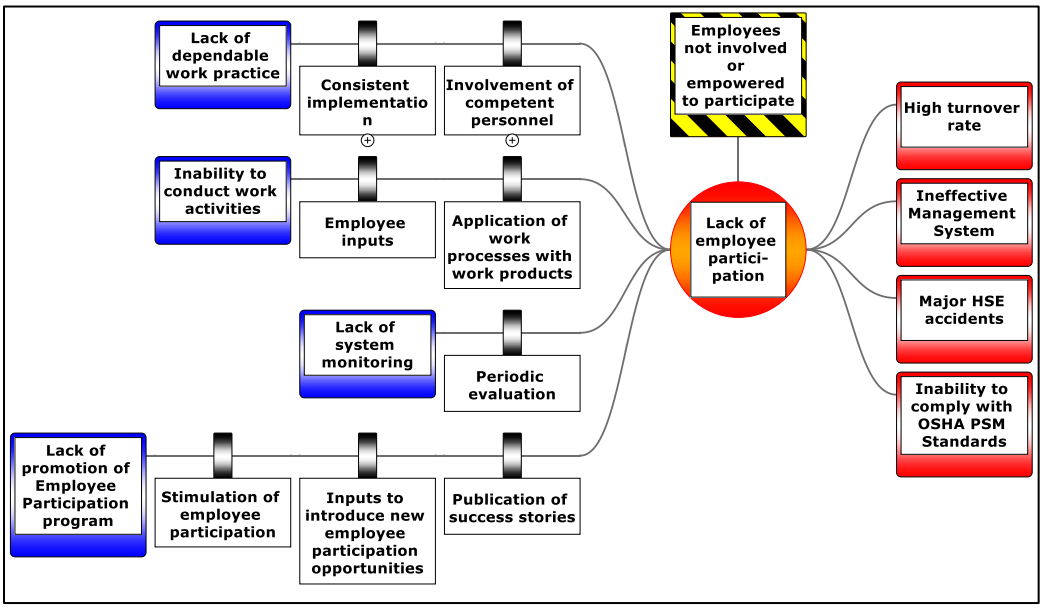

Figure 7 Bow Ties for Employee Participation Management System Element (Ref. /2/)

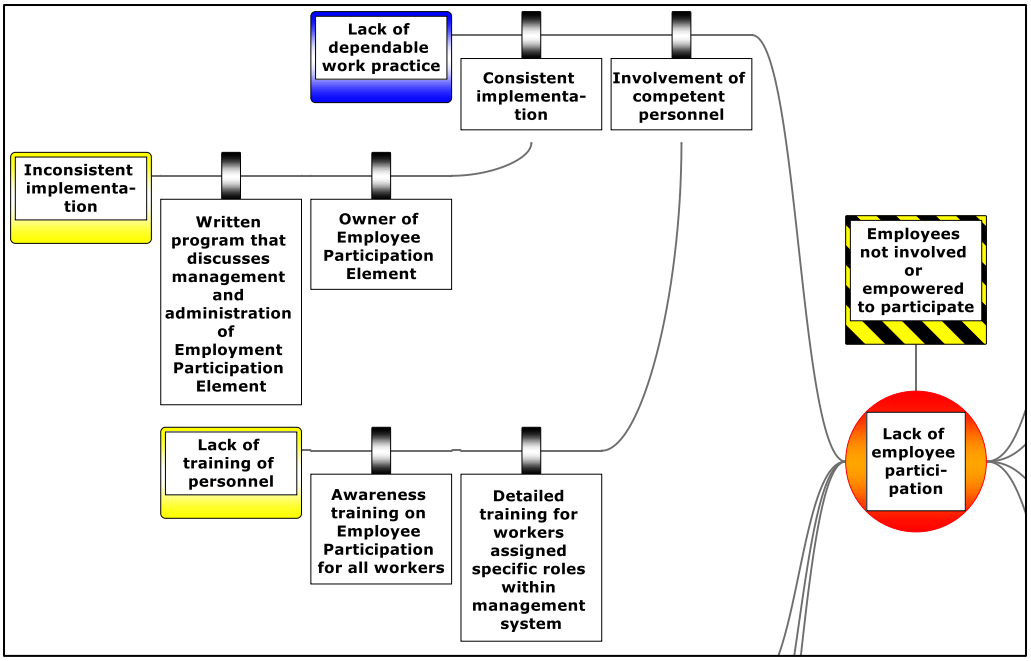

Figure 8 Bow Tie for Employee Participation Management System Element (with focus on Dependable Work Practice) (Ref. /2/)

Various Applications of Bow Ties to Support OSHA PSM Elements

Bowties can be used in other ways to engage employees in implementing the elements of a management system. This section shares some examples of how this can be accomplished.

Employee Participation

Bow ties can be used to monitor the success of an existing program in engaging the workforce at a high level as well as monitor the success of workforce involvement within each Management System Element. An example of an element-specific bow tie for Process Hazards with focus on employee participation is shown in *Figure 10* (on the following page). Figure 10 shows the degradation factors and degradation controls associated with the preventive barrier of “PHA activities” and “Involvement of competent personnel” to prevent “Lack of dependable work practice” (Ref. /2/).

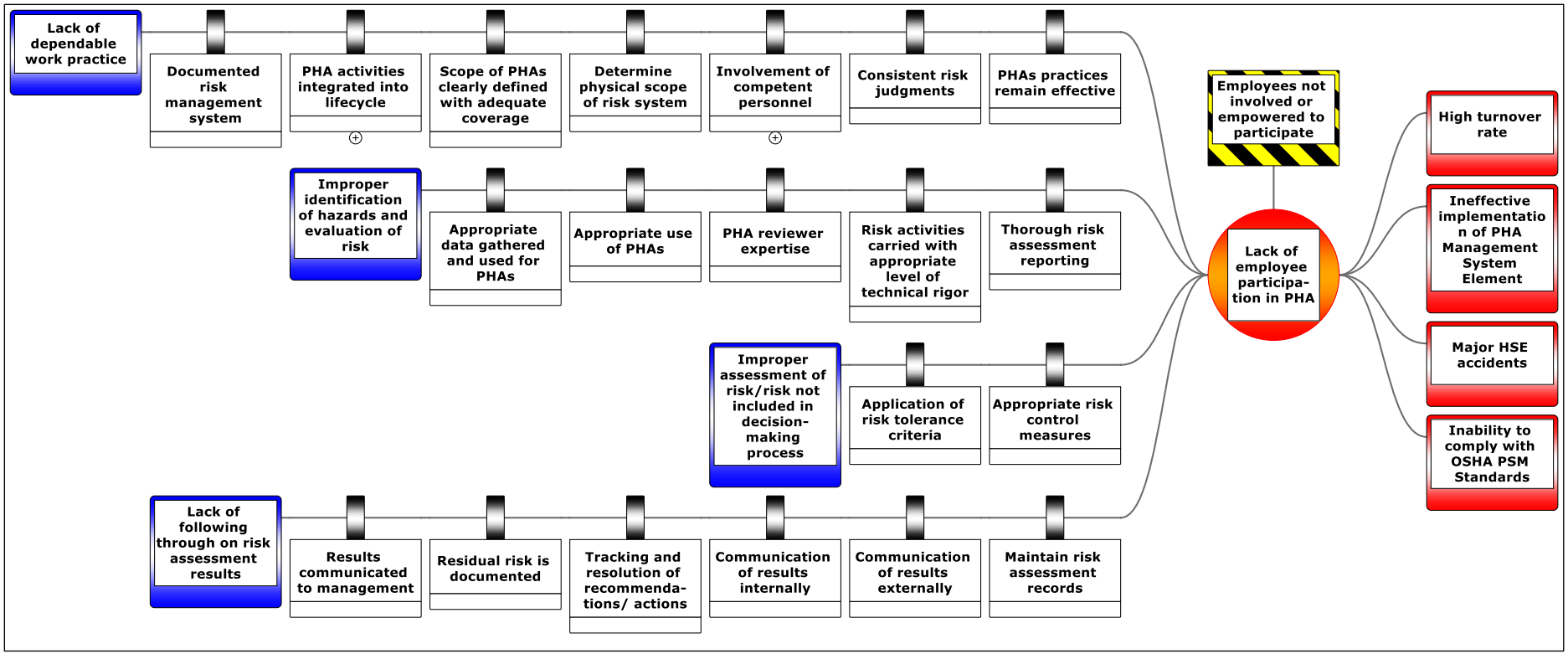

Figure 9 Bow Tie for Employee Participation within Process Hazards Analysis Management System Element (Ref. /2/)

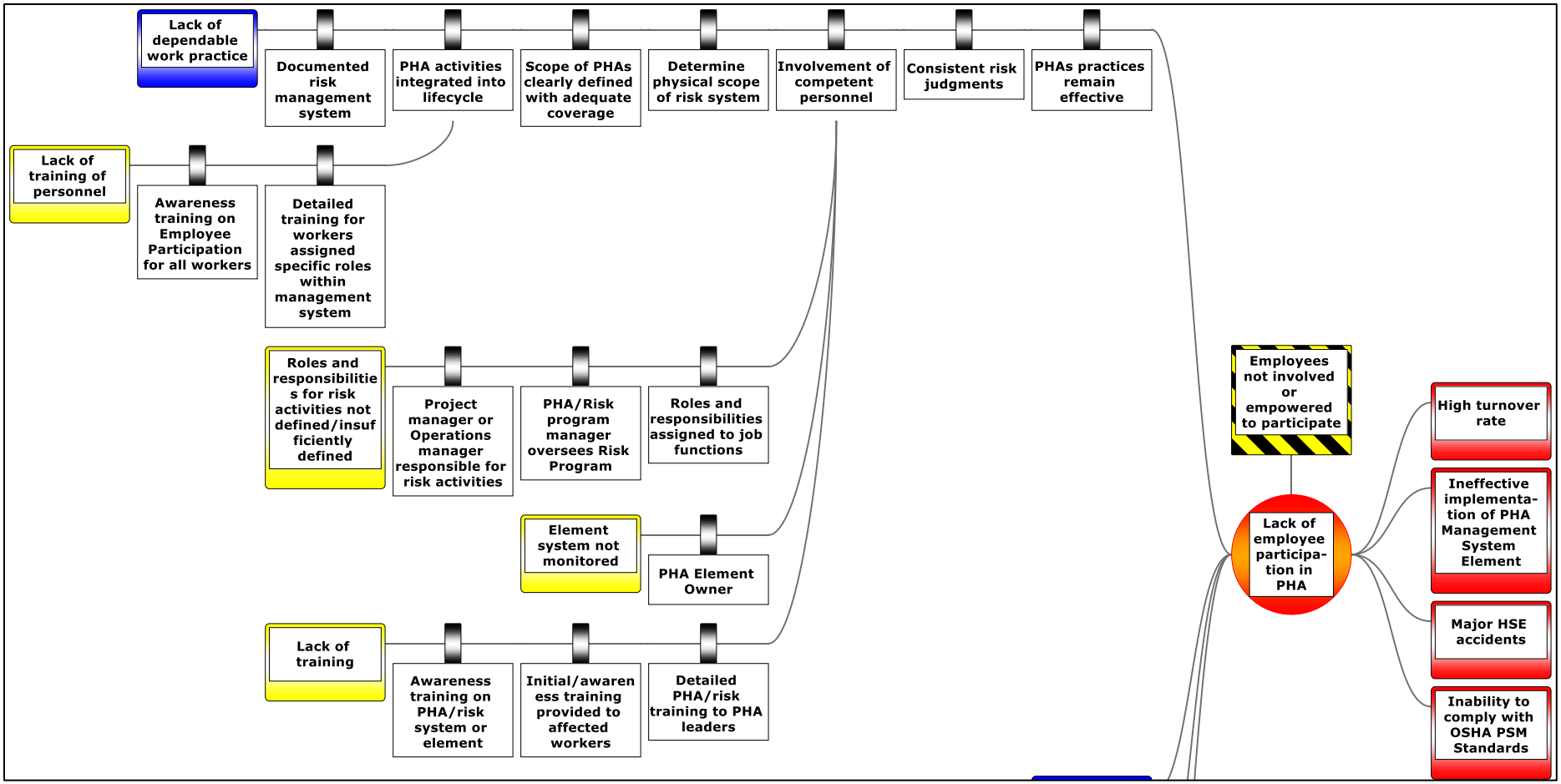

Figure 10 Bow Tie for Employee Participation within Process Hazards Analysis Management System Element (with focus on Dependable Work Practice) (Ref. /2/)

Process Safety Information

Established Process Safety (PSI) and relevant standards employed are required for covered processes in accordance with OSHA PSM 1910.119 (d). A bow tie can be an accountability tool for PSI and compliance with relevant standards associated with barriers. This type of information is referred to as barrier metadata in the joint publication by CCPS & Energy Institute on *Bow Ties in Risk Management: A Concept Book.* If PSI for a barrier or degradation control is missing, a barrier can be considered as not in place during the bow tie workshop. Therefore, the bow tie could be considered incomplete until the PSI is verified or acquired. It should be noted that the bow tie would be used as a mapping tool, not a repository for documents.

Operating and Safe Work Procedures

The employer must develop and implement written operating procedures, consistent with the process safety information, that provide clear instructions for safely conducting activities involved in each covered process in sections in accordance with OSHA PSM 1910.119 (f). OSHA PSM 1910.119 (k)) specifically focuses on the requirements for hot work. Procedures must be established to assure that there are no deficiencies in the barriers. The existing standard operating procedures and safe work procedures and relevant sections of the procedures can be documented in the bowtie. This shows the connection of the procedural steps to the bow tie to enforce the criticality of the procedure and specific sections or steps in preventing or reducing the likelihood of a major accident event. Procedures are shown as a degradation control. A poor or missing procedure can degrade a barrier. The use of bowtie for operating and safe work procedure is illustrated in Figure 11. The degradation control "Neighbouring firefighting units in remote areas" references the "Bridging Document" as necessary for the barrier "Active firefighting system" to be in place.

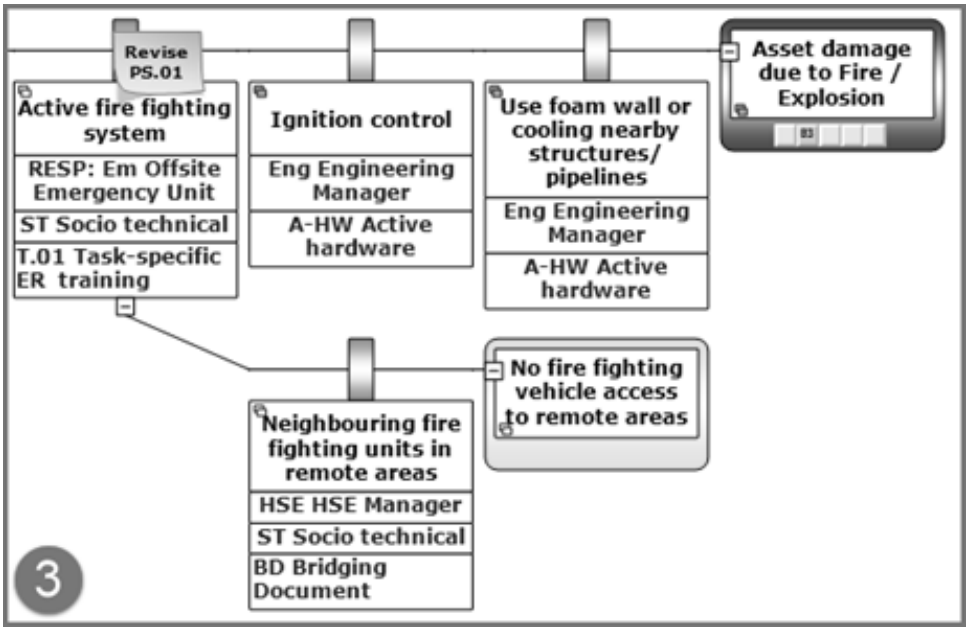

Figure 11 Illustration of Bow Tie with Operating Barrier Degradation Controls

Training

OSHA 1910.119 (g) states that the implementation of an effective training program is one of the most important steps that an employer can take to enhance employee safety. Training programs with periodic refresher courses should be established to assure that there are no deficiencies in the barriers. The company can include the applicable bow tie barriers or degradation controls critical to an employee's role or more specifically to a task or procedure. This is illustrated in Figure 11. The barrier "Active firefighting system" references "T.01 Task-specific ER training" as necessary for the barrier to be in place as an example, since personnel at the facility will need training to address a fire scenario. Additionally, the roles of personnel can be connected to barriers, also shown in Figure 11. The HSE Manager is assigned to the degradation control "Neighbouring firefighting units in remote areas"; it is the HSE Manager's responsibility to assure that firefighting units can access the facility otherwise, the barrier "Active firefighting system" may not be in place during a fire.

Contractors

OSHA PSM 1910.119 (h) includes special provisions for contractors and their employees to emphasize the importance of everyone taking care that they do nothing to endanger those working nearby who may work for another employer. Contractors can be provided copies of the bow ties applicable to their area of work. The company can orient the contractor supervisors and employees on the bow ties and discuss how the successful execution of their activities is important to keeping the facility safe.

Pre-Startup Safety Review

OSHA PSM 1910.119 (i) requires the employer to perform a pre-startup safety review (PSSR) for new facilities and for modified facilities when the modification is significant enough to require a change in the process safety information. The bowties can be effective during PSSR review in the following ways:

- illustrations to PSSR team members for importance of barriers in the process,
- review of the outstanding PHA actions, especially those actions related to barriers that address risks with MAEs, and
- assist in assigning priority to PSSR action items

Mechanical Integrity

Companies must maintain the mechanical integrity of critical process equipment to ensure it is designed and installed correctly and operates properly, per OSHA PSM 1910.119 (j). Mechanical integrity program must be established to assure that there are no deficiencies in the barriers, this is especially important with relief valves, SIS, and other safeguards. Bow ties can be used in the same way for tracking maintenance procedures and the associated roles of personnel as it can for the Operating Procedures by associating the maintenance and inspections procedures and roles of personnel to the applicable bow tie barriers and degradation controls.

Management of Change

OSHA states that changes to a process must be thoroughly evaluated to fully assess their impact on employee safety and health and to determine needed changes to operating procedures (1910.119 (l)). When changes in the facility include barriers, the use of the bow tie can illustrate the impact

of these changes to the barriers and its associated degradation controls. A barrier may need to be modified after an MOC review. It could be the case that the MOC procedure needs to be modified to ensure impacts on barrier effectiveness are adequately considered in the risk assessment.

Incident Investigation

OSHA requires the investigation of each incident that resulted or could have resulted in a catastrophic release of a highly hazardous chemical in the workplace (1910.119(m)).

Barrier-based Systematic Cause Analysis Technique (BSCAT) is the use of a bow tie to map out the events based on failure of barriers during each part of the scenario. Root causes of barrier failures and near-miss barrier failures can be mapped to the related management system element to determine where there are deficiencies. BSCAT diagram is shown in Figure 12 (shown on the following page) for the Lac Mégantic train incident in Canada (2013). A close-up of the left-hand side is shown in Figure 13 (shown on the following page). The barrier "Locomotive Temporary Repair" between the Threat "Locomotive Fault (8 Months Before)" and Immediate Event "Locomotive starts to smoke badly on July 5" was not effective at that time in preventing the next immediate event since Management System Factor (MSF) "MSF10.1 Maintenance Program" did not address follow up of temporary repairs, in the example shown. In this case, there were systemic issues with Mechanical Integrity.

Emergency Planning and Response

OSHA requires emergency pre-planning and training to make employees aware of, and able to execute, proper actions (1910.119 (n)). For this reason, an emergency action plan for the entire plant must be developed and implemented in accordance with the provisions of other OSHA rules (29 CFR 1910.38(a)). Bow ties can be used as communication tools for onsite employees as well as municipal emergency responders to help all parties understand the MAEs and the importance of having a robust emergency response plan as well that is executed periodically through drills.

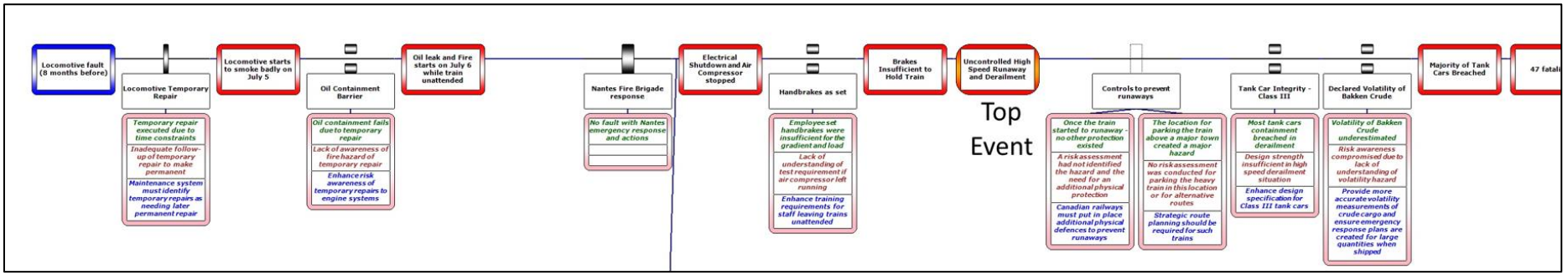

Figure 12 Illustration of BSCAT for Lac Mégantic Accident (Canada, 2013) (DNV GL)

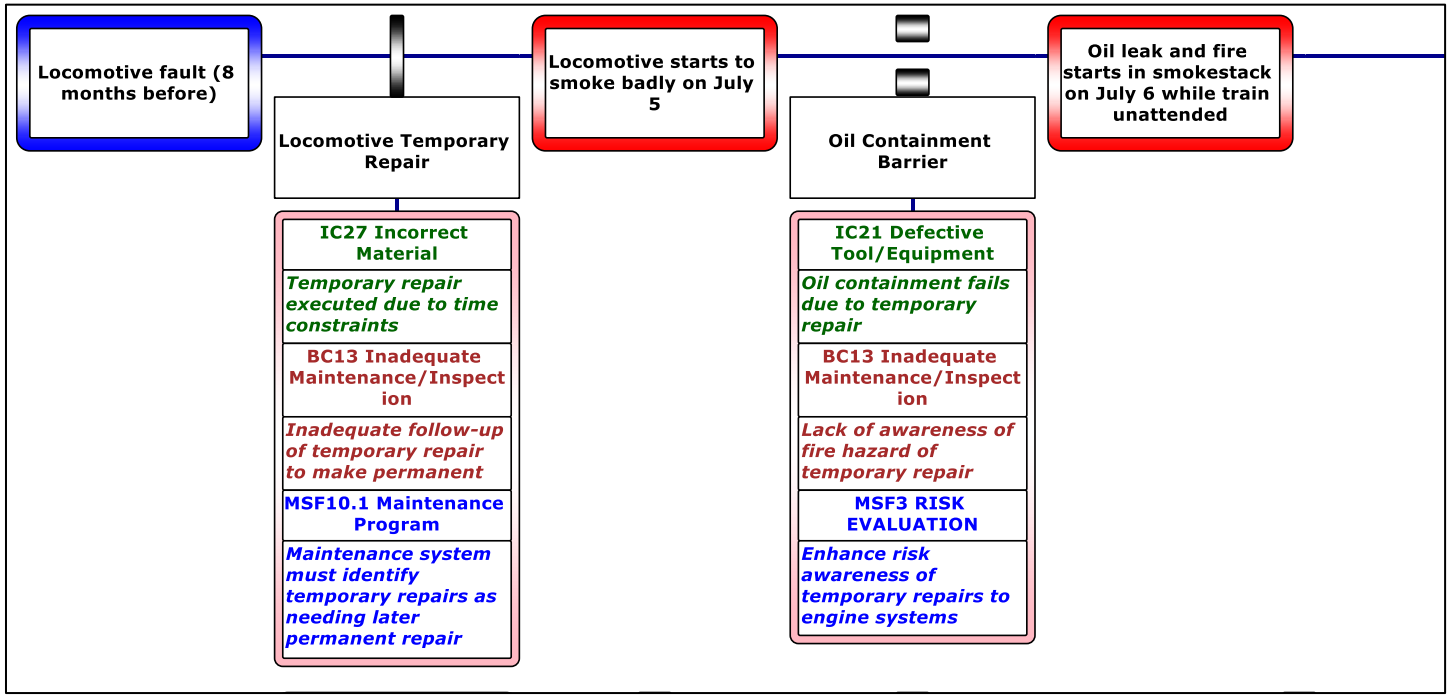

Figure 13 Close-up of Left Hand Side of BSCAT for Lac Mégantic Accident (Canada, 2013) (DNV GL)

Trade Secrets

OSHA states that employers must make available all information necessary to comply with PSM to those employees who are responsible for compiling the process safety information, those developing the process hazard analysis, those responsible for developing the operating procedures, and those performing incident investigations, emergency planning and response, and compliance audits, without regard to the possible trade secret status of such information (1910.119(p)). The completed bow ties are a demonstration that relevant information is being shared.

Conclusions

Bow ties reestablish direct connections to operations in a quickly visualized way transforming the perception of a PSM program using an engagement tool that can inspire ownership at all levels of the organization. Bow ties can help a company focus their efforts on efficiently developing a management system, maintaining a management system and addressing deficiencies in their management systems to manage their most important risks. Bowties can be applied to the assure a management system covers the fourteen PSM elements in various ways.

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