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Assessing Risk in the Supply Chain Using the Bowtie Method

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Abstract

After a number of recent incidents involving the transportation and storage of hazardous materials, many industry end-users wish to understand their level of risk exposure during the supply chain. This exposure can either be via actual ownership or when the product can be associated with the concerned party. Ultimately, this may mean that an end-user's procurement group will want to see that their suppliers of products and services are performing as needed in the control of these risks.

A qualitative risk assessment is a technique by which these risks can be identified, understood, and evaluated. This paper will describe the application of one such method, where the bowtie barrier analysis is central to the means by which this assessment is completed. The barriers identified are those necessary to prevent and mitigate undesired events that could result in a fatality or a catastrophic incident to the environment, public, or a company's reputation.

The overall method employed in this process includes the following steps:

1. Hazard identification
2. Bowtie diagram development and barrier identification
3. Barrier screening to identify safety critical elements - those that provide a credible reduction in the risk of fatalities or other major consequence
4. Performance standard development for the safety critical elements

The performance standards are then enforced appropriately throughout the supply chain. This will ensure that the transportation and handling of hazardous materials meet the purchasing concerned company's expectations with regards to proper risk management.

A quantitative risk assessment can also be completed to provide additional risk knowledge to aid in prioritization and decision-making.

Introduction

Nowadays dangerous goods (DG) are used in a wide range of industrial activities. These DGs include materials that are radioactive, flammable, explosive, corrosive, oxidizing or toxic. Accidents leading to release of DG can be lethal to human beings and damage the environment and public/private properties. Due to the dangerous nature of these goods, safety measures have to be considered along the entire supply chain. Therefore, regulations and safety standards are implemented to mitigate the risks related to the DG supply chain.

A supply chain is a system of organizations, people, technology, activities, information and resources involved in moving a product or service from supplier to customer [1]. Over the last decade, many companies have been facing extreme supply chain challenges that stretched their capabilities to the breaking point. The transportation of dangerous goods is considered as the most critical and complex activity. Transportation of dangerous goods depends on various modes of transport namely, road, railway and sea.

After a number of recent incidents involving the transportation and storage of hazardous materials, many in the industry wish to understand their level of risk exposure during the supply chain. This exposure can either be via actual ownership or when a material can be associated with the concerned party. Ultimately, this may mean that a supplier or end-user will want to see that their internal systems, as well as their suppliers, are performing as needed in the control of these risks.

It is important to identify the high priority risk in the supply chain that allows determining which risks require a mitigation plan and which are the low impact risks. To manage the supply chain risks, there is a need to identify, prioritize and mitigate the risk.

The system of supply chain is to be involved in the organization of the safety measures of the company for the incident. This can involve the safety of the supply chain. Mitigation is better than prevention of the accidents. There is a system of implementation of risk to manage the impact from an unwanted event.

Approach to Risk Assessment in Supply Chain

The approach to risk assessment consists of a number of stages and steps that, in principal are sequential. Initiation of the process can be triggered by a combination of various factors at any given point of time and varies from simple to very complex and detailed analysis. A preliminary qualitative analysis is conducted initially then followed by a more detailed quantitative analysis if deemed necessary. The initial step of qualitative analysis starts with understanding the supply chain for the hazardous material being sold/procured to identify the risk generating activities that include identifying the routes, frequency, modes of transport, and storage. For example, the elements in the truck transport of a material from the supplier to the facility include:

Supplier storage – Loading in the truck – Road transport – Unloading at facility – Facility storage

Once all the supply chain elements have been identified, the second step is to identify the appropriate data sources and collect risk relevant information and data.

The next step would be to conduct a qualitative risk assessment on potential credible scenarios to identify and evaluate the risks. The risks that are identified to have major consequences are further assessed with the development of bowtie diagrams and critical controls, performance standards, and verification checklists.

The final step in the process is to conduct a detailed quantitative risk assessment for the hazardous materials with potentially catastrophic consequences. This will aid in the understanding of the greatest levels of risk exposure in the supply chain.

Qualitative Risk Analysis

Initial qualitative risk analysis commences with the hazard identification to identify the causes or threats involved in the supply chain or what consequence a disruption would have. Hazard identification is a brainstorming process, involves consideration of previous risk assessments, and might involve surveys or other efforts to identify and list potential hazards within the supply chain. The process proceeds with listing of the unwanted events for each hazard and their consequences with the evaluation of severity and likelihood of each event. The output of this process is a supply chain hazard register listing the unwanted events for each step along with the unmitigated consequences... Rating is done using severity definitions of the risk matrix. Risk tolerable levels will depend on the criteria the organization has established for assessing the risks. The below figure demonstrates an example of risk assessment matrix.

	Consequence				
Likelihood	1 - Minor	2 - Medium	3 - Serious	4 - Major	5 - Catastrophic
A - Almost Certain	Moderate	High	Critical	Critical	Critical
B - Likely	Moderate	High	High	Critical	Critical
C - Possible	Low	Moderate	High	Critical	Critical
D - Unlikely	Low	Low	Moderate	High*	Critical
E - Rare	Low	Low	Moderate	High*	High*

Figure 1. Risk Assessment Matrix

The initial hazard register, even if including all identified risks for mapped processes, will likely not most significant risks to the supply chain. It is a starting point to identify relevant supply-chain risks. Moreover, a hazard register is an evergreen document that evolves from incident learning and research findings. Once the top risks have been identified, a more sophisticated method such as the bow-tie method is used to fully understand the nature of the risk and to fine-tune rating the likelihood and consequence of the inherent risk. Typically there are many ways of initiating an event that can lead to the release of a hazard. At its simplest, a bow-tie diagram is a way of describing the relationship between an undesired event (top event), its potential causes (threats), consequences, and the preventative or mitigation measures in place. The top event can be thought of as the point at which control of a hazardous material is lost. For example, for the storage of flammable liquids, control is lost when there is an unplanned release of material that can escalate to a fire or explosion.

The left hand side of a bow-tie diagram considers potential causes (e.g. corrosion, mechanical impact, incorrect operation of a valve) and the measures in place to ensure that these will not be realized. The right hand side considers the potential consequences (e.g. environmental damage, health, safety, equipment damage etc.) and the measures in place to mitigate these consequences.

Any known factor that can jeopardize the efficiency of a control is included in the Bow-tie diagram as an escalating factor. When controls are present to mitigate these escalating factors, they are also included and characterised using the same criteria as the controls that apply directly to a threat or a recovery measure. Figure 2 shows the graphical representation of a bow-tie diagram.

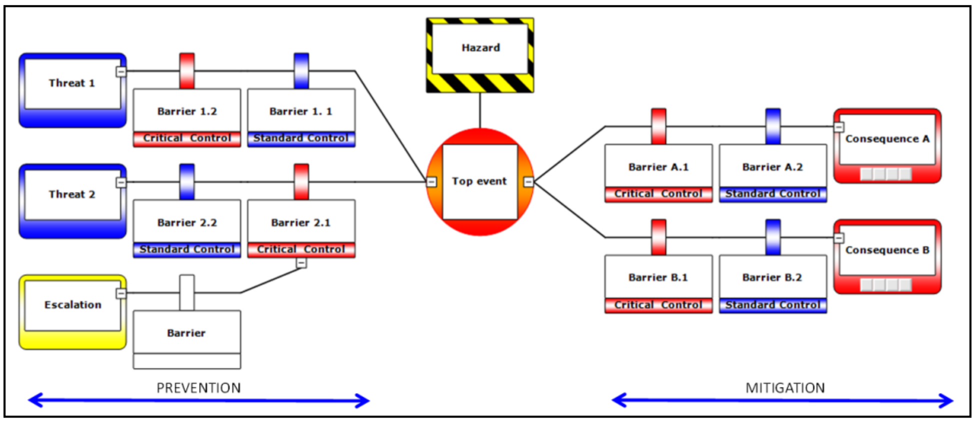

Figure 2. Graphical Representation of a Bow-tie Diagram

The bow-tie assessment allows drilling into each of the control and recovery measures to better understand the overall effectiveness of the control strategy. Each of the controls identified in the bow-tie assessment is characterized according to the following criteria:

- Control type
- Control effectiveness
- Control criticality
- Control owner

Now not all controls have the same significance and importance. Some can be defined as “critical” to raise their visibility and surveillance. When identifying the critical controls, the following screening criteria have to be applied:

- The control on its own stops the threat or prevents the consequences
- The control used against multiple threats or to mitigate multiple consequences
- The only control against a threat/only control to prevent the consequences

Critical Control Monitoring Plan

Once critical controls are identified, a monitoring plan is developed to define the expected performance of the control and the activities required to maintain its functioning as intended. The monitoring plan defines the critical controls' objectives, performance requirements, and how performance is verified in the field for each critical control identified on the bow-tie diagrams. The two parts of the monitoring plan include, the operational side of the critical control; or what are the critical tasks associated with the control and the reliability part; or what needs to be done to make sure that the control will work as expected when needed. The monitoring plan template developed for the supply chain comprise a set of questions and the monitoring plan has to be completed with the involvement of operators, engineering, procurement team and other subject matter experts. Table 1 depicts the operation part of the control and Table 2 depicts the reliability part of the control.

Table 1. Operation Part of the Control

Critical Control	Control Hierarchy	Control Objective	Safety Critical Tasks	Training and Competence Requirements	Control Execution	Control Owner
Name of control	Type	What is the objective of the barrier that prevents or mitigates the major hazard and makes it critical?	What are the essential tasks that people must perform to operate or maintain the barrier?	What specialist knowledge and skills are required to perform the tasks? How will this be provided and assured?	Who (what role) will perform these tasks?	Who (what role) will check their performance?

Table 2. Reliability Part of the Control

Performance Criteria	Measuring Process	Measuring Equipment	Test Frequency	Target	Responsibility	Assurance Measure

What is the target performance of the barrier? What are the availability and reliability criteria?	How is performance measured?	How are the sensitivity, availability and reliability to be assured?	How often is the assessment required to be performed?	What is the target for measurement?	Who is responsible for measurement?	What is the evidence that the assessments are completed satisfactorily?

Critical Control Verification Checklist

Once the monitoring plans are populated, a verification checklist has to be developed for each critical control. Each critical control verification contain individual assurance activities that should be used by the individual assigned to verify the control's health. Information regarding each critical control is gathered on behalf of the critical control owner who reports on the status of each critical control to the owner of the control. This information is designed to efficiently communicate variances between expected and actual critical control performance.

Performance Standards

Performance, measurement and monitoring criteria to assure the reliability and availability of critical controls are then defined to assure the performance of the controls. Critical controls are of no value unless they consistently perform when needed as expected. Performance standards define and document the attributes of the control. They ensure that the controls are inspected, maintained and tested, so it is not degraded overtime. Performance standards for the supply chain are developed as a verification checklist in a table format with queries related to the functioning of the critical controls that has to be filled in by the front line leaders and verified by the operational leaders. Figure provides an example of supply chain performance standards in the form of critical control verification checklist.

Critical Control Verification Checklist						
Dangerous Good						
Supply Chain						
Supplier						
Review performed by:						
Unwanted Event	**Critical Control**	**Purpose**	**Questions**	**Yes**	**No**	**NA**
Road - Accident	Periodic maintenance on truck	To ensure the truck is in working condition to prevent truck failure	Are any of the trucks used to deliver AN overdue for maintenance?			
Road - Accident	Truck pre-startup check list	To ensure the truck is in working condition to prevent truck failure	Have all deficiencies reported on the pre-startup check list been addressed before the truck was allowed on the road?			
Road - Accident	Defensive driving	To increase the situational awareness to prevent a road accident	Are any of the drivers overdue for defensive driver training (at least once every two year)?			
Road - Accident	GPS monitoring with feedback to the driver	Reduce bad driving habits	Have all alerts from the vehicle GPS monitoring system have been addressed in a timely manner?			
Road - Accident	Emergency response plan (external)	To notify the response team and the stakeholders, secure incident scene and clean-up the area	Is there a report documenting a drill, simulation or debriefing after incident to test the emergency response to an incident involving an AN Prill delivery truck in that is less than a year old?			
			Have the corrective actions from the previous report been addressed?			
Road - Accident	Emergency response plan (internal)	To notify the response team and the stakeholders, secure incident scene and clean-up the area	Is there a report documenting a drill, simulation or debriefing after incident to test the emergency response to an incident involving an AN Prill delivery truck in that is less than a year old?			
			Have the corrective actions from the previous report been addressed?			

Figure 3. Critical Control Verification Checklist

The performance standards developed will be enforced appropriately throughout the supply chain. This will ensure that the transportation and handling of hazardous materials meet the concerned party's expectation with regards to proper risk management.

Quantitative Risk Analysis

The final step in the process of supply chain risk assessment is to conduct a detailed quantitative risk assessment for the hazardous materials with potentially catastrophic consequences. Quantitative analysis is used for most catastrophic events that need more precise numerical analysis to estimate the damage and frequency of occurrence. This quantitative analysis will aid in prioritization and decision-making with regards to managing the risk of the supply chain. The process starts with the identifying the DG with greatest level of risk exposure with societal consequence (fatality risk). Then the risks from multiple supply chain elements are added to assess the total simulation with one criterion and to determine the risk drivers. An F-N curve is constructed with the estimation of occurrence for each event.

The resulting F-N curves for the supply chain events are plotted separately by supply chain element and for all elements combined. The F-N curves include the societal risk criteria presented in HIPAP 4 [7] to illustrate the as low as reasonably practicable (ALARP) principle. A level of risk above the dashed red line is indicative of an intolerable level of risk, while a level of risk below the green dashed line is indicative of a negligible level of risk. The region between the two lines is indicative of risk in the ALARP range and mitigation measures would be expected to be implemented to reduce the risk, unless the reduction of risk was grossly disproportionate to the effort required. HIPAP 4 emphasizes that the criteria shown are indicative and provisional, and do not represent a firm requirement.

QRA Case Study Results

In the case study presented for illustration, hazardous material 1 is transported as cylinders or drums in a truck navigating through sparsely populated areas. Hazardous material 2 is transported by rail from densely populated areas and is stored at a storage location surrounding a major city.

Figure 4 and Figure 5 depict the F-N curves for hazardous material 1 & 2. Hazardous material 1 risk is in the negligible region of the F-N curve. Hazardous material 1 risk is small because of the small amount of material handled (both quantity handled and frequency of handling), as well as a limited population exposure to release events.

Hazardous material 2 risk is in the ALARP region of the F-N curve, and approaches, but does not cross, into the intolerable region. Hazardous material 2 risk is mostly from rail transport because the route includes many densely populated regions, many with small set-back distances from the rail route. The storage risk from storage facility is greatly limited by the limited number of persons exposed due to the 0.5 mile distance to the nearest highly populated areas.

High transport risk follows from a combination of high population densities (higher number of potential fatalities) and long route exposure distances (which results in higher event frequency in the vicinity of highly populated areas). The actual rail risk might be lower than reported here, if the actual rail route would bypass some of the high density populated regions.

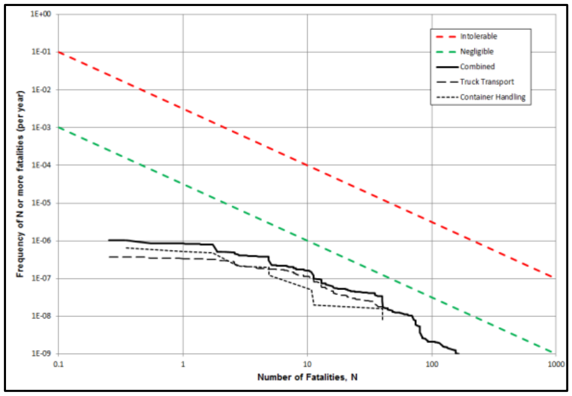

Figure 4. F-N curve for Hazardous Material 1

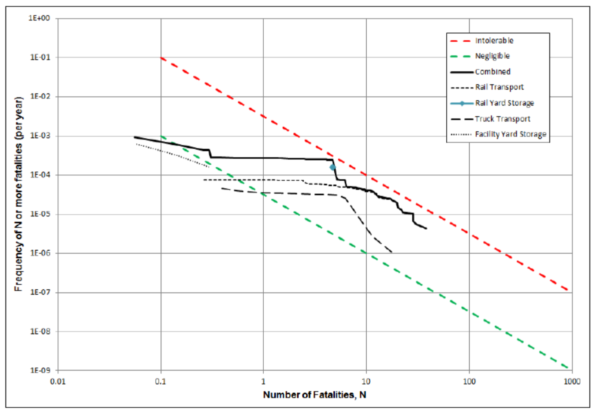

Figure 5. F-N Curve for Hazardous Material 2

The transport risk involved with the transport of hazardous material 1 & 2 can be compared from the figure below. Left corner section of Figure 6 presents the transport route of hazardous material 1 representing the truck transport through sparsely populated areas. Middle section of the figure indicates the storage location of hazardous material 2 and the consequence distance in the event of an explosion. The red line in the right section of the figure indicated the transport route of hazardous material 2 through densely populated areas and the radial distance that an explosion could affect.

Figure 6. Transport Route of Hazardous Materials 1 & 2

Conclusion

The overall risk analysis is a collaborative method involving personnel from procurement, product supplier, HSE & Operations, Transportation Authority, Transport and storage providers. Effective supply chain risk analysis is essential to a successful organization. It is important to understand the potential risks associated with the type of goods that are being procured by the organization and the detailed understanding of this process goes beyond legal requirements on transportation of dangerous goods.

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