# Barrier Based Approaches to Risk Modeling for Pipeline Safety: Making Regulations, Standards and Practices More Effective

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**Abstract**

In order to advance risk modeling methodologies for gas transmission and hazardous liquid pipelines and non-pipeline systems, new approaches to risk modelling should be considered by operators and regulators in the US pipeline industry. Barrier based approaches in combination with traditional semi-quantitative tools are one such consideration. In contrast to the traditional fate and transport studies relying on quantitative dispersion modeling, the barrier based approaches of Bow-Ties and Tripod Beta spend most of the modeling effort on identifying, assessing and maintaining preventative and mitigating controls (barriers) to major accident events.

Bow-tie diagrams and Tripod Beta trees are graphical methods for modeling the cause and effect relationships around major accident events such as loss of containment and collisions.

For many years, the Bow-Tie and Tripod-Beta methods have been used in Europe and Australia as cost effective approaches to look at the integrity of barriers in the petroleum, chemicals and aviation industries. Furthermore, in the wake of the Macondo offshore well disaster of 2010, these approaches are being adopted for US offshore oil and gas exploration and production facilities.

This paper shows how Bow-Tie diagrams could be applied to pipeline safety. It illustrates the method through a step-by-step overview accompanied by representative examples of its application to pipeline safety management. It touches on how Tripod Beta trees demonstrate not only the *how*, but the *why* behind barrier failures of specific accidents for use as lessons learned.

## Background

Over the past 5 years, the US oil and gas pipeline and offshore exploration and production industries have some things in common: a few high profile accidents followed by significant public outcry and congressional calls for regulatory reform. Of particular note are the 2010 PG&E San Bruno disaster, the Exxon Mobil Arkansas Spill, the 2010 BP Macondo Gulf of Mexico disaster and most recently the Plains All American pipeline system spills in California and Illinois. In the case of the BP Macondo disaster resulting in the loss of 11 lives and over 3 million barrels of crude spilled into the ocean, the result has been a fundamental reconsideration of the way operators, contractors, service companies and regulators model and monitor offshore risk. Because of the pipeline and mining industry accidents this summer, the US pipeline industry may be at a crossroad similar to that of the offshore oil and gas industry in 2010: a mandate for a new risk modeling approach. After being developed and deployed in Europe and Australia, barrier based approaches using bow-tie diagrams are now being adopted by US offshore oild and gas industry regulators in response to catastrophic accidents in the US Gulf of Mexico.

## Bow-Tie Diagrams and Risk Identification and Communication

The bow-tie diagram is a hazard analysis tool which graphically demonstrates the cause and effect relationships behind a potential major accident event in one, easy-to-understand picture. Two things we should say about bow-tie diagrams. First, the bow-tie diagram is principally a qualitative hazard (as opposed to quantitative risk) management tool. This is important because bow-ties manage a desired, but potentially dangerous business activity (i.e. hazards). They are only part of a system for managing both the likelihood and impact of events (i.e. risks). Secondly, the bow-tie diagram is not new. It was developed by Imperial Chemicals and Royal Dutch Shell for use in the UK and Australia over 25 years ago. Even so, bow-ties were not widely used among risk practitioners in the US until recently.

Risk management is concerned with what ***could*** happen under various potential scenarios while accident investigation is concerned with what ***did*** happen along one particular scenario. Barrier based approaches add one additional dimension to traditional risk and and accident investigation: an intense focus on ***the mechanism*** behind why a major accident could (or did) occur. This mechanism we call a ***barrier***. [1] In this way, barrier based risk management and accident investigation can be considered two sides of the same coin. Both involve understanding the cause and effect relationship, developing scenarios and focusing intensly on barriers.

When bow-ties are used as part of a risk management *system* that includes an electronic database, portable graphic display and real time development, they also become a powerful risk communication technique. The Tripod Beta Diagram describes an accident using a diagram. The technique methodically describes the instrumental cause, the context, and the systemic causes for why an accident occurred. Together bow-ties and tripod beta diagrams form a powerful toolbox for barrier based risk and accident management. The barrier based approach has its own symbols to represent different elements of potential scenarios. Examples of these diagrams and their symbols are shown in Figures 1 and 2 below:

**Figure 1: The Structure and Symbols of a Bow-Tie Diagram for Hazards**

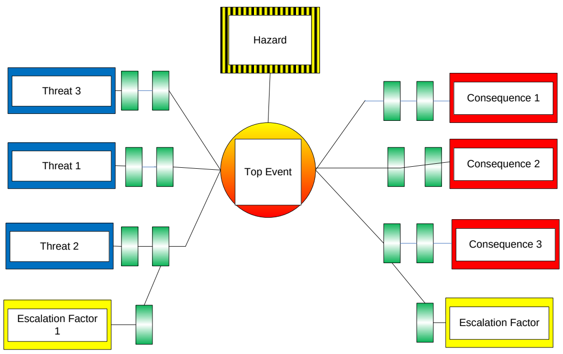
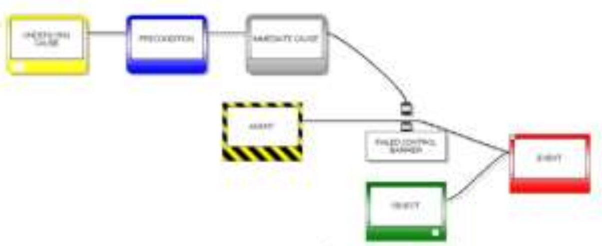



**Figure 2: The Structure and Symbols of a Tripod-Beta Diagram for Accidents**



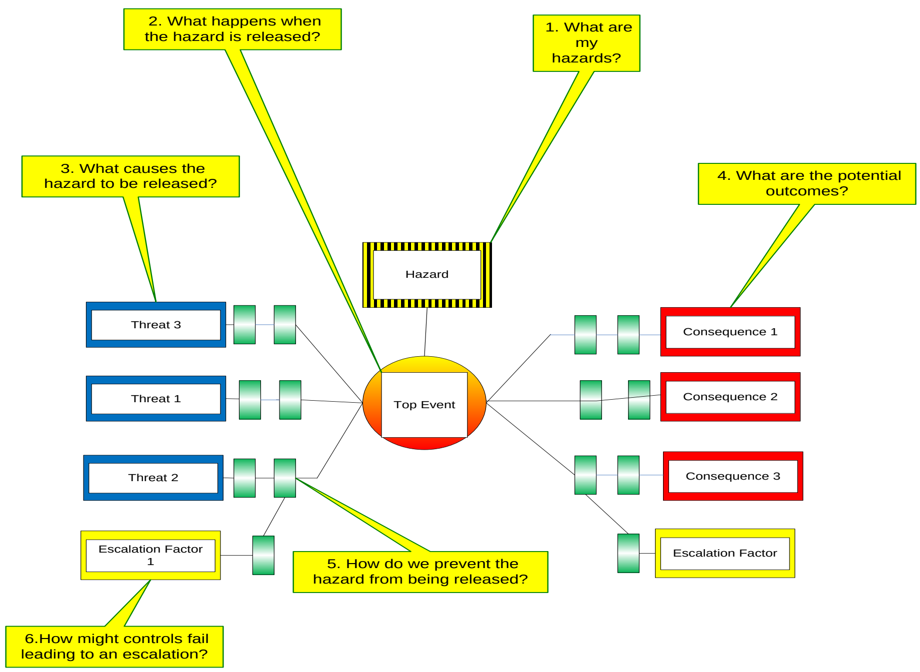
Although similar, the two diagrams represent different "views" of an event: the bow-tie looks forward to risk scenarios and tripod beta looks backward to the accident scenario. In the case of the bow-tie diagram, the purpose is to model the cause and effect relationship between how a threat creates an event and how to keep this from occurring through the placement of various barriers.

The power of a bow-tie diagram is that it shows a summary of several plausible risk scenarios in a single picture <u>and</u> it clearly demonstrates the barriers along various threat paths. Because they are graphic (as opposed to textual) bow-ties can be a very effective form of risk and hazard communication across different levels of employees within an organization.

[1] Sometimes also called a ***control*** when on the preventive side of the bow-tie diagram. For purposes of this discussion we will use the term barrier throughout.

Figure 3 is a simple illustration of the bow-tie concept with some probing questions used to develop each of its elements:

**Figure 3-The Development of a Bow-Tie Diagram**




As mentioned above, outside the US, bow-tie diagrams have been widely used as a hazard assessment technique. They are one of the key supporting methodologies behind the Safety Case approach used by regulators in oil and gas development in the North Sea, Australia and other non-US jurisdictions. Over the past 3 years, the US Food and Drug Administration (FDA) and the Federal Aviation Administration (FAA) have started using bow-tie diagrams to model food testing and air traffic control hazards respectively. After 2010, the US Bureau of Safety and Environmental Enforcement (BSEE) also started to use this barrier based approach for regulation of the US offshore oil and gas industry.[2]

Finally, the barrier based approach has been adopted for ***pipeline risk management*** by the Dutch pipeline regulator, the State Supervision of Mines (SSM). SSM uses a "base-case" bow-tie model to both evaluate pipeline risks in their pipeline network and as a starting point for accident investigation.[3] The time has come for application of barrier based risk management in the US pipeline industry as well. As an illustration, consider some recent pipeline events through the lens of the bow-tie diagram.

Though the investigation into the cause of the pipeline rupture that spilled crude on Refugio Beach in Santa Barbara is not concluded, looking at the preliminary findings through the bow tie method brings into focus the way in which the event can be described as a set of failed or missing barriers.

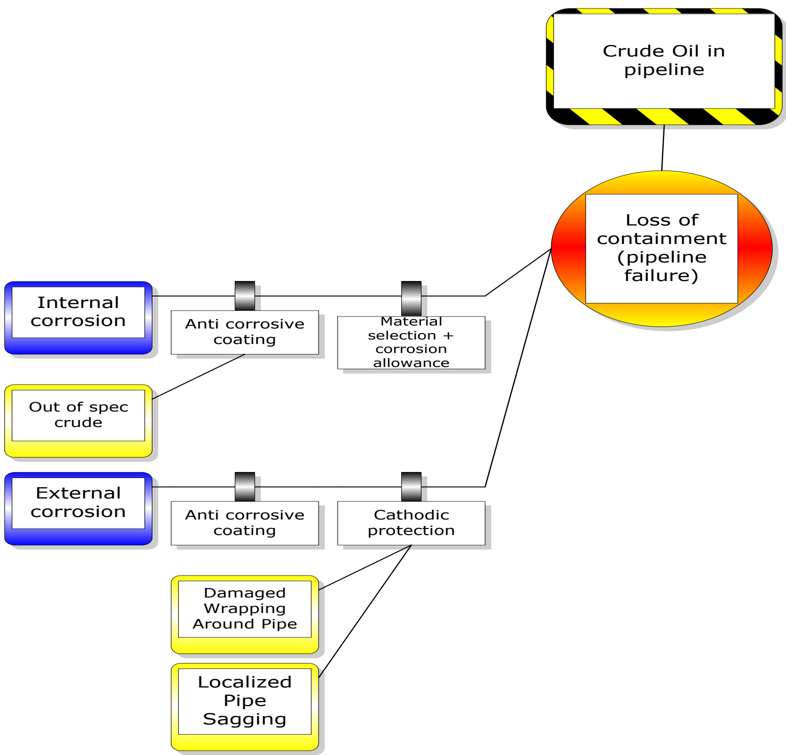
[2] *US Bureau of Safety and Environmental Enforcement*, 2014 Annual Report, www.bsee.gov

[3] Government of the Netherlands, State Supervision of the Mines, Ministry of Economic Affairs, *Strategy and Programme, 2012-2016*, www.sodm.nl/english/publications

With the Refugio Beach event, there was substantial external corrosion of the pipe. It is not yet known whether there was significant internal corrosion as well. However, let's consider both possibilities for purposes of our illustration. Plains reported to PHMSA that the May 5th third party survey revealed metal loss of approximately 45% of the original wall thickness in the area of the pipe that failed on May 19. This was not localized corrosion. In at least 3 other areas along the pipe, the survey showed metal loss at each area between 54 and 74% of the original pipe wall thickness.[4] We can consider this through the lense of barrier failures by developing a bow-tie diagram.

On the left side of the bow tie, possible threats are internal and external corrosion. If we consider at least two barriers in place on each "threat path", we could develop the following Figure 4 to illustrate what happened.

**Figure 4-The Threat Side of a Pipeline Failure Due to Corrosion**

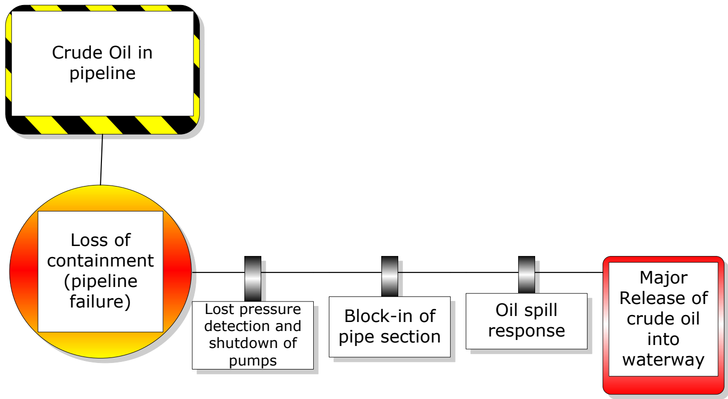



Initial investigation revealed the cathodic protection system appeared be adequate at different points along the pipeline. However, it is not clear at this point whether the operator (Plains All American, or PAA) had anti-corrosive coating in place. The cathodic protection did somehow not completely work, and thus this barrier was "defeated". In our diagram, the yellow colored rectangles are situations that defeat the barriers. In bow-tie terminology these barrier defeating agents are called, "escalation factors."

On the right side of the bow tie, once the rupture occurred and crude began making its way to the ocean, three barriers may have failed, and deserve closer scrutiny. Most systems use a lost pressure detector that alerts the control system and either a manual or automatic shutdown occurs. In this case, the sensor failed, and PAA did not have automatic shut off valves installed, and it is claimed that the manual shutdown was delayed. The third barrier is oil spill response, and it has been said in the media that the response was poor. A citizen, not PAA, reported the spill, and PAA was not able to contact workers near the break to get information required to alert federal emergency officials in a timely manner. For contrast, PAA's response to the spill in SW Illinois was said to be rapid, indicating a barrier that proved to be effective toward mitigating a catastrophic consequence. In a bow-tie diagram, this consequence side could be illustrated as shown in Figure 5 below:

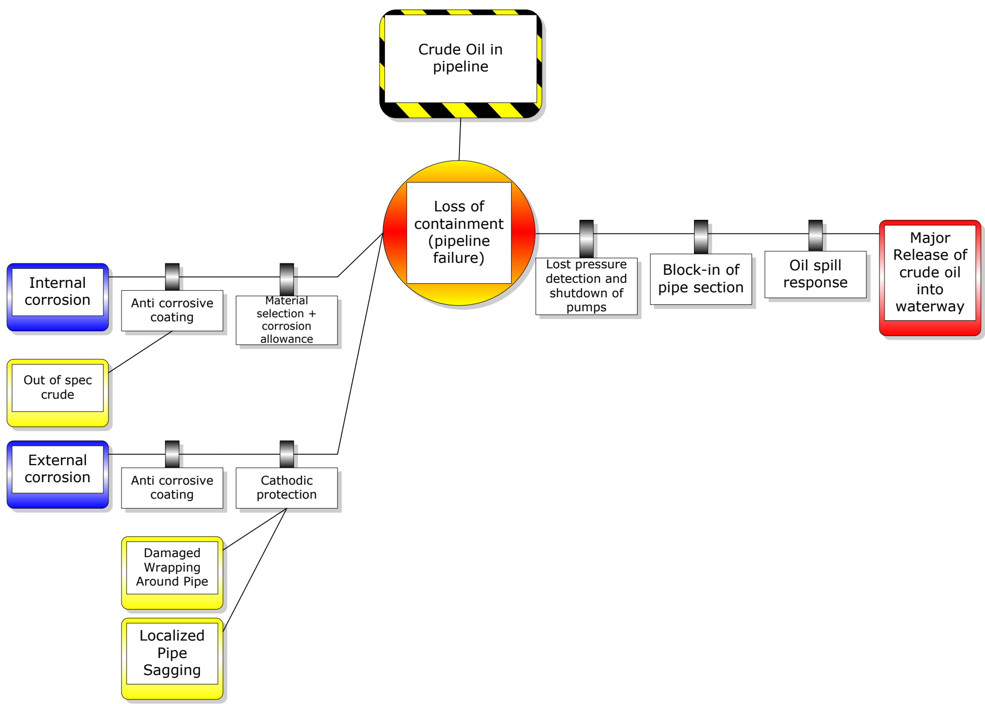
**Figure 5- The Consequence Side of a Pipeline Failure Due to Corrosion**

[4] Amended corrective action order, CPF No. 5-2015-5011H, US Department of Transportation, PHMSA, June 3, 2015.



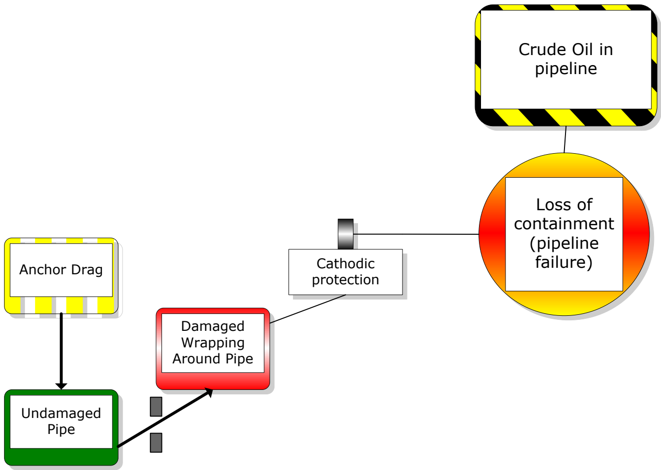

If we were to string together the threat and consequence side of the diagram, we could illustrate the event in one graphic as shown in Figure 6 below:

**Figure 6- Simplified bow-tie of PAA Pipeline Failure Due to Corrosion**




Thus, the bow-tie diagram can be an effective way to model, visualize and communicate the cause and effect relationships and the mechanisms for past and future pipeline failures. As useful as a bow-tie might be as a graphic, it is still a simplified model and leaves some questions unanswered. Among these are: Why did the barriers fail? Will these barriers likely fail again in the future? Are there other barriers, under similar situations that will also fail? How can we guage whether a barrier will fail and what should we do to prevent it? These are difficult, but important questions for those involved in accident investigation. For risk managers, they create important challenges that span not only the technology of metallurgy, but the effectiveness of management systems and the complexities of human behavior. To deal with these questions, another barrier based modeling approach called the Tripod Beta method may be useful. Tripod Beta takes the bow-tie analysis one step further to discover why barriers fail. It applies an in-depth technique for illustrating the failure mechanism. It also provides a framework for understanding systemic and contextual factors. A detailed description of Tripod Beta is beyond the scope of this paper. We can however, graphically illustrate the mechanism and causality for how the cathodic protection barrier could fail through a Tripod Beta diagram showing in Figure 7 below, showing a dragged achor as the mechanism for damaged pipe wrapping.

**Figure 7- Tripod Beta Diagram Illustration of Barrier Failure Mechanism**




This presentation and discussion has shown the mechanics of barrier based risk management through illustrations based on a recent US pipeline accident. Barrier based approaches focus on failure mechanisms (what actually causes accidents) rather than attempting to analyze the precise likelihoods and consequences of the risk itself. Additionally, the graphical nature of the bow-tie and tripod beta diagrams greatly improves communication of risk to a broader group of stakeholders. Finally, barrier techniques are used around the world and at other regulatory agencies within the US government. From this discussion, workshop attendees and others can understand how barrier based risk management approaches could be effective for US regulators and operators to model pipeline risk.

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**About the Authors**

***Scott Randall, Managing Director, North America, Global Business Management Consultants (GBMC), LLC***. Mr. Randall runs the North America operations for GBMC, a project and risk management training and consulting company. Prior to joining GBMC, Mr. Randall had been founder and Managing Director of PlusAlpha Risk Management Solutions, LLC, a risk management company dedicated to helping energy companies achieve a competitive advantage through risk management. He has over 25 years of experience across the fields of project management, financial and operational risk management, due diligence for mergers and acquisitions, international marketing, strategic planning and capital project development.

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Ms. Johannson has a Bachelor's degree from Houston Baptist University and holds a number of quality and leadership related certifications.