# Improving Operational Discipline Programs to Prevent Loss of Containment Incidents

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## Abstract

Process safety and risk management systems are implemented to reduce injuries and process incidents. The effectiveness of these systems is dependent on the company's implementation and support for Operational Discipline (OD)-related programs to ensure that the Process Safety Management (PSM) system requirements are rigorously followed day-to-day at all levels of the organization. However, OD-program-related problems continue to contribute to process incidents, including Loss of Containment (LOC) incidents, especially since they may not be formally addressed during incident investigations. This paper provides a brief historical overview of major LOC incidents, describes how poor OD increases process safety risk and can contribute to LOC incidents, and presents an example of how to track and identify weaker OD characteristics – the OD-related "root causes" – using OD characteristic data obtained during incident investigations.

**Keywords:** operational discipline, incident investigation, conduct of operations, loss of containment, process safety management, risk reduction, root cause failure analysis, near miss, human factors, leading indicator, lagging indicator, process hazards analysis

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# 1. Introduction

Prior work has described how the commitment to Operational Discipline (OD) and reducing at-risk behavior across all levels of the organization can help reduce process safety risk [1, 2, 3]. This paper reviews several major LOC events to emphasize the role of OD in causing LOC incidents, considers how OD affects process safety risk, leading to LOC incidents, and provides an incident investigation tool to help identify OD characteristics as root causes. The framework for both evaluating and improving OD programs is discussed based on the following OD characteristics [2]:

| | | |
|---|---|---|
| Organizational | 1. Leadership Focus |
| | 2. Employee Involvement |
| | 3. Practice Consistent With Procedures |
| | 4. Excellent Housekeeping |
| Personal | 1. Awareness |
| | 2. Knowledge |
| | 3. Commitment |

By tracking these OD characteristics, both systemic Organizational and individual Personal OD weaknesses can be identified, OD program improvements recommended and the risk of LOC incidents reduced.

# 2. Background

### *2.1 Major Loss of Containment Incidents*

Although significant chemical industry events involve Loss of Containment, they are not generally thought of directly as LOC events. Major LOC incidents include toxic events, such as the Seveso incident resulting from loss of containment of a toxic dioxin from a burst reactor rupture disk and the Bhopal incident, resulting from the unmitigated loss of containment of toxic methyl isocyanate (MIC) gas from a storage tank's relief system after its contents were contaminated with water. Similarly, and more recently, the BP Texas City explosion in 2005 occurred after loss of containment of hydrocarbons from a stack during a system start-up after maintenance. Seveso, Bhopal and BP Texas City resulted in severe, irreversible consequences: toxic environmental and personal exposures, fires, explosions and fatalities [4, 5, 6, 7, 8, and 9].

This section provides a brief description of these three major LOC incidents that can be attributed, in part, to poor OD programs. The Seveso incident led to development of Europe's EC Directive on Major Accident Hazards of 1982, also known as the "Seveso Directive" [4]. Bhopal was a "watershed" event for hazards assessments in the chemical industry. The US responded with three legislative efforts around emergency response (EPCRA, 1986), managing hazards and protecting workers within the fenceline (OSHA PSM, 1992), and managing hazards and protecting the communities and environment beyond the fenceline (EPA RMP, 1996) [22, 23, 24]. In response to Bhopal, as well, AIChE formed the Center for Chemical Process Safety

(CCPS) in 1985. The BP Texas City incident led to one of the most comprehensive PSM-focused investigations, both internal to BP and externally through the US Chemical Safety Board and through the "Baker Panel Report. [9]" The BP Texas City incident prompted emphasis on improving a company's "safety culture," including recent AIChE conferences related to the "softer side of engineering" and Human Factors.

The impact of OD on each of these incidents is shown by a matrix in a table for each LOC incident: the incident's PSM-related learnings are listed in the rows of a table; the OD-characteristics are listed in the columns. If there is an interaction (a "relationship) between the PSM learning and a corresponding OD characteristic, the matrix is marked with a "1." The OD characteristics identified for each LOC is discussed in this section, with an overall LOC Organizational and Personal OD-characteristic "trend over time" using a different perspective is discussed in section 2.2 below.

Seveso, Italy

In 1976, a small amount of TCDD, one of the most toxic chemical dioxins known, was released when a rupture disc burst on a chemical reactor. The release dusted the environment with a white solid powder as it drifted across the area downwind. Over the next few days animals died and people in the contaminated area fell ill [4]. After the contaminated area downwind had been characterized and zoned, the most contaminated zone was fenced off, more than 70,000 potentially contaminated animals were killed, and more than 700 people were relocated [10]. As is shown in Table 1, the "Leadership Focus," "Knowledge," and "Awareness" OD characteristics accounted for most of the PSM-related learnings. Studies have shown health and environmental issues in the Seveso area many years later [10, 11, 12, 13, and 14].

Bhopal, India

In 1984, over 40 tons of highly toxic methyl isocyanate (MIC) gas was released when a relief valve lifted on a storage tank contaminated with water. The toxic plume drifted downwind, collected in the valley, and poisoned the residents in the neighborhoods located at the fenceline. More than 2,000 people died within a short period, with tens of thousands injured and countless livestock killed [4]. As is shown in Table 2, the "Leadership Focus" and "Knowledge" OD characteristics accounted for more than half of the PSM-related learnings. Like Seveso, many health and environmental issues, including water contamination, still exist over 25 years later [15, 16, 25].

BP Texas City, USA

In 2005, hydrocarbons overflowed from an oil refinery isomerization unit stack during a system start-up. The hydrocarbons formed a large vapor cloud in the immediate area which subsequently ignited and caused a series of explosions. An occupied contractor's trailer sited in the explosion zone was destroyed, 15 people died and 180 people were injured [5]. OSHA levied severe fines and the CSB concluded that "Organizational and Safety Deficiencies at All Levels of the BP Corporation" caused the disaster [6]. As is shown in Table 3, almost all of the OD characteristics applied to more than half of the PSM-related recommendations. Unfortunately, the site's culture could not change quickly enough, and other PSM-related issues at the BP Texas City refinery prompted more fines after a six month follow-up audit in 2009 [17].

### *2.2 A Different LOC Perspective Using OD*

Although these major LOC incidents prompted specific regulatory and industry-wide changes, the specific OD characteristics have not traditionally been formally addressed during the incident investigation process. Root cause failure analysis (RCFA) training techniques do not formally note "OD Root Causes" [18, 19]. In general, RCFA's identify the root causes of events within one or a combination of three broad categories: 1) equipment failure; 2) human failure; and 3) systems failure. Equipment failure may be due to weaknesses in mechanical integrity programs or poor equipment reliability and potential for catastrophic failure. Human failure, attributed to weaknesses in Personal OD characteristics, may be due to poor training or poor decision-making during unfamiliar situations or emergency responses. This human failure category is difficult to identify and address because it deals with humans and their behavior, and is the major focus of minimizing the potential for human error within Human Factors-related risk-reduction strategies. However, it is the third category, the systems-related failure, which is significantly impacted by improving Organizational OD-related weaknesses. Fixing system failures has the greatest overall impact on LOC incidents due to the leveraging effect of system-level fixes. Improving the Organizational OD characteristics – the business' safety culture – impacts all employees in the organization. This includes improving the leadership focus on, support for, and communication of expectations that everyone performs to meet the organization's "code of conduct" (see a definition for OD below).

A different image of the changing nature of our PSM efforts to reduce risk evolve over time can be captured with the familiar DNA double-helix model shown in Figure 1. Think of climbing up the spiral ladder as time (evolution over time; longer molecules are more complicated and have more "understanding"). The rungs represent the building blocks of the ladder (the amino acids); consider that OD could be the weak hydrogen bonds that hold the blocks together. The major LOC incidents are shown over time on our climb where significant gaps occurred in the rung (i.e., previously unknown or un-addressed "weak bonds" caused an incident). Imagine yourself climbing up the ladder, only to look back down at a later date and see our goal (reduced process safety risk) from this different perspective, the view that has more experience. Every major and often tragic LOC has provided us with new opportunities for learning. Hence, over time, our initial qualitative incident investigation tools have evolved to include better and more quantitative techniques [20].

With this different perspective in mind, the OD-characteristics noted in the three major LOC incidents above were compiled and summarized in Table 4, and are shown with the change in OD characteristics "recognition" over time in Figure 2. More Organizational OD weaknesses are being identified today than two decades ago. Hence, as we acquire a better view on improving process safety risk reduction efforts, the trend has shifted from identifying and correcting mostly Personal OD weaknesses (the "individual" human failures) to finding better ways identifying and improving Organizational OD weaknesses (the systemic and cultural failures). It is interesting to note that over time more and better investigation tools have been developed and shared (our building blocks), consistent with the development of the numerous publications by the CCPS and many other publishers during the last two decades. It is hoped that this different perspective supports the case for our need to reducing LOC incidents by measuring and focusing on

Organizational OD-program weaknesses (the gaps, the weak bonds between our building blocks) so that we get closer to our goal: reducing process safety risk.

### *2.3 The Impact of OD on Risk*

The seven Organizational and Personal OD characteristics were listed in the Introduction. These seven characteristics provide a framework for both identifying OD-related problems and for developing appropriate improvements to OD programs at a facility. The concept showing that OD underlies and impacts all aspects of an effective Process Safety Management (PSM) system is shown schematically in Figure 3 [1, 2, 21, 22]. This section of the paper defines OD and describes how OD impacts risk.

What is OD? A definition proposed for "Operational Discipline" is as follows [2]:

> The deeply rooted dedication and commitment by every member of an organization to carry out each task the right way every time.

How does OD affect risk? First, risk must be defined. The overall goal of all PSM efforts is to reduce the risks of the process and its associated hazards (fires, explosions, toxic releases). One useful way of describing the methods to reduce these risks is to modify the normal risk equation and consider the impact of OD with the following equation [2]:

$$\text{Risk} = \boldsymbol{f}\{ (\text{Frequency x Consequence}) / (\text{Operational Discipline}) \} \qquad \textbf{(1)}$$

In this equation, risk is directly related to both a Frequency term and a Consequence term and is indirectly related to an OD term. The concept is simple: decreasing the frequency term reduces the risk; decreasing the consequence term reduces the risk; and decreasing the OD term raises the risk.

The frequency is often determined by the effectiveness of engineering and administrative controls to prevent a possible hazardous event., such as safety systems and operating procedures. Improving engineering and administrative controls will reduce the potential frequency of the event and hence, reduce the risk. The "worst case scenario" consequence term is characterized by the potential LOC event that could result in a fire, explosion, or toxic release. The consequences are determined with the hazardous properties of the materials (e.g., flammable, toxic, etc.), the amount of hazardous material in the system and the processing conditions required store, handle, and transform the raw materials to the final product. Reducing the consequence, such as those defined within inherently safer design principles, will reduce the risk, as well. Note that improving engineering systems and administrative procedures may reduce the consequences, as well. These improvements include more sensitive detectors, earlier and faster event-detection alarms, and faster system shutdowns to a safer state, faster emergency team responses, and improved mitigation procedures.

How does OD affect risk? As is defined in this risk model, risk is inversely related to an OD term. This OD term is expressed in fractional form, where 1.0 represents perfect OD program implementation, and reflects some of the behavior-related aspects within the risk equation, such as the organization's Conduct of Operations (COO) and Human Factors principles. For example, safety systems and operating procedures are designed to reduce the frequency and consequences of the risk. If there is poor OD, the safety systems will degrade and short cuts may prevail, either to personal choice or supervisor decrees. If one-half the time the safety procedure is not followed and the safety systems are not maintained – say 50% compliance to OD - the risk is doubled. Hence, a reduced OD term – poor OD - increases the risk. OD programs must be sustained, maintained and followed to ensure 100% effectiveness of the safety systems and procedures developed to reduce risk.

As is shown in the risk matrix in Figure 4, a system with an acceptable risk ("green") will move toward the unacceptable zone ("red") when poor OD exists. An example for illustration: a process risk is identified as acceptable if it is operated within its safe operating limits. However, the actual process is routinely operated outside of these safe operating limits to meet production demands (and for some reason, this behavior doesn't adversely affect the product's quality!). If this OD characteristic, Practice Consistent with Procedures, is not addressed, the actual risk may be higher due to higher potential (frequency) for the hazardous event and its consequences. Improving this "weak" OD characteristic back toward 1.0, such as enforcing the procedures, will ensure a stronger (higher) OD-related term and prevent the risk from moving toward the unacceptable red zone.

## 3. Preventing LOC Incidents

Before improving OD programs, not only must a set of OD "metrics" be determined and measured, but any changes proposed must be "knobs" that we can turn (we have some sort of influence over the metric). Product quality improvement tools are designed to find knobs on machines to improve their reliability and measure their product's performance. However, human-related reliability and performance improvement tools are not as so easy to find – which "knob" do we turn? As was discussed in Section 2.2 above, more Organizational OD characteristic weaknesses are being identified today than two decades ago. The trend from the Personal OD focus to a more systemic Organizational OD focus reflects a better understanding that more effective risk reduction efforts will occur when system weaknesses are addressed and resolved. Hence, identifying and monitoring an Organizational OD-characteristic metric will more effectively help reduce risk. To proactively prevent LOC incidents, we need to answer the question: "How do we determine the leading indicators, measure and monitor them, and then improve our OD program?" This section explores the extent of LOC incidents, ranging from near misses to catastrophic events, the importance of identifying leading indictors versus simply measuring lagging indicators, and proposes a "principles" metric that measures "adherence" based on the human actions (Personal OD - at-risk behavior) which may have contributed to the incident. Future work will focus on better Organization OD metric identification and analysis.

The LOC incident pyramid, shown in Figure 5, helps visualize how improving OD to reduce LOC incidents can help reduce major flammable, explosive and toxic releases. This pyramid contains different levels with decreasing number of events represented by smaller areas at higher levels within the pyramid. The largest area at the bottom represents the number of "foundation" level events, such as minor releases or spills with no irreversible personal, process or environmental harm. The smallest area at the top represents a relative smaller number of catastrophic events, such as Seveso, where the LOC caused irreversible harm to personnel and the environment. ("All fires start out small, even the big ones.") The concept to reduce the number of major incidents is relatively simple: if there are fewer minor spills and releases at the lower levels (hence, a smaller "foundational" area), then there should be relatively fewer catastrophic LOC incidents at the top level.

Responding to LOC event that have occurred, a lagging indicator, is known as reactive LOC incident management. Recently, CPPS published guidance on identifying leading indicators to provide metrics for proactive PSM system improvements [26]. Note that this guidance document provides potential leading indicators which are designed to better develop, nurture and sustain all of the PSM Elements (Figure 3). As is described below, focusing on and improving the weaker OD characteristics proactively "attacks the base" of the incident pyramid (Figure 5) and will help reduce the number of LOC incidents.

### *3.1 The Impact of OD on LOC Incidents*

As is described and shown in the risk equation above (Equation 1), the impact of improving OD is to reduce the risk. Poor performance to any OD characteristic, whether it is organizational or personal, will increase the risk. Note that proactive LOC incident investigations should include "near miss" incidents. These types of incidents could have been much worse had conditions or human actions been slightly different: just a matter of a few centimeters to the left or to the right, or just a few seconds earlier or later and a catastrophic LOC could have occurred ("we were lucky"). Effective OD programs will recognize, monitor and track this type of leading indicator as a learning and improvement measurement tool, as well.

It is important to recognize that LOC incident investigations need to identify the contribution of the different OD characteristics to the incident. From this data – the OD program feedback – site-specific OD characteristics that are causing incidents can be identified and targeted for improvement. For example, one site may see "Practice Consistent with Procedures" as the weaker characteristic, whereas another site, reflecting a different safety culture, may identify "Leadership Focus" as its weakest characteristic. Improvements will be and must be based on the site-specific issues. If the different contributions and impact of OD characteristic weaknesses are not being addressed in the incident investigation process, important information needed to reduce LOC incidents will be overlooked.

### *3.2 Preventing LOC Incidents by Improving OD*

This section describes part of an OD improvement incident investigation strategy that is being discussed through Cabot's FMO division to help prevent LOC events and reduce FMO's safety and environmental risks. Although the current incident investigation approach notes the following OD-related leading indicators (the "base" of the pyramid in Figure 5),

1) Is the incident a "Near Miss?"
2) Did we adhere to the "Principle?"
3) Was the incident as a result of an "Unsafe Act?"

this paper describes an approach being proposed to monitor and address the second indicator, the FMO's "Principles of Operation," only. Future work will address data pertaining to near misses and unsafe acts. Connecting the OD characteristics to reducing individual "At Risk" behavior, as is identified with a weakness in an OD-related Principle, will help with improving OD and reducing risk.

The eight FMO "Principles of Operation" were developed in 2007, issued in 2008 and subsequently implemented into the incident investigation procedure in early 2009. The Principles capture and correspond to the basic characteristics of PSM and are linked with the incident investigation procedure, as is shown with the matrix in Figure 6.

The Principles are FMO's code of conduct (a "Conduct of Operations") is as follows:

1. Always operate equipment and processes within designed safety and environmental limits.
2. Always move to a safe controlled condition OR location when a situation is not understood.
3. Always seek assistance and involve people with expertise in changes or improvements that affect equipment or procedures.
4. Always understand and address deviations and ensure proper corrective actions are implemented AND communicated.
5. Always report environmental or safety deviations promptly and accurately.
6. Always follow safe work practices and written procedures and act to stop unsafe conditions and behaviors.
7. Always address abnormal conditions and clarify / understand all procedures before proceeding.
8. Always use tools/equipment/processes for their intended use. Never compromise any safety systems and/or interlocks.

In general, these principles focus on the “Knowledge” characteristic of Personal OD and are actively supported and discussed through the “Leadership” characteristic of Organizational OD.

The Principles are specifically listed in part of the investigation team’s form, as is shown in Figure 7. The team fills out this part of the investigation form by answering the question “Did we adhere to the Principle?” with a “Yes,” “No,” or “Not Applicable” response. A strong Principle receives a “Yes” response. For example, if the employee reports a minor LOC spill immediately, the answer to Principle #5 is “Yes.” An example of a weak Principle (one that was not followed) is if the employee decides to substitute a cheaper and subsequently less resistant gasket without confirming its suitability leading to an LOC. In this case, the answer to Principle #3 would be “No.”

The team is required to address each of the “No” responses with at least one specific action. The expectation is that all “No” responses will have a specific OD-improving action noted to address and correct the gap. These actions may be combined into a recommendation that is issued with the final incident investigation report. Hence, by monitoring adherence to the Principle, we are measuring an “At Risk” Behavior and can track the Principles to identify and improve the weaker OD-related characteristics.

Initial data analysis from selected incidents over the latter part of 2009 is discussed next. This trending approach indicates that each FMO site and the FMO business will be able to monitor and track poor adherence (lack of OD) and then can address its “weaker Principles” to help improve OD and reduce risk. The Principles trending approach is shown in Figure 8. Since the goal is to focus on weaker principles, those that tend to receive more “No” answers, show up as principles that have the most “No” responses relative to the others. From the 32 incidents noted at this point in Figure 8, it is clear that the weaker principles are “Following Procedures” (Principle #6, at 44%) and “Operating Safely” (Principle #1, at 31%). Do note that these principles are not independent. However, this result indicates that we are struggling to adhere to our safe work practices, an essential element required for effective PSM systems (Figure 3). Assuming that a sufficient LOC incident data set is available, this “trend” indicates that we must re-emphasize across the entire organization the importance of ensuring knowledge of and operating within safe operating limits to help prevent LOC incidents.

## 4. Summary and Conclusion

The example incident investigation approach described in this paper, proactively measuring and trending an “Operational Discipline” characteristic, may be useful for reducing the number of LOC incidents by improving OD. This paper provides a different perspective on incident data analyses using OD-characteristics, shows that poor adherence to one of the Principles (in particular, “poor OD”) can be determined during an LOC incident investigation. More robust trending analysis will provide managers with OD-program focus areas for making OD-characteristic and PSM-related improvements. These OD program improvements should reduce the LOC risk by reducing the frequency of LOC incidents. Therefore, the effectiveness of safety systems and procedures in reducing LOC incidents is dependent on the company's implementation and support for OD-related programs to ensure that the system requirements are rigorously followed day-to-day at all levels of the organization.

## 5. Future Directions

Work on better data acquisition and analysis of OD characteristics is currently underway; additional work will be performed on existing near miss and unsafe act data already being documented in Cabot FMO's final incident reports.

Note that the frequency and/or consequence risk-reduction approach described in Section 2.3 is the basis for Process Hazards Analysis (PHA) Team evaluations, and helps provide PHA Teams with a framework for proposing practical recommendations that reduce the LOC risk to an acceptable level. However, if poor OD occurs once the process is operating, the actual risk may be higher and unacceptable when compared to the PHA Team's conclusion. Although this will be the subject of a future paper, a brief overview of the PHA Team's process is described here to help elucidate how failure to consider the impact of poor OD increases the risk. First, a PHA team evaluates the frequency and consequences of a LOC event based on a review of hazards of the proposed or existing design of the process. This review includes the all known process safety information: the hazards of the materials, the process design and the equipment design. Then the Team determines potential LOC release scenarios and failures, both without any safeguards (the "worst case scenario") and with existing and/or proposed safeguards. If the risk is deemed unacceptable, the Team must develop additional risk-reduction strategies and propose recommendations for management review and approval. If OD is not considered by the PHA team, then the actual risk may be higher than the calculated risk as some of the safeguards may not function as planned. Consideration of how OD characteristics impact risk to help prevent LOC incidents is therefore an important part of the risk function and should be considered by PHA Teams.

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**Table 1. Matrix Relating the OD Characteristics to the Seveso LOC Incident PSM-related Learnings**

| | Operational Discipline Characteristic | Organizational | | | | Personal | | |
|---|---|---|---|---|---|---|---|---|
| | Seveso PSM-related Learning | 1 Leadership Focus | 2 Employee Involvement | 3 Practice Consistent With Procedure | 4 Housekeeping | 1 Awareness | 2 Knowledge | 3 Commitment |
| 1 | Public control of major hazard installations | | | | | | | |
| 2 | Siting of major hazard installations | 1 | | | | 1 | | |
| 3 | Acquisition of companies operating hazardous processes | 1 | | | | | | |
| 4 | Hazard of ultratoxic substances | | | | | 1 | 1 | |
| 5 | Hazard of undetected exotherms | | | | | 1 | 1 | |
| 6 | Hazard of prolonged holding of reaction mass | | | | | 1 | 1 | |
| 7 | Inherently safer design of chemical processes | | | | | | | |
| 8 | Control and protection of chemical reactors | | | 1 | | | | |
| 9 | Adherence to operating procedures | | | 1 | | | | |
| 10 | Planning for emergencies | 1 | | | | | | |
| 11 | Difficulties of decontamination | | | | | | 1 | |
| | Sum | 3 | 0 | 2 | 0 | 4 | 4 | 0 |

## Table 2. Matrix Relating the OD Characteristics to the Bhopal LOC Incident PSM-related Learnings

| | Operational Discipline Characteristic | Organizational | | | | Personal | | |
|---|---|---|---|---|---|---|---|---|
| | Bhopal PSM-related Learning | 1 Leadership Focus | 2 Employee Involvement | 3 Practice Consistent With Procedure | 4 Housekeeping | 1 Awareness | 2 Knowledge | 3 Commitment |
| 1 | Public control of major hazard installations | | | | | | | |
| 2 | Siting of and development control at major hazard installations | 1 | | | | | | |
| 3 | Management of major hazard installations | 1 | | | | | | |
| 4 | Highly toxic substances | | | | | | 1 | |
| 5 | Runaway reactions in storage | | | | | | 1 | |
| 6 | Water hazard in plants | | | | | 1 | | |
| 7 | Relative hazards of materials in process and in storage | | | | | | 1 | |
| 8 | Relative priority of safety and production | 1 | | | | | | |
| 9 | Limitation of inventory in the plant | | | | | | 1 | |
| 10 | Set pressure of relief valves | | | | | | | 1 |
| 11 | Disabling of protective systems | 1 | | 1 | | | | 1 |
| 12 | Maintenance of plant equipment and instrumentation | | | | 1 | | | 1 |
| 13 | Isolation procedures for maintenance | | | | 1 | | | |
| 14 | Control of plant and process modifications | 1 | | | 1 | | 1 | |
| 15 | Information for authorities and public | | | | | 1 | | |
| 16 | Planning for emergencies | 1 | | | | 1 | | |
| | Sum | 6 | 0 | 1 | 3 | 3 | 5 | 3 |

**Table 3. Matrix Relating the OD Characteristics to the BP Texas City LOC Incident PSM-related Recommendations**

| | Operational Discipline Characteristic | Organizational | | | | Personal | | |
|---|---|---|---|---|---|---|---|---|
| | BP Texas City PSM-related Recommendation | 1 Leadership Focus | 2 Employee Involvement | 3 Practice Consistent With Procedure | 4 Housekeeping | 1 Awareness | 2 Knowledge | 3 Commitment |
| 1 | Process Safety Leadership | 1 | | | | | | |
| 2 | Integrated and Comprehensive Process Safety Management System | | 1 | 1 | 1 | 1 | 1 | |
| 3 | Process Safety Knowledge and Expertise | | | | 1 | 1 | 1 | |
| 4 | Process Safety Culture | 1 | 1 | 1 | 1 | | | 1 |
| 5 | Clearly Defined Expectations and Accountability for Process Safety | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | Support for Line Management | 1 | 1 | | 1 | | | 1 |
| 7 | Leading and Lagging Performance Indicators for Process Safety | 1 | | | 1 | 1 | 1 | |
| 8 | Process Safety Auditing | 1 | | 1 | 1 | | 1 | |
| 9 | BP's Board Monitoring | 1 | | | | | | |
| 10 | Industry Leader | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Sum | 8 | 5 | 5 | 8 | 5 | 6 | 4 |

**Table 4. Compiled Matrix Summarizing the Relationship Between the OD Characteristics and the LOC Incident PSM-related Learnings**

| Loss of Containment (LOC) | Year | Number of Learnings | Organizational: 1 Leadership Focus | Organizational: 2 Employee Involvement | Organizational: 3 Practice Consistent With Procedure | Organizational: 4 Housekeeping | Personal: 1 Awareness | Personal: 2 Knowledge | Personal: 3 Commitment | Organizational total | Personal total | Organizational % | Personal % | Operational Discipline Characteristic total | Average OD / LOC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sum from LOC Incidents | | 37 | 17 | 5 | 8 | 11 | 12 | 15 | 7 | 41 | 34 | | | 75 | |
| BP Texas City PSM-related Recommendations | 2005 | 10 | 8 | 5 | 5 | 8 | 5 | 6 | 4 | 26 | 15 | 63% | 37% | 41 | 4.1 |
| Bhopal PSM-related Learnings | 1984 | 16 | 6 | 0 | 1 | 3 | 3 | 5 | 3 | 10 | 11 | 48% | 52% | 21 | 1.3 |
| Seveso PSM-related Learnings | 1976 | 11 | 3 | 0 | 2 | 0 | 4 | 4 | 0 | 5 | 8 | 38% | 62% | 13 | 1.2 |

**Figure 1. A Different LOC Incident Investigation Perspective Using OD**

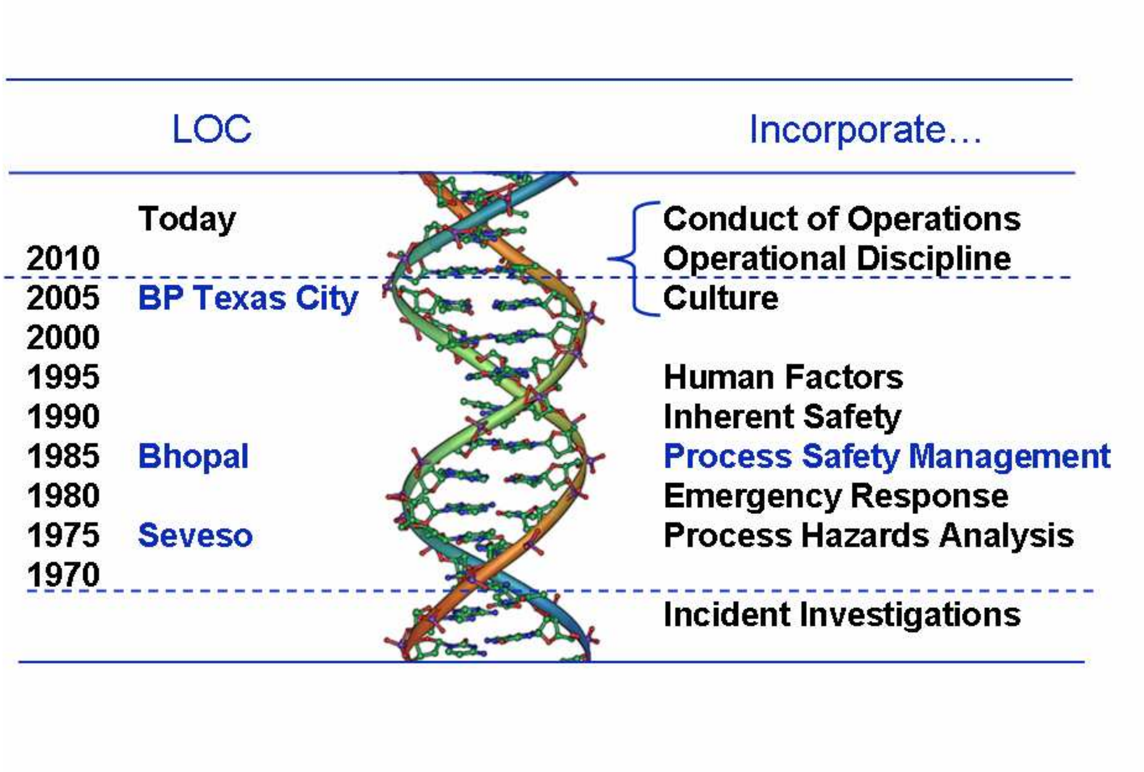



**Figure 2. The OD Characteristics Trend from the Three Major LOCs**

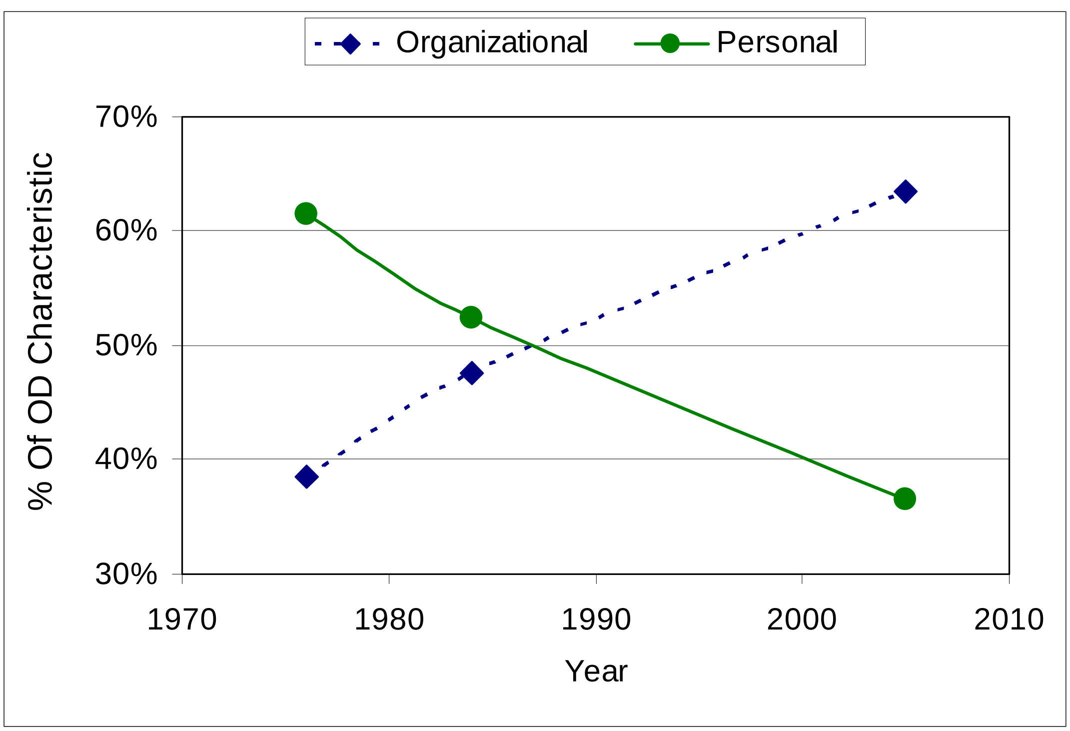


**Figure 3. A Link Between the Process Safety Management (PSM) Elements and OD**

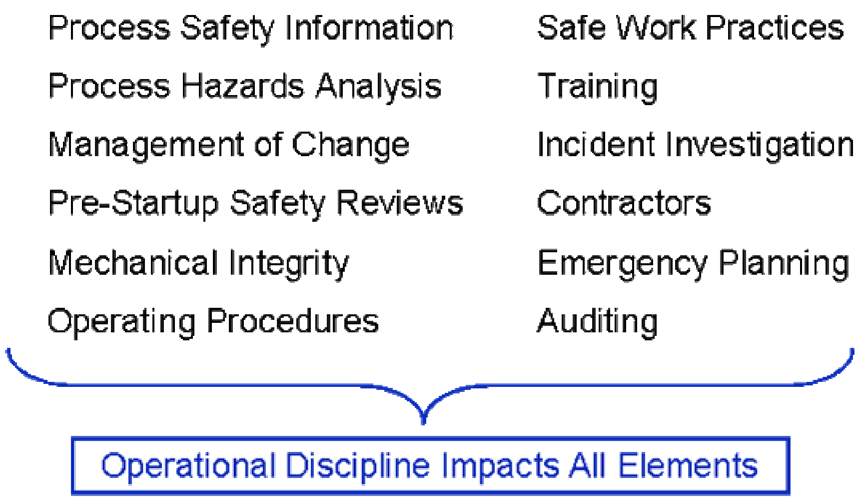
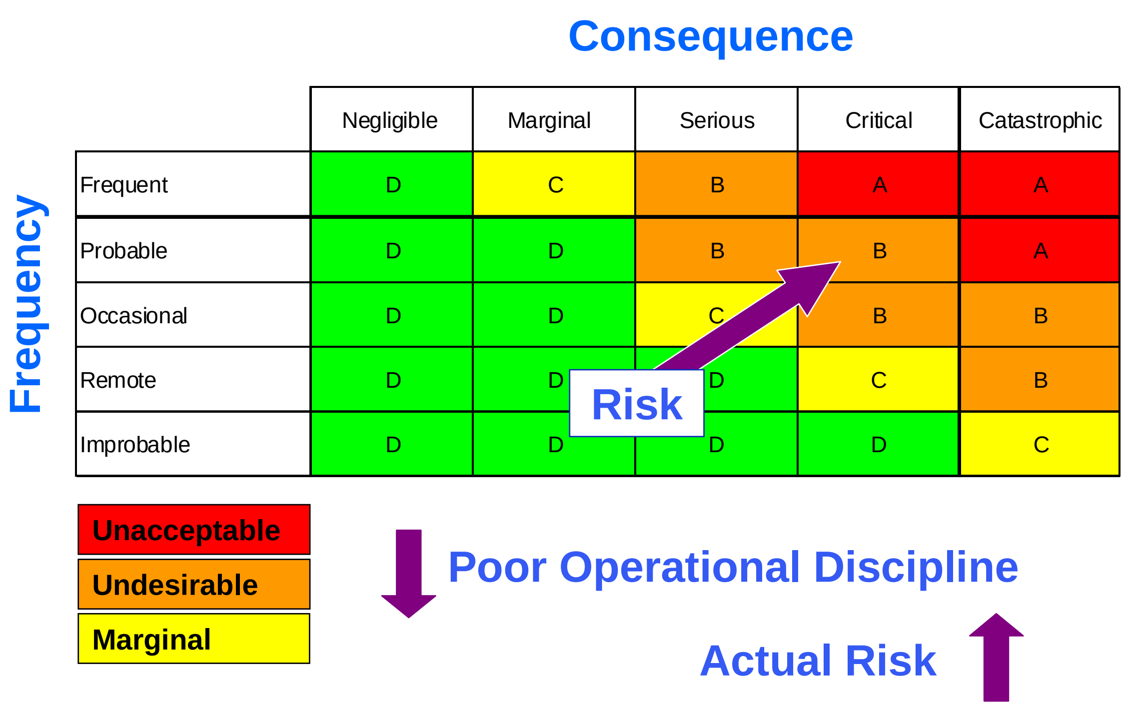
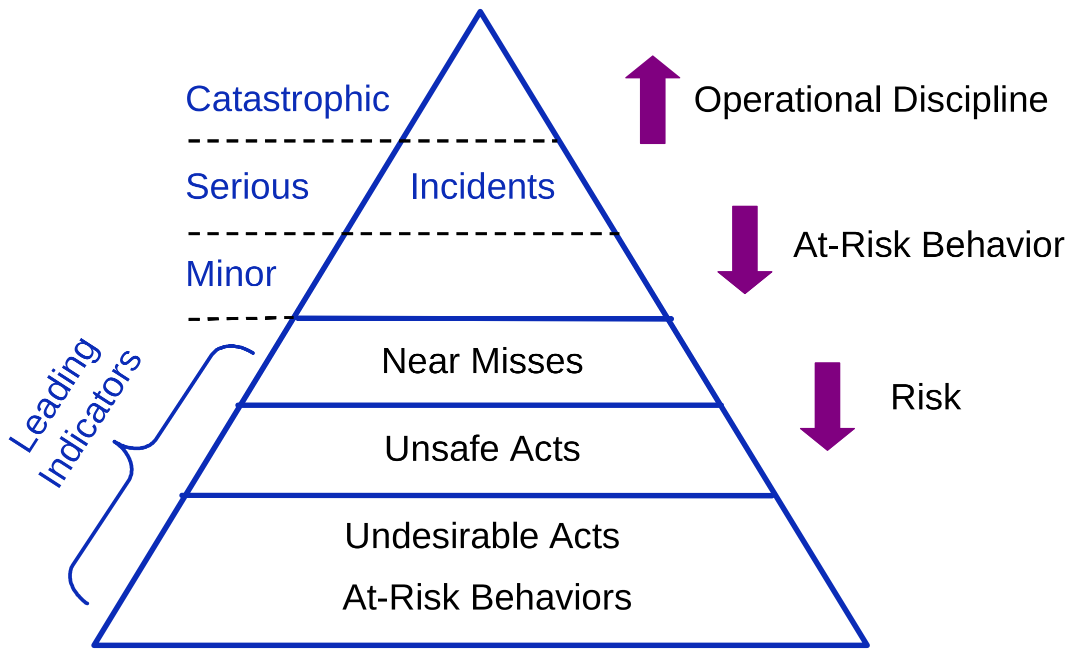



**Figure 4. The Impact of Poor OD on the Actual Risk**




| | Negligible | Marginal | Serious | Critical | Catastrophic |
|---|---|---|---|---|---|
| Frequent | D | C | B | A | A |
| Probable | D | D | B | B | A |
| Occasional | D | D | C | B | B |
| Remote | D | D | D | C | B |
| Improbable | D | D | D | D | C |

**Figure 5. The Effect of OD on the Incident Pyramid**



## Figure 6. The Link Between the FMO Principles, LOC Incidents and PSM

| Process Safety Management Element | Principle of Operation: Operate Safely | Move to Safety | Seek Help | Ensure Corrections | Report Promptly | Follow Procedures | Address Deviations | Use As Intended |
|---|---|---|---|---|---|---|---|---|
| Process Safety Information | X | | X | | | | X | |
| Process Hazards Analysis | | | X | X | | X | X | |
| Management of Change | | | X | X | | X | | |
| Pre-Startup Safety Reviews | | | X | X | | X | | |
| Mechanical Integrity | | | | | | X | | |
| Operating Procedures | X | | | | | X | X | |
| Safe Work Practices | X | | | | | X | | |
| Training and Performance | | | X | | | X | | X |
| Incident Investigation | | | | | X | X | | |
| Contractors | | | | | | X | | |
| Emergency Planning and Response | | X | | | | X | | |
| Auditing | | | | X | | | | |

Incidents

## Figure 7. The Cabot Incident Investigation Principles Discussion and Action Form

| Unrecognized or Unchallenged Hazard | |
|---|---|

| | Principle of Operation | Adhere to Principle? Yes | n/a | No |
|---|---|---|---|---|
| 1 | Always operate equipment and processes within designed safety and environmental limits | | | |
| 2 | Always move to a safe controlled condition OR location when a situation is not understood | | | |
| 3 | etc. | | | |

| Shared Learning Discussion from Review of Incident |
|---|
| Discussion: |
| **Action:** |
| Discussion: |
| **Action:** |
| |
| |

**Figure 8. Example of Principles Data Analysis from Incident Investigations**

| Noted as "Yes" - Following Principle | | No - Not Following Principle<br>Need to re-emphasize Principle | |
|---|---|---|---|
| | | | |
| 31% | Operate safely | 31% | Operate safely |
| 34% | Move to safety | 13% | Move to safety |
| 31% | Seek help | 13% | Seek help |
| 63% | Ensure corrections | 19% | Ensure corrections |
| 78% | Report promptly | 9% | Report promptly |
| 34% | Follow procedures | 44% | Follow procedures |
| 53% | Address deviations | 19% | Address deviations |
| 28% | Use as intended | 16% | Use as intended |
| | | | |
| | Stronger Principles | | Weaker Principles |
| | | | |
| | Prompt reporting | | Following procedures |
| | Ensuring corrections | | Operating Safely |
| | Addressing deviations | | |

Weaker

OD

Elements