Our Process Safety Journey Continues: Operational Discipline Today[1]

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Abstract

In the late 1980's, DuPont defined Operational Discipline (OD) as the deeply rooted dedication and commitment by each member of an organization to carry out each task, the right way, each time. Many other companies have similar "operational discipline" definitions, and this emphasis has not changed. Furthermore, the dedication and commitment to OD has grown stronger. Operational discipline continues to reflects the strength of an organization's safety culture in making process safety programs effective and in providing tangible results for preventing injuries and incidents through effective process safety systems. What has changed is how we better apply Operational Discipline as one of the three essential process safety foundations. When combined with both a strong Safety Culture and Leadership and robust Process Safety Systems, the company's strong Operational Discipline foundation helps improve process safety performance. This paper describes how collaborative efforts have helped us to better evaluate Operational Discipline in context of the Risk Based Process Safety's element Conduct of Operations, briefly presents how OD programs can be implemented using an example from the Dow Chemical Company, and provides some practical guidance and approaches that a company can use on their process safety journey to improve their OD program.

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Every block of stone has a statue inside it and it is the task of the sculptor to discover it.

~ Michelangelo

Every day has learnings inside it and it takes operational discipline to discover them.

~ Bruce K. Vaughen

1 Introduction

As was noted ten years ago, we defined Operational Discipline (OD) as "the deeply rooted dedication and commitment by each member of an organization to carry out each task, the right way, each time" [1]. Many companies and groups have similar OD-related definitions, and the emphasis on "doing the right thing" has not changed. Examples of OD-related descriptions and concepts include "everyone do it right every time" [2], "…what occurs in a plant on a daily basis" [3], "the performance of all tasks correctly every time…[by everyone in their] day-to-day activities" [4], "…[to] execute system requirements correctly every time" [4], "as displaying behaviors within a system of checks and balances that help ensure that things are done correctly and consistently" [5], "a consistent pattern of behavioral choices that support success" [6], and the "Tenets of Operation" [7, 8]. If anything, the dedication and commitment to OD across many industries has grown stronger in the last decade. Operational discipline still reflects the strength of an organization's safety culture in making process safety programs effective and in providing tangible results for preventing injuries and incidents.

What has changed since our work ten years ago is how we better apply Operational Discipline as one of the three essential process safety foundations [3, 9]. These foundations will be described in more detail in Section 3.2. When combined with both a strong Safety Culture and Leadership foundation *and* a robust Process Safety System foundation, a company's strong Operational Discipline foundation helps improve its overall process safety performance. Discipline is expected from everyone in every group for an effective process safety program.

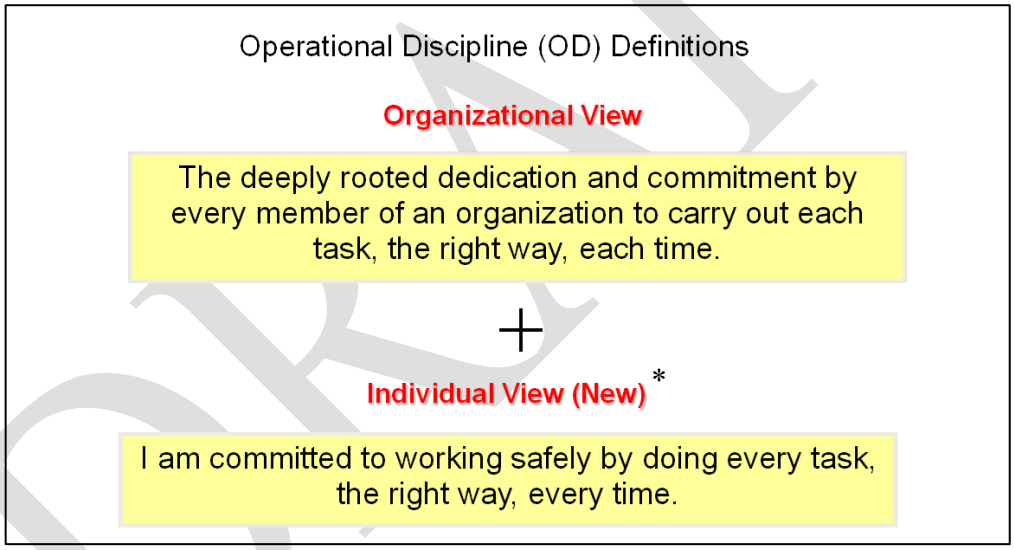
This paper describes how collaborative efforts over the years have helped us to better evaluate Operational Discipline (OD) in context of the Risk Based Process Safety's element "Conduct of Operations," provides an overview of current process safety definitions to help orient those who are new to the field or who have not seen how these terms are being used today, briefly presents how OD programs can be implemented using a practical example from the Dow Chemical Company, and provides some approaches that a company can use on their process safety journey to improve their OD program and the effectiveness of their process safety programs.

1.1 Operational Discipline Ten Years Ago

Although organizations were using the operational discipline and conduct of operations concepts for improving their operations, including their process safety performance, the term "Operational Discipline" does not show as such in the process safety literature until the late 1980's. Since then, there has been a significant increase in the number of presentations and publications using OD-related terms over the last decade. However, before discussing this trend in Section 1.2, this

section sets the stage for what we presented ten years ago at the 2007 Global Congress on Process Safety (GCPS) [1 *(PPSS)*, 10 *(CCPS)*].

The new, revised OD approach presented at the GCPS' Process Plant Safety Symposium in 2007 added a personal, individual component to the existing organizational commitment, as is shown in Figure 1. This approach reflected the development in everyone being personally committed to process safety, resulting in the OD definition focusing on "everyone does it right" for operational excellence (Figure 2). For a company to improve its process safety program effectiveness, an OD-related commitment is needed from *everyone at a personal level*, no matter where they are in the organization: senior leadership, managers, supervisors, engineers, operators, electricians, mechanics, technicians and purchasers. In particular, everyone who directly or indirectly affects the equipment life cycle must have the discipline to follow their procedures and standards. The decisions from people at all levels in an organization that impact the processes and equipment integrity is discussed in greater detail elsewhere [9, 11, and 12]. Too many incidents have occurred due to poor operational discipline by individuals or groups in an organization. The impacts on the severity of incidents due, in part, to poor operational discipline are described in more detail in Section 4.5. As will be described in more detail later in this paper, examples of good Operational Discipline are shown in Table 1.



(* "New" at the time of the paper's publication.)

Figure 1. Adding Personal Commitment to the Organization's Operational Discipline [1]

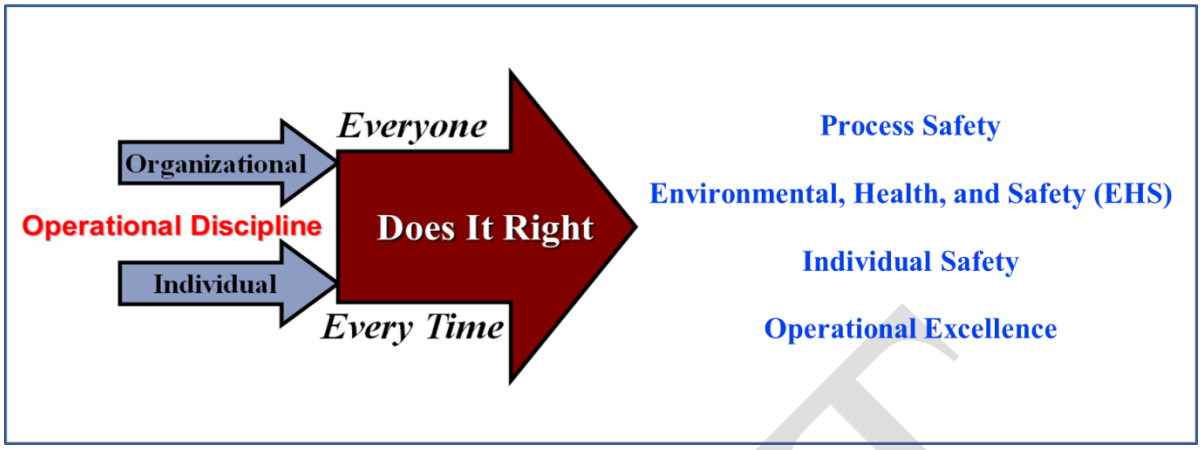


Figure 2. The Operational Discipline Model [Adapted from 1, 2, and 10]

1.2 An "Operational Discipline" Literature Search

The number of OD-related presentations and publications increased over the last decade (2007 to 2017), as is shown in Figure 3 using the results of a literature search counting the number of conference-related presentations, journal publications, white papers, and books (or parts of books) located at the time this paper was prepared. Although a search over the internet provided some of these references, most of them were obtained directly from the source publications and publishers noted below. The search through "ResearchGate" identified many of these publications, too, but there were many OD-related hits from other industries where companies have struggled to effectively manage their operational risks, as well [13].

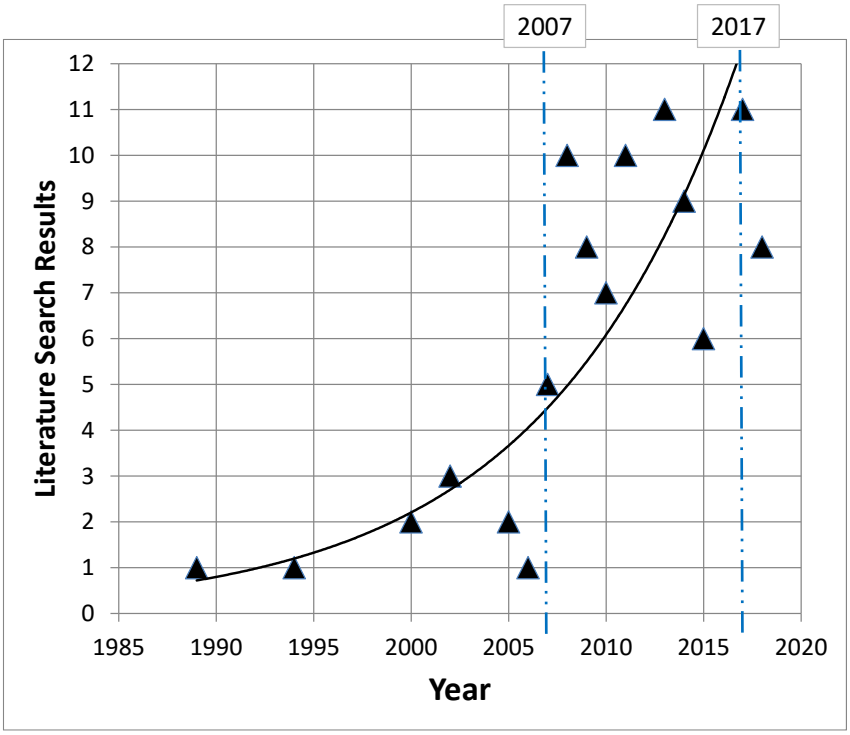


Figure 3. Results from the Operational Discipline-related Literature Search (1989-2018)

The search-related specifics for the more than 170 references counted in Figure 3 are as follows:

1. The OD-related search terms included:
    a. "operational discipline" and variations thereof ("operating discipline," "operat," "discipline," and "discipl")
    b. "conduct of operations" and variations thereof ("conduct")
2. The presentations identified with OD-related terms in their titles or abstracts at conferences included:
    a. The Global Congress on Process Safety (GCPS) tracks from 2006-2018, including:
        i. Center for Chemical Process Safety International Conference (CCPS)
        ii. Loss Prevention Symposium (LPS)
        iii. Process Plant Safety Symposium (PPSS)
        iv. Process Safety Management Mentoring (PSMM)
        v. Perspectives on Process Safety from Around the Globe
    b. No other conference-related presentations were identified at the time this paper was prepared using the OD-related search terms noted in item 1 above.
3. The journals with published OD-related subjects included:
    a. Process Safety Progress
    b. Process Safety and Environmental Protection
    c. Journal of Loss Prevention in the Process Industries
    d. Chemical Engineering Progress

    e. And "isolated" hits in these publications: *Occupational Health & Safety, Chemical Engineering Education*, *Current Opinion in Chemical Engineering, Harvard Business Review*, *International Journal of Production Economics*,
4. The books and OD-related discussions included publications by:
    a. Wiley [i.e., 14, 15]
    b. Elsevier [i.e., 16]
    c. CRC Press (Taylor and Francis) [i.e., 9, 17, 18]
    d. Other [i.e., 19, 20]

A summary of the total count of publications located for each type of search noted above during the years 1989 to 2018 is as follows:

- Conference presentations: 47
- Journal publications: 113 (Note: 42 from *Process Safety Progress*)
- Books and chapters/sections in books: 13

Although the concepts for "operational discipline" have been used for effectively managing process safety risks for decades, this literature search did not locate any publications using the term "operational discipline" before 1989.

The operational discipline concept continues to evolve, as is evidenced with a paper published after the conference on how to achieve Process Safety Management (PSM) excellence [21]. The same combined organizational and individual operational discipline approach shown in **Figure 1** is being used today – over a decade later - to help an organization improve its process safety performance by focusing on improving process safety risk awareness at all levels in the organization [22].

Process safety risk awareness can be used to shift organizational mindset from a focus on safety towards understanding and better managing process safety risks [21]. Whereas safety is "binary" (either safe or unsafe) and reactive, risk awareness is "continuous" (ranging from low to high risks) and is proactive. Incident investigations have shown over the years that many warning signs were overlooked from smaller, sometimes near-miss, incidents, which were not recognized or simply not addressed before a significant incident occurred [5]. Since risks are continually present and need to be continually managed, improved risk awareness helps reduce complacency (especially in organizations with excellent safety records), increase sensitivity to the operations, and even lead personnel to search for others who may have the expertise needed to assess unusual or unexpected situations. Thus, organizations with strong OD programs have:

> Individuals recognize unanticipated situations, keep (or put) the process in a safe configuration, and seek involvement of wider expertise to ensure personal and process safety [4].

These attributes are inherent in a disciplined and highly reliable organization, as has been shown through studies in other disciplines with high-risk endeavors, such as the medical profession, law enforcement, firefighting, aviation, naval operations, and nuclear power generation [23, 24]. They continue to discover each and every day.

2 Reducing Process Safety Risk

Why reduce process safety risk?

Process safety programs are designed to lower the process safety risk involved when storing, handling, and using hazardous materials and energies. The hazardous materials may be toxic, flammable, explosive, and/or reactive (unstable); the hazardous energies or processes include temperature extremes (e.g., cryogenic, high), pressure extremes (e.g., vacuum, high), and flow rate extremes (e.g., high). For this reason, process hazards and risk analyses are performed on hazardous processes to ensure that deviations from "normal" operating conditions – the unexpected extremes - have been evaluated and addressed [9, 14, and 25]. Lowering the process safety risks will help reduce the likelihood of severe process safety incidents which can result in fatalities, injuries, environmental damage, property loss, business interruption, and/or fines [26, 27].

Since the term "Operational Discipline" has been used in different approaches for effectively managing process safety risks, it is important to understand its definition as it is being applied today. Thus, this paper provides a definition for risk and Operational Discipline, and briefly discusses the impact of Operational Discipline on risk. Use of the barrier model and how it can be used to help reduce the process safety risks is revisited, and a brief discussion follows on how the barrier model can be applied in context of the bow tie model to help identify, depict, and manage process safety risks.

2.1 Definition of Risk

The process safety risk associated with the hazardous materials is defined as [28]:

> **Risk:** A measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury. A simplified version of this relationship expresses risk as the product of the likelihood and the consequences (i.e., Risk = Likelihood x Consequence) of an incident.

Thus, risk of a specified scenario is a function of the potential likelihood or frequency, usually expressed in years ("events/year"), multiplied by the potential consequence, such as fatalities, environmental damage, property loss, or some other consequence (e.g., "fatalities/event"), to give units such as "fatalities/year." The commonly accepted and simplified risk equation used for assessing risk is shown in Equation 1:

$$\text{Risk } (R) = \text{Frequency} \times \text{Consequence} = F \times C \qquad \text{Equation 1}$$

The goal is to reduce process risks by evaluating and implementing different risk management strategies to proactively reduce the frequency and/or potential consequences of hazardous incidents.

2.2 Definition of Operational Discipline

The current definition of Operational Discipline is as follows [28]:

> **Operational Discipline (OD)**: The performance of all tasks correctly every time; Good OD results in performing the task the right way every time. Individuals demonstrate their commitment to process safety through OD. OD refers to the day-to-day activities carried out by all personnel. OD is the execution of the Conduction of Operations (COO) system by individuals within the organization (please see discussion on COO in Section 3.1).

However, before moving on to how Operational Discipline impacts process safety risk, it is worth noting that our traditional experience with discipline is often based on blame, resulting in punishment. This negative aspect of discipline poses challenges to those implementing an OD program, such that OD must be defined in context of how OD *can be* - and *is* - effectively applied to our process safety and risk management programs. A compilation from different definitions presenting the positive and negative aspects of "discipline" includes the following:

Discipline:

1) An activity, exercise, training or a regimen that develops or improves a skill (positive)
2) A prescribed set or system of procedures, rules, codes, and/or regulations (neutral)
3) A punishment inflicted to correct disobedience, poor behavior, or poor performance (negative)

We should focus on the positive synonyms associated with discipline, such as training, drills, teaching, and coaching, instead of its rebuking synonyms, such as punishing and penalizing. This approach does not remove personal accountability and responsibility, as punitive actions are necessary when established and trained safety procedures are disobeyed and violated. If we have to discipline, the person should be disciplined without taking away their dignity as a human being [24]. "Discipline" is used in our context as a good habit, such as brushing our teeth twice daily - how many times do you floss each day? Or from an industry perspective, are you following the safe operating procedures - not exceeding the safe operating limits – each and every day?

As we noted earlier, for a company to have an effective process safety and risk management program, it must have leadership with the operational discipline to manage their corporate process safety systems, policies, standards and guidelines, and the individual must have a disciplined regimen consisting of good habits – good behavior - to do the right thing every time.

2.3 Impact of Operational Discipline on Risk

The impact of Operational Discipline on process safety risks can be expressed by qualitatively modifying the risk equation (Equation 1) by adding an Operational Discipline (OD) expression to the denominator. Since there are many individual and organizational factors which affect Operational Discipline, including their impact on the frequency (e.g., the initiating causes and the probability of failure for process equipment), the impact of OD on risk, with the risk being a function of the OD-related "measure," is shown in Equation 2 [1]:

$$\text{Risk (R)} = \frac{\text{Frequency x Consequence}}{\text{f (Operational Discipline)}} = \frac{\text{F x C}}{\text{f (OD)}} \qquad \text{Equation 2}$$

Consistent with traditional risk reduction approaches, the

- Frequency (F) of a possible hazardous incident is often determined by the effectiveness of the process safety systems and multiple protection layers (a function of OD), and
- Potential Consequences (C) are characterized by the inherent material and processing (energy) hazards.

As an example of how Operational Discipline (OD) affects the risk in Equation 2, we can qualitatively express OD a simple fraction, such as:

- 1/1 (or "1") for 100% OD, where everyone does everything right *every time*, or
- 1/2 (or "0.5") for 50% OD, where everything is done correctly – or incorrectly – *only half of the time*.

Thus, using Equation 2, the actual risk at 50% is ***twice*** the expected risk. As OD performance increases, including improved adherence to process safety system procedures, standards, and guideline and maintaining the equipment life cycle, the process safety risk is reduced. Conversely, poor OD results in higher risks – and more incidents with more severe consequences. Examples of good Operational Discipline are shown in Table 1; if these parts of the process safety systems (described in more detail in Sections 3.2 and 3.3) are poor, then an organization's operational risks will increase. As was noted in Section 1.2, an increased safety awareness through improved OD programs will help an organization reduce its risk exposure [22]. Although Equation 2 cannot adequately represent the complexities inherent when managing process safety risks, this simple approach illustrates that poor OD will contribute to a company's poor process safety performance.

2.4 The Swiss Cheese Barrier Model

As noted in Section 2.3, Operational Discipline can adversely affect risk by impacting the frequency or likelihood of an incident. For example, poor OD contributed, in part, to the significant incident which occurred at the BP Texas City refinery, where personnel did not effectively follow safe work procedures (i.e., permit to work; job safety analyses), and did not perform an effective pre-startup safety review [9]. To help understand the impact of poor OD,

this section briefly covers a simplified incident-causation model, with OD's impact on process safety systems depicted through the Bow Tie model briefly discussed in Section 2.5. The simplified incident-causation model is often portrayed as a linear event where there are failures to the multiple protection layers (also known as barriers) which are intended to help prevent the incident – such a loss of containment of a hazardous material - and to help reduce the consequences if a loss of containment occurs. This multiple protection layer concept can be represented in Figure 4, the Swiss Cheese incident causation model [9, 29, and 30]. The process hazard – using this linear approach – is prevented from causing a hazardous event with barriers designed and in place to stop the event sequence. Although this model oversimplifies the complexity inherent when managing chemical processes, it serves as an excellent visual model for describing the weaknesses in the protection layers (depicted as holes in the barrier, with the barrier appearing as a piece of "Swiss Cheese").

2.5 Applying the Barrier Model to the Bow Tie Model

When the linear barrier incident causation pathways - introduced in Section 2.4 – are combined and depicted on a bow tie diagram, the impact of poor Operational Discipline on the process safety systems can be assessed [30]. In particular, the bow tie model can be used to represent both the preventive and mitigative barriers which represent the pieces of Swiss Cheese in the incident causation model shown in Figure 4 [9, 30, and 31]. These preventive and mitigative protection layers are shown in Figure 5, reflecting that weaknesses (holes, gaps) in these barriers – once aligned - will most likely result in an incident. In this case, the "Top Event" is the loss of containment of a hazardous material or energy.

For those who have performed one of the many types of hazards analysis techniques, such as a Hazards and Operability Study (HAZOP) or a Fault Tree Analysis (FTA), the "top event" term has different meanings and is used in context of the technique (or techniques) used to evaluate the impact of an incident scenario that is evaluated during a Hazards and Risk Analysis (HIRA) [14 and Section 3.1]. The bow tie model is a model that helps hazards analysis teams better understand the types of preventive barriers which can be used to help reduce the frequency of the loss of containment event (the "top event"), and the barriers which can be used to help reduce the impact – the consequences – of the loss of containment.

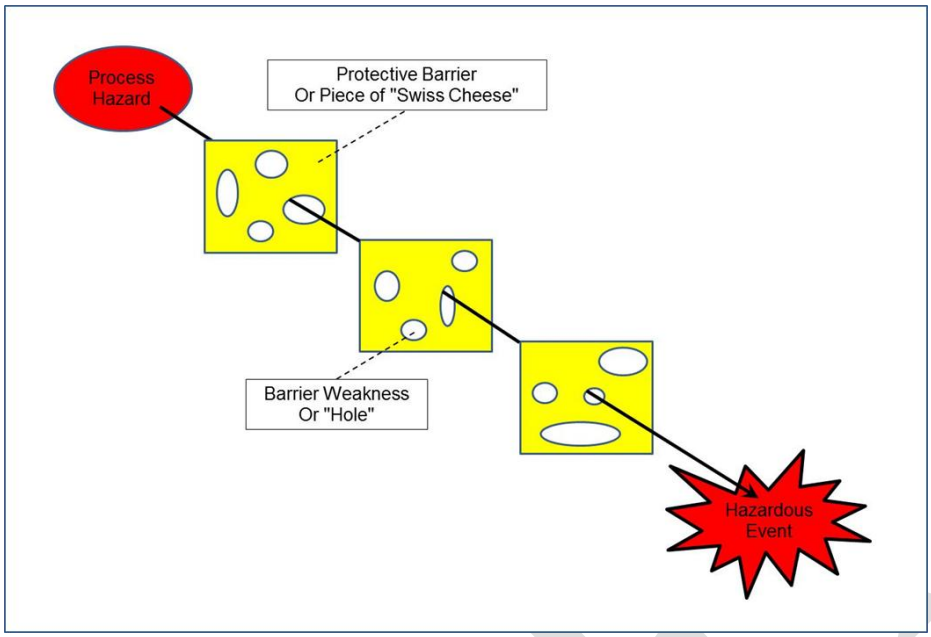
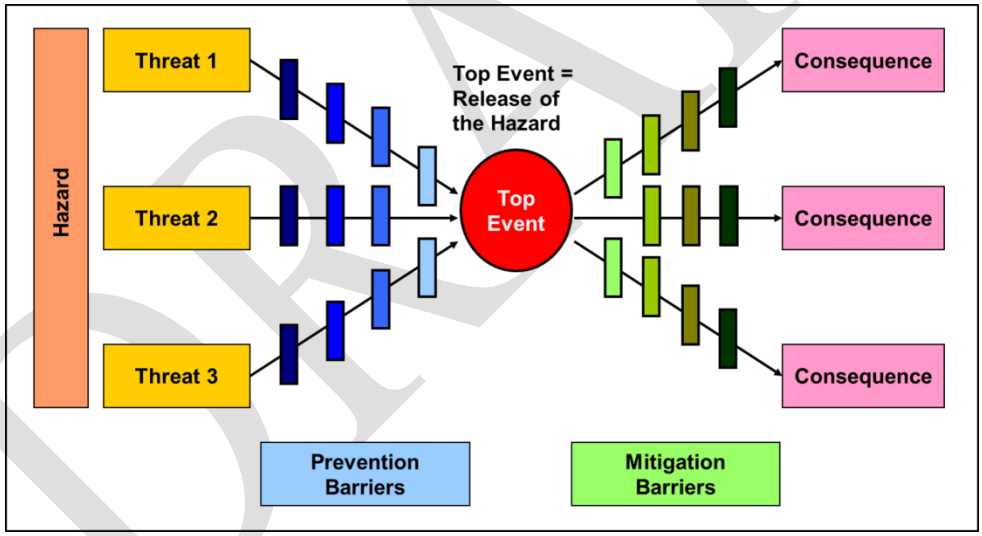


Figure 4. The Swiss Cheese Barrier Model [Adapted from 9]



Courtesy Charles Cowley, CCPS

Figure 5. The Bow Tie Model

3 In Context of Risk Based Process Safety

This section provides a brief overview of the Risk Based Process Safety (RBPS) approach, specifically highlighting two of its twenty elements: Conduct of Operations and Operational Discipline. This section concludes with a brief discussion on how OD is but one of the three

process safety program foundations that are essential for effective management of process safety risks.

3.1 The Risk Based Process Safety Approach

CCPS created and issued its Risk Based Process Safety (RBPS) approach in a Guideline to help organizations design and implement more effective process safety management systems [14]. The Guideline provides methods and ideas on how to

- design a process safety management system,
- correct a deficient process safety management system, and
- improve process safety management practices.

The RBPS approach is used to differentiate the hazards and their associated risks within facilities and across organizations. When an organization applies its resources to tasks that address higher-risk activities, it improves its effectiveness when managing its overall operating risks.

The twenty Risk Based Process Safety (RBPS) elements shown in Figure 6 are associated with four pillars:

1. Commit to Process Safety
2. Understand Hazards and Risk
3. Manage Risk, and
4. Learn from Experience

These twenty elements are used to help design, correct, or improve process safety management systems based on an understanding of:

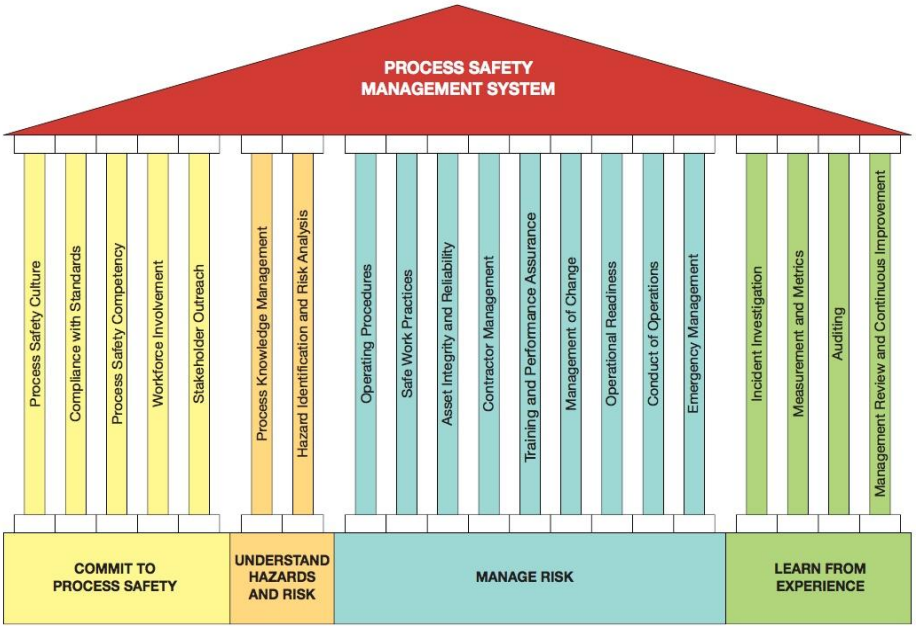
- the risks associated with the hazardous materials and energies at each facility,
- the demand for process safety-related activities and associated resources, and
- how the process safety culture influences the effectiveness of these process safety-related activities.

The focus includes monitoring and improving the effectiveness of the process safety risk reduction efforts as a function of performance and efficiency – each and every day as we learn from our experiences and learn from other's experiences. This paper will briefly focus on the Conduct of Operations element. Please refer to the literature for additional details on the other elements [14, 32].

The Conduct of Operations (COO) element is in the Manage Risk pillar and is the "deliberate, faithful, and structured" way of how the management and operational tasks are performed across the organization [14]. The definition for COO is [28]:

> The embodiment of an organization's values and principles in management systems that are developed, implemented, and maintained to (1) structure operational tasks in a manner consistent with the organization's risk tolerance, (2) ensure that every task is performed deliberately and correctly, and (3) minimize variations in performance.

As was noted with the definition of Operational Discipline in Section 2.2, the Conduct of Operations element goes hand-in-hand with OD [4]. Poor COO across an organization – i.e., poor OD – will most likely result in an increased risk and poor process safety performance, as was depicted using Equation 2 in Section 2.2. Thus, it is essential that good process safety performance is obtained with good COO and good OD (see examples of good OD in Table 1).



Courtesy David Guss, Nexen, Inc.

Figure 6. The CCPS Risk Based Process Safety (RBPS) Model [32]

3.2 The Three Process Safety Program Foundations

To achieve effective process safety performance and consistently manage process hazards and risks, effective process safety programs must consist of three inter-related foundations, as shown in Figure 7 [9]. The three foundations are:

1. **Safety Culture and Leadership**: A strong process safety culture is based on a deep commitment by everyone in the organization – at all levels of leadership - to the core values for all safety, health, and environmental issues.
2. **Process Safety Systems**: A comprehensive process safety program integrates the process safety and risk management systems using a framework that combine the distinct "elements" used to manage the process risks.
3. **Operational Discipline**: The day-to-day behavior and discipline by everyone to complete their daily work tasks correctly, successfully transforming the process safety systems into reality.

Like the legs required for a three-legged stool, these three foundations are essential for effectively managing the risks associated with hazardous materials and energies. One weak or missing foundation – a missing leg - can cause poor process safety performance and lead to serious incidents and injuries.

These foundations are obviously interrelated: A strong safety culture and leadership depends on effective process safety systems and operational discipline - commitment - by everyone, but effective systems and strong discipline in turn are influenced by the safety culture and leadership. Although the OD-related term shown in the risk equation, Equation 2, is difficult to measure, its adverse impact on the effectiveness of an organization's process safety systems (the adverse systemic impact shown in a Bow Tie diagram [30]), must be understood and addressed when improving process safety performance. As was noted earlier, examples of good Operational Discipline are depicted in Table 1. In the next section we explore how the "Operational Discipline" foundation applies to all aspects of an organization, including leadership.

3.3 Discipline and the Overall Company Risk

Recall that the definition of "Operational Discipline" applies 1) to the "day-to-day activities carried out by all personnel," and 2) at both the organizational and individual level (Section 1.1). For this reason, we include everyone: engineering, operations, maintenance, management, and other support personnel, such as purchasing and warehousing. In context of Conduct of Operations, the word "operational" in "Operational Discipline" is intended to include the risks to a company's overall business and its operations: to how internal and external business-related pressure affects the decisions made by senior executives and managers ("leadership"), as well. Those running the business must understand the affects their decisions make on all risks, including the process safety risks. Thus, it is important to recognize that no matter what type of operating risk is being evaluated or managed, Equation 2 applies, whether it is for process safety risks, environmental risks, purchasing risks, or business-related risks, such as marketing or investments. Everyone has a role in helping a company reduce its overall operational risks [6, 9, 33]. Everyone's conduct and behavior affects the risk.

The best operational discipline an organization can have to reduce the operational risk as much as possible is when OD is equal to 100%. Although this is the goal to strive for, people and the systems and equipment they design, construct, operate, maintain, and sustain are not perfect (and are not at 100%). Thus, human factors-related protection layers must be in place to recognize and respond quickly to potential and actual human error to help reduce the risks. In particular, to process safety, to help prevent loss of containment incidents from occurring or to help mitigate the consequences of a loss of containment if it does occur. Please refer to the literature for additional efforts related to specific process safety-related human factors efforts [e.g., 38].

> "Every accident is due to human error; someone, usually a manager, has to decide what to do; someone, usually a designer, has to decide how to do it; someone, usually an operator, has to do it. All of them can make errors but the operator is at the end of the chain and often gets all the blame [39]."

Process safety risks can be reduced when everyone is aware of, knowledgeable about, and committed to process safety [8, 9, and 14]. Thus, the "operational" aspect encompasses operations (where operators and technicians "do" things), maintenance (where mechanics and electricians "do" things), engineering (where engineers "do" things: design, assess, analyze, and act), and management (where managers "do" things; decisions on strategies, providing resources, identifying systemic gaps, and the prioritizing and addressing the gaps). Thus the activities – the operations of - management, engineering, operations, and maintenance are interrelated to help manage a company's overall process safety risks.

For company's struggling to understand process safety risks relative to other business-related risks, it is worth noting that monitoring, assessing, and responding to critical process safety-related indicators and metrics is one way to ensure that senior management can effectively manage their overall business risk. Please refer to Table 1 for examples of good Operational Discipline and to Section 4.4 for a brief overview of the literature describing additional process safety-related metrics efforts [34, 35, 36, and 37].

Operational Discipline does not focus on the person turning the valve only, it applies to everyone.

Figure 7. The Three Process Safety Program Foundations [9]

4 Applying Operational Discipline

Effective Operational Discipline programs help ensure successful implementation of the process safety systems and help achieve consistent, desired, day-to-day performance. This section provides some insights on how OD is applied to incident investigations, provides an example of how the Dow Chemical Company applies the process safety foundations (including OD), describes some factors that can help successfully influence implementation of OD programs and provides

some practical OD program approaches. This section concludes with a brief overview of some significant incidents where poor operational discipline contributed, in part, to incident severity (conversely, please refer to Table 1 for good OD examples).

4.1 The Incident Triangle

The incident triangle, shown in Figure 9, is a simple illustration showing qualitatively how significant consequences, such as serious injuries or catastrophic incidents are often the result of, or predicted by, a larger number of smaller, undesirable, unsafe acts or behaviors (a larger "area" in the triangle). A discussion on this idealized model's practical application to represent complexity is beyond the scope of this paper. The dichotomy of a planning and "control operator" versus a responding and "emergency operator" is further explained as having the discipline to be able to control and respond to ever-changing emergent situations simultaneously [24].

When an organization focuses on minimizing or eliminating issues at the bottom of the triangle (reducing the area), the number of more serious incidents at the top – in theory – should be reduced, as well. Guidance is provided in the literature on recognizing "warning signs" which could be due, in part, to poor OD [5]. Improving operational discipline can be used to help prevent loss of containment incidents [40]. Thus, an effective operational discipline program works to reduce the number of unsafe acts and undesirable behaviors in the organization, as seen at the base of the incident triangle, helping to prevent more serious incidents and injuries.

Taking this "attack the base" approach further when identifying and addressing operational discipline issues, we can be more effective when searching for the root causes of incidents by digging deeper into the systemic issues which led to the incident. This approach, focusing on the interrelationship between the three foundations described in Section 3.2, is shown in Figure 10 [41]. The effect of unmonitored - poor - operational discipline on incident severity is discussed in more detail in Section 4.5. An example of how operational discipline can be improved using a behavior-based safety program is also described in detail elsewhere [8].

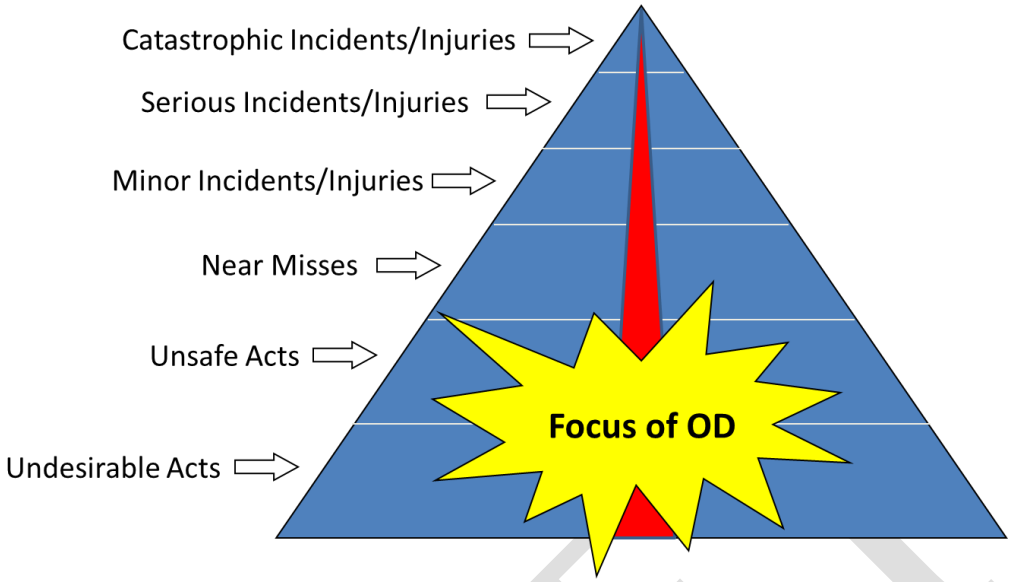


Figure 9. "Attacking the Base" of the Incident Triangle – Focusing on Operational Discipline [9]

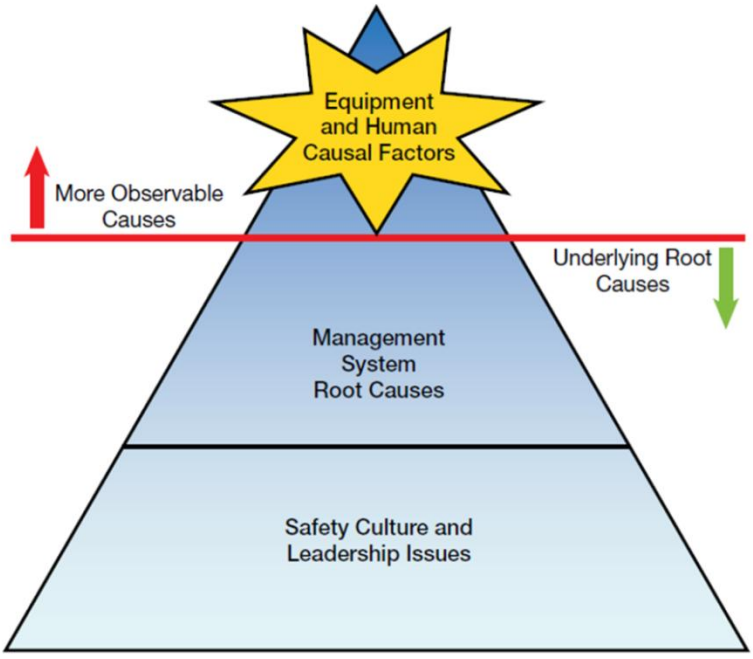


Figure 10. "Attacking the Base" of the Incident Triangle – Focusing on the Three Foundations [41]

4.2 How the Dow Chemical Company Applies the Foundations

The Dow Chemical Company recognized and has effectively applied the three process safety program foundations, shown in Figure 7, to successfully manage its process hazards and risks [3]. The three foundations are being applied as follows:

1. **Safety Culture and Leadership:** Leadership support and resources at all levels of the organization – sponsored by the Board of Directors - sustains success in its process safety programs. Dow Chemical Company's commitment to continuously improve both personal safety and process safety performance aligns to corporate core values, with its Environmental, Health, and Safety (EH&S) efforts as the top priority of the company. All employees are responsible for the safety and measures, with both business and employee safety-related performance measured with clear goals and expectations across the company.
2. **Process Safety Systems:** The globally implemented Operating Discipline Management Systems (ODMS) shown in Figure 11 includes Dow Chemical Company's Process Hazards Analysis (PHA), Layer of Protection Analysis (LOPA), Global Mechanical Integrity Safety Standards (GMISS), and its Loss Prevention Principles (LPP), as well as its personal safety standards, pollution prevention programs, and many other environmental, safety, and health standards and guidelines (its "Responsible Care umbrella"). Dow Chemical also has Process Risk Management Standards (PRMS) which are used for guidance throughout the company [3].
3. **Operational Discipline:** Leadership reinforces operational discipline - what occurs in each plant on a daily basis – to effectively execute and maintain its process safety systems.

ODMS also has another umbrella section on Common Management Systems, several which are directly related to or are used when managing process safety risks: Management of Change (MOC), procedures, investigations, audits, and Corrective and Preventative Actions (CAPA). ODMS includes leadership responsibilities and communication, connecting these systems to Dow Chemical Company's safety culture and leadership foundation. In addition, the Dow Chemical Company also recognizes and addresses the critical tasks and critical protection layer and associated management systems essential for safe operations.

4.3 Factors that Influence Success

As was noted earlier, there are different effort levels that factor into successfully implementing and applying operational discipline programs. These levels are depicted in Figure 12, where reactive incident investigations with an OD-focus can involve many resources to investigate, analyze, and then follow-up to address identified gaps in the process safety systems. As will be discussed in Section 4.4, proactively monitoring OD-related metrics and performance allows time for groups to anticipate what might happen and resolve identified gaps or issues in advance.

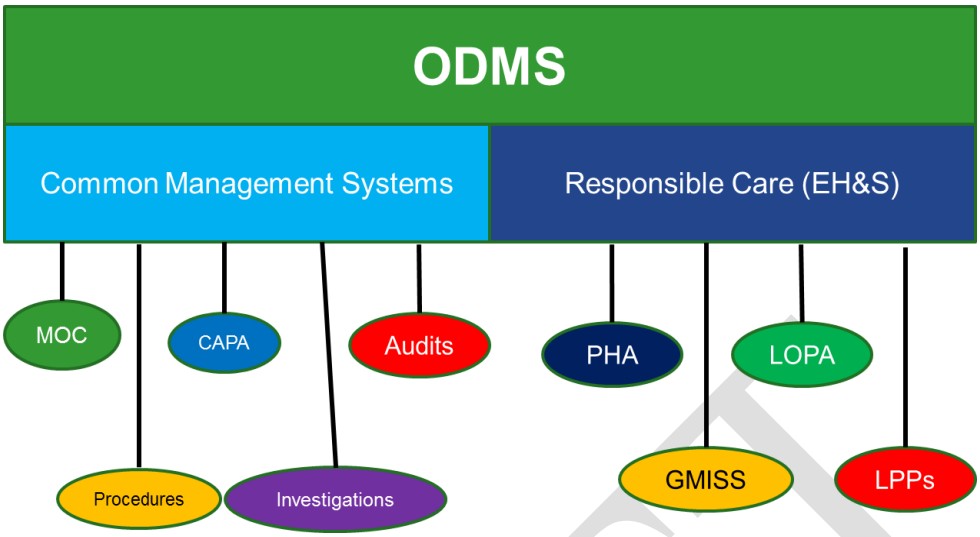


Figure 11. The Dow Chemical Company's Operating Discipline Management System (ODMS) [3]

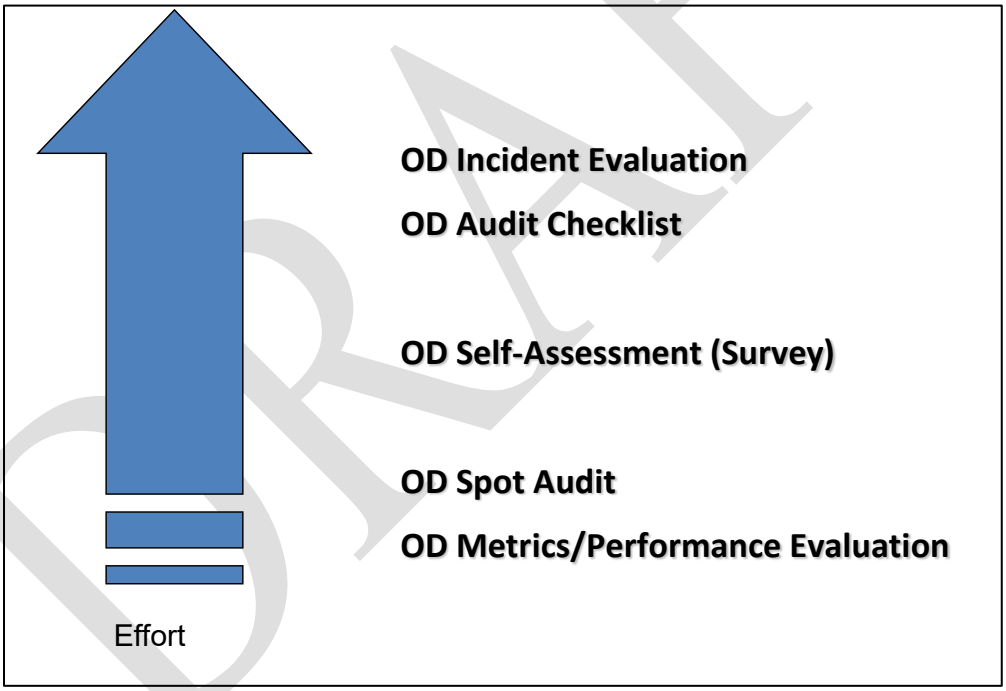


Figure 12. The Effort Needed to Effectively Implement Operational Discipline Programs [1]

4.4 Practical Approaches

Some of the practical approaches which can be used to apply an operational discipline program include a combination of various aspects from 1) a "toolbox" of specific OD-related efforts, 2) a

selection of OD-related metrics, and 3) a specific "classification tier" for potential incidents. These approaches are described briefly in this section.

The toolbox framework is based on a simple concept similar to a car mechanic who chooses different tools from his toolbox depending on the type of maintenance [1]. A company's OD Toolbox database can be used to provide facilities with different "OD-improvement tools" (i.e., recommended practices). The toolbox approach helps to provide flexibility to facilities – each with potentially different needs - in choosing how to improve their OD program. The OD Toolbox database is organized using the "roadmap" shown schematically in Figure 13. The Toolbox consists of both the Organizational OD elements (Leadership Focus, Employee Involvement, Practices, and Housekeeping) and the Individual OD elements (Knowledge, Commitment, and Awareness). Each organization needs to evaluate the current state of its OD program the facility before it can select from the tools and then prioritize its OD-related program improvement efforts [1, 42]. It is worth noting that the types of improvement practices will vary due, in part, to the organization's process safety culture and leadership. A good starting point to identify a company's "current state" would be to ask the OD evaluation questions listed in Table 2 for each of the Safety, Health, and Environmental (SHE) systems to determine whether organizational (i.e., leadership), individual, or both types of characteristics need to have gaps addressed and improved [Adapted from DuPont, 56]. A practical implementation example reflecting a company's strong process safety culture and leadership was described in Section 4.2 for The Dow Chemical Company.

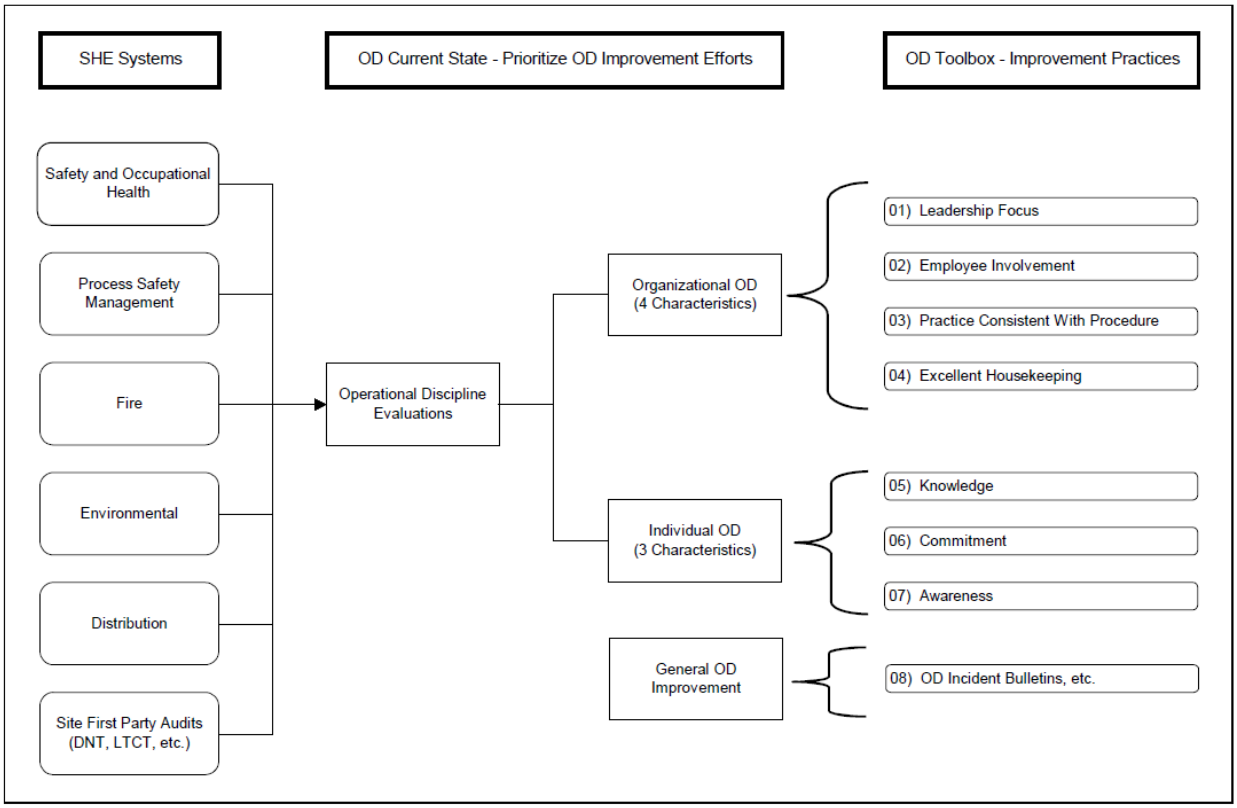


Figure 13. A Roadmap for the Operational Discipline Toolbox [Adapted from 1]

For companies beginning to understand where their process safety efforts are, it may seem like an insurmountable goal to evaluate and understand their current state. It is worth noting at this point that guidance is available using the RBPS approach to help a company evaluate its current state and also help reduce duplication of its management efforts as it improves its process safety performance. The company can identify and prioritize its process safety-related risks across its separate safety, health, environmental, quality, and security groups (SHEQ&S), helping ensure that decisions made at any level in the company, whether corporate, regional, or local, do not increase its overall risk. For example, the loss of containment of a hazardous material, such as ammonia, has the potential for both significant process safety (i.e., toxicity, flammability) and environmental impact. A model illustrating this approach is shown in Figure 14, where the "intersection" of the different management systems provides the company with leading indicators and metrics [34, 35]. In the case of ammonia, both the process safety and environmental management systems benefit by choosing between groups to track and address risk based ammonia-related metrics in one system, only.

These metrics can be evaluated based on the current API RP 754 guidance for identifying incidents, shown as "tiers" in Figure 15 [36, 37]. Note that Tier 3, Challenges to Protective Systems, depicted in Figure 15 includes near miss (or near hit) incidents. Tier 4, Performance Reviews, includes proactive evaluations and continuous improvement efforts, such as Operational Discipline surveys [4], field observations (e.g., behavior-based observations [8]), management reviews [14], and process safety management system audits [15]. Similar to the incident triangle (Figure 9) and leadership foundation (Figure 10), the tiers in Figure 15 reflect proactive measurements at the bottom (the leading indicators) and the reactive measurements at the top (the lagging indicators). In particular, a company with a weak safety culture and leadership can proactively monitor the undesirable acts – poor OD - at the base using metrics determined lower tiers depicted in Figure 15. When the RBPS SHEQ&S integration efforts are combined with the API guidance, a company can establish and improve its operational discipline performance in concert with improving its overall process safety performance. Again, improvements in OD have shown improved process safety performance [3, 8].

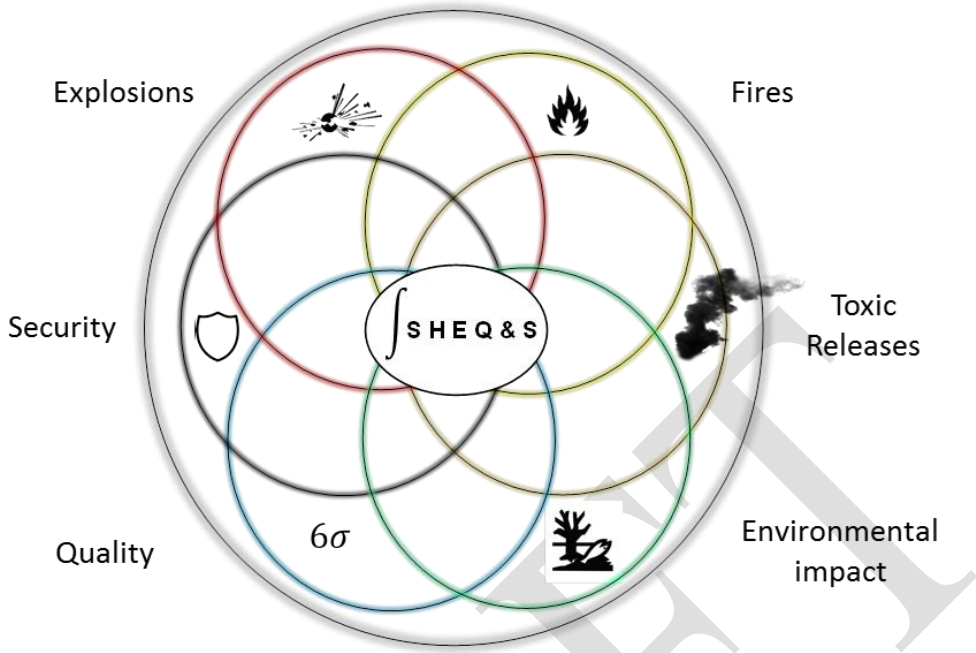


Figure 14. A Model for Integrating Management System Metrics

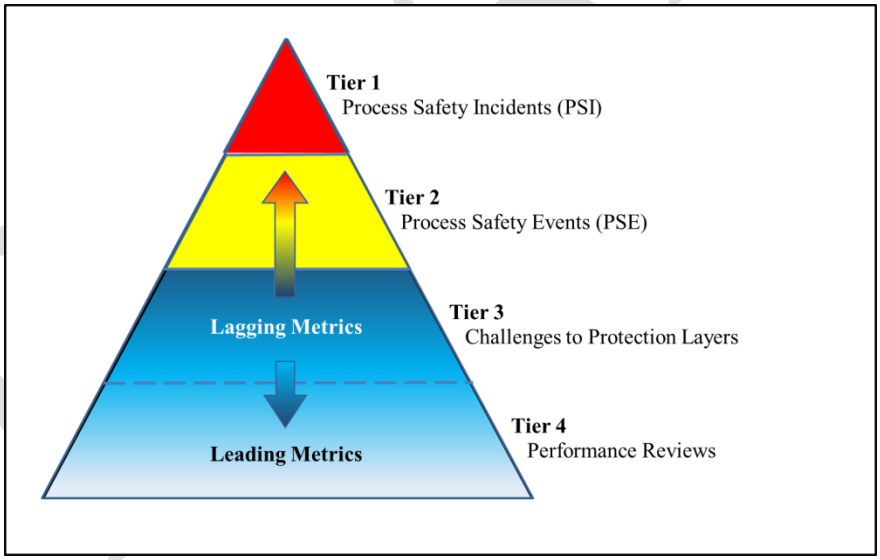


Figure 15. A Model Used to Rank Process Safety Metrics [37]

4.5 Effect of Poor Operational Discipline on Incident Severity

When improving process safety performance, it is worth remembering to "attack the base" of the incident triangle – focusing on operational discipline – is to help reduce the severity of incidents (Figure 9). Everyone in the organization must understand the risks associated with their decisions, whether they are touching the valve or allocating resources to support a process safety program. Progressive companies today identify and address the foundational weaknesses when investigating their incidents, reporting their cultural, leadership, systemic, and discipline-related findings. The investigation's OD-related findings may be similar to those identified in the Baker Panel report on the BP Texas City incident:

> *While some refineries are far more effective than others in promoting process safety, significant process safety culture issues exist at all five U.S. refineries, not just Texas City. Although the five refineries do not share a unified process safety culture, each exhibits some similar weaknesses. The Panel found instances of a lack of operating discipline, toleration of serious deviations from safe operating practices, and apparent complacency toward serious process safety risks at each refinery* [43].

As noted earlier in Section 3.2, a strong safety culture and leadership depends on effective process safety systems and operational discipline - commitment - by everyone, but effective systems and strong discipline in turn are influenced by the safety culture and leadership. A learning organization continues to improve – it takes a mindful discipline to discover its learnings [23, 24]. If we revisit the findings from incident investigations which did not specify the term "operational discipline" as an issue, we can still detect a lack of operational discipline in various process safety systems, elements, and foundations, such as:

1. 1974, Flixborough – poor operational discipline to effectively manage changes
2. 1976, Seveso – poor operational discipline to effectively identify hazards, assess risks, and respond in emergencies,
3. 1988, Piper Alpha – poor operational discipline to effectively manage changes, identify hazards, assess risks and to respond in emergencies,
3. 2005, Texas City – poor operational discipline to effectively manage process start-up after a turnaround,
4. 2005, Buncefield – poor operational discipline to effectively manage asset integrity,
5. 2010, Deepwater Horizon – poor operational discipline to manage operations, contractors, and learn from experience,
6. 2012, Amuay – poor operational discipline to effectively manage asset integrity
7. 2013, West Fertilizer – poor operational discipline to effectively identify hazards, assess risks, and respond in emergencies,
8. 2017, Airgas – poor operational discipline to effectively address hazards, identify risks, provide effective barriers, and manage process safety systems.

Additional details on these incidents - and many others - are provided elsewhere [44, 45, 46, 47, 48, 49, and 50]. We must note a common theme over the years: a common lack of operational discipline at some level in the organization, whether making decisions to manage the company's operations or when operating or maintaining the equipment handling the hazardous materials and energies [9, 11, 27, 30, 51, and 52]. In addition, the process safety systems required to effectively

manage the individual barriers to effectively manage the risks for safe and reliable operations were either not developed or were weak (i.e., had holes in the barriers), as was depicted in Figure 4.

Examples of good operational discipline that correspond to each of the process safety systems and associated elements are provided in Table 1. The lack of operational discipline in one or many of these elements increases the process safety risk by increasing the frequencies and/or the consequences of a loss of containment incident (Equation 2). Critical equipment and their barriers (whether as safeguards or as layers of protection) must be designed, constructed, installed, commissioned, operated, maintained, changed, and decommissioned correctly to reduce the process safety risks, both in reducing the likelihood that the incidents occur as well as the severity if an incident does occur. Everyone from the beginning to the end of the facility's life cycle must be aware of the risks and do the right thing every time.

5 Summary – Continuing Our Process Safety Journey

Our conclusion for safe and reliable operations:

> Everyone across the entire organization must have the discipline to do the right thing – to make the right decisions - each and every day.

When the operational discipline is weak during any or all of the phases of a process and equipment life cycle, from design, construction (fabrication and installation), commissioning, operation, maintenance, and to subsequent decommissioning, the operating facility is at greater risk for a significant incident. Often everyone's behaviors and actions will either directly or indirectly influence the way equipment and process changes are made, with each day an opportunity to discover and learn how to be safer. As is shown in Figure 16, facilities that operate at a point outside of the safe operating zone – at an unsafe operating point - incidents will happen.

Our goal is to improve process safety performance on our journey by preventing incidents, every day [40, 51]. Operational Discipline is just a part of each day's journey. We have learned that effectively managing process safety risks relies on each of the inter-related process safety program foundations, where a weakness in any one of the foundations increases the process safety risk and increases the potential for an incident.

It is worth noting, as well, that many of the references published from 2014-2018 (described in Section 1.2) included discussions, in part or as their focus, on the following subjects:

- Leadership
- Culture
- Human Factors
- Behavior

For improved process safety performance, it is apparent that we are continuing our efforts to learn how to better:

1. manage our complex processes through strong leadership and safety culture [54]
2. understand our human/technology interfaces (human factors) [38], and

3. instill commitment from everyone in an organization (i.e., operational discipline and associated behaviors) [9, 14].

Some closing thoughts for your consideration:

> "… even the most inherently risky industry can be made much safer, given the right incentives and disciplined systems, sustained by committed leadership and effective training. The critical common element is an unwavering commitment to safety at the top of an organization: the CEO and board of directors must create the culture and establish the conditions under which everyone in a company shares responsibility for maintaining a relentless focus on preventing accidents [55]."

> "[Leadership]…strategies fail slowly over an extended period of time as lack of discipline results in poor implementation, execution, and follow through [56].

> "Lack of operational discipline often generates problems that more corrosive than explosive in nature. … [with lack of operational discipline manifesting themselves] … as errors caused by 'deficient procedures, deficient training, conflicting priorities, inadequate labeling of equipment and instruments, or lack of effective administrative controls' rather than a deliberate act [56]."

> "What you do every day is what you do in an emergency."
>
> Joe Martin, retired Battalion Chief, Los Angeles City Fire Department [57].

Our future is just beginning.

Figure 16. An Unsafe Operating Zone When the Operational Discipline Foundation is Weak [Adapted from 9 and 30]

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Table 1

Examples of Good Operational Discipline Within Each Process Safety System [Adapted from 53]

Process Safety System		Examples of Good Operational Discipline
Design Safe Processes	Process Safety Knowledge	Understanding potential hazards; considering inherently safer designs; using current process, equipment, and barrier (aka. safeguards, protection layer) technology, using current standards, guidance, and best industry practices; networking with other industrial technology groups; and effectively documenting process safety knowledge and technical information
Identify and Assess Process Hazards	Hazards	Identifying hazardous materials or processes, including material hazards (e.g., toxicity, flammability, explosivity, stability/reactivity, energetics) or processing hazards (e.g., temperature, pressure, or processing extremes); and effectively documenting process hazards information
Evaluate and Manage Process Risks	Risks	Defining "tolerable" risk; evaluating for risks; resourcing hazards analysis teams adequately; using correct hazards analysis methods {e.g., What/If, Hazards and Operability Studies (HAZOP), Failure Mode and Effect Analysis (FMEA), Energy Barrier Analysis (EBA), Fault Tree Analysis (FTA) and/or bow tie}; evaluating for adequacy of protection layers (e.g., Layer of Protection Analysis (LOPA)); documenting hazards analyses; and effectively revalidating process hazard analyses
Operate Safe Processes	Procedures	Resourcing the operating facility adequately; writing safe operating procedures, including defining safe operating limits; following safe operating procedures (e.g., do not exceed safe operating limits); maintaining procedures; ensuring shift-to-shift consistency; and reviewing and validating critical procedures
	Training	Defining position qualifications (e.g., managers, first line supervisors, engineers, operators, mechanics, electricians, technicians, etc.); using qualified instructors; testing for theoretical understanding; qualifying through skills demonstration; and scheduling essential refresher training *Note:* This includes applicable process safety-related awareness training as well as specific job-related expertise
	Contractors	Using qualified contractors (e.g., to install equipment or to inspect and refurbish/maintain barriers); training contractors to the facility hazards and risks; counting contractor incidents; and monitoring contractor performance
Maintain Process Integrity and Reliability	Asset Integrity	Ensuring an effective Inspection, Testing and Preventive Maintenance (ITPM) program, which includes: Identifying critical equipment and their barriers; resourcing maintenance teams adequately; scheduling planned maintenance on the critical barriers; testing and inspecting barriers; using qualified personnel to inspect and test barriers; using qualified personnel to refurbish barriers; evaluating, trending, and documenting equipment and barrier testing and inspection results; responding to and investigating barriers that fail to perform as expected

Table 1 - *Continued*

Examples of Good Operational Discipline Within Each Process Safety System [Adapted from 53]

Process Safety System		Examples of Good Operational Discipline
Change Processes Safely	Changes	Defining and identifying changes; resourcing change management teams adequately; evaluating the risks associated with the change; properly approving and authorizing changes; effectively communicating changes; and effectively documenting changes
	Operational Readiness	Following safe work procedures (e.g., permit to work; job safety analyses; hot work, electrical isolation, etc.); performing operational readiness / pre-startup safety reviews; and effectively managing and documenting handovers
Manage Incident Response and Investigation	Emergency Response	Creating an emergency response plan; resourcing response teams adequately; scheduling and performing drills (both table top and actual responses); holding de-briefing/learning meetings after drills; identifying and addressing weaknesses; and sharing findings
	Incident Investigations	Identifying and evaluating incidents, including near misses; resourcing investigation teams adequately; identifying causal factors (e.g., incipient and latent; systemic); identifying systemic or cultural issues and not assigning blame to personnel (includes effectively understanding potential "hindsight bias"); proactively evaluating unexpected events, including near misses/near hits; reviewing, approving, and implementing investigation team recommendations; sharing findings; and implementing learnings from incidents at other locations (within and external to company)
Monitor Process Safety Program Effectiveness	Metrics	Identifying, tending, and tracking leading and lagging indicators; addressing findings; and sharing findings (within and external to company, as appropriate)
	Audits	Scheduling audits; resourcing audit teams adequately; documenting findings; addressing findings; and sharing findings (within and external to company, as appropriate)
	Management Reviews	Scheduling area management reviews; resourcing review teams adequately; documenting findings; addressing findings; sharing findings (within and external to company, as appropriate)

Table 2

Questions to Ask about Operational Discipline [Adapted from 56]

Questions that can be asked about Operational Discipline		Response		
		Yes	No	Evidence or Follow-up Actions
1	Is leadership felt by employees? In particular, are there clear examples of "walking the talk" in a consistent manner?			
2	Does leadership practice what it preaches?			
3	Is leadership providing sufficient resources to support operations and manage the related risks?			
4	Are lines of communication working - up, down, and across the organization - like a central nervous system?			
5	Is teamwork strong, with collaboration, cooperation, and common objectives at all levels?			
6	Are employees actively involved and engaged in running the business and improving it?			
7	Does everyone share common values about matters such as ethics, the environment, and health and safety?			
8	Is documentation of the procedures, records, and recommendations up to date?			
9	Are practices consistent with procedures?			
10	Are tasks completed as written and planned?			
11	Do employees avoid shortcuts? In particular, do they do the right job the right way every time?			
12	Does the housekeeping reflect orderliness and consistency in all areas?			
13	Is there pride in the company?			