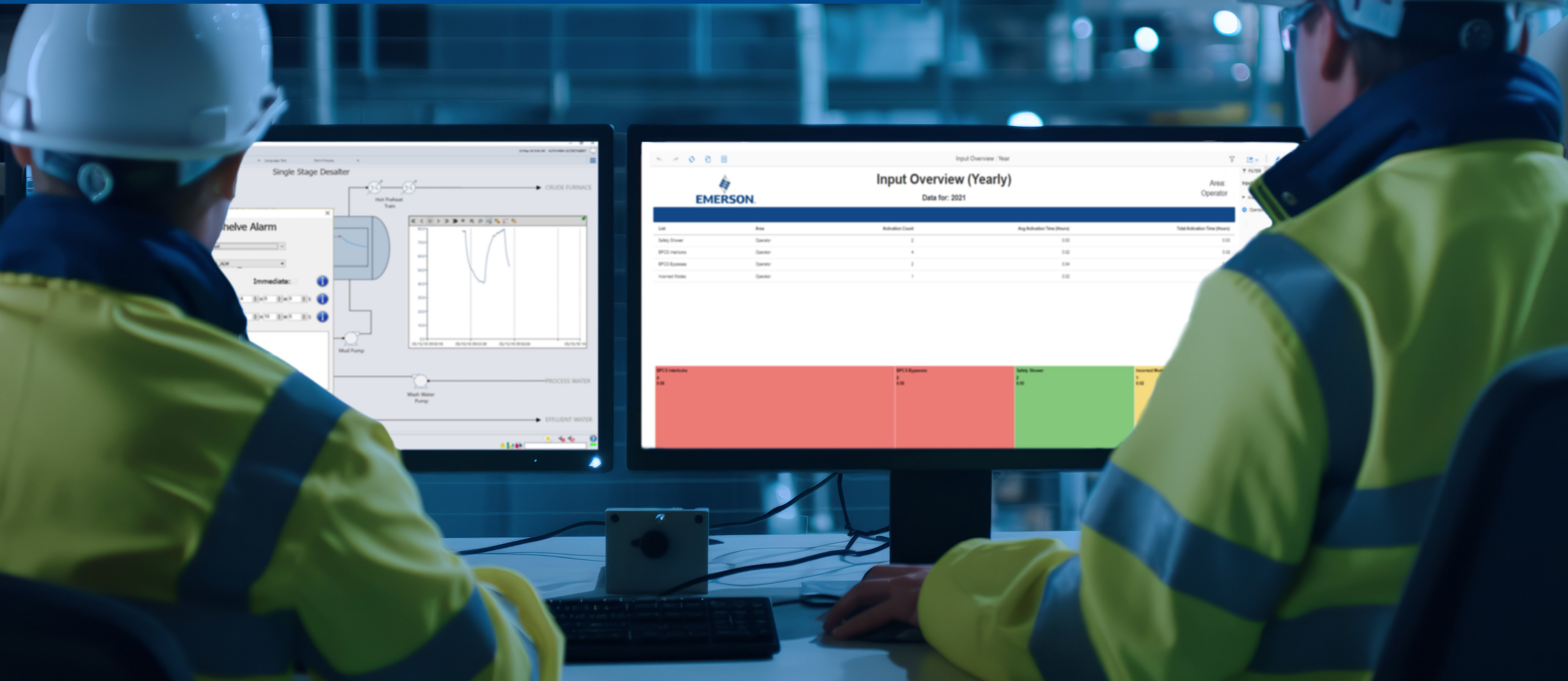
Operational Limits: A Practical Guide to Monitoring Safety and Performance



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Introduction

Operational Limits not only include established concepts such as boundary management and integrity operating windows, but also provide a comprehensive framework that promotes enhanced operational efficiency and safety. By embracing this broader perspective, organizations are able to implement a more integrated and proactive strategy for managing their operations.

This white paper examines common use cases for managing operating limits and monitoring safety and performance across industrial operations. It outlines practical methods to detect inefficient or unsafe conditions, strengthen compliance, and identify opportunities for targeted training and system health management.

- **Operational limits monitoring:** Track deviation from the optimal operating window to identify inefficient operation and prioritize process improvements.
- **Boundary limit approach and safe operating limit monitoring:** Track excursions and excursion frequency relative to boundary limits or Safe Operating Limits (SOLs) to detect emerging safety concerns early.
- **Quality limit monitoring in Good Manufacturing Practice (GMP) operations:** Track how often processes approach quality limits to improve compliance and reduce out-of-specification events.
- **Alarm and safety system coupling:** Analyze alarm and flood rates alongside Independent Protection Layer (IPL) demand frequency to assess safety margin erosion and identify trends that may indicate impending safety system demand.
- **Targeted operator performance monitoring:** Track critical events (e.g., key pump usage and significant vessel level variance) to identify skill gaps and focus site-specific training.
- **Bypass tracking:** Record and analyze bypass events to detect degraded interlocks or reduced Safety Integrity Level (SIL) protection as a leading indicator of safety system health (often due to instrument failures, hardware degradation, or faulty logic configuration).
- **Interlock and safety function demand reporting:** Report actual demand on interlocks and Safety Instrumented Functions (SIF) to identify higher-risk operation trends across the enterprise.
- **Field personnel safety monitoring:** Track activations of safety showers, eye wash stations, and gas sensors to monitor and improve personnel safety.

Acronyms: Safe Operating Limit (SOL); Independent Protection Layer (IPL); Safety Integrity Level (SIL); Safety Instrumented Function (SIF); Good Manufacturing Practice (GMP).

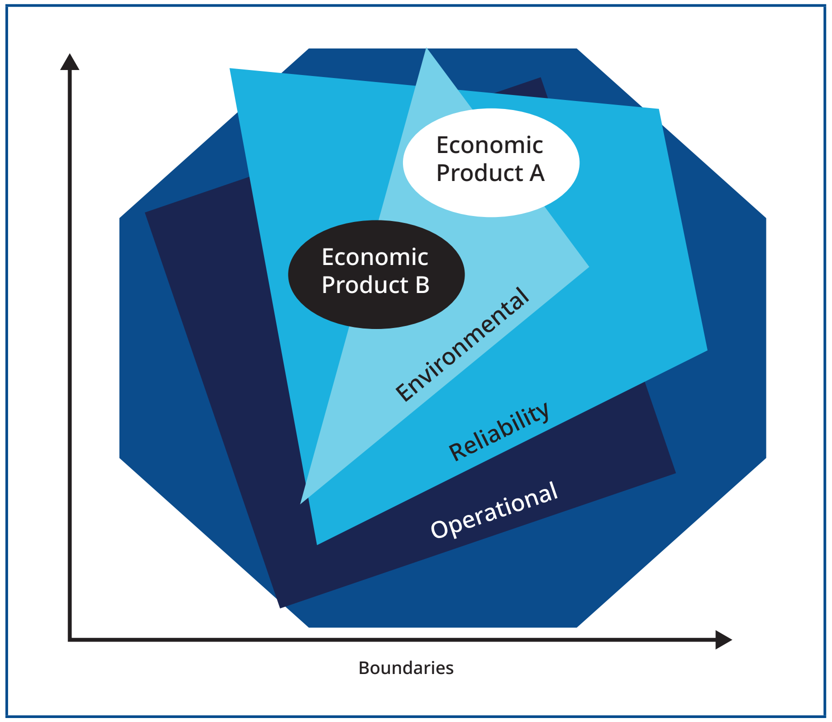
What are Boundaries and How Does That Relate to Operations Limit Management?

In its simplest form, a boundary is a limit value. If a process operates beyond its boundaries, negative consequences can occur. These consequences range from inefficient operation to loss of containment, or anything in between.

Some examples of sources of boundaries include:

- Safety limits
  - Maximum Allowable Working Pressure (MAWP), design temp, runaway reaction initiation
- Environmental limits
  - Max permissible emissions
- Equipment limits
  - Max / min pumping capability, vibration, flow rate
- Quality / Product limits
  - Reactor feed ratios, separation capabilities
- Operability / Control limits
  - Efficient operating ranges and valve limits

Collecting and actively verifying process boundaries, ensuring they are known, documented, and supported by appropriate controls and safeguards, is essential for operating within limits and maintaining them over time. Boundaries on a piece of operating equipment are varied, and a single process variable may be subject to multiple boundaries at the same time. Each boundary typically has different owners, ranges, conditions of applicability, and criticality. Understanding when the most important boundaries are exceeded helps organizations identify where risk or loss may be occurring. An example of how this can be depicted visually is shown below.



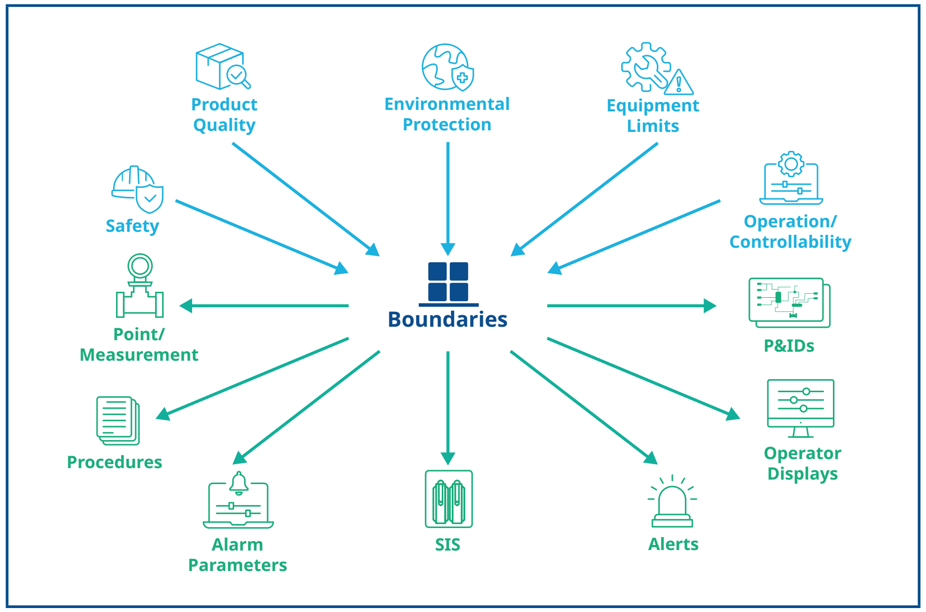
Once established, boundaries can be used to guide fixed settings and references such as:

- Safe operating limits
- Operating procedures / help guides
- Interlock and SIS settings
- Alarm settings
- Instrumentation ranges / re-ranging if needed

Boundaries also help ensure internal consistency for information required under PSM (29 CFR 1910), including limits such as:

- Max intended inventory
- Equipment limits
- Safe operating limits (with consequences and actions)
- Controls, alarms, interlocks
- Safety systems
- Operating procedures

These boundaries come from various sources and have applications beyond the examples listed above.



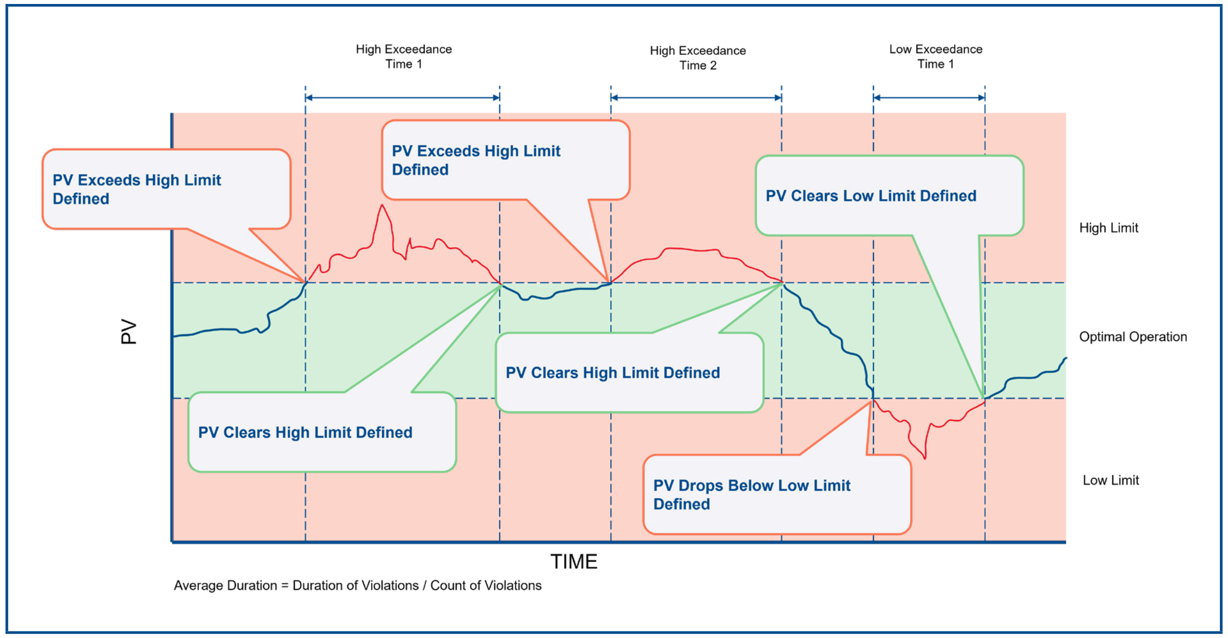
Many organizations find boundary management challenging to fully understand and implement, which can hinder their ability to realize its benefits. Effective boundary and operational limits management can significantly enhance a facility's efficiency, profitability, and safety. To assess how well boundaries are maintained, it is essential to record and monitor adherence over time.

Organizations typically fall into several categories regarding boundary management. Some lack sufficient understanding to use boundaries effectively and therefore disregard them. Others recognize their value but are unsure how to track them efficiently, instead prioritizing other measurable areas. A third group appreciates the importance of boundaries but invests significant effort in reporting excursions, often using different mechanisms for each boundary type.

This paper is intended to help organizations understand common boundary types and practical use cases for tracking them they encroach or exceed the boundary limit. This list is not exhaustive; it is meant to clarify the concept, scope, and value of boundary management. The methods for recording and reporting can then be standardized under the broader umbrella of operational limits management. In this framework, Emerson can apply common tools and reports to support consistent configuration, maintenance, and reporting for boundary tracking.

Operating Limits Monitoring

Operating Limits and Operating Windows, sometimes called operating boundaries, can be used to track when a facility is operating outside an efficient range. Operation in this range may be inefficient due to increased costs, such as poor product conversion, excessive energy consumption per unit product, or increased equipment wear that drives higher long-term maintenance costs and more frequent downtime. Deviations from the optimal operating range may not trigger an alarm or safety system action, so operators may not see them as a significant issue in the moment. However, sustained operation in an inefficient band can lead to financial loss, reduced operating efficiency, or poorer product quality. For that reason, these excursions should be tracked and reported so facilities can identify opportunities to optimize operations. The optimal range can also shift over time based on market conditions or organizational goals so need to be a bit more mailable than a fixed limit such as an alarm setting. An example of how this is tracked is shown next.



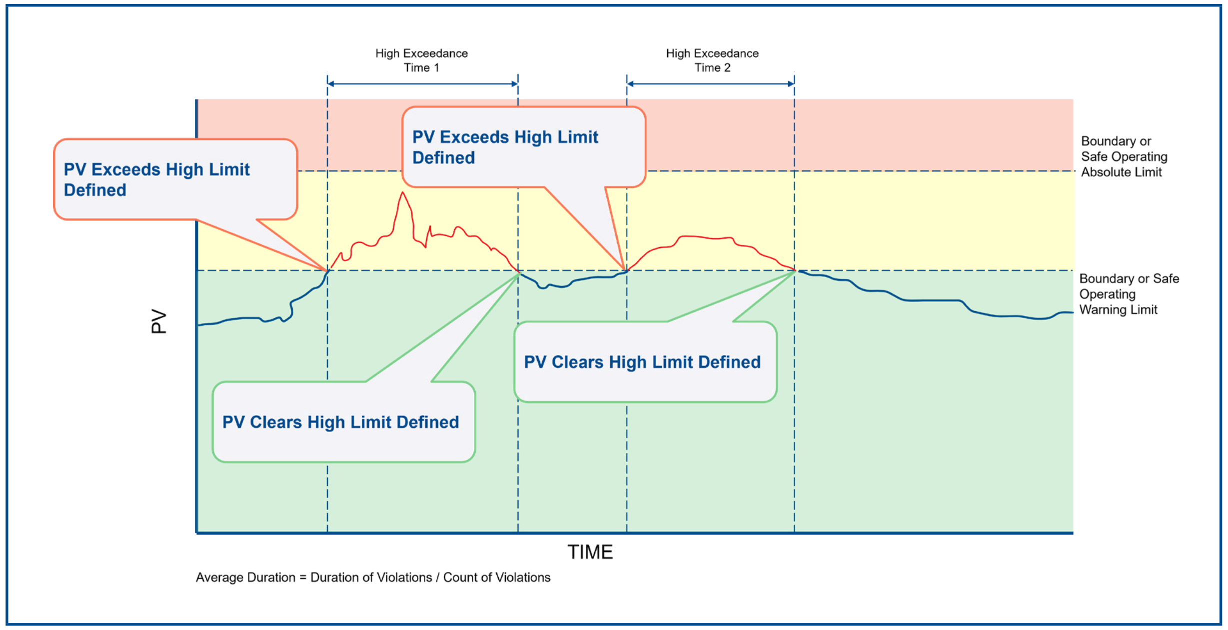
Analog and Operational Window Tracking.

Reporting total excursion count and time spent in the excursion band helps decision makers determine the significance of those excursions. For example, a few brief excursions may not meaningfully affect overall unit efficiency, but a single excursion lasting weeks or months may indicate a general decline in performance that needs correction to prevent avoidable long-term losses.

Boundary Limit Approach and Safe Operating Limit Monitoring

Operational limits describe ranges where efficiency may degrade, but some limits should not be exceeded at all. These include maximum and minimum safe operating or environmental boundaries and SOLs. Exceeding these limits places the facility or environment in an unsafe state. Approaching them typically triggers a pre-alarm and may even initiate an automated action to return the process to a safe state. Reaching a safe state often involves downtime and restart activities, so avoiding SOL excursions is important for both safety and productivity.

These limits typically have alarms associated with them. When an alarm is part of an IPL, tracking the alarm can help a site identify repeated approaches to a SOL. Both the time spent near the limit and how often it occurs are key indicators of elevated risk and increased likelihood of a safety system demand. An example is shown next.

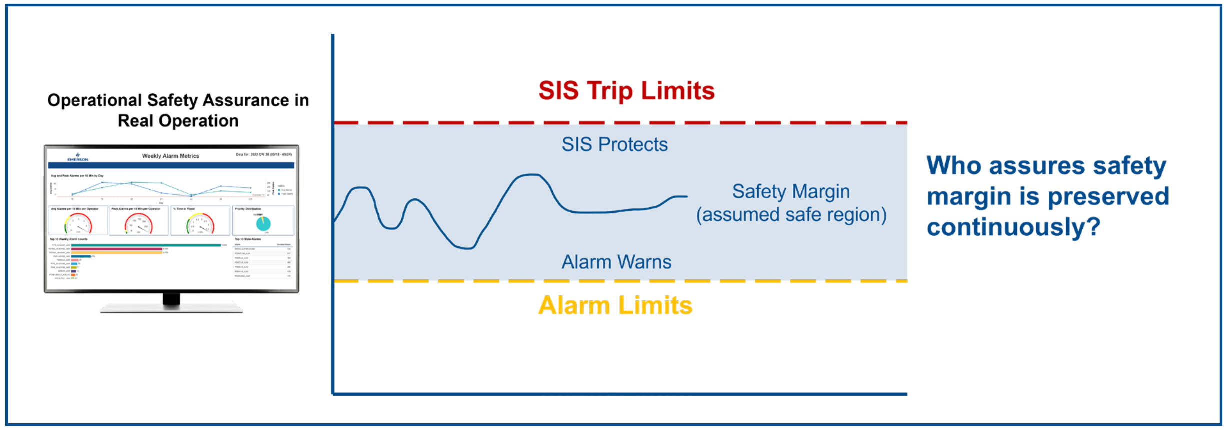


Boundary and Safe Operating Window Tracking.

The longer and more frequent operations run near this limit, the higher the risk of a shutdown or unit failure. Trending the duration and frequency of operation in this range helps management determine whether risk is increasing or decreasing over time.

Safety Margin Management

As an extension of the above concept, safe operation relies on maintaining a safety margin. The safety margin is the operating range between the point where operators are alerted that action may be required and the point where the safety system is demanded. This band is intended to provide enough time for operators to respond and correct the deviation before a trip or protective action occurs.



In the example above, if the alarm limits are set too high, the safety margin is reduced by squeezing the band from the bottom. Monitoring how often a variable operates within the safety margin, and how long it stays there, provides an indication of the risk a site is taking on during normal operation. When a unit operates within this band, the safety margin is already eroded, and the probability of a safety system demand is significantly higher because the process is closer to the trip or protective action threshold. Tracking operation in this higher-risk range is therefore a key leading indicator of safety system demands. Proactively monitoring safety margin encroachment can help prevent unnecessary shutdowns and excessive safety system demands.

Alarm and Safety System Coupling

Analyze IPL alarm occurrence frequency and alarm flood rates alongside IPL demand frequency to evaluate safety margin encroachment. Trend these indicators over time to identify patterns that may signal an increased likelihood of a safety system demand or an overloaded operator response. Compared with duration-based excursion reporting, this approach is simpler because it focuses primarily on event counts. It can serve as a quick screening method for operational risk. Because this method relies on configured alarm settings and event data streams, repeated IPL alarms or recurring alarm flood conditions should be treated as warning signs that warrant further investigation of limit approach and underlying causes.

Quality Limit Approach in Good Manufacturing Practice (GMP)

A similar concept applies in GMP environments, typically in pharmaceutical manufacturing or other facilities producing products for human consumption. A quality limit is defined, similar in intent to a safety system trip limit, to determine whether a product can be released to the market. While exceeding a quality limit may not shut down a batch, it can result in a batch being rejected or requiring rework. For that reason, monitoring how closely and how often a process operates near its quality limits is an important leading indicator of risk. Proactively reducing higher-risk operations can save millions of dollars per year, depending on the product value and batch cycle time.

Operator Effectiveness Limits

Monitoring operationally significant events, such as PID loops left in manual mode, critical pump usage, and significant vessel level or process condition variance, can help identify operator skill gaps and target training at a site. This type of tracking is typically based on discrete states or defined optimal operating conditions. The resulting data can help identify which operators run the process more consistently and smoothly. High-performing personnel can then be identified, and their practices can be captured and shared to improve consistency across shifts and crews. Knowledge transfer may be as simple as updating operating procedures, or more rigorous by incorporating these scenarios and performance indicators into operator training simulators or digital twins. Effectiveness can be measured by reviewing the same limit reports after the improvement plan is implemented to confirm the desired reduction in variability.

Operational Limits Instance Status [Limits]

List	Description	Area	Enabled	Total	Active
Safety Showers	Safety Showers	Operator	Enabled	2	1
BPCS Interlocks	BPCS Interlocks	Operator	Enabled	2	0
BPCS Bypasses	BPCS Bypasses	Operator	Enabled	1	0
Incorrect Modes	Incorrect Modes	Operator	Enabled	0	0
H2S Monitors	H2S Monitors	Operator	Enabled	0	0
HighTank Levels	High Tank Levels	Operator	Enabled	0	0
SOC UR	SOC Upper Range	Operator	Enabled	0	0
SOC LR	SOC Lower Range	Operator	Enabled	0	0
IPL	IPL	Operator	Enabled	0	0
Pump Starts	Pump Starts	Operator	Enabled	0	0

Bypass, Interlock and Direct Safety System Health Indicators

Bypass tracking is a key safety system health indicator. Frequent bypasses can indicate degraded interlock protection or reduced SIL/SIF protection. They often point to instrumentation degradation that needs to be addressed, or to faulty logic configuration. Because a bypassed input or output can create hidden risks in monitoring safe operations, reporting on bypasses is crucial to understand how safely a facility is operating.

Similarly, reporting actual demand on interlocks and safety instrumented functions (SIFs) is important for identifying high-risk operations across an enterprise. A demand indicates that prior alarms, controls, and protection layers were not sufficient to prevent the deviation from reaching the final layer of protection. Reviewing demand events helps teams identify root causes and prioritize corrective actions to improve safety at a site. Many demands can be avoided through earlier detection, for example by tracking approach to demand limits and monitoring operation within the safety margin. Pairing operational risk indicators with degradation indicators (bypasses, bad inputs or outputs, hardware health tracking, and related metrics) provides a more complete view of safety system and interlock health.

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Input Overview Yearly

Data for 2025

Area: Operator

List	Area	Activation Count	Avg Activation Time (Hours)	Total Activation Time - Year
Safety Showers	Operator	5	1.98	9.90
BPCS Interlocks	Operator	7	5.62	39.32
BPCS Bypasses	Operator	5	4.42	22.08

Field Personnel Safety Monitoring

Tracking field safety events, such as safety shower use, eye wash station activation, or gas sensor activation, can provide leading indicators of unsafe field conditions, equipment leaks, or higher-risk work practices. Trending these specific events over time helps teams identify recurring issues, prioritize corrective actions, and improve personnel safety performance.

Data Sources for Operating Limit and Safety System Reporting

A natural next question is how these limits should be tracked. One approach is to use event data by querying event logs to extract the required information. This works when the condition of interest is reliably recorded in the event stream. However, this is not always available, especially for non-alarmed conditions based on analog values. Even alarm-related data may be missing if an alarm is disabled, or if the event is not captured in the expected format.

A better approach is to use live data and detect limit events by evaluating user-defined conditions against the current process variable value. This enables limit monitoring without changing control system configuration. It also avoids building and maintaining complex event-log queries. This approach can also be applied to historized data, but historians often compress data, which can reduce resolution and make it harder to evaluate limit criteria accurately. For that reason, a direct read from the control or safety system is typically preferred when available.

For organizations with varied data sources, such as multiple control systems, PLC skids, or different safety systems, a consistent, platform-agnostic approach should be selected. Using a common tooling and methodology supports consistent configuration, maintenance, and reporting for the limits being managed. This provides significant efficiency for enterprises with global reporting requirements and limited resources to implement and sustain these monitoring programs.

What Kind of Operational Limits are Relevant for Me?

To get the most benefit from monitoring operational limits, facilities typically use a combination of the limit types described above to provide an overall view of site safety, efficiency, and productivity.

Some industries require specific conditions to be tracked, such as quality limits in GMP environments. Some sites may not have a dedicated safety system, but safety margin concepts can still apply because there are often boundaries that should not be approached or exceeded.

This paper does not describe every possible operational limit. Depending on the industry, additional tracking and reporting requirements may apply, ranging from external emissions compliance to internal production targets. While the tools and methods used to track and report limits are often similar, the practical applications vary widely. This variety is a common source of confusion about boundary and limit management. The intent of this paper is to provide a clearer foundation so readers can identify additional use cases relevant to their own systems.

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