A detailed alarm management report as a tool for the treatment of bad actors at a gas logistics plant

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Abstract.
BACKGROUND: The treatment of bad actors consists of analyzing the most triggered alarms at a plant, seeking to make modifications that provide workers with more efficient and safer operational conditions. The consideration of plant operators' practical knowledge in these proposed changes is both an opportunity and a challenge, as specific conditions are required.
OBJECTIVE: To present and discuss how an alarm management report (AMR) could support the treatment of bad actors by promoting structured debates on real work situations and its contribution in improving the solutions proposed by alarm management committees (AMCs).
METHODS: Data from nine AMC meetings were gathered and parsed using qualitative content analysis to classify the kind of information that the AMC used to justify the proposed changes and how these changes were decided.
RESULTS: More than 60% of the changes were justified by information provided by the AMRs, indicating broad application and adoption. However, our findings suggest that the structured debates addressed variability and emerging strategies and may consider entire subsystems instead of single alarms.
CONCLUSION: The use of structured debates is feasible for the treatment of bad actors and is an appropriate option that includes operating experience feedback for alarm optimization in industrial facilities.

Keywords: Alarm management, oil industry, human factors, bad actors, operating experience feedback

1. Introduction

An alarm system should inform the plant operator of events that warrant action – unwanted or abnormal conditions within the plant–as a control variable outside the expected value or faulty equipment. To ensure proper functioning of such a system that displays the right alarm at the right time, a set of techniques called alarm management may be applied from the early stages of the alarm design process up until it is fully operational to contribute to safer and more efficient operations. Alarm management is applied to a wide variety of industries, such as refineries, water treatment plants, manufacturing, batch industries, and power plants. Alarm management is a set of organized practices and processes that can be implemented in a system, aiming at both efficiency and safety gains. They can range from the design and implementation of the system to monitoring and improving the system during use [1–6].

Several publications outline systematic approaches to the organization of the alarm management process

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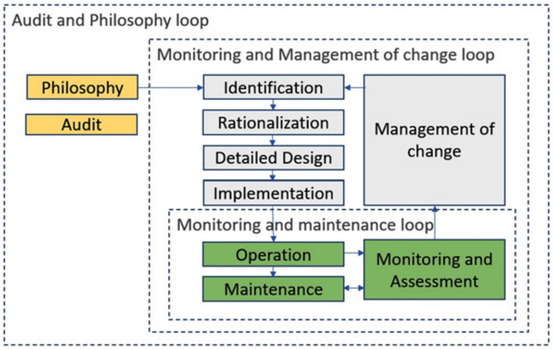

Fig. 1. Alarm management lifecycle [2].

[1–6]. The macro process suggested by ANSI/ISA 18.2 [2], which is one of the most cited among all major publications, organizes the process into three big loops: monitoring and management of the change, monitoring and maintenance, and audit and philosophy loops, as illustrated in Fig. 1. The monitoring and management of the change loop fits the alarm into the philosophy standards and evaluates its relationship with the plant, suggesting the following definitions: setpoints, prioritization scale, consequences, and corrective actions [2].

During the plant lifecycle, it is assumed that is necessary to readjust some alarms due to a diverse number of reasons such as implementation of technological improvements, changes in production processes, and continuous learning, all of which potentially foster changes in the alarm system. The monitoring and maintenance loop considers the operation of the system and its maintenance. Both processes are bound by monitoring and assessment, which prioritizes treatment of alarms and is connected to the monitoring and management of change loop [2].

The alarm management philosophy, cornerstone of the process, is a document that describes all work processes and organization during the plant lifecycle. It includes criteria for alarm handling and evaluation, establishes definitions, and delineates responsibilities. Audit grants that all processes can be scrutinized and held accountable. The audit and philosophy loop includes all the aforementioned processes [2].

In the monitoring and assessment loop, the treatment of bad actors is a possible method for selecting alarms that require readjustment. Bad actors are the alarms most frequently announced in a unit. The literature suggests that the announcement of alarms follows the Pareto principle: 20% of the most frequent alarms represent 80% of the total announcements. Thus, resolving issues with these bad actors could significantly improve the alarm system [2, 3].

The traditional methodologies of alarm management focus on technological aspects, with poor consideration of the workers' experience and needs during operations. However, there is a vast literature that emphasizes the importance of incorporating real work situations and worker experience into the design of working systems. Inappropriate management of these dimensions could hinder safety and efficiency improvements [7–24].

Given these points, a case study is developed to create and analyze an alarm management report (AMR) by the alarm management committee (AMC) about real work situations. This information is then used to treat bad actors and support alarm changes by structured debates. It provides better results regarding adherence to events outside prescribed situations, leading to safer and more efficient operations.

In the following section, we present the theoretical framework that supports inclusion of the structured debate about real work situations to improve industrial safety, especially in the alarm management field. This framework serves as a base for the structuring and analysis of the case study presented in this paper.

2. Materials and methods

2.1. Designing alarms for safety

Historically, several industrial disasters have been related to inadequate alarm system performance. In the oil and gas industry, the Longford gas explosions, the Milford Haven Refinery, and the Buncefield Oil Storage Depot are the most representative events of poor alarm system performance. The deterioration of alarm performance is related to announcement failures, alarms announced outside the ideal time range, an avalanche of alarms that prevents the plant operator from diagnosing the situation, or alarm avalanches that cause some critical alarms to not be announced [1, 2, 4].

To prevent these issues, several efforts have been made to improve alarm systems, synthesized as alarm management [1]. From a wider perspective, the alarm rates and interface are elements in which diverse organizational and human factors play an important role in industrial safety. Therefore, operating experience feedback (OEF) is essential in the alarm management process, including work system design and modifications aimed at safety improvement [16, 20]. Recent studies based on empirical data have reinforced the importance of tacit knowledge in the construction of safety and how these aspects interact with explicit rules [15].

A qualitative study on safety in the oil industry highlighted the importance of operational procedures – work prescriptions- as the most frequent organizational factor influencing safety. The data were collected through interviews with workers from diverse backgrounds and positions within the organizations involved in fatal accidents [17]. As OEF can help reduce the gap between prescriptions and real work constraints, it allows the practical knowledge of plant operators to support the enhancement of alarm systems [6].

Interdisciplinary by definition, the AMC *raison d'être* is to conciliate multiple points of view and logic, to propose suited changes in the system. Sometimes referred to as debates or dialogs, the idea of discussing work is an essential resource for interventions of this kind. To avoid any consideration based on common sense, we will use the term proposed by Rocha [8] – structured debate – since it implies a situated and planned activity. But it may take less structured forms, as identified by Leuridan [18].

We agree with Leuridan's [18] considerations about the actual state of the art not allowing further explanations on the inner workings and different forms of debates, as it may contribute to transforming work. Yet, the literature allows us to describe this process and characterize conditions that may foster the expected results.

The application of structured debate by organized groups can improve health, safety, and efficiency by considering real work conditions and constraints [12, 20, 21]. Rocha et al. [5] stress the principle that long-term benefits can be reaped by the implementation of solutions provided by those on the lower levels of the organization's hierarchy, called as principle of subsidiarity.

Structured debates should be centered on real work activities, taking into consideration the activity ergonomics approach [16, 21]. It is suggested that reference to real work situations must be frequent to support the debates, but should not aim for an exhaustive detailing of the activity. The debates should be part of a long-term strategy offering consistent results and evaluations contributing to the reliability of the method.

Structured debates require a designated work debate space and their institutionalization is based on the assessment of the situation through observations and interviews with workers. In this way, goals can be adjusted and workers can be mobilized. Additional support is also required, such as technical and human resources [8, 9].

The configuration of these spaces has been described by Detchessahar et al. [23] in two dimensions: the material substrate, which includes the environment and devices available for the debate; and the conventional substrate, which includes the knowledge of the participants and the adopted norms and behavior of the debate. Instead of making an exhaustive list of requisites, Detchessahar [23] suggests a reflection on how these elements may hinder or foster the debates, allowing the process to be optimized. Rocha et al. [9] argues for the necessity of incorporating structured debates into existing managerial meetings. This implies the versatility of this procedure and introduces the possibility of implementing structured debates without the need for additional meetings.

The use of structured debates brings a wide range of potential improvement opportunities in addition to the initial goals set. When plant operators and other professionals participate in debates, the opportunity to make further reflections about real work practices allows for the development of expertise and builds a collective work experience. The sharing of multiple perspectives allows workers to respond better to real-time situations, improving performance on related issues. It is also possible for participants to develop a more proactive attitude, allowing the anticipation of probable future issues [8, 9, 20].

In an organizational culture approach, Leuridan [18] posits that debates may contribute to the reliability and resilience of a plant through feedback on discussed situations. In addition, structured debates may shed light on important but not well-characterized activities, which the author classifies as "interstitial" activities [24]. These activities are not focused on traditional approaches to risk assessment and reliability, but play an important role in these properties.

2.2. Method

This study conducted exploratory qualitative research through the development of a case study. The first part of this Section presents the context in which the practical need arose and the approach to the solution over time – the development of an Alarm Management Report (AMR) to determine AMC decisions through structured debates. The second part presents the AMC meeting routine, composition, and goals, and the procedures of data collection. The last part of the protocol, using qualitative content analysis, extracts and analyzes the AMC's actions to evaluate the use of the AMR and its influence on the proposed changes [25].

2.3. Context of the case study

The case addressed in this study was in a gas logistics plant. The main objective of the plant is to store and move gaseous hydrocarbons, such as liquified petroleum gas (LPG), from and to tanks, pipelines, and ships. This requires the operation and storage conditions to be monitored. In particular, the operation of transferring gases from pressurized storage (at room temperature) to refrigerated storage (between –25°C to –43°C) requires control of flow and temperature to keep the tank inside operational limits, which requires close monitoring.

Since August 2019, AMCs have been installed in several units of said oil and gas logistics company by the director's determination. The company's standard for alarm management was inspired by ANSI-ISA 18.2, which uses the same process structure of the mentioned standard along with adaptations and improvements. At the gas logistics plant considered, AMC meetings were held monthly.

Regarding the conditions for a structured debate [8, 9], the monthly meeting already had characteristics of a work debate space, such as institutionalization, well-defined goals, and availability of technical and human resources [8, 9], including workers involved in the plant operation and maintenance. The structured debates aimed to investigate the characteristics of bad actors and applied techniques to reduce or remove unwanted announcements from the system.

Prompts are virtual points of control that are linked to sensors on the plant and may trigger when a certain value or signal is reached. If the prompt was set as an alarm, it was announced to the plant operator when triggered. Therefore, the AMC was required to decide whether an alarm needed to exist, and if so, on which values should it be set. The focus on handling signals and adjusting the absolute and variation limits is important, but may be insufficient to resolve issues of decision-making and interpretation in real work situations, as noted by the AMC.

With the impossibility of resorting to monthly ergonomic work analysis [22] or another method for analyzing real work situations, an alarm management report was developed. It discussed the list of alarms with plant operators to build a work context or scenario and was used to guide the debates of the AMC with elements of real work.

2.4. Alarm management report building

In the first two AMC meetings, the debates were guided by operational procedures, alarm adjustment techniques recommended in the company's internal procedures, and a list of the 20 most announced alarms in the month. The preparation of the AMRs was rooted in the perception that the information discussed in the AMC meetings was insufficient to support the changes in the alarm system. In some cases, the AMC could not understand what caused an alarm to be triggered and, at first, the abnormality of the process was unknown and the conditions did not clearly fit the workers' experiences of operation and maintenance. As a result, some alarms were considered "under investigation," impairing the ability to make immediate meaningful changes.

In pursuit of using real work information to better understand the operations and promote changes, AMRs were developed to be supplementary in AMC meetings. The reports were made by a control room operator, the main author of this study. The AMR structure was developed during the meetings, considering the perceived needs of the AMC meetings and the theoretical input.

The final version of the AMR consists of the descriptions of the real work situations in which each alarm considered as a bad actor was triggered, including the operations, worker strategies, and the status of the equipment associated with the alarm. Four elements were identified as components of narrative building: operational information, operational information validated with peers, equipment information, and briefings. Table 1 illustrates the additions of these elements corresponding to the AMC meetings in which they were implemented.

The first version of the AMR was used in the third AMC meeting. It was built using operational information –a list of all operations that occurred in the month (operations summary), and a description of unexpected or unwanted conditions associated with systems where bad actors were found. This information was based on change-of-shift reports and personal observations discussed inside the shift group.

Starting at the sixth AMC meeting, bad actors identified as operations and shifts displaying unwanted

Table 1
AMR elements per meeting

Additions /Meetings	M1	M2	M3	M4	M5	M6	M7	M8	M9
Operational information			✓	✓	✓	✓	✓	✓	✓
Operational information validated with peers						✓	✓	✓	✓
Equipment information								✓	✓
Briefing								✓	✓

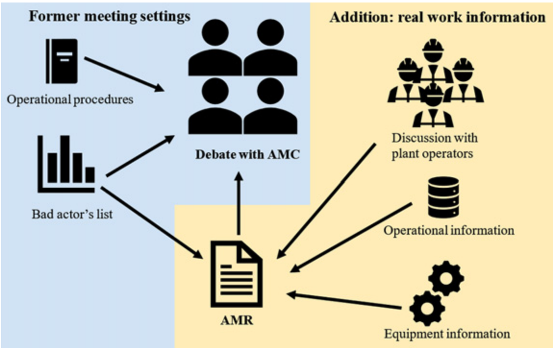

Fig. 2. AMR elements.

behavior, were analyzed. Then, descriptions of the operation relevant to the sensor/alarm and eventual deviations on the process were discussed with the on-duty shift workers. As the details of operational conditions or particular issues were discussed with coworkers of at least two teams to get multiple perceptions and an agreement about the plant state, this procedure was categorized as operational information validated with peers. Equipment information included maintenance notes, reports of odd behavior, or malfunctioning of equipment involved in the investigated alarms. A quick briefing of the major findings was added to begin structured debate within the AMC. All elements are illustrated in Fig. 2.

The description of the operational conditions was carried out via a discussion with the plant operators directly using a systematic approach. It mainly consisted of an interview conducted during change-of-shift meetings and aimed to unveil the causes for unwanted alarm behavior. The placement of an additional routine at the change-of-shift meeting does not show any issues so far. The sources for each element are summarized in Table 2.

In a larger picture, one could consider that two instances of debates were related to this process: the debates with users, which produced the report, and the debates within the committee using the report. Our study focuses the debates held inside the AMC.

These elements were used to build real scenarios in which every alarm was triggered, and these situations were discussed in the AMC meetings. For illustration purposes, a scenario is presented[1] related to an alarm of low pressure on a vapor separator:

> "The refrigeration system has been operating more than usual in the last few weeks. Because the indicated refrigerant gas was not available, we have been using a product blend. Thus, it is more difficult to adjust the process within the recommended operating parameters, causing abrupt variations in the level and pressure of the heat exchangers. The scenario becomes more critical because only one compressor is available and it is not possible to put another compressor in use when the parameters of the machine reach their operational limits, which normally occurs at the start of the operation. These conditions also apply to alarms #4, #5, #9, and #13, which are bad actors, as well as other level and pressure sensors of the system.
> Equipment information: Only one of the three compressors was available, and there was no report of malfunction or maintenance during the period, these conditions apply for the utilities[2] as well."

Naturally, some scenarios were simpler and did not require much elaboration as a sensor was damaged or a setpoint was mistakenly adjusted.

2.5. *Research participants and procedures of data collection*

The participants of this case study were the members of the AMC for the gas logistics plant composed of the following professionals: two maintenance representatives, an operational coordinator, and a control room operator.

[1] Sensible information about the process was adapted with no prejudice for the general understanding of the scenario.

[2] Referring to industrial utilities, e.g., electric energy, compressed air, coolant water or another.

Table 2
Information sources for each AMR element

Elements of the report	Information sources	
	Systems	Workers
Operational information	Operations summary, change of shift report, bad actors list	Discussion with workers of the same team as the report builder
Operational information validated with peers	Operations summary, change of shift report, bad actors list	Discussion with workers from different teams operating the plant when the alarm was triggered, and inside the own team when the alarm was triggered on a shift only
Equipment information	Change of shift report	Discussion with workers from different teams operating the plant when the alarm was triggered, and inside the own team when the alarm was triggered on a shift only
Briefing	All sources	

Nine AMC meetings were held between September 2019 and August 2020. The first four meetings lasted four hours, and the subsequent five had an average duration of 2.5 hours. The aim of these meetings was to assess, based on a list of the 20 most triggered alarms in the plant, whether the alarm announcements were relevant, and propose changes in the system aiming for better operating conditions.

These changes may occur in alarm systems, plants, or work procedures. The nature of the changes are as follows:

- At the alarm system/control system: removing or creating an alarm, changing its priority, or enabling or disabling the setup of variable limits.
- At the plant: repairing or calibrating a sensor, changing the sensor type, changing the sensor location, or installing a new sensor.
- At work procedures: readjusting alarm limits, monitoring routines, or relating processing variables to sensors.

Accordingly, some changes may unfold in multiple orders. For example, a new sensor would require installation on the plant, making its information available at the system and considering its use in work procedures.

It is worth noting that not all 20 alarms were discussed in all of the nine AMC meetings. Minutes were recorded for every meeting, administrative matters were registered, orders and tasks were monitored. Changes regarding alarms, which were gathered from the maintenance notes and operational duties, were also recorded. The data collection strategies included the participative observations of nine AMC meetings and the analysis of the minutes of those meetings.

2.6. *Data analysis procedures*

Data derived from field notes of participative observations and AMC meeting minutes were analyzed using qualitative content analysis procedures. Participative observation data were used to describe the motivations and development of the AMR as well as the three debated situations. The AMC meeting minutes were analyzed to identify the type of information the AMC used to justify the proposed changes. In this way, it was possible to understand the utility of the AMR in structured debates and analyze its influence on the proposed changes [22].

3. Results

The first Subsection presents the results of the qualitative content analysis of the AMC meeting minutes. The second Subsection illustrates some notable scenarios where the debate about real work situations had a significant impact on the resolution of bad actors.

3.1. *Analyzing alarms through structured debates*

Minutes covering nine meetings and 11 months of operation were analyzed (September 2019 to August 2020). The meeting minutes were organized as a table in numbered rows, with columns corresponding to deliberations, responsible persons, and deadlines. The rows regarding the treatment of bad actors contain the following items:

Tag: short name of the prompt; **alarm description** – description of the prompt, as shown for **plant** operators; **new description** – in case of description adjustment**; justification** – reasons to support

Table 3
Occurrences and percentage of categories

Codes	Short description	Occ.	%
Signal treatment	Treatment based on adjustments of process variables	3	3,3
Supported by operational procedure	Treatment based on adequacy to prescribed procedures	8	8,9
Supported by experience	Treatment based on past experience but not related to the episode where the alarms were announced	22	24,4
Supported in a real work context	Using work experience applied with information from the activity performed when alarms were announced, or equipment maintenance information, provided by the report	57	63,3

the change; and **recommended action** – changes required to improve alarm efficiency.

In qualitative content analysis, building a coding frame allows for a systematic description of the data [22]. To inquire how real structured debates based on the AMRs influenced the treatment of bad actors, we analyzed the cells corresponding to each justification and recommended action. Thus, the change proposed by the AMC was classified by the evidence that supported the decision. Our analysis was based on one dimension, "decision support," indicating the nature of the information that was used in the structured debate to support the proposed change. The following four categories were identified[3]:

1) The signal treatment is based on the behavior of the readings of the sensor, and its changes consist of the adjustment of variable signals and tolerance values, mainly taking into consideration the sensor properties and project limit requirements.
2) Decisions supported by operational procedures are based on written standard procedures considering system design requirements, risk assessment analysis, quality standards, and other technical specifications.
3) The decisions supported by experience use unwritten work procedures and reasoning backed by the workers' experience in dealing with the plant itself and not necessarily related to the scenarios described in the AMR.
4) The decisions supported by the real work context also use the workers' experience but it is applied to information about the real work context where the alarms were announced, as provided by the report. Therefore, this category represents the changes supported by AMR.

[3]The QCA identified other categories that are omitted in the article for the sake of simplicity, as administrative choirs.

A short description of each category is shown in Table 3, with total occurrences depicted through numbers and percentages. The results show that treatment using the signal treatment and operational procedures – prescribed methods – made up 12 % of the occurrences. Most of the solutions relied on workers' practical knowledge. Although the AMR was not available in all AMC meetings, most resolutions for bad actors were based on structured debates about real work situations (63 %).

The percentage of alarms treated per justification is illustrated in Fig. 3. Meeting 3 did not have a treated alarm, since it was identified as an issue in the database, and the registered alarms were not representative. The use of the AMR began at meeting 3.

The number of AMC meetings and the number of treated alarms did not allow us to make a proper statistical treatment of the data. However, with some caution, it is possible to adopt the use of an AMR in the structured debate routine. It is noticed that the decisions supported by operational procedure were not used after meeting 4. The frequency of changes supported by experience decreased but was still sufficient to justify some changes. Signal treatment support was only applied in very specific cases, mostly addressing sensor sensibility.

3.2. Examples of structured debated scenarios

In some instances, an increased scope was noted in the changes proposed by the AMC. Three examples of structured debate scenarios using the AMR were described to illustrate these extended changes, followed by considerations on how the scenario would be solved without the information of the AMR. Scenario #1 describes how the information provided by the AMR was used to challenge sensor reliability and promote an alternative method to monitor an operation. In Scenario #2, the AMR allowed the AMC to

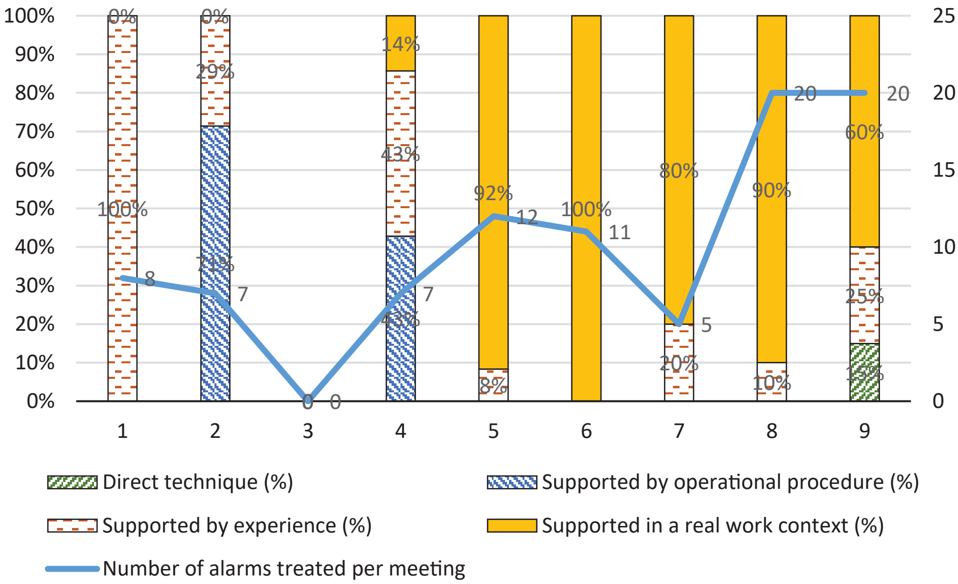

Fig. 3. Percentage of alarms treated by justification per meeting.

recognize the strategy adopted by the plant operators under exceptional situations associated with an alarm. Scenario #3 shows how the AMR helped the AMC formalize an unprescribed condition considering the variables of the complete system. In addition, a new alarm adjustment interface is proposed for the level and pressure alarms.

Scenario #1: Mass transfer with a high rate of false alarms – a discussion on estimates and sensor reliability based on operational information.

This scenario shows how an estimate of flow is unreliable using level indicators and should be performed using other variables. In the operation of receiving gas from ships, many variables, such as pressure, flow, and temperature are monitored. A huge number of alarms announced for level rates was identified as bad actors. As verified by the AMR, this operation did not have any odd episodes, such as leakage or overpressure. In this specific system, there was no flow meter, and the level rate was used to estimate the transfer flow. The level sensor was a floating-gauge device calibrated for a still surface. It was argued that although flow monitoring is important, the transfer disturbs the liquid's surface sufficiently for the gauge to oscillate, generating false high and low flow indications (false alarms). It was concluded that this alarm should be removed because it is unreliable. The variable can still be observed for estimating the rate and comparing it with the ship information, and monitoring should be based on multiple pressure sensors available. Thus, it is possible to estimate flow variations instantly by pressure oscillation.

Conclusions: Without real work information to ensure that the operational conditions were optimum, it would not have been possible to challenge the reliability of the level sensor for estimating the rate or propose another method to monitor the operation.

Scenario #2: Restrictions change alarm usage and operational strategy.

In this scenario, an unusual operating condition and its effect on alarm rates are portrayed, highlighting an operational variable related to performance.

The terminal has two kinds of gas tanks with two different storage conditions: refrigerated storage (temperatures around –40°C and maximum pressure 0.1 kgf/cm^2) and pressurized storage (temperatures over 10°C and pressure above 3 kgf/cm^2). The operation of transferring gas from low-temperature tanking to high-pressure tanking is performed using a heat exchanger to warm the gas using seawater.

The pipelines involved in the operation of pressurized gas are built to withstand temperatures ranging from 10°C to 50°C. Usually, the temperature of the gas leaving the heat exchanger stays between 15°C and 18°C. Because the plant is situated in a tropical area, there is no risk in lowering the temperature of the pipeline. The low-temperature alarm was set at 13°C. When the temperature is below 13°C, the plant operator should increase the flow of seawater or reduce the flow of gas. This is a stable process, and the alarm has rarely been announced. Surprisingly, this alarm was featured as a bad actor in one AMC meeting.

The structured debates used to build the AMR helped us understand this issue. In a certain transfer operation, originating from refrigerated storage at the shore to a ship with pressurized storage, the vessel had problems dealing with high pressure. This caused the vessel to request lower transfer rates and even to halt the operation. To make the transfer as efficient as possible, the team decided to transfer the gas with the lowest possible value within safe limits to minimize the pressure on the ship tanks. This alarm was announced several times in a transfer because the operation required multiple corrective interventions, and controlling the temperature was difficult because the backpressure of the ship made it difficult to maintain a steady flow. Despite appearing to be a bad actor, an assessment of the situation allowed us to conclude that all of the alarms were relevant. This strategy allowed the best possible transfer rate inside the safety limits, contributing to a quicker operation. However, this context was considered sufficiently rare to justify any change in the system.

Conclusions: The AMR information revealed a strategy applied to overcome a situational constraint, making it possible for the AMC to be sure about the relevance of the alarm. It helped avoid unnecessary actions such as sensor calibration or changing the limits of the alarm.

Scenario #3: System working outside prescribed conditions

This scenario describes a system operating under normal operational conditions and its effects on all associated alarms. It used real work information from the scenario described in Subsection 3.2 and an alarm log from the system.

When transferring from pressurized storage to refrigerated storage, the gas must be cooled from –30 ºC to –40°C. The cooling operation is performed using a compressor unit, which uses a cooling fluid in a closed gas circuit at low temperatures, removing the heat from the gas in two heat exchangers in series. This operation is particularly complicated because the rate and temperature of the two gas streams must be matched to maintain the exchanger liquid/vapor levels and pressure. High coolant levels on the exchangers could cause liquid to reach the compressors, which is a very dangerous situation. The system automatically shuts down the process when the levels reach a threshold, which avoids an accident but causes a loss of cooling fluid and time. The use of a cooling fluid without ideal characteristics and a mechanical problem in the compressors that reduced the efficiency of the system caused an abnormal fluctuation in the pressure and levels of the heat exchangers. As a result, level and pressure alarms appeared as bad actors. As these two conditions – different cooling fluid and performance issues of the compressors – could occur again, the AMC decided to propose a formal change in the procedure, recommending new level goals, pressures, and alarm margins. An interface feature was installed, allowing the margins to be changed more easily depending on the coolant composition and behavior.

Conclusions: The AMR allowed the AMC to analyze a less than ideal situation and set operational limits for several sensors involved. Additionally, based on the difficulties reported by the workers, a new interface was designed to make it easier to adjust the alarm limits for the level and pressure alarms, and reduce unwanted triggers.

These scenarios illustrate that, when supported by real work information, proposed changes can be relevant and applied widely throughout the system. Prior to AMR usage, the changes were limited to the alarm setting itself.

Regarding the differences between discussions with plant operators and structured debates within the AMC, we noticed a slight difference. The structured debates with plant operators were more descriptive, as they tried to explain their reasoning and expose the strategies used in different real work situations. Naturally, as the AMC has more disciplines involved, the structured debates considered the plant operator needs and working strategies as starting points and used the collective AMC knowledge to propose feasible changes for overcoming difficulties.

Transfer operations typically have continuous process characteristics with frequent starts and finishes and a high variability in the number of operations and operating conditions from one month to the next. Therefore, the evolution of alarm rates cannot be used as an indicator of success for the approach.

The evolution of the types of justification for alarms is also an unreliable metric, considering that the series is short, and that the nature of the alarm may or may not require structured debate on real work situations. For example, when an alarm is triggered many times owing to sensor failure, the treatment should repair and calibrate the hardware. Therefore, no consideration of this activity is required.

4. Discussion

At the gas logistics plant, the use of structured debates and their requirements [4, 5] was compatible with the routine of the treatment of bad actors, with minor adjustments. The monthly meeting was already institutionalized with work debate space, resources and managerial support, as well as long-term commitment and subsidiary conditions, which are the standards used by most companies nowadays [1, 2, 5, 6]. All structured debates with the plant operators were conducted within shift changes, following the recommendations that additional AMC meetings were undesirable [4].

The coding frame of the alarm justifications showed that 63% of the cases used the AMR to support the proposed changes, which suggests a wide application of the provided information.

In some instances, the information made available by the AMR enabled a situated discussion about the alarms. When debating the control of a variable according to the procedures and work experience, the alarms were discussed within a real operational context, taking into account the quality of the inputs, state of maintenance of the equipment, emerging strategies, and needs of other required actors.

It is worth noting that the monitoring of maintenance service orders allowed the identification of unavailable or malfunctioning equipment in the system. This indicated how the real work conditions of the plant differ from the ideal technical conditions– the situation in which the prescribed conditions are based. It was also noted that some sources of variability influence more than one process variable. Thus, the resolutions could treat subsystems, covering variables and alarms that did not appear as bad actors in that situation.

Structured debates about real work situations allow a dialog beyond the technical knowledge formalized in the procedures and manuals. It recognizes the process variations and emergent operational strategies associated with it. Hence, it guides the discussion and complements the understanding of the occurrences, respecting the technical dimensions of the system. These results are consistent with the considerations of Gauthey [16] and Judon et al. [26], where the quality of OEF increases with methods that allow the analysis of real work situations. Further, the AMC could articulate their knowledge around real work information, provide solutions with higher chances of achieving the desired results, and provide the maintenance crew with a better picture of how operations are to be carried out. Considering the structured debated scenarios, it seems that the experience of the plant operators, when detached from real work situations, lacks in addressing variability and unpredictability and relies on prescribed conditions, rarely matching situations where the alarms were announced. The benefits of using real work conditions as an interface for contextualized changes and mutual learning were described in studies applied to different situations and objectives [26, 27], and were identified here as well.

Alarm management techniques can be used to solve problems based on techno-centric projects, as they update knowledge, produced by plant operators, back to the system. The excess and redundancies of sensors and alarms have been described since the 80 s, due to the increasing digital automatization of these processes [28]. This issue, when approached by an AMC with real activity information, sufficient resources, and organizational support, may provide the system with better delimitation of operational margins – the plasticity, as stated by Béguin [10].

As the system recommends changes that result in lower alarm rates and better control of the plant, this initiative matches the model proposed by Daniellou et al. [20]. They revealed that human and organizational factors, when coordinated with work activity, increase safety and production levels.

This approach is confined to experienced situations. Plant-workers' behavior under unprecedented abnormal situations, such as near misses, incidents, or accidents, cannot be assessed by this method. Therefore, additional inquiry methods should be considered. Advanced alarm resources, such as online alarm prioritization or other decision support tools, also offer possible solutions.

5. Conclusion

This research demonstrates the development and use of an AMR in structured debates to support changes by an AMC. The structured debates, based on the information provided by the AMR, supported majority of the recommended changes by the AMC. It also incorporated the plant's operational context in addition to the prescribed situations, to develop solutions that reduce bad actors and contribute to safer and more efficient operations. However, under some conditions, the entire subsystem is treated.

We understand that generalization is a fundamental limitation of case studies because it contributes to characterizing in-depth particular situations with details that cannot be fully understood only through the measurement of variables. It is also a limitation for this study.

However, we plan to apply this method to other industrial units in the same company to investigate the reproducibility of the results. One of the possibilities that we expect for further inquiry is the elaboration of a list of requirements for the alarm data extraction tool. It can better support the analysis of real work situations, for example, showing multiple variables on a timeline. This was the major technical need identified and should improve the quality of the structured debates, as expected by Conjard et al. [19].

Ethical approval

Not applicable.

Informed consent

Not applicable.

Conflict of interest

The authors have no conflict of interest to declare.

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