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Utilizing Scenario-based Risk Assessment Methodology to Support Operations Teams during Abnormal Events

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Abstract

In today's world, organizations are constantly being challenged by the fast changing economic environment in which the need to remain competitive is the key to ultimate survival. In the downstream oil sector, these challenges are real, on-going and refineries are constantly adapting and evolving to ensure that they continue to operate responsibly, effectively, efficiently and minimize loss to avoid those economic realities such as closure. To remain in business, the downstream oil sector is looking toward and relying more on the use of improved technology and the support of the individual organization's internal management systems.

The outcome of such economic realities is creating a work environment that is becoming more complex to navigate and the human component is increasingly being identified as a key risk element that need to be effectively managed to be—or remain—competitive.

There have been many incident analyses conducted that have improved our understanding of how human factors (HF: Chapanis, 1996; Salvendy, 2012) have contributed to major process safety events in the downstream oil sector (e.g., HSE, 1997; Kletz, 2009; US CSB, 2007). Some of the HF elements identified by these analyses relate to organization culture, human reliability and performance, work structures, practices and behaviors, and operating philosophy (reactive or proactive) to name a few.

The Abnormal Situation Management® Consortium (ASMC)[1] has initiated a number of research studies for process related industries (Bullemer & Laberge, 2010, 2011; Bullemer & Reising, 2014; Laberge, Bullemer, & Whitlow, 2008). The aim of these studies is to improve the effectiveness and interaction between technology, system and people within the operating environment during abnormal and emergency situations.

An early ASMC article, captured the challenges that operations groups have to deal with on a daily basis and their impacts to effectively manage abnormal events (Bullemer, & Nimmo, 1998). The substance of the article is perhaps more relevant today as to when it was written due to continual effects from major process safety events, increased technological capabilities, increased risk & environmental requirements, further centralization of console operation, separation of work teams and workforce rationalization within the downstream oil industry.

Over the past 29 years, this author has personally experienced his share of normal, abnormal and emergency events in the refinery operations environment, having served in various roles from field operator, to console operator, shift team leader, day operation specialist, and operations area superintendent. On reflection, most operation groups are still challenged when it comes to managing abnormal events. The main challenge being the organization's ability to provide and maintain the required knowledge and skills needed to effectively operate and manage abnormal events as a collaborative work group. While most organizations have improved their training support systems, the majority of these efforts have focused on unit-based, individual-role competencies rather than multiple-unit, team-role competencies or collaborations, which are essential during abnormal events.

The following is an excerpt (*italics*) from the article "Tackle Abnormal Situation Management with Better Training" (Bullemer & Nimmo, 1998):

Effective training to handle abnormal situations requires more than high-fidelity simulation-based training or individual role based training strategies. The operations task is typically a collaborative activity involving other operational team members, as well as people from other functional groups. Effective training should include dealing with conflicts about goals, negotiating resources and constraints, and handling the ways in which individual decisions can propagate effects to other people and processes. Hence, training should avoid oversimplifying interactions among tasks, communication constraints, or complexity due to human limitations and possibilities for error.

The body of this document will specifically focus on a tool designed to capture those collaborative activities, the operation team's goals, workload and interaction activities during abnormal events. The document will exhibit an approach utilizing Scenario-based Risk Assessment (SBRA) methodology in order to capture and then examine those tasks and activities that support the teams goal during such events.

1 Introduction

This Scenario-based Risk Assessment (SBRA) tool for abnormal events is a qualitative process, derived from business process mapping techniques (Rummler & Brache, 1995), specifically

[1] The Abnormal Situation® Management (ASM) Consortium is a group of leading companies, human factor specialist and universities involved with process industries that jointly invest in research and development to create knowledge, tools, and products designed to prevent, detect, and mitigate abnormal situation that affect process safety in the control operations environment.

designed to capture those time-imperative activities, tasks, and interactions that individual team members perform in a collaborative manner during abnormal process events. The methodology is a basic task analysis process of that identifies various aspects of successfully addressing the abnormal process event, such as but not limited to:

- the number of individuals needed to perform the tasks
- the time needed to complete the tasks
- the location and frequency of the task

Or conversely, if there may not be enough time to

- detect and diagnose the problem
- perform two or more nearly-simultaneous actions, etc.

Moreover, potential hazards are identified for each task, including the potential loss initiators caused by the hazard and a simple risk assessment is performed. The final stage is to identify and/or develop any mitigating strategies, where these mitigation strategies can be further reviewed outside the intent of this process.

The described methodology may also be used to help sites define a minimum staffing level required for abnormal event management or used to cover other operational situations that do not necessarily lead to a full-plant shutdown.

There a several guiding principles that underpin this particular SBRA tool for abnormal event(s) that need to be understood and applied to ensure a successful, value-added outcome.

The guiding principles—which are in no specific order of importance are—as follow:

- Establish a clear understanding of what constitutes an "abnormal event" including "abnormal event management"
- Establish a clear understanding of the operations team goals during the scenario
- Establish a clear understanding of the abnormal event time line (i.e., what constitutes the end of the scenario, e.g., safe controllable condition, 'safe park' or full unit re-start)
- Ensure appropriate operations subject matter expert (SME) representation (input) from across functional groups such as the different operation shift teams, role disciplines (e.g., operations supervisor, process specialist, console operator, field operator) and experience levels
- Conduct the process in a workshop setting facilitated by an experienced SBRA facilitator with knowledge or experience of operational abnormal events and abnormal event management strategies
- Facilitator must remain process-driven not outcome-orientated
- A separate workshop session conducted for each operations team's "span of control" (typically characterized by the console operator positions' span of control).

To ensure that the SBRA tool for abnormal event(s) guiding principles are clearly understood and consistently applied the following definitions and information is provided.

Abnormal event (ASM®C definition[2]):

- *A disturbance or series of disturbances in a process that cause plant operations to deviate from their normal operating state.*
- *The nature of the abnormal situation may be of minimal or catastrophic consequence. It is the job of the operations team to identify the cause of the situation and execute compensatory or corrective actions in a timely and efficient manner.*
- *A disturbance may cause a reduction in production; in more serious cases it may endanger human life.*
- *Abnormal situations extend, develop, and change over time in the dynamic process control environments increasing the complexity of the intervention requirements.*

Abnormal event management ("Encyclopedia of Industrial Chemistry" definition):

- *Abnormal event management (AEM) involves the timely detection of an abnormal event, diagnosing its casual origins and then taking appropriate supervisory control decisions and actions to bring the process back to a controlled, safe-operating state.*
- *Also known as Abnormal situation management (ASM) or Abnormal condition management (ACM)*

It is important to understand that determining the abnormal event timeline is a critical aspect for this SBRA process for abnormal event(s) to be effective. Capturing actions and activities after the abnormal event is considered back in a controlled, safe-operating state may lead to a misunderstanding of the team's goal, actions or effective resourcing considerations. Once the process is back in a controlled, safe-operating condition, subsequent actions should be considered as follow-up actions such that they are required to return the process back to a normal (pre-abnormal event) state or prepare the process or equipment for maintenance intervention. These follow-up actions, which could involve calling in personnel to assist and which are typically performed under a more structured situation, may still be driven by time- or resource-considerations, nevertheless the abnormal process event no longer exists.

Gaining an understanding of how operations teams learn, interact and maintain situation awareness as a team is another essential requirement for this process to be beneficial. Bullemer and Nimmo (1998) point out that operations teams tend to informally share knowledge via 'war stories', there is a challenge in maintaining expertise for the 'rare event', and organizations have historically relied on each team member implicitly knowing what everyone else is supposed to be doing during an abnormal event.

Bullemer and Reising (2013) identified the risks attributed to situation awareness issues either as an individual or as a team and their resultant root cause manifestations in major process incidents. The paper describes the differences between individual situation awareness and team situation awareness and the need to develop and maintain effective shared situation awareness particularly when a situation changes from a normal state, to an abnormal and emergency state or condition. Effective shared situation awareness relies heavily on establishing a high degree of individual awareness, continually sharing that individual awareness within the team context to establish common goals, specific roles and role interdependence.

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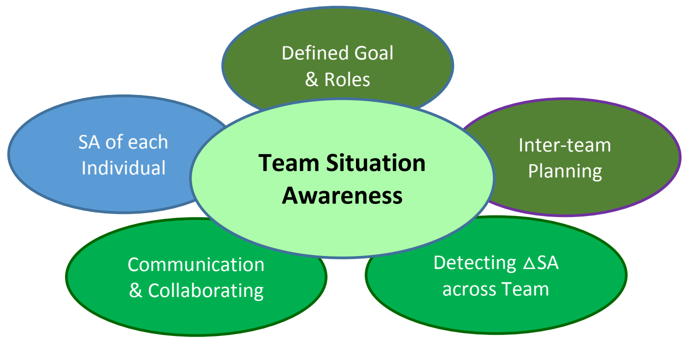
[2] Refer to ASMC website

Figure 1 below designates the contributing elements to team situation awareness (Endsley et al, 2003)



The following is a list of benefits that this SBRA tool for abnormal event(s) is designed to deliver along with some key challenges that an organization may confront:

Benefits:

- Capture and share individual knowledge/experiences of abnormal and emergency event(s)
- Establish a shared understanding of goals, roles, responsibilities, and risks during different abnormal events
- Identify operations resource requirements
- Identify hazards or potential risks and develop mitigation strategies
- Build team competencies and task interdependence
- Proactively establish team goals
- Verify and validate existing plant emergency procedure and/or work practices
- Establish span-of-control (multi-plant) priorities, e.g. prioritize the order in which furnaces are shut-down across a single console operator's span-of-control during certain abnormal events
- Integrate learnings into training program e.g. incorporate the SBRA tool for abnormal event(s) outcomes into abnormal/emergency response exercises
- Identify potentially different goals and response strategies across shift teams

Challenges:

- Releasing operation personal to participate
- Ensuring active participation
- Maintaining the workshop intent & boundaries
- Allocation of resources
- Ensuring a balanced representation, e.g., between roles and functions, levels of experience, across disciplines
- Resolving differing opinions on the preferred goal or response strategy

2 Scenario-based Risk Assessment (SBRA) Process for Abnormal Event(s)

To support the operations team during an abnormal event, this methodology documents the subjective resources, the time and workload requirement of each console and field operator involved during the analyzed process upsets using a scenario-based task analysis. Scenarios analyzed may require extensive operator action, may be particular difficult to execute, or may carry critical consequences if not performed flawlessly. The analysis involves facilitating a group of operations subject matter experts (SMEs), including console and field operators, supervisors, and engineers, through the scenario to identify critical aspects of successfully completing the scenario tasks in a workshop setting. An activity sequence, documenting each role's activity, is developed for each scenario, coordinated via a subjective timeline across the roles involved, as part of the workshop session. Each activity sequence is then assessed for risks, such as the time needed to complete the task, the number of individuals needed, the location and frequency of the task, whether or not there is enough time to detect and diagnose a problem, whether or not there is enough time to perform two or more nearly-simultaneous actions, and so on. Where risks are identified, potential mitigation strategies are also identified for further study.

Because the SBRA is conducted in a workshop setting, with operations SMEs associated to the process area span(s)-of-control analyzed, the methodology makes several critical assumptions for the purpose of completing the SBRA for any given scenario. Specifically, the SBRA does not account for ‘perfect storm’ scenarios where personnel, safety-instrumented systems (SISs), or other safe guards simultaneously fail to perform the appropriate actions. To that end, the following assumptions are made, to avoid ‘infinite loops’ and ‘infinite what-if’ permutations that might otherwise arise:

- Individuals expected to respond in the upset or emergency scenario are fully trained and qualified, even if they have not personally experienced the specific scenario themselves, and therefore would be expected to have the knowledge and competency to respond accordingly, in an accurate and timely manner
- Any safety-instrumented system (SIS) in place – and other automation and process equipment for that matter used in responding to the initiating event in the scenario – performs as designed and intended;
- The onset of the scenario has a clearly defined initiating event, even if that event is an alarm indication either in the field or at the console
- The process conditions and equipment availability are stated up front (e.g., reflux drum level is within normal range with typical operating inventory; the main bottoms pump is in primary service with spare pump in hot stand-by)
- The scenario involves only one ‘event’; that is, there are not multiple failures simultaneously occurring, such as a reactor temperature excursion and simultaneously power failure in the unit

To ensure that each workshop session can be efficiently managed within a set timeframe (normally 8-hour sessions), aim to cover at least 4 - 6 scenarios for each span of control. Scenarios are typically solicited in advance of the workshop. Scenarios can be fires, spills, releases, equipment failure, unexpected workload increase, and so on.

The list below is an example of scenarios identified for a Hydrotreater unit (HTU), where the bold, italicized scenarios were prioritized by the SMEs for the analysis in the workshop for this particular refinery.

- ***Loss of HTU feed***
- ***Loss of gas compressor***
- ***Partial power loss***
- Flange fires on high temp/pressure vapor
- Large release of liquid hydrocarbon – e.g. valve packing and pump seals
- Separators overpressure
- Furnace tube failure

The list below is an example of scenarios identified for a Fluid Catalytic Cracking Unit (FCCU), where the bold, italicized scenarios were prioritized by the SMEs for analysis at a different refinery.

- ***Flow reversals between reactor-regenerator***
- ***Main air blower trip***
- ***Loss of hydraulic oil pressure (e.g. pump failure, control element failure etc)***
- ***Loss of instrument air***

- ***Loss of 2700kpa steam (usually together with 1000kpa)***
- Total power failure – including emergency power
- Partial loss of main air blower
- Loss of saltwater cooling (partial)
- Fractionator bottoms pump leak (corrosion)/loss of Frac bottoms oil
- Control system (DCS) failure
- Loss of top reflux flow
- Loss of 1000kpa steam due to weather
- Steam trap failed on transmitter; valve shut & cuts feed
- Both O2 analyzers fail and led to a carbon build up within the regenerator
- Partial power failure
- Exchanger failure (with the fire)
- Low suction pressure on the feed pump
- Control oil failure on compressor(s)
- Gas compressor trip requiring going to circulation
- Loss/failure of stabilizer overhead exchanger, PSV lifts & HCs goes to atmosphere

These examples also illustrate the range of what scenarios for different plants, process areas, and spans of control, that could be generated and/or analyzed at the workshop sessions.

Scenarios are then defined in terms of the team goal(s), operations roles required, each role's tasks, time requirements of each tasks, communication and collaboration requirements between roles, hazards, impacts, and improvement opportunities.

The purpose of the scenario analysis is to identify

- any gaps in personnel coverage of the activities required
- opportunities for improvements in areas such as procedures, training, unit monitoring tools and techniques, and controls
- hazards to the team or risks to successfully managing the abnormal event

The resulting workflow map (i.e., timeline indicating a 'successful' response to a given scenario) should ***NOT*** be taken as a guarantee that all operations teams would always be able to respond successfully to the initiating event and assumptions characterizing a given scenario. All possible conditions, circumstances, and possible combination of influences cannot be anticipated in the workshop setting. However, the analysis should identify potential subjective risks that the SMEs could reasonably be expected to recognize as a result of completing the workshop.

The table below summarizes the various symbols used to depict different types of actions taken during the scenario (workflow map).

Scenario Action	Action Description
Initiating event	A brief description of the initiating event or early warning sign
Monitor Action	A monitoring action, typically performed by the console operator via the HMI operating displays or other automation tool
Control Action	A control action performed by the console operator via the HMI, be it a set point change, valve position adjustment, or other action via the control system
Communication Action	A radio or telephone communication initiated by the operations team member whose ‘lane’ contains it
Field Action	An action performed by one or more unit operators in the field
Operational Decision	An decision point in the scenario that must be made and may cause a ‘branched’ response, depending on the resulting decision
CSC Action	A Safety System-initiated action performed automatically by the automation itself
On the Move ←→	An indication that one or more unit operators must physically move between areas or equipment locations before performing the next field action
Improvement Recommendation	An improvement recommendation identified by either the participants or facilitator, during the process of creating the process map timeline

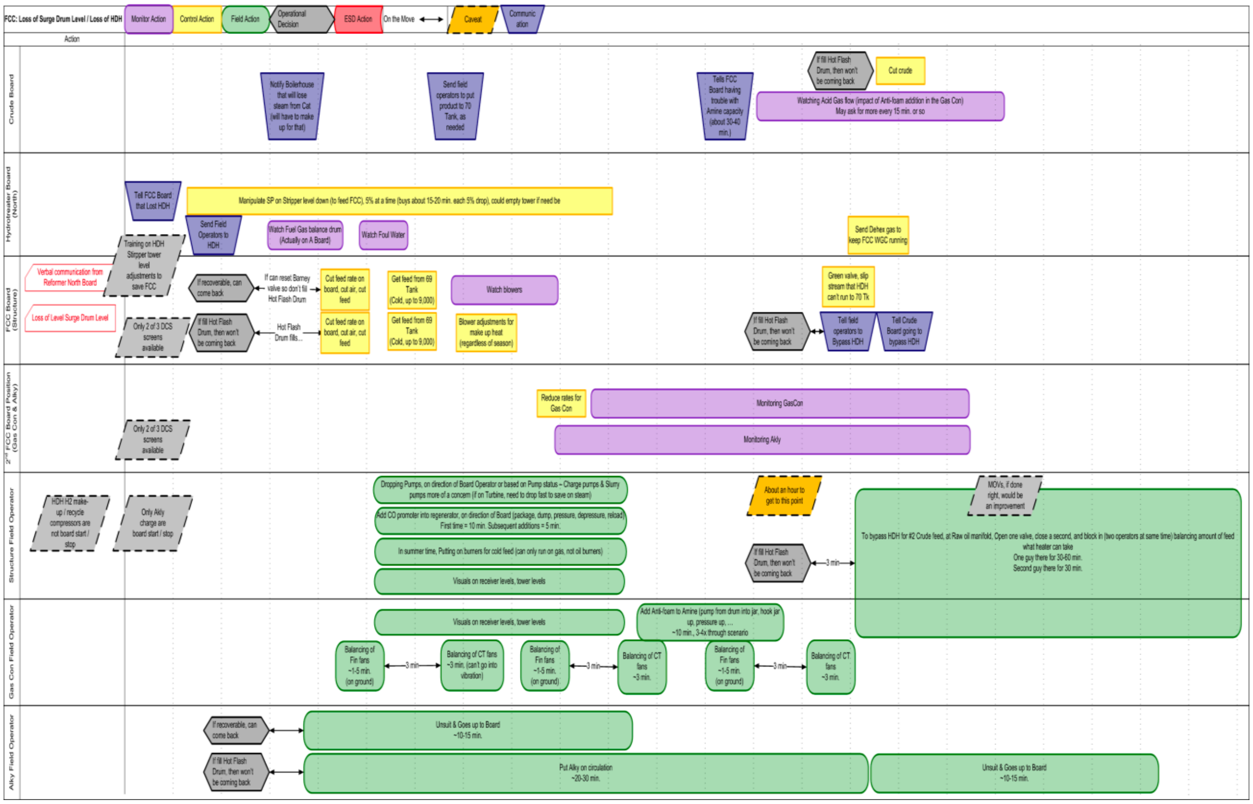
If an action has an extended duration, then this additional time is qualitatively represented by a longer (i.e., ‘stretched’ shape). In other instances, an action may be performed continuously—or may need to be performed one or more times throughout the scenario—in which case the symbol is also stretched out over the respective qualitative timeframe. Where more than one role is required for a task, that task is drawn to span the required roles.

3 SBRA for Abnormal Event Analysis Examples

Figure 2 depicts typical results expected from a SBRA Abnormal Event Analysis. The figure utilizes a “swim-lane” workflow map for the scenarios analyzed. The swim lanes correspond to each role or member of the operations team (e.g., supervisor, console operator, and field operators) involved in dealing with the scenario.

The scenario mapped out in Figure 2 depicted the actions SMEs identified in an event in which a HTU upset caused a loss of feed to its downstream FCCU. The operating team’s goals in this scenario were first to cut their HTU and FCCU run rates, then to bypass the HTU to enable the FCCU to take “colder” feed directly from the Crude unit—because the run from Crude was approximately 350 F, whereas tank temperatures would be at ambient, which is hard on the FCCU heaters—to keep the FCCU from having to shut down completely. The challenge was that the bypass typically took approximately 30 minutes to put in place, and the FCCU's charge drum capacity could only provide the team with sufficient feed to keep running at reduced rates for about 5 to 10 minutes.

Figure 2: HTU loss of feed to FCCU example



As it turns out, not only were opportunities identified to reduce the overall time to put the bypass in place by installing motor-operated valves controlled from the DCS, but one team of console operators had also worked out a solution for buying the additional time needed within their own shift team.

Their shift team's solution was as follows: The HTU stripper tower (the last piece of equipment in the Hydrotreater unit the feed leaves before heading to the FCCU charge drum) was always kept at a fairly high level. When the HTU shut down, the valve allowing the flow from the stripper to the FCCU charge drum closed automatically to maintain level in the stripper. However, because of its size, the operators had determined that by occasionally cutting the level in the Stripper by 5%, they could in turn keep filling the FCCU feed drum, and buy the FCCU team the time needed to put the bypass in place to enable them to run on the feed from the Crude unit.

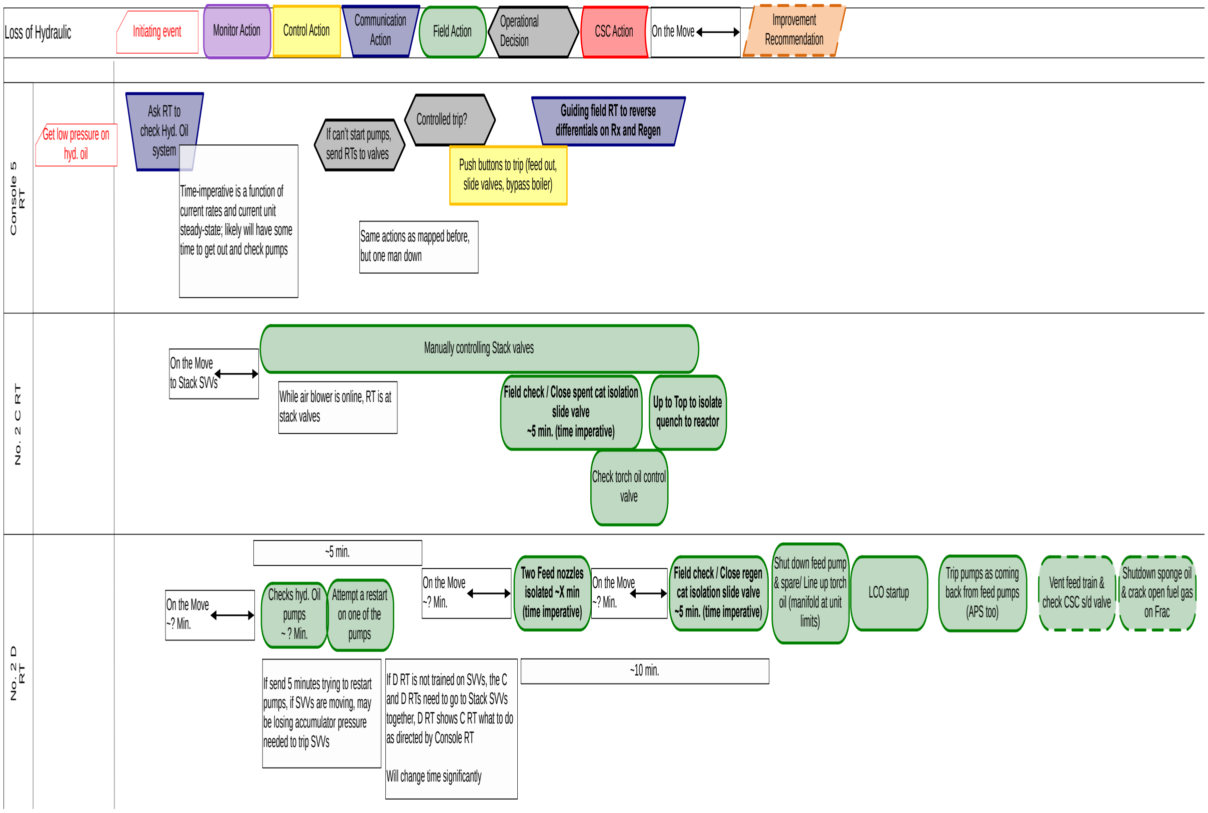
As a result, the plant decided that this solution should be documented in a procedure, and all of their console operators should be trained on its execution.

The table below summaries the findings and recommendations:

Scenario Description	Loss of HTU feed
Causes	• FCCU direct feed from the HTU; Loss can happen immediately • The FCCU charge drum size was not big enough • Not enough physical space for a larger drum to be installed
Early warning signs	• Only advanced warning for FCCU console operator would be verbal from HTU console operator • If the level in HTU hot flash drum bounced, then the SIS took over and cut feed
Potential impacts	• If the team could not drop 10,000bbl in 4 minutes, then the FCCU was going to trip • If HTU console operator did not know to help the FCCU console operator, the FCCU would go down hard, rather than a graceful cutback • On the FCCU side, if the charge drum level drops fast – faster than the field make-up valve can be manually opened, the FCCU trips; Cold make-up feed will hit FCCU heater hard (and max out on high gas pressure)
Operating team goals	• Cut back rates • Cut level in HTU Stripper by 5%, this will fill the FCCU feed drum quickly; and buy the FCCU time to set up the run from the Crude unit; the HTU Stripper level cut can be done for approximately 30 minutes probably and help limp the FCCU through the HTU loss • Line-up direct feed from Crude unit (Crude is 350 F) minimizing impact to heaters from cold feed ex tankage • Line-up takes time to switch to Crude feed / supplement feed from HTU stripper
Scenario Roles and Responsibilities	• FCCU console operator reduces feed/monitors bypass progress • HTU console operator secures HTU and reduces stripper level as required to feed FCCU • Field operator (1) goes to assist at HTU board by monitoring non-critical areas (additional units in span of control) • FO (2) goes to assist with crude bypass setup • FO (3) works with HTU board to monitor and control lower rates
Risks / Improvement Recommendations	• Limited knowledge by all operators and operations specialists of HTU stripper level reduction process for FCCU • Provide training, reduce HTU Stripper level by 5%, which will fill the FCCU feed drum quickly; and buy the FCCU time to line-up from the Crude unit; This HTU Stripper level reduction can be done for ~30 minutes enough time for line-up to FCCU • Create procedure for the HTU Board on how to protect the FCCU with this Stripper level cut

Figure 3 depict the results from the analysis of "Loss of Hydraulic Oil" scenario for a FCCU (as taken from the example scenario list) at a different refinery.

Figure 3: Loss of Hydraulic Oil scenario example for a FCCU



The scenario mapped out in Figure 2 above describes the actions operators took for the scenario for a loss of hydraulic oil (system) within an FCCU. The operating team's goals in this scenario were to restore hydraulic oil pressure while maintaining control of the reactor-regenerator pressure differential and subsequently preventing the likelihood of a flow reversal. In this particular scenario, one field operator was required fulltime to manually control RX/Regen pressure (the valve is located on the twelve level of the Regenerator structure with stair-access only), under these conditions only one field operator remained available to perform all other tasks. The recommendations highlighted the need for additional automated safety system hardware.

The table below summaries the findings and recommendations:

Scenario Description	Loss of hydraulic oil • Electric pump fails/ spare does not start • Lose oil to two SVV (accumulators on Spent Cat and Regen SVV, but after time will lose) and the two Stack SVVs (no accumulators – lose control on those; in static position)[DCR1] • A person could be needed at each valve (three persons, and there are only two field operators and if both are on the structure, then no one is on the ground in case of other ‘time-critical’ tasks arise)
Causes	• Two pumps have failed • Substantial leak in system • Plugged filters
Early warning signs	• Low discharge pressure alarm on oil system • Low level alarm on oil drum before get pressure alarm perhaps • Plugged filters – can see on trends
Potential impacts	• Ability to control Stack valves and Regen / Reactor SVVs • Potential for reversal (if can’t restore hydraulic oil pressure) • Follow-up impact might be to pull feed • To other areas - None initially
Operating team goals	• Restore pressure on hydraulic oil system • Restore some control on for pressure on Regen / differential across SVV • Prevent likelihood of reversal (have lost pressure control)
Risks	• Loss of pressure control • Flow reversals • Environmental • Negated CSC coverage with loss of SV
Improvement Recommendations	• There was a field action to go “Up Top to isolate quench to reactors”. Given the physical distance – and the typical location of this field action in the sequence – a feasibility and cost-benefit study of an automated control valve, DCS-initiated isolation valve, or comparable solution should be considered. • There was a field action “Two feed nozzles isolated” that is noted as “time imperative”. Given the time imperative nature of the action – and the typical location of this field action in the sequence – a feasibility and cost-benefit study of an automated control valve, DCS-initiated isolation valve, or comparable solution should be considered.

4 Summary

The SBRA methodology for abnormal operating events has been designed to capture and analyze the collaborative activities or simultaneous actions, span of control interdependency and teamwork that are essential to ensure an effective AEM outcome. Moreover, the workflow map itself is an effective tool for documenting the knowledge captured for each individual scenario analyzed in the workshop sessions. The SBRA process for abnormal events should be regularly conducted similarly to other risk assessment tools within a process safety management framework.

The key benefits:

- Capture and share individual knowledge/experiences of abnormal and emergency event(s)
- Establish a shared understanding of goals, roles, responsibilities, and risks during different abnormal events
- Identify operations resource requirements
- Identify hazards or potential risks and develop mitigation strategies
- Build team competencies and task interdependence
- Proactively establish team goals
- Verify and validate existing plant emergency procedure and/or work practices
- Establish span-of-control (multi-plant) priorities, e.g. prioritize the order in which furnaces are shut-down across a single console operator's span-of-control during certain abnormal events
- Integrate learnings into training program e.g. incorporate the SBRA tool for abnormal event(s) outcomes into abnormal/emergency response exercises
- Identify potentially different goals and response strategies across shift teams

Tell me and I'll forget.
Show me and I may remember.
Involve me and I learn.
Benjamin Franklin

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