Human Factors Issues in Turnarounds (TARs)

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Turnarounds (often abbreviated to TARs) are planned events where significant sections of a process plant are shut down to enable maintenance or projects to be carried out. They are recognised as tasks where there is an increased risk of process safety incidents. This is for a number of reasons. For example, shutting down nd starting-up equipment may create process conditions that would not arise in normal steady-state operation, significant numbers of individual maintenance operations will increase opportunities for failure, and the requirement to test multiple systems that have been worked on during the TAR will test Control of Work processes.

There are also a number of more general related Human Factors (HF) issues. For example, although planned activities, TARs are non-routine, and the staff supporting the work may not have taken part in such activities for several years. They are resource intensive, with the higher than usual levels of workload. As the plant is shutdown, and therefore unproductive, there is the potential for pressure, whether implicit or explicit, to complete the preparation and reinstatement activities as quickly as possible. They also often involve additional input from third-party, often transient, contractors, whose presence on site needs to be managed. From a planning perspective, there will often be multiple simultaneous operations with a requirement to maintain an understanding of progress and track actions.

As part of the planning activity for a significant TAR at a large process plant, shut-down and start-up tasks were, over a period of several months, subjected to a form of HF Critical Task (CTA). This resulted in the identification of a number of specific HF issues, but it also became clear that many of these issues were relevant across all of the plant units, and potentially to any facility undertaking a TAR. This paper summarises and discusses the general TAR issues identified by these reviews. Areas covered by this paper include: TAR planning, plant issues (e.g. equipment identification, access), procedures, competence, isolation management, purging, gas testing, and leak testing.

1 Background and scope

In the UK, sites governed by the Control of Major Accident Hazard (COMAH) regulations are required to identify COMAH-critical tasks, analyse them to establish where they are vulnerable to human failure, and review the factors that might make those failures more likely (HSE, 2016). This process typically includes some form of task analysis, failure analysis, and Performance Influencing Factor (PIF) analysis. Ultimately, the aim is to optimise the performance of people undertaking COMAH-critical tasks, by ensuring, with reference to ALARP and Hierarchy of Control (HoC) principles, that control measures are appropriate and PIFs have been optimised (for more detail on this type of analysis, see, for example, Energy Institute, 2020).

This process is variously referred to as Human Reliability Analysis (HRA), Safety Critical Task Analysis (SCTA), Human-HAZOP, or Human Error Analysis (HEA). Most versions of these processes, have their roots in the Systematic Human Error Reduction and Prediction Approach (SHERPA) developed in the 1980s as an HF analogue to qualitative engineering risk analyses (Embrey, 1986, 2018).

HRA has worked in this area for many years and carried analyses at different COMAH sites. One type of task that this frequently identified are tasks related to Turnarounds (often abbreviated to TARs). TARs are planned events where significant sections of a process plant are shut down to enable maintenance or projects to be carried out. They are recognised as tasks where there is an increased risk of process safety incidents. This is for a number of reasons. For example, shutting-down and starting-up equipment may create process conditions that would not arise in normal steady-state operation, the significant numbers of individual maintenance operations will increase opportunities for failure, and, on reinstatement, the requirement to test multiple systems that have been worked on during the TAR will test Control of Work processes.

There are also a number of more general related Human Factors (HF) issues. For example, although planned activities, TARs are non-routine, and the staff supporting the work may not have taken part in such activities for several years. Therefore, even if they have prior experience in the tasks, they may not recall some of the specific issues they encountered when they were last involved in a TAR In addition, the supporting administrative systems (e.g. quality assurance, critical valve histories) may also have not been used for a while and/or have been developed by individuals that are no longer in the organisation.

TAR preparation and reinstatement is resource intensive, with higher than usual levels of workload. This is potentially an issue for individuals involved in the TAR, as a result of longer, more intensive, days, but can also result in additional strain on supporting systems and processes. For example, there will be large numbers of maintenance operations, all requiring supporting paperwork (e.g. permits, isolations certificates), which will need to be generated, issued and policed by site staff. They also often involve additional input from third party contractors, whose presence on site needs to be managed. From a planning perspective, there will often be multiple tasks happening in parallel, with a requirement to maintain an understanding of progress and track actions. As the plant is shutdown, and therefore unproductive, there is the potential for pressure, whether implicit or explicit, to complete the preparation and reinstatement activities as quickly as possible.

2 Identification of issues

The catalyst for this piece of work was an HF review carried out in advance of a planned TAR at a large process facility. This was modelled on the SCTA process described in Section 1.

The review covered the tasks required to prepare the system for maintenance work during the TAR (e.g. shut-down activities, isolation of systems, removal of inventory, purging to make safe for access) and tasks required to reinstate the system following the maintenance work (e.g. leak testing, purging, removal of isolations, hand-back to operations).

Whilst there were issues specific to each individual sub-unit, many of the issues that arose from the analyses were generic, with relevance across site units and potentially to any process system where these types of tasks were required. Therefore, the specific outputs were used to develop a checklist for future reference when preparing for a TAR. This paper summarises and discusses the general TAR issues identified by these reviews. Areas covered by this paper include: TAR planning, plant issues (e.g. equipment identification, access), procedures, competence, isolation management, purging, gas testing, and leak testing.

In addition, between them, the authors have had prior experience of TAR preparation and maintenance, as well as an interest, and qualifications, in related HF issues. This prior experience has also been used to inform the content of the paper.

3 Potential HF issues in TARs

Practical factors when assessing Human Factors (HF) issues in TAR preparation and reinstatement

The very nature of TARs (i.e. infrequently performed, complex tasks), can make them more difficult to assess than tasks that are performed more frequently. Often, as they are resource intensive and draining activities, individuals involved in TARs can be reluctant to think about them until they absolutely have to, not least because their day-to-day jobs are also usually demanding. However, the complexity of the tasks means that any preparation needs to be done far enough in advance to give enough time to complete the assessments.

If sufficient time is scheduled, then there are issues of familiarity. As the tasks being considered will not have been thought about for several years, the individuals being asked to contribute may have difficulty remembering important issues that arose the last time they carried out the task. With this in mind, the best time to do these types of reviews may be immediately after a TAR. However, in practice, this may be difficult to achieve, as there is likely to be a desire to move on. Therefore, doing reviews in advance of the TAR, but allow sufficient time, both in terms of the lead up and for the assessments, is likely to be the most practical approach. This may be as far as a year in advance, to try to secure the input of individuals with prior TAR experience. It is likely that the individuals that will be most useful for the analyses (i.e. those with experience of operations on the site) will have other demands on their time.

In terms of the analysis, the SCTA technique (see introduction) works very well for analysing tasks involving a sequence of actions, such as the shut-down and start-up procedures used in TAR preparation and reinstatement. The task analysis process can be used to break the tasks into meaningful sections, if this has not already been done in the procedures (e.g. isolate, depressurise, drain, purge). The systematic analysis of failures, and factors affecting the likelihood of failures, can be used to identify critical actions within the individual procedures, and, if done sufficiently far in advance, provide the opportunity to make improvements to reduce the likelihood, or prevent the consequences, or failures.

However, the number and complexity of procedures involved in TAR preparation and reinstatement means that the SCTA process has to be applied carefully. Given the likely scale of the procedures involved, analysing every step in every procedure is unlikely to be practicable (or even desirable, as many of the steps may be unrelated to MAH outcomes). To address this, some form of task screening is likely to be necessary. There are many ways this could be done, but a screening process that accounts for the potential severity of consequence (if things do go wrong), the existing level of control (i.e. the degree to which the task relies on human performance, rather than, for example engineered control measures), and the vulnerability of the task to failures (given the nature of the tasks), will help to ensure that the analysis time is directed at tasks with both the most significant consequences, and with the greatest potential impact from human performance (i.e. those where there is the greatest scope for improvement).

For example, one way of doing the screening could be as a two-part process. Part one could consider TAR related procedure to determine related MAHs. This could then be potentially be scored to give some differentiation.

1. Low – No MAH potential (no further analysis required)
2. Med – MAH potential (but impact confined to unit)
3. High - Significant MAH potential (impact beyond unit or any other reasons)

This would then enable the procedures to be considered in order of MAH priority, enabling the subsequent analyses to be focussed on the procedures related to the highest potential consequence.

This could then be further refined by considering the sections within the procedures, to establish those requiring the most detailed HF analysis. Again, there are many ways to do this, but one way would be to first consider whether the section has a potential MAH consequence (yes or no). For those sections that are related to MAH-consequences, a scoring process could be used. One example (with two dimensions, 'degree of existing control' and 'vulnerability to failure'[1]), is described below:

Degree of existing control:

1. High – Should not lead to MAH (e.g. because of existing hardware controls – trips, relief valves)
2. Med – Could lead to MAH (e.g. alarm warning of issue, planned opportunity for recovery)
3. Low – Could result directly in MAH (e.g. no associated control measures, relies entirely on the correct performance by the operator or technician).

Vulnerability to failure:

1. Low – (e.g. very simple, one person, no interruptions)
2. Med – Assumed score unless strong reasons to change
3. High – (e.g. complex, multiple roles, multitasking, interruptions)

The scores for these two dimensions can then be multiplied together to give an overall task-section criticality score, indicating where analysis effort should be directed. No prioritisation process is perfect, and there is always a danger that some important procedures, or sections of procedures, could be missed. However, given the scale of the TAR preparation and reinstatement tasks, some form of prioritisation is likely to be essential. If the start-up and shut-down tasks have been previously analysed as part of an ongoing process of SCTA at the site, then these existing reviews could be used as the basis for this analysis. However, note that start-up and shut-down procedures in normal operation may be slightly different in the context of a TAR (e.g. in terms of task preconditions – see discussion on procedures, below).

Planning and tracking progress through the TAR

TARs involve multiple combinations of tasks. Individual, existing site procedures are often used as the basis for the TAR (e.g. Shutdown Unit A, Purge system B in preparation for maintenance). Tracking the progress of these individual procedures, some of which may be being carried out in parallel is an important requirement.

Many sites will use project management-style diagrams to track the progress of these different procedures. One benefit of such diagrams is that they can be displayed in a shared space to help maintain awareness of current progress through the TAR team.

However, often these procedures have been written as standalone documents, without consideration of their role within a TAR. This is where difficulties can arise with tracking progress. Potential issues include:

- Where tasks have been written for general use they may have preconditions that are not relevant in the context of a TAR. Reviewing task preconditions in advance of the TAR will help to identify whether any revisions are required. Without this, users will have to determine for themselves which preconditions are important, and this may result in omissions.
- Some procedures may have actions that will not be completed for some time, whilst the main actions are considered complete enough to continue to subsequent procedures. For example, a general maintenance preparation task may have a final requirement for a flow purge. This could potentially be left on a system for hours or even days. Such actions are easily forgotten, if, in terms of overall TAR progress, the procedure is considered complete.
- Sign-offs by relevant roles at the end of a procedure (potentially also captured on progress diagrams) are a good way of demonstrating that a task has been completed. However, it is important to consider the availability of individuals required to sign-off tasks (e.g. if the required individual is only available on days, then this may cause delays if a task is completed out-of-hours).
- A related issue is the resourcing of these supervisory roles. For example, if there is only one discipline engineer that has sign-off authority, it is likely they will be very busy, and may increase the likelihood of tasks being assumed to be completed without the required checks.
- Some preparation and reinstatement procedures may have an impact on more than one unit (e.g. isolation of a common flare system). Adding a requirement for both parties to accept the action, should help to reduce the likelihood of confusion.
- The timings of actions may have an impact on workload. For example, if a key part of the process is shut down early in the morning, the knock on effects may create workload issues for operators towards the end of their night shift, when they are likely to be tired and potentially less alert. Taking such considerations into account when planning actions may help the TAR preparation or reinstatement proceed smoothly.
- TARs often involve support from partner organisations. Individuals working for these companies may be less familiar with the site than employees. Use of pictorial reference points can be helpful in assisting those with

[1] This is based on the approach described in guidance on human factors safety critical analysis (EI,2020).

unfamiliar with the site. Similarly, use of acronyms, abbreviations and site specific jargon should be limited during pre-work communications for individuals from offsite.

Procedures

In addition to the planning issues, described above, there are additional procedures issues often associated with TAR preparation and reinstatement. Well written procedures will make it easier for operators to carry out their tasks. This is particularly the case for infrequently performed, complex tasks such start-ups and shut-downs. These are the types of tasks for which traditional step-by-step instructions are best suited. TAR-related issues include:

- In a standard procedure, operators would take responsibility for confirming that task pre-conditions are in place. However, in a TAR, there may be a different individual organising the work (e.g. a TAR coordinator). It is possible that an operator might believe that the person issuing the procedure has already confirmed that the preconditions are in place for them to have allowed the task to proceed. Including signature points for TAR Project Coordinator and/or the operator might help to address this, by making clear what has and has not been completed prior to the start of the task.
- Where prerequisites require confirmation, the procedure should make clear whether a visual field check is required or a confirmation of paperwork is sufficient. Failing to make this clear could lead to omissions. For example, a user might assume that a paperwork check is sufficient, when there is a critical field check that needs to be repeated.
- Clearly organised procedures, with sub-sections grouped into sub-goals (e.g. purge feed line, depressurise vessel), are important in any procedure, but especially so for TAR-related procedures, where they assist in keeping track of the task position. They also provide natural hold and handover points, which will make shift handovers more straightforward.
- Wherever possible, procedures should minimise unnecessary operator movements. For example, a procedure that requires an operator to check for the success of a purge at a vent at the top of a column, then open drain valves at the bottom of the column, before being asked to return to vessel top to lock open the vent is likely to result in frustration, increase fatigue, and may increase the likelihood of omissions (e.g. 'I'll put the lock on the next time I'm up there'). However, where this is not possible, e.g. for process safety reasons, this should be explained in procedures and training.

Competence

Competence is closely related to procedures. As always, it is important that individuals both know how to carry out tasks and understand associated hazards. Whilst the processes are the same, the nature of TARs may mean that additional hazards are present, or that hazards are more likely to be released.

- For critical actions, with associated MAH-potential, providing pre-task briefings for operators can help to ensure they understand the potential relationship between their actions and the hazards (this can be further supported in the procedure notes). For TARs, this is even more important, as the tasks being performed are likely to be moving the system out of its normal operating parameters. This may create different hazards, or more significant versions of hazards that might be encountered more frequently in day-to-day operations.
- The SCTA process (see introduction), where task steps and failures are identified and analysed, will help to identify those steps that have potential associated MAH issues. As described in the bullet above, these steps could be reviewed with the performing individuals prior to the task, to help ensure that everyone has the same understanding of the key MAH issues in the task. For example, when repressurising a system, an understanding that opening a valve too quickly could create the conditions for cold metal embrittlement, and ultimately, equipment failure and loss of containment, should help the operator to carry out the task correctly. (Ideally, of course, if this is a possibility resulting from human failure then consideration should be given to Hierarchy of Control (HoC) improvements. For example, automated control of re-pressurisation rates. But this may not be possible to implement in advance of the TAR, even if it is identified as a necessary improvement).
- In some TAR scenarios there may be situations where operators have to make decisions that, again, they may not have to typically make during normal operations. If this is the case, identifying these aspects of tasks in advance, and providing guidance on the factors to consider when making these choices, will help reduce the likelihood of decision making failures.

Purging

TAR preparation and reinstatement will require a significant amount of purging (e.g. to eliminate flammable atmospheres, to make a system safe for access). Depending on the system involved, there may be several different types of purge required, involving different substances (e.g. steam, nitrogen, air) and processes (e.g. flow, pressure). The process of purging will usually be very familiar to the operating team, but during a TAR there will be additional considerations such as the availability of the purging medium (given the large numbers of purges likely to be required), and the sheer volume of purges may make it difficult to keep track of ongoing purges.

- Often individual purge procedures will have been written by different individuals using different formats. This can become especially apparent in a TAR where multiple procedures with purge elements are used. Spending the time to develop a standard format to purge descriptions can help aid clarity. This will include addressing some of the specific elements discussed in the bullets below.
- Where different types of purge are possible (e.g. nitrogen, steam, flow or pressure), giving a brief explanation at the start of the purge as to why the specific type of purge is required, will help the operator to understand the goal of the purge. For example, the nature of the material to be purged may be more hazardous (e.g. a lighter fraction) than in a similar system, therefore a nitrogen purge is required.
- Also, where there are unusual requirements (e.g. reversing the direction of a purge to more effectively clear a dead leg), then the provision of a brief explanation giving the reasons for this should reduce the risk of omissions (e.g. if an individual incorrectly assumes they have already completed a similar purge).
- Providing clarity on the specifics of the purge should help to reduce the likelihood of errors by the performing individual. For example:
    - specifying whether a flow or pressure purge (or combination) is required,
    - detailing the number of pressure purges required,
    - stating the required duration of the purge,
    - describing whether the system is to be left under pressure.
- When there are multiple purges taking place, providing clarity on the purge medium injection points can help the efficiency of the process. For example, if steam has been introduced from multiple points, then, when it comes to stopping the purge, unless there is a record of the injection points used, the operator may have to hunt around to stop the steam purge, resulting in delays.
- Establishing whether a purge has been successful is another area where it is important to be specific. Use of subjective assessments, such as asking an individual to judge whether the smell from a vent is still strong, may be difficult to avoid, but are, by definition, open to interpretation. Subjective assessments may be appropriate in certain situations (e.g. if the purpose of the check is to establish whether gross failures have occurred, such as failing to line-up the purge correctly, or failure to turn on the steam supply, with a more formal assessment to follow at a later point). In these cases, providing reasons as to why a subjective assessment is appropriate should be given. Where this is required, this also creates a competence requirement to ensure that all operators are able to make these subjective judgements. In the context of a TAR, it might be that there is a requirement for more experienced operators to be available to carry out these assessments.

Gas and oxygen testing

Testing is a critical part of TAR preparation and reinstatement. Following purging, gas and oxygen tests will be used to confirm whether a system is safe to break into, and, in conjunction with leak tests, to confirm that a system is safe to reinstate. In TAR preparation and reinstatement, there will potentially be many tests taking place. Some potential issues include:

- Where lab tests are required, the volume of tests necessary during a TAR will create additional demands on the laboratory functions. For example, the number of tests being undertaken will potentially put more pressure on the systems in place for identifying samples and communicating results.
- Similarly, the volume of testing will place demands on the available equipment. Therefore, in the planning phase it is important to ensure that there will be sufficient calibrated gas testers available.
- The timing of tests may also be an issue. For example, it may not be necessary in site systems to prove that a system is safe for entry until immediately before that entry. However, the purge that has been used to create the safe condition may have been completed hours, or potentially even days before. Procedures should make clear whether there is a requirement to repeat tests prior to entry (this might include some conditions around when the first test had been performed).
- In preparation and reinstatement procedures, often tests are embedded within a wider task description (e.g. in a description of a leak test). Giving tests their own high level goal within a procedure emphasises their criticality, and reduces the likelihood of inadvertent omission.
- Providing space to record the results of tests in the accompanying procedure, will help to give confidence that a test has been performed. In the context of a TAR, where an individual may be carrying out multiple tests, it will

be much easier to lose place in the task and omit a test (e.g. believing it has already being completed). A space to record the results should help to prevent or capture these types of omissions.

- In addition, positively recording the result of the test (as opposed to just signing to say it has been completed) gives additional confidence that the test has been performed. This can be further enhanced by ensuring that the space in the procedures for recording the test results includes a clearly stated target result (with allowed tolerances where relevant).
- As with purging (and procedures in general), it is good practice to give specific requirements and to provide an explanation where there are variations in methods. For example, if tests are not required following a steam purge where, perhaps, the presence of steam at vents and drains is taken as sufficient indication that a system is oxygen free, then the reasons for this should be explained in the procedure. This clarification should help to reduce the likelihood of omissions where an operator assumes that a test is not necessary because the previous procedure for a similar system did not require one.
- Another aspect of testing, where being specific is important, is in the identification of test points. Specifying where tests should be performed on the system (or locations for samples to be taken) should help ensure that operators do not mistakenly test at a point where the sample might be unrepresentative, or where the sample may not recover failures (e.g. by testing at a point close to where steam/nitrogen is introduced). Where multiple test points are required this should also be specified, along with reasons as to why this is necessary.
- Where local tests are required (i.e. where samples are not sent to a laboratory for analysis), then training and competence is important (e.g. how to use gas testers, how to insert tubes into test points, requirement for small positive pressure in system). In a TAR, there may be more demands on those individuals that have been trained in this area, so this should be taken into account in planning.
- Procedures should also give guidance on what should be done if the test result does not meet the required target. In some cases, it may be as simple as repeated the purge, but there may be situations where a different approach is warranted.
- Due to high additional task volumes associated with TARs, larger sites may engage third-party contractors to provide support for tasks such as gas-testing. If this is the case, it is important that these individuals are sufficiently qualified and experienced to carry out the role. This tends to be less of a concern at smaller sites where contractors are typically used for more specialist work.

Leak testing

Establishing that a system is sound, prior to the reintroduction of process liquid and gasses is an essential part of the reinstatement process following a TAR. As the maintenance work performed during the TAR will have typically involved disassembly and reassembly there will have been multiple opportunities to leave leak paths in place. In addition, depending on the system, there may be different leak test requirements, with steam being sufficient in some cases, whereas in others there may be a requirement for a formal pressure drop test (i.e. filling a system with a test medium such as nitrogen and waiting to see if it holds its pressure).

- Where different types of leak checks are in use (e.g. visual checks for steam, soapy water leak checks, helium leak checks). Ensure that the requirements for each system are clearly specified and, where higher standards are required, explain why this is the case. Again, this will help to prevent the choice of the incorrect method.
- Identifying points where work was carried out during the TAR (i.e. where containment was broken) may help operators direct their attention (particularly on larger systems) when carrying out leak testing.

Links to Control of Work (CoW) systems

Most sites will have well developed CoW systems for managing work (e.g. isolation certification, permitry). These systems will frequently involve different kinds of locks and tags to ensure that work on systems is controlled. For larger sites, in particular, there is the possibility that these systems may operate differently in the context of a TAR. Whilst this is not necessarily an issue, it is important that any differences are managed. In addition, the sheer number of isolations required in a TAR preparation and reinstatement can put additional demands on these systems.

- Some sites may modify the requirements of their isolation management systems for TARs. For example, if an entire system is being shutdown and made safe for work, then there may not be the same level of control around specific elements (e.g. there may only be locks and tags applied to isolation boundaries, whereas in normal operation all individual elements would be locked and tagged to prevent inadvertent operation whilst working on adjacent systems). Ensure that procedures make clear what the isolation requirements are for the TAR, and give guidance on when isolations should be applied.

- Checks on critical systems (e.g. relief valves and flare systems, blinds at boundaries between high pressure and lower pressure systems), are typically performed in a piecemeal manner as encountered in individual procedures. Given their criticality, consider whether additional independent checks (i.e. by a different person to the person that completed the procedure) of all critical equipment should be performed as part of reinstatement.

3 Summary

Preparation and reinstatement of systems for a TAR are recognised as tasks where there is an increased risk of process safety incidents, and where there will be additional HF issues that contribute to this risk. Systematically considering HF issues in advance of a TAR, using, for example, a SCTA process, will help to identify specific concerns giving the opportunity to manage them in advance of, and through, the TAR process. This paper has summarised some general issues identified by carrying out this type of assessment.

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