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Integrating Prospective and Retrospective Human Error Analysis: A New Methodology

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Abstract

Human error remains a dominant contributor to major accidents in high-hazard industries, despite advances in engineering safeguards and process safety. Traditional incident investigations often focus retrospectively on identifying root causes, while proactive human reliability analyses aim to predict and prevent failures before they occur. However, these two approaches are rarely integrated within a single coherent framework.

This paper introduces TABIE (Task Analysis Based Incident Evaluation), a structured methodology that integrates prospective and retrospective human error analysis to strengthen both incident investigation and proactive risk reduction. TABIE enables analysts to trace accident pathways from immediate operational failures back to latent organisational and task design weaknesses.
The methodology is illustrated through a process industry case study involving maintenance-related latent failures, The analysis demonstrates how precursor failures propagate into operational phases and how the systematic evaluation of PIFs supports identification of the most cost-effective risk reduction strategies.

Keywords: Human error, Incident investigation, Human reliability, Performance Influencing Factors, Hierarchical Task Analysis, Safety Critical Task Analysis, Root cause analysis, Process safety, Barrier management, Risk reduction

1. Introduction

Human error remains the most significant contributor to major accidents and process safety incidents across the oil, gas, and chemicals industries. While great strides have been made in process and engineering safety, many incidents still arise from failures in human performance, poor task design, inadequate procedures, or latent organisational conditions. Addressing these failures effectively requires not only analysing incidents after they occur but also understanding how similar failures might be predicted and prevented in the future.

This paper introduces TABIE (Task Analysis Based Incident Evaluation), which integrates both prospective and retrospective approaches to human error management. TABIE combines structured task analysis with causal reasoning to identify both the immediate causes of human error and the precursor conditions that made such errors more likely.

The approach is based on the established SHERPA (Systems based Human Error Reduction in Process Analysis methodology) (Embrey, 1986, 2013).

The objective is to trace incident pathways back to their systemic origins—such as latent organisational weaknesses, inadequate labelling, or flawed procedures. TABIE also incorporates a risk forecasting element: for each identified causal factor, the methodology allows analysts to estimate the likelihood of recurrence and model the effectiveness of alternative interventions in reducing this risk.

2. TABIE Case Study

In this section, we provide a process industry incident analysis to illustrate the tools used in the TABIE process. The example has been simplified to focus on the methodology aspects. In a

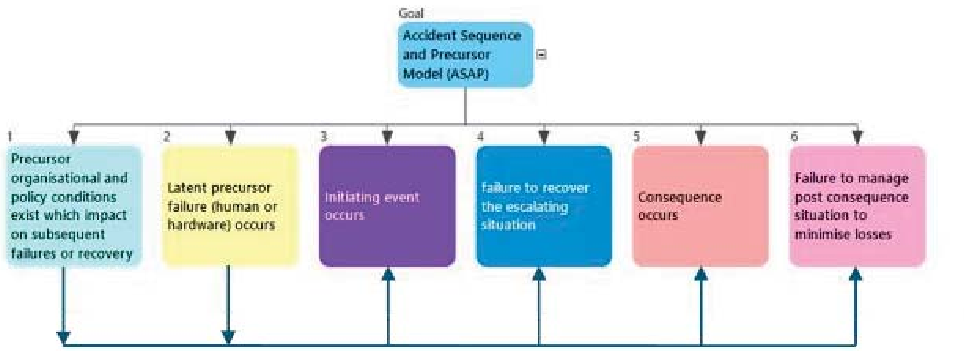

Figure 1 Accident Sequence and Precursor analysis (ASAP)

production process, an exothermic reaction takes place in a reactor vessel in a chemical process plant. A pump circulates coolant in a jacket around the reactor vessel to remove the heat produced by the reaction and therefore avoid a thermal runaway situation. Several safety barriers exist. These include an alarm that warns the Control Room Operator (CRO) if the flow rate (and hence the rate of cooling) falls below an acceptable level, based on the outputs from a flow rate meter. If a manual action is not taken to increase the coolant flow, a standby circulation pump should automatically operate. In the scenario being evaluated, a critical circulation pump bearing was not lubricated during a maintenance session prior to startup. Although this did not lead to immediate failure, after repeated process operations, the bearing collapsed, and the pump became unavailable. During the same maintenance session, the low flow alarm sensor had been overridden to test the sensor without giving rise to spurious alarms in the control room.

After the maintenance session, this was not reinstated to the correct settings to sound the low flow alarm and activate the backup circulation pump in the event of loss of coolant. The absence of the low flow alarm meant that the loss of coolant flow was not immediately indicated on the control panel, nor did the automatic trip and activation of the backup pump occur. As the rise in temperature was initially quite slow, the Control Room Operators did not detect that the reaction was going out of control by other indications. Eventually the exothermic reaction accelerated, and an explosion occurred. The stages of the incident are shown in Figure 2.

3. Overview of TABIE workflow for analysing accident sequences

TABIE consists of a set of tools and techniques which are applied in an integrated manner to address various aspects of incident investigation. Many of these tools are also utilised in proactive risk assessments such as Safety Critical Task Analysis (SCTA).

The tools utilised in TABIE are as follows:

- **Precursor analysis** is used to assess the impact of precursor events on the likelihood of failures leading to the scenario. This is based on the accident sequence and Precursor analysis (ASAP) model shown in Figure 1
- **Hierarchical Task Analysis (HTA)** is used to map the structure of the task. Figure 2 sets out the accident sequence in the form of an HTA, including the precursor events.
- **Activity analysis** determines the types of activities being carried in the task, e.g. actions, checking, monitoring, which may involve different types of failures which contribute to the scenario.
- **Failure analysis** identifies specific failure modes associated with the activity types. For example, Actions could be omitted completely or carried out on the wrong pump.
- **Performance Influencing Factors (PIF) analysis**
  PIFs are the conditions that determine the probability of the failure modes Some of these, such as workload, are

generic in nature, in the sense that they could affect the likelihoods of failures regardless of the type of activity being carried out. Others, such as level of distractions are more task specific.

- **Calculation of the Quality Index (QI)**
  The QI is a measure of the combination of PIFs that influence the failure of a task step.
- **Calibration of the QI to provide a failure probability**
  The QI is used to predict the likelihood of an error as a function of the quality of the PIFs.

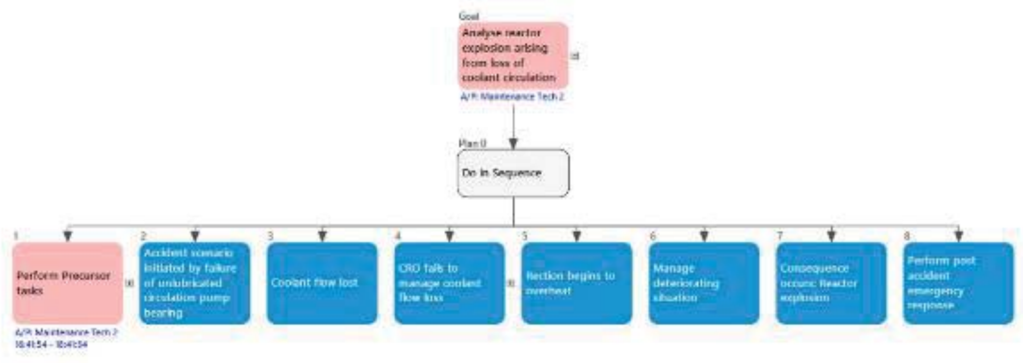

Figure 2: Stages of the Case study incident scenario

4.1 Accident Sequence and Precursor (ASAP) analysis

The ASAP model shown in Figure 1 is used within TABIE for analysing the precursor events that give rise to latent failures in incidents. Latent failures are vulnerable states of the system that in conjunction with certain operating conditions, give rise to failures with significant consequences. A typical example would be where a flange that had been opened during maintenance operations was not restored correctly such that the bolts were not tightened sufficiently to prevent a leak under subsequent high pressure operating conditions.

Another type of latent failure could arise because of inadequate policy decisions that increase the likelihood of hardware or human failures. An example would be the lack of an effective policy for maintaining the labelling of critical plant items. As shown in Figure 1, ASAP allows the identification of precursors that may have created failures occurring during subsequent stages of the incident scenario, such as detecting the initiating event and managing recovery before the consequence (e.g. an explosion) occurs. The ASAP model can also include precursors that impact on the effectiveness of post consequence management. The stages of ASAP are very similar to those considered in Bow Tie Analyses. The incident specific ASAP stages shown in Figure 2 illustrate this similarity.

In the case study, the precursor steps involve performing maintenance operations on the circulation pump bearings and testing a low flow alarm with a connected trip which starts a back-up pump if the circulation flow rate is inadequate.

4.2 Hierarchical Task Analysis (HTA)

Hierarchical Task Analysis (HTA) is used for graphically mapping the structure of complex tasks. As shown in Figure 3, HTA breaks down a complex task into increasing levels of detail. The top level of the HTA specifies the functions that need to be performed for the overall task objective to be achieved, in this case the completion of the maintenance schedule for the lubrication of the circulation pump bearing and the low flow alarm and associated backup pump operation in the maintenance task. Each top-level function is then successively broken down to the level of individual steps.

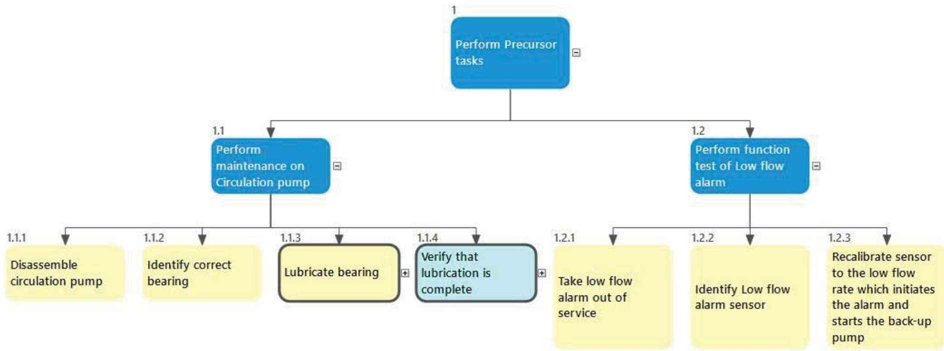

Figure 3: Hierarchical Task Analysis for Precursor tasks (simplified)

4.3 Classifying of the activities carried out in the task involved in the accident scenario

The analyst uses an inbuilt set of Activity types used by both SHERPA and TABIE to categorise the bottom level steps (called leaf nodes) in each branch of the HTA under consideration. Example categories are:

- Actions
- Checking,
- Communications
- Data entry
- Monitoring

4.4 Evaluation of Failure modes associated with Activity types

This process associates the failure modes that have been identified as possible paths leading to the observed outcomes in the accident scenario. For example, in the case study, the bearing lubrication step was an action, so two potential pathways or failure modes could have led to the failure:

- ***Action omitted***-the lubrication was not performed at all
- ***Right action on wrong object***-The intention to perform the action was formed and executed correctly, but on the wrong pump

The analyst can identify which of these alternative failure modes / pathways actually occurred in the scenario, and which might have occurred had conditions been slightly different

4.5 PIF evaluation

Once the analysis has identified all of the potential failure modes which could have given rise to the consequences of the scenario, the next stage is to evaluate the state of the Performance Influencing factors (PIFs) that gave rise to these failures.

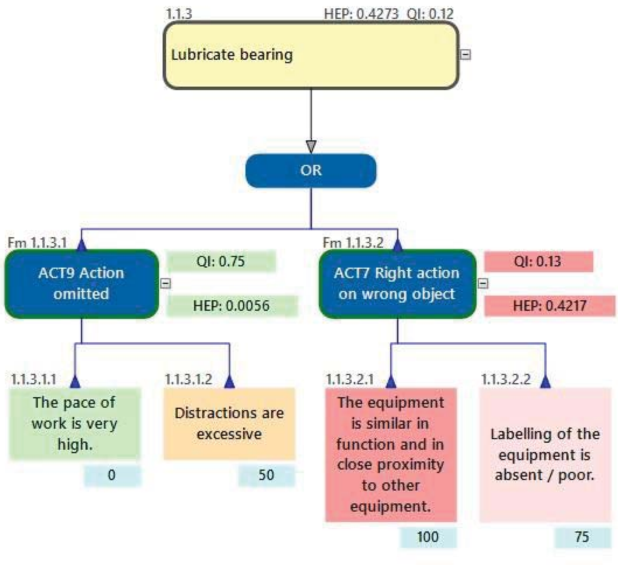

Figure 4: Rating the PIFs associated with the pump bearing lubrication task to evaluate the Quality Indices and human error probabilities (HEPs) for each failure mode

5. The Quality Index (QI)

The QI is a central concept in both proactive (SHERPA) and retrospective (TABIE) assessments of human error. It allows HEPs to be assessed as a function of the quality of the PIFs that give rise to success or failure. The Quality Index (QI) is a measure of the combined quality of all of the PIFs that may affect the probability that a specific failure will occur. The QI is calculated from the ratings of the PIFs quality and the relative strength of their influences, (known as weights) on the likelihood of the failure. The use of weights allows the analyst to consider the fact that some PIFs have a stronger influence than others in determining the likelihood that a failure mode may occur.

The Quality Index can be used to make decisions about which PIF to improve to maximise the reduction of errors. The basic assumption is that the actual error probability will be directly related to the QI, since this combines the quality of all of the PIFs that have been assumed to drive the human error probability (HEP).

The QI is obtained by rating and weighting the combined quality of the PIFs which determine the likelihood of an error and combining them to produce a numerical index. The resulting Quality Index is on a scale from 1 (Best case, where all PIFs optimal-error unlikely to error) to 0 (Worst case, all PIFs at their worst case-an error is very likely to occur).

The QI calculation is made using the following formula:

$$QI = \Sigma \ (Ri \times Wi)$$

Where:

Wi=Normalised weights (each individual weight divided by the sum of all the weights)

Ri=PIF Rating where: 1.0=best case and 0= worst case (sometimes the ratings are made on a scale of 1-100 rather than 0 to 1 This does not affect the calculation of the QI except that it will also be from 0 to 100)

Improvements in the PIF ratings associated with a failure mode will increase the QI and reduce the likelihood of error. In that case, where all the PIFs are at their best case the QI will be 1. It is usually assumed that a QI of 1.0 will result in a residual HEP, even if this is very low, e.g. 10^{-3}.

Conversely, as the QI approaches zero the HEP will increase and can be assumed to be 1.0 in the worst-case situation, where all the constituent PIFs are rated as being worst case.

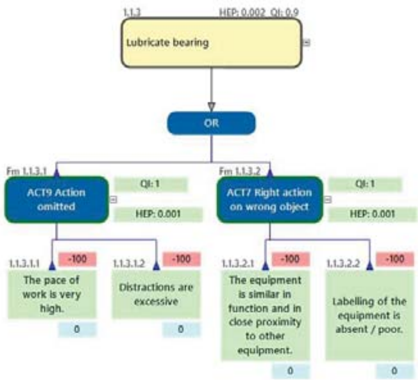

Figure 5: Illustration of the effect on failure probability of optimising all the PIFs impinging on the two failure modes.

5.1 Example of QI calculations for PIFs in figures 4 and 5

In this section we calculate the probability of the ***Right action on wrong object*** failure mode occurring as a function of the quality of the PIFs.

The PIF ***Proximity of similar items*** shown in figure 5 is a factor that increases the likelihood of the ***Right action on wrong object*** failure if it is high, i.e. objects are easily confused. As it is rated at 100, this indicates the worst-case situation is present, i.e. the maximum negative conditions for this PIF exist. and the likelihood of a ***Right action on wrong object*** is high. However, the -100 above the box 1.1.3.2.1 contains a negative number, which indicates the PIF scale is reversed in terms of its effect on the Quality Index. Thus, a high PIF rating of 100 will decrease the QI which will give rise to an increased failure probability. Similarly, for the base case for PIF ***Labelling of the equipment is absent / poor*** PIF, the rating is poor (75), and this will also reduce the QI and increase the failure probability.

In order to minimise the probability of ***the right action on wrong object*** failure mode arising, we need to optimise both of the failure modes and their related PIFs that determine this probability. For this, we need to change the state of the PIF ***Similarity of the equipment being selected*** from its worst-case rating of 100 shown in Figure 4, to the optimal rating of zero, which indicates minimal confusability. If similar optimisations are applied to the PIF ratings for the other main failure pathway, ***Action omitted***, the overall QI is 0.9, which corresponds to an HEP of 0.002. This is the probability that a similar incident will arise from these two failure modes in the future if all of the PIFs have been optimised.

This analysis of the impact of improving PIFs on the likelihood of the scenario being repeated provides a means for evaluating the benefits of optimising the underlying causal factors. If the relative costs of implementing these strategies compared with other improvements is known, a cost benefit evaluation could be made to select the best options.

5.2 Illustrative calculation of the QI index,

This uses using ratings for the ***Right Action on wrong object*** failure mode based on the formula discussed in section 5:

QI= Σ (Ri x Wi)

Where:

Wi=Normalised weights (each individual weight divided by the sum of all the weights)

The details of the calculation are shown below and the conversion of the QI to a failure probability is described in Section 5.4.

Total Absolute Weight (200) = 100 + 100 (Assumes all weights are equal)

QI (1.0) = (100/200*(100-0) + 100/200*(100-0)) / 100

The QI can be used to measure of the extent to which the best- or worst-case conditions have been achieved by optimising all of the deficient PIF ratings to bring the resulting QI closer to 1.

5.3. Identifying which failure modes could have initiated the incident sequence

In Figure 4, two possible failure modes, ***Action omitted*** and ***Right Action on Wrong object*** have been assigned by the TABIE analyst as potential pathways for the lubricate bearing step being omitted. This approach can be used to predict the likelihood of any scenario where these failure modes are possible. The approach also provides an indication of the failure pathways that are the most likely to have occurred. This assumes that the most likely pathways are those with the highest probability of occurring, based on the TABIE analysis.

5.4 Mapping QIs on to a numerical Human error probability (HEP) scale.

If a human error probability is required, this involves developing or assuming a numerical relationship between QIs and their resultant HEPs. The most commonly used relationship is log linear of the form:

Log HEP = A.QI + B

Where A and B are constants.

This captures the fact that as the PIFs increase to their best-case ratings (QI=1), they tend to be less effective in reducing the failure probability. A similar asymptotic relationship would also apply at the other end of the scale where the QI is trending towards the worst-case condition where it is assessed as zero.

In order to quantify the constants A and B it is necessary to evaluate a sample of tasks each of which has known QIs (calculated from ratings for the PIFs) and the observed failure probabilities for the corresponding tasks

In some cases, it is useful to use two boundary conditions to calculate the A and B constants to provide a generic conversion equation. For example, it could be assumed that in the worst-case condition the QI =0 and in the best case, a residual failure probability of 10^{-3} (1 in 1000) will remain even if all the PIFs are optimised. This approach was used for the example in Section 5.1.

It is recommended that these probabilities are used for primarily for comparative purposes, by evaluating the degree of improvements that can be achieved by improving the ratings of the PIF. If the relative costs of the improvements are known, this together with the results of the QI calculations can be used to determine which interventions are the most cost-effective for reducing the risks of similar scenarios arising in the future.

These are shown as HEP values in Figure 4. These HEPs indicate that the right action on wrong object failure mode had much higher probability of occurrence (P=0.42) than Action omitted (P=0.006). This is therefore the most likely failure mode that gave rise to the accident. The PIF that has the greatest potential for improvement for the failure mode is reducing the proximity of the items that could be confused. This is because it is currently rated as being the worst case as it has a rating of 100 on the degree of proximity scale. In these discussions, we have assumed that all of the PIFs are equally weighted. However, it is possible to use weights from people who are experienced in a task to determine consensus estimates of the weights using techniques such as Paired Comparisons.

6. Strategies for minimising the likelihood of future incidents

One of the most important benefits of TABIE is its ability to specify improvement strategies for reducing the risk of future failures in the most cost-effective manner. Applying the TABIE process across the whole scenario being investigated will provide the following outputs:

- Detailed HTA maps of the steps that were being executed during the main accident sequence (Stages 3 to 6 in the ASAP model shown in Figure 1).
- Similar HTA maps of the precursor tasks (Stages 1-2 of the ASAP model) that could have contributed to the occurrence of Latent failures in the main scenario.
- Identification of possible Failure modes that could have been the initiating events for the incident sequence
- The consequences of these failure modes, either immediate or latent if they occurred in the precursor stage of the scenario
- Ratings of the quality of the PIFs that determined the likelihood of these Failure modes
- QIs calculated from the PIF ratings, that measure the overall likelihood that the Failure mode could recur.

These data can then be used to provide the following information relevant to the prevention of similar accident scenarios in the future:

- Identification of Failure modes which could have potentially been involved in the accident sequence being analysed
- Identifying the PIFs that determined the likelihood of the Failure modes leading to the incident pathways that actually occurred, in the scenario being investigated.
- The work required to optimise any deficient PIFs which impact on failure modes with significant consequences.
- The relative costs of implementing these changes.

This information can be used to specify which PIFs should be selected to provide the most cost-effective strategy for reducing the likelihood of the scenario or similar scenarios occurring in the future. This process consists of the following steps:

- List each of the failure modes that did or could have given rise to a significant consequence, in terms of safety or other factors such as quality or financial costs.
- Rank order the Failure modes in terms of their severity of their potential consequences.
- Evaluate the costs of improving the current quality of the PIFs (as measured by their ratings) to their optimal states (for example changing a PIF state such as distractions from its current evaluation as high, to very low).
- Evaluate the reduced cost of the consequences of the scenario, if the likelihood of its occurrence is reduced by optimising the contributory PIFs

6. Conclusions

In addition to providing support for the analyst on deciding which failure pathways were the most likely to have occurred, the processes used in TABIE provide a comprehensive evaluation of the current states of the PIFs when the scenario occurred. This is vital information for minimising the overall vulnerability of the system to human and hardware failures. It also goes beyond the mistaken focus on a limited set of potentially deficient PIFs and assuming that if these factors are fixed, the scenario will never occur in the future.

TABIE therefore encourages a systematic approach which considers the impact of other deficient PIFs that could give rise to similar or more severe accident scenarios in the future. The methodologies described in this paper therefore combine the best aspects of proactive techniques such as SCTA, with retrospective approaches such as TABIE.

The ability to develop cost effective interventions to improve the quality of PIFs that impact on critical failures is seen as a major benefit of the TABIE methodology. TABIE also provides a risk analysis management tool when it is applied to near misses with minor consequences rather than to actual high consequence scenarios. This approach also identifies scenarios and evaluates the most cost-effective interventions to minimise the likelihood of future losses. Potentially both TABIE and traditional SCTA analyses could be both be deployed to provide an in-depth risk assessment for proactive risk analysis in the context such as COMAH reports submitted to regulatory authorities such as the HSE in the UK.

References

Embrey, D. (1986). SHERPA: A Systematic Human Error Reduction and Prediction Approach. In: *Proceedings of the International Topical Meeting on Advances in Human Factors in Nuclear Power Systems*. American Nuclear Society, pp.184–193. Available at: https://www.researchgate.net/publication/289967701_SHERPA_A_systematic_human_error_reduction_and_prediction_approach.

Embrey, D.E. (2013) *An Error Reduction and Prediction Approach to Modelling and Assessing Human Reliability in Complex Tasks* Proceedings of the European Safety and Reliability Conference (ESREL) Amsterdam

Embrey, D. and Zaed, S. (2010). A Set of Computer-based Tools for Identifying and Preventing Human Error in Plant Operations. In: P*roceedings of the 6th Global Conference on Process Safety American Institute of Chemical Engineers*. Available at:

https://www.humanreliability.com/downloads/a-set-of-computer-based-tools-identifying-and-preventing-human-error-in-plant-operation/.