Human Dependency in Tanker Offloading Operations

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Introduction

High hazard sites operating under the EU ‘Seveso’ Directive are required to identify credible Major Accident Hazard (MAH) scenarios and demonstrate that relevant good practice is being applied to reduce risks to ‘as low as reasonably practicable’ (ALARP). For many MAH scenarios where the critical safeguards are hardware based, such as safety instrumented or pressure relief systems, this demonstration involves meeting appropriate standards and ensuring reliability of equipment through suitable inspection and testing. For MAH scenarios where the risk is dominated by human factors the demonstration is more difficult, requiring a detailed assessment of the task in order to minimise the likelihood of error and to provide a quantitative estimate of human error probability.

On chemical manufacturing sites a common activity where MAH scenarios are often dependent on human performance is offloading of hazardous substances from road tankers. This is due to the impracticability of providing hardware safeguards to prevent scenarios such as connecting a tanker to the wrong storage tank, and hence there is a need to rely on robust procedural controls. This paper will describe an assessment covering this type of operation, where the potential to offload a road tanker of chemical A into chemical B storage tank, could result in the release of toxic gas from the tank. This scenario was modelled in preparation of the site Safety Report and shown to result in serious toxic effects that could cause fatalities to both on-site and off-site populations.

The company had carried out a safety critical task analysis (SCTA) on the offloading procedure to identify potential errors and optimise the factors that avoid such errors. This qualitative assessment identified key performance influencing factors such as use of a clear checklist, different offloading bays, locked offloading valves and different connection types. As a further stage of assessment it was required to demonstrate ALARP by quantifying the frequency of the MAH scenario and assessing the need for further measures to reduce risks to a tolerable level. Frequent road tanker deliveries of these chemicals provide a large number of opportunities for error, and in order to demonstrate that company risk criteria has been met, the human error probability (HEP) for connecting to the wrong tank needs to be very low.

The paper will describe two different methods used to estimate the HEP for this activity. Firstly using a ‘top-down’ approach based on generic HSE data for tanker connection errors, taking account of the type of facility and assessing as below average, average or above average. Secondly a ‘bottom-up’ approach considering that offloading into the wrong tank could only occur following a series of errors by a number of people. Using an HEP for these errors in isolation would give a non-conservative value as it does not account for inter-dependency between the errors, i.e. having made the first error the second and subsequent errors are more likely. An approach will be described based on the Technique for Human Error Rate Prediction (THERP) human dependency model. The results of the ‘top down’ and ‘bottom up’ approaches for the HEP estimate will be discussed, and how these were used to demonstrate ALARP.

Background

The chemical manufacturing site for this assessment is ‘upper tier’ under the UK COMAH Regulations and has several bulk storage tanks for raw materials at various locations on the site. The potential for offloading a road tanker into the wrong tank was considered during preparation of the site Safety Report, and it was identified that two raw materials in particular presented a significant hazard if mixed in error. These will be referred to as chemical A and chemical B in this paper, and the consequence of mixing these chemicals is an instantaneous reaction that generates a brown gas that is very toxic by inhalation.

Consequence assessment of this event had been carried out, calculating the maximum gas generation rate based on road tanker offloading rates, and then carrying out gas dispersion modelling to determine the extent and severity of the toxic gas plume in various weather conditions. This work established that the event would exceed threshold toxicity doses both on-site and off-site, with the potential to cause major injuries or fatalities. The event was therefore classified as a Major Accident Hazard (MAH) and a demonstration included in the Safety Report that ‘all measures necessary’ had been taken to reduce the risk to a tolerable level against HSE and company risk criteria.

The MAH scenario associated with tanker offloading was assessed in the Safety Report as one of the highest risk events on the site. Based on the criticality of procedural controls to prevent this scenario, the HSE requested a further ALARP demonstration, including a Safety Critical Task Analysis (SCTA) and a quantified risk assessment that assessed the likely frequency of this event. A qualitative SCTA was carried out by the company using a standard approach, considering each step in the road tanker delivery procedure, identifying what could go wrong and assessing practical improvements to make errors less likely.

This paper describes the quantitative estimate of event frequency that required an estimate of the overall Human Error Probability (HEP), taking into account a series of errors that would need to occur to allow offloading into the wrong tank.

Process description

Chemical A in a standard road tanker and chemical B in an iso-tanker are delivered to site at approximately one delivery of each material per day. Tanker offloading occurs in dedicated offloading bays into storage tanks located in different tanks farms within a common raw materials area of the site.

The key steps in the tanker receipt and offloading procedure are summarised below. These are carried out by the Operator following a written procedure and completing an offloading check sheet. These steps include a number of improvements introduced by the company following the SCTA that they completed ahead of the work described in this paper:

- Road tankers of chemical A or iso-tankers of chemical B arrive at site entrance weighbridge, the paperwork is checked and contents identified, registered and weighed by the Operator.
- The Operator obtains the correct key at the Weighbridge office to open the offloading valve and accompanies the road tanker to the correct offloading bay.
- The Team Leader confirms the tanker is in the correct offloading bay and signs the offloading check sheet to allow the operation to proceed.
- The Driver connect the offloading hose to a clearly labelled and unique connection point (flanged and screwed connections for chemicals A and B respectively)
- The Operator uses the key to open the offloading valve.
- Offloading from road tanker to storage tank is commenced by the drivers, using a pump for chemical A and compressed air for chemical B.
- The Operator confirms a rising level in the tank before leaving the offloading area, the Driver stays throughout the offloading operation.
- On completion of offloading, the hose is removed, offloading valve closed and locked, tanker moved off-site via the weighbridge, and key returned to the Weighbridge office.

If offloading from a road tanker of chemical A into the storage tank for chemical B was to occur, or vice versa, an instantaneous reaction occurs in the storage tank releasing a gas that is readily identifiable due to a familiar brown colour. The Operator and Driver are in attendance at the start of offloading when generation of brown gas would occur. It is expected that within 5 minutes the offloading operation will have been stopped by the Driver or Operator using the emergency shut-down buttons around the offloading bay area that automatically shut the offloading valve.

The potential for the wrong material to be delivered to site in error was judged to be extremely unlikely in this scenario, given that different suppliers were used for chemicals A and B in visibly different types of tanker. The likelihood for error therefore focussed on the activities that followed arrival of the road tanker at the site.

Risk assessment appproach

The overall quantified risk assessment (QRA) for this MAH scenario used a combination of the hazardous event frequency and gas dispersion modelling results for a range of outcomes depending on weather conditions and speed of response to isolate the offloading operation. This paper focusses on the first requirement to determine the event frequency at which offloading of chemical A occurs into chemical B storage tank, or vice versa.

In order to estimate the event frequency, it is necessary to use the frequency at which there is an opportunity to make an error, based on the tanker delivery rate, multiplied by the probability that a series of errors occur to allow offloading into the wrong tank.

Hence,

Toxic gas release frequency = Tanker delivery frequency x Overall Human Error Probability (HEP)

Two approaches were used to determine the overall HEP for this event, firstly a ‘top down’ approach looking at the standard of operation at the facility and guidance figures provided by the HSE, and secondly a ‘bottom up’ approach considering the series of errors required for this scenario, taking account of dependency factors between the tasks.

‘Top down’ HEP estimate

Guidance from the Regulator (HSE, 2012) provides data applicable to scenarios whereby two incompatible substances are accidentally mixed during a delivery, for example, the contents of a tanker being off-loaded into the wrong tank. This is judged to be directly applicable to this MAH scenario, with error rates dependent on the type of operations as shown in Table 1, with the assumption that operations are carried our without any unreasonable time pressures:

Site Type	HEP (per delivery)	Site Description
Below Average	6×10^{-6}	The process of receiving a tanker to site and the delivery itself is not always well managed. The off-loading points are not locked and are not clearly separated, well laid out or well labelled.

		Incompatible connectors are generally used.
Average	1 x 10^{-7}	The process of receiving a tanker to site and the delivery itself are well controlled by operating procedures. The off-loading points are normally locked and are well laid out and labelled. Incompatible connectors are used.
Above Average	5 x 10^{-8}	The process of receiving a tanker to site and the delivery itself are well controlled by operating procedures. In addition, there is evidence that the site is working to maximise the safety and reliability benefits of the acknowledged operating conditions and to continuously improve. The off-loading points are normally locked and keys are controlled. The off-loading points are physically separated, well laid out and clearly labelled. Incompatible connectors are used.

Table 1: HSE error probabilities for tanker offloading

As discussed above, the facilities, methods and culture at the site covered by this assessment are considered to demonstrate that all 'relevant good practice' has been followed, based on risk assessments for the Safety Report and subsequent SCTA that resulted in a number of improvements to both hardware and procedural controls. On this basis the site is judged to at least meet the description "Average Site", which supports the selection of an overall HEP for this MAH scenario of 1 x 10^{-7} per delivery.

Use of THERP dependency model

THERP (Technique for Human Error Rate Prediction) is a human reliability assessment technique (Swain, 1983) that can be used to evaluate the effectiveness of cross-checking activities, as stated in the post-Buncefield guidance for fuel storage sites (HSE, PSLG, 2009), assuming the assessment is made by a competent human reliability specialist and based on information provided by the site operator. THERP has also been assessed as a suitable technique for human reliability assessment (HSE, RR679, 2009), with the conclusion that "THERP was designed for nuclear industry application but is a generic tool that can be applied in other sectors".

THERP contains a model that takes account of potential dependency between related tasks, where a degree of dependency will increase the probability of error on the next task, given an error on the preceding task, for example due to the operator being in an "error prone" state having made the first error.

Several dependency levels are defined in the model as summarised in Table 2.

Dependency Level	Example Descriptions
Zero	Performance of first task has no effects on subsequent tasks. Error in reading several similar instruments displaying different readings. Not suitable for person checking another person's performance.
Low	Interaction between two newly acquainted operators, as confidence in the other has not been gained there is likely to be more independent checking. Cases where there is doubt over 'zero' dependency assessment.
Moderate	Obvious relationship between the performance of one task with the subsequent task. Shift supervisor checking of performance by an operator (at best).
High	Performance of one task very substantially affects subsequent task. People less likely to question other person due to their authority/prestige. Interaction between two familiar operators, as the second operator does not expect the first to make an error.
Complete	An error on task 1 inevitably results in an error on task 2. Operator opening valve A and immediately opening valve B in same location. Unusual between two people, except for example if the first person reads a set of instructions but does not check the performance of the second person.

Table 1: THERP summary of dependency levels

Having assessed the level of dependency for task 2 based on the links with task 1, the dependent HEP for task 2 can be determined from Figure 1 which has been derived from equations in THERP. Firstly the HEP for task 2 is determined assuming no dependency and taking account of any relevant performance shaping factors. Starting with this value on the x-axis, move vertically on the graph to where this value crosses the appropriate dependency curve, then move horizontally to read the dependent HEP for task 2 on the y-axis. For example, a task with basic HEP of 0.1 and moderate dependency on the previous task, would have a dependent HEP of 0.23. The graph shows that with high dependency the best HEP that can be achieved for task 2 is 0.5 regardless of the basic HEP, and likewise 0.15 for moderate and 0.05 for low dependency.

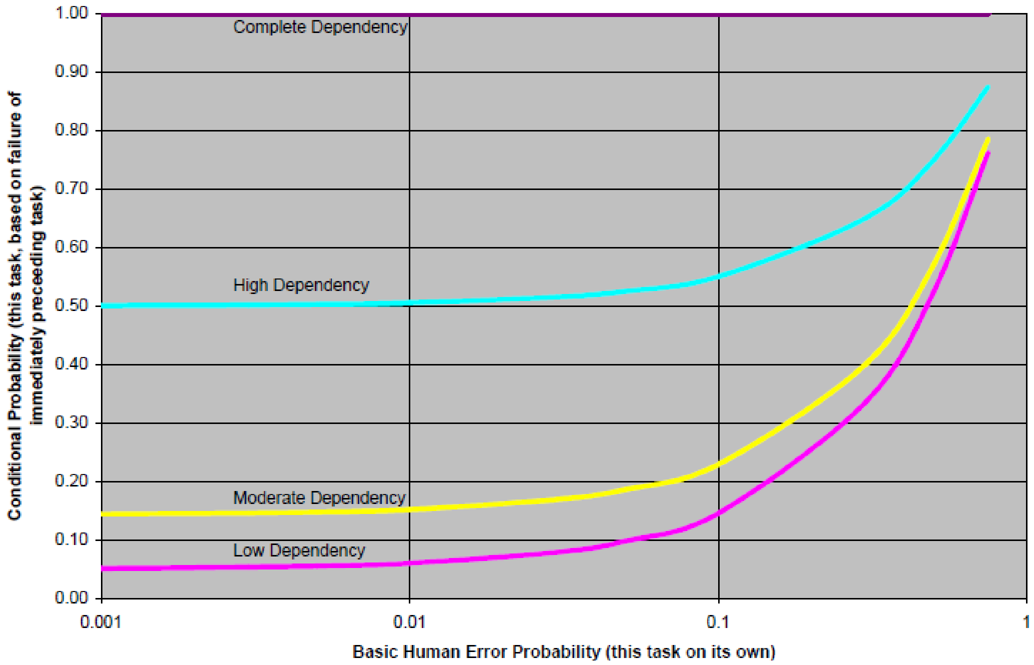

Figure 1: Dependent HEP based on THERP model

‘Bottom up’ HEP estimate

This approach considered the series of errors that are required to allow an initial error in determining the road tanker contents at the Weighbridge to result in offloading to the wrong tank. This initial error needs to be followed by a further error by the same Operator at the storage tank, an error by the Team Leader when authorising offloading to start, and an error by the Driver when connecting the offloading hose. Each of these errors is assessed below taking account of any dependency between the tasks using the THERP model as described above.

HEP 1: Error by Operator at Weighbridge

Operator fails to check road tanker contents or makes error when checking and assumes road tanker contains chemical A when actually chemical B, or vice versa. This error is influenced by the following factors:

- Written procedure in place and check sheet completed for each delivery whilst carrying out procedure.
- Routine task carried out more than 10 times per week by operating staff.
- Check of road tanker number and signs against delivery paperwork including UN number, with Check Sheet signed by Operator.
- Unique key with chemical name label selected from board for the appropriate off-loading valve.
- No time pressure generally given that tankers are scheduled during day hours.
- If operator is correct with decision on tanker contents, but selects the wrong key, he will not be able to open off-loading valve and will need to return for correct key.

The basic HEP for this task was assessed as an “error in simple routine operation” with value 0.001 (Kirwan, 1994).

HEP2: Error by Operator at Tank

Operator fails to cross-check that road tanker is at correct tank when preparing for the hose connection to be made and opening the offloading valve. This error is influenced by the following factors:

- Operator accompanies road tanker from Weighbridge to correct off-loading bay.
- Different location for off-loading bays for all tankers.
- Chemical A delivered in road tankers, chemical B in iso-tankers so visually different.

- Unique connection at off-loading point, this would be incompatible with the tanker connection if an error had been made.
- Off-loading valve locked, requires correct key from Weighbridge Office to open. If operator is correct with decision on tanker contents and selects the correct key, but directs the tanker to the wrong off-loading bay, it will not be possible to open the off-loading valve and will need to move tanker to correct off-loading bay.

The basic HEP for this task was assessed as an "error of omission of an act embedded in a procedure" with value 0.003 (Kirwan, 1994). It is necessary to account for dependency, because the same operator carries out the cross-check at the tank and makes the initial check at the Weighbridge, where an initial error could have been made. Low Dependency is assessed, as although the same operator is involved, the tasks are carried out at separate times and in different locations. If the error occurs at the Weighbridge, the operator can correct the error by observing the differences between the road tankers and off-loading connection point, looking at signs and hose connection types. Low probability basic HEP errors with Low Dependency have HEP = 0.05, this accounts for the operator being convinced about the tanker contents having made the initial error.

HEP3: Error by Supervisor at Tank

Supervisor fails to confirm that road tanker is at correct position prior to connection at off-loading point. This error is influenced by the following factors:

- Tanker check sheet signed by Supervisor with road tanker in off-loading bay prior to making connection.
- Chemical sign on road tanker can be compared with sign at off-loading connection, and compare with unique UN number on check sheet.
- Unique connection at each tank, difference with connection on road tanker can be detected by supervisor if checks done at off-loading bay.
- However, performance may be influenced by adverse weather conditions.

The basic HEP for this task was assessed as "Supervisor does not recognise the operator's error" with value 0.1 (Kirwan, 1994). This value equates to mid-way between Low and Moderate Dependency on the THERP model for low probability basic HEP. Moderate dependency (HEP=0.15) would be assigned between supervisors and experienced operators where the supervisor interacts with the operator in carrying out the check, whereas Low Dependency (HEP=0.05) may be assigned for a new operator where the supervisor checks more carefully. The value for HEP of 0.1 is justified by the supervisor making a visual check at the off-loading bay and being required to sign off the check sheet to allow off-loading to commence.

HEP4: Error by Driver making hose connection

Driver has access to adaptor to allow off-loading hose to be fitted to off-loading connection at wrong tank. Although this is a mechanical device, the decision to change it can be considered a human act and thus an HEP factor is applied. This error is influenced by the following factors:

- Unique connection at each off-loading point, e.g. chemical A flanged whereas chemical B screwed. Connection is only possible if the driver provides an adaptor.
- Drivers come from separate sites and do not deliver more than one chemical to the site.
- Driver would detect that the road tanker is at the wrong off-loading bay, either because of their site knowledge from previous deliveries or from the different signs and hose connections.
- However, performance may be influenced by Operator decision that tanker position is correct

The basic HEP for this task was assessed as an "Error in simple routine operation" with value 0.001 (Kirwan, 1994). It is necessary to account for dependency as the Driver may be influenced by the Operator's decision that the tanker is in the correct position. "Low Dependency" on the THERP model is assumed, as the driver is dedicated to a single chemical and will have familiarity with the tanker offloading bay location on the site, and would need to use an adaptor to make the connection. Low probability basic HEP with Low Dependency have HEP = 0.05, this accounts for the Driver being influenced by the Operator.

Overall HEP

The overall probability that the series of errors discussed above occur is the product of the individual HEPs that take into account any dependency factors.

Hence,

Overall HEP = HEP1 x HEP 2 x HEP3 x HEP4

= 0.001 x 0.05 x 0.1 x 0.05

= 2.5 x 10^{-7} per delivery

It is noted that the overall HEP using the basic HEP values given above for each error would be 3 x 10^{-10} per delivery, a factor of 1000 times lower than the estimated figure that has taken account of dependency.

Risk assessment

The estimates for HEP on this task have been estimated above to give the following values:

'Top down': 1 x 10^{-7} per delivery for an average site

'Bottom up': 2.5 x 10^{-7} per delivery taking dependency into account

It is noted that these values are both below the Human Performance Limiting Value of 1 x 10^{-5} that has been proposed for activities where errors are solely dependent on human performance. The use of these lower values is justified by the process design with dissimilar couplings for the offloading hoses that would require the tanker Driver to obtain a suitable adaptor and would be a violation of the offloading procedure.

For the QRA carried out for this MAH scenario, the 'bottom-up' HEP value was used as a more conservative value which is a fairly close agreement with the 'Top down' value based on HSE guidance. An Event Tree Analysis was carried out using the estimated event frequency, combined with probabilities for the speed to isolation of the offloading valve, likelihood of different weather conditions and probability of escape for people caught up in the dispersing gas cloud.

The calculated frequencies for a range of outcomes was combined with the consequence modelling results to determine the overall level of individual risk for people on-site and off-site. The risk to people on-site was found to be at the bottom end of the 'Tolerable if ALARP' region, and therefore no further risk reduction is justified. For people off-site the risk level is within the 'Tolerable if ALARP' region, requiring an assessment of further risk reduction measures.

Conclusions

The conclusion of the QRA was that further risk reduction measure were not justified for this MAH scenario. Safeguarding is highly dependent on procedural controls given the nature of the tanker offloading operation, and the controls in place based on a Safety Report risk assessment and an SCTA are considered to represent 'relevant good practice'. The option to install further hardware safeguards, such as an analyser on the offloading lines to detect the wrong chemical and carry out an automatic shut-down, were judged to be impracticable due to the nature of the chemicals and unreliable reputation of analysers, in addition to the cost for such a system being considered grossly disproportionate given the low likelihood for this event.

This paper has looked at a number of methods for determining an overall HEP for connecting the road tanker to the wrong storage tank and starting the offloading operation. Using guidance from the HSE for this type of error and based on an assessment of the standard of operation at the site, gave an HEP of 1 x 10^{-7} per delivery. An alternative approach that considered a series of errors that need to occur for this event, and assessing dependency between these tasks using a method derived from THERP, gave a slightly higher HEP of 2.5 x 10^{-7} per delivery, showing good agreement with the HSE data. It was noted that failing to take dependency into account with this second approach would have given an unrealistically low HEP of 3 x 10^{-10} per delivery, i.e. 3 orders of magnitude lower than the calculated value.

The approach in this paper may be appropriate in other cases where a series of interrelated errors need to occur in order for a hazardous event to be realised, particularly where there is a degree of dependency between the performance of later tasks having made an error during a previous task.

References

1. HSE (2009), Review of human reliability assessment methods, RR679, HSE Books
2. HSE (2009), Safety and environmental standards for fuel storage sites, Process Safety Leadership Group (PSLG), HSE Books
3. HSE (2012), Failure Rate and Event Data for use within Risk Assessments, HSE website, http://www.hse.gov.uk/landuseplanning/failure-rates.pdf.
4. Kirwan, B. (1994). A guide to practical human reliability assessment. Taylor & Francis, London.
5. Swain AD and Guttmann HE (1983). Handbook of human reliability analysis with emphasis on nuclear power plant applications. US Nuclear Regulatory Commission), Washington, DC. NUREG/CR-1278.