Appendix 12.10

Human Error Assessment & Reduction Technique (HEART)

A12.10-1 HUMAN ERROR ASSESSMENT & REDUCTION TECHNIQUE (HEART)

A12.10-1.1 OVERVIEW

In order to assess how likely it is that a process will fail based on the potential of human error, a human reliability assessment (HRA) has been undertaken. HRA addresses the following questions:

- Which types of human error may occur (e.g. action error, information retrieval error, communication error, violation)?
- What is estimated probability of such errors being made?
- What factors may influence this probability (e.g. time pressure, stress, poor working environment, low morale)
- How can the identified human errors be prevented in the design or how can their impacts be reduced by additional mitigating controls?

The Human Error Assessment and Reduction Technique (HEART) is a HRA method based on human performance literature; it has been used in this assessment to quantify human error probabilities related to chlorine truck loading and transport. HEART assesses the interactions between humans, their specific tasks and performance shaping/human factors or error producing conditions (EPCs).

A12.10-1.2 HEART METHODOLOGY

The HEART technique was developed by Williams (1986) [1] and is based on human performance literature. The human factors analyst must undertake the steps summarised in *Table 1.1* in order to estimate the probability of failure for a specific task.

Table 1.1 ***HEART Methodology***

Step	Task	Output
1	Generic Task Unreliability: Classify the task in terms of its generic human unreliability into one of the 8 generic HEART task types (*Table 1.2*)	***Nominal human unreliability probability***
2	Error Producing Condition & Multiplier: Identify relevant error producing conditions (EPCs) to the scenario/task under analysis which may negatively influence performance and obtain the corresponding multiplier (*Table 1.3*)	Maximum predicted nominal amount by which unreliability may increase (***Multiplier***)
3	Assessed Proportion of Effect: Estimate the impact of each EPC on the task based on judgement	***Proportion of effect*** value between 0 and 1

(1) Williams, J.C., HEART – A Proposed Method for Assessing and Reducing Human Error, 1986.

Step	Task	Output
4	Assessed Effect: Calculate the 'assessed impact' for each EPC according to the formula: $((Muliplier - 1) Assessed\ \ Proportion\ of\ \ Effect) + 1$	***Assessed impact value***
5	Human Error Probability: Calculate overall probability of failure of task based on the formula: $Nominal\ \ human\ unreliability \times Assessed\ \ impact\ 1 \times Assessed\ \ Impact\ 2 \ldots\ \ etc.$	***Overall probability of failure***

Table 1.2 Generic Task Unreliability

Generic task		*Proposed nominal human unreliability (5th–95th percentile boundaries)*
A	Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55 (0.35–0.97)
B	Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26 (0.14–0.42)
C	Complex task requiring high level of comprehension and skill	0.16 (0.12–0.28)
D	Fairly simple task performed rapidly or given scant attention	0.09 (0.06–0.13)
E	Routine, highly practised, rapid task involving relatively low level of skill	0.02 (0.007–0.045)
F	Restore or shift a system to original or new state following procedures, with some checking	0.003 (0.0008–0.007)
G	Completely familiar, well-designed, highly practised, routine task occurring several times per hour, performed to highest possible standards by highly motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids	0.0004 (0.00008–0.009)
H	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage	0.00002 (0.000006–0.00009)
M	Miscellaneous task for which no description can be found. (Nominal 5th to 95th percentile data spreads were chosen on the basis of experience suggesting log-normality)	0.03 (0.008–0.11)

Table 1.3 Error-Producing Conditions (EPCs)

Error-producing condition		*Maximum predicted nominal amount by which unreliability might change going from 'good' conditions to 'bad'*
1.	Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel	× 17
2.	A shortage of time available for error detection and correction	× 11
3.	A low signal-to-noise ratio	× 10
4.	A means of suppressing or overriding information or features which is too easily accessible	× 9
5.	No means of conveying spatial and functional information to operators in a form which they can readily assimilate	× 8
6.	A mismatch between an operator's model of the world and that imagined by the designer	× 8
7.	No obvious means of reversing an unintended action	× 8
8.	A channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information	× 6
9.	A need to unlearn a technique and apply one which requires the application of an opposing philosophy	× 6
10.	The need to transfer specific knowledge from task to task without loss	× 5.5
11.	Ambiguity in the required performance standards	× 5
12.	A mismatch between perceived and real risk	× 4
13.	Poor, ambiguous or ill-matched system feedback	× 4
14.	No clear direct and timely confirmation of an intended action from the portion of the system over which control is to be exerted	× 3
15.	Operator inexperienced (e.g. a newly qualified tradesman, but not an 'expert')	× 3
16.	An impoverished quality of information conveyed by procedures and person–person interaction	× 3
17.	Little or no independent checking or testing of output	× 3
18.	A conflict between immediate and long-term objectives.	× 2.5
19.	No diversity of information input for veracity checks	× 2.5
20.	A mismatch between the educational achievement level of an individual and the requirements of the task	× 2
21.	An incentive to use other more dangerous procedures	× 2
22.	Little opportunity to exercise mind and body outside the immediate confines of the job	× 1.8
23.	Unreliable instrumentation (enough that it is noticed)	× 1.6
24.	A need for absolute judgements which are beyond the capabilities or experience of an operator	× 1.6
25.	Unclear allocation of function and responsibility	× 1.6
26.	No obvious way to keep track of progress during an activity	× 1.4
27.	A danger that finite physical capabilities will be exceeded	× 1.4
28.	Little or no intrinsic meaning in a task	× 1.4
29.	High-level emotional stress	× 1.3
30.	Evidence of ill-health amongst operatives, especially fever	× 1.2
31.	Low workforce morale	× 1.2
32.	Inconsistency of meaning of displays and procedures	× 1.2
33.	A poor or hostile environment (below 75% of health or life-threatening severity)	× 1.15
34.	Prolonged inactivity or highly repetitious cycling of low mental workload tasks	× 1.1 for first half-hour × 1.05 for each hour thereafter
35.	Disruption of normal work-sleep cycles	× 1.1
36.	Task pacing caused by the intervention of others	× 1.06
37.	Additional team members over and above those necessary to perform task normally and satisfactorily	× 1.03 per additional man
38.	Age of personnel performing perceptual tasks	× 1.02

Each scenario has been analysed separately in the following sections to determine the overall probability of human failure. Hence for each contributing error, the following sections present and discuss the generic HEART task type and the EPCs and their impacts, culminating in an overall probability of failure.

A12.10-1.2.1 General Assumptions

- Five experienced individual operators with independent tasks are involved in loading the drums onto the truck from the barge and performing checks. One operator operates the crane. One operator is on the barge delivering the drums. One operator is on the truck receiving the drums by guiding the drums from the crane into position on the truck and fastening the lashing around the drums. One operator is on the ground fixing the clamps onto the drums. The last operator performs the leak test by spraying ammonia near the valve;
- The working environment is in an open space outdoors. Since deliveries are not daily, it is assumed that weather conditions are always favourable and loading of drums do not occur under poor weather conditions;

- For tasks requiring visual recognition without additional aid such as checking for drum defects, it would be difficult to recognise defects across the entire surface of the drum. Therefore, a low signal-to-noise ratio EPC and its corresponding multiplier were selected to represent the difficulties in detecting drum defects along the drum surface by visual check without equipment aid;
- The *assessed proportion of effect* was based on an assessment of the conditions and circumstances which may lead the EPC being applicable for the task being considered. For example, the *low workforce morale assessed proportion of effect* of 0.3 indicates that there is a 30% chance that *the low workforce morale* could be a significant EPC. It should be also noted that, for instance, *shortage of time available for error detection & correction* EPC may have a larger *assessed proportion of effect* for an operator conducting a complex task requiring numerous repetitions under a quick-paced environment; compared to if another operator was required to perform a similar task in a relaxed environment; and
- The overall failure probability for each scenario is presented per truck trip.

A12.10-2 SECURING DRUMS DURING TRUCK LOADING AT THE DOCK

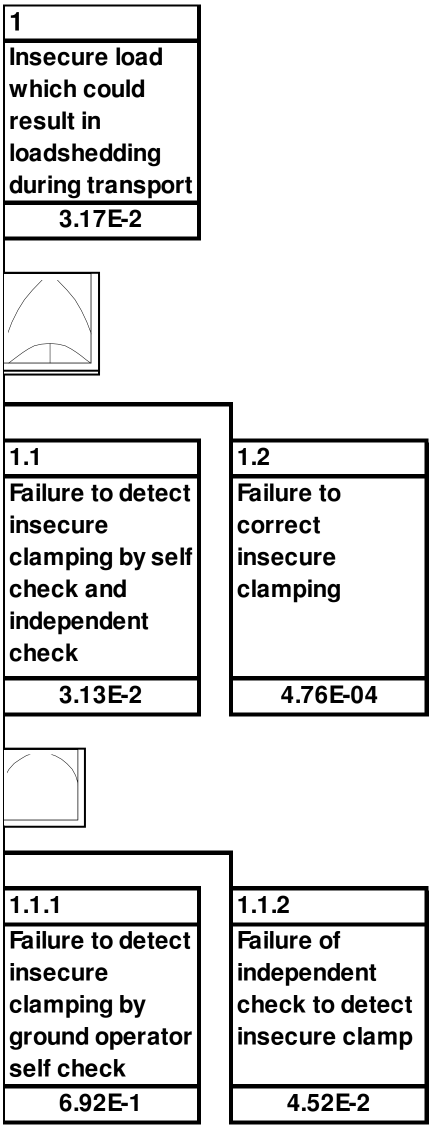
A12.10-2.1 EVENT 1: INSECURE LOAD

Once the operator on the truck lowers a drum into position, the drum is secured in place with lashing belts to prevent the drum from rolling or sliding off the truck during transport. Since these lashing arrangements already exist, no further credit has been taken. The drums are then further secured by custom-designed clamps by an operator on the ground. It is recommended to have the operator on the truck perform an independent check of the clamps to ensure that the load is secured.

Based on the failure of some or all of the tasks analysed below, the overall probability of failure to detect or take corrective action for an insecure drum load during truck loading is **3.17E-2**.

As a review of the credit given for the lashing arrangements, the task of securing the drums with lashing can be considered similar to the clamps. Two lashings are required for each drum, and the operators performing the task would be subject to similar EPC's as for the clamps. Independent checking is recommended to ensure that the load is secured.

Although HEART focuses on human error, it is noted that the clamps may be subject to stress-related mechanical failures. However, considering that under normal operation, the clamps do not bear any load and thus will not experience any fatigue. To avoid mechanical failure, the clamps will be designed, tested, and independently verified by a certified engineer to ensure the failure due to stress excluding external impacts is negligible compared to human error. Chlorine release due to failure of the clamps from stress caused by external impacts (i.e. collision/ rollover) is already considered as part of the governing collision/ rollover scenario. Hence, mechanical failure of the clamps is not further considered.



A12.10-2.1.1 *Event 1.1: Failure to detect insecure clamping by ground operator self check and independent check*

The overall probability of failure to detect an insecure load by the operator on the ground and independent check by the operator on the truck is **3.13E-2,** based on the failure of the tasks analysed below.

1.1.1 Failure to detect insecure clamping by ground operator self-check

Once the drum is in position on the truck, an operator on the ground secures the drum with custom-designed clamps to prevent load shedding during transport. The generic HEART task type taken to represent this task of clamping and ensuring it is secure is "*Fairly simple task performed rapidly or given scant attention*" for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in *Table 2.1*. The human error probability is higher on a complex task and this task was conservatively considered as a complex task involving the securing and checking of 12 clamps (2 clamps per drum) in a relatively short amount of time and the nominal unreliability is 0.16. The operator may feel "rushed" while performing the task, and hence the *shortage of time* EPC was given a higher proportion of effect and was considered as a main contributing factor to potential human error for this task. The value of 0.3 (~half order of magnitude) has been used as rush situations are normally not expected given the infrequent transport frequency and ample time available for the overall transport.

Table 2.1 ***HEART Calculation***

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
Failure to detect insecure clamping by ground operator self-check	0.16	Shortage of time available for error detection & correction	11	0.3	4	6.92E-1
		Little or no intrinsic meaning in a task	1.4	0.05	1.02	
		Low workforce morale	1.2	0.3	1.06	

* Values obtained from Williams (1986)

† Proportions of effects lie in the range of 0 to 1

Based on the above estimates, the likelihood of failure to detect insecure clamping by ground operator self-check is **6.92E-1**.

1.1.2 Failure of independent check to detect insecure clamp

After fastening the lashing around the load, the operator on the truck will proceed to check the clamps to ensure that the load is secured. The generic HEART task type taken to represent this task of clamping and ensuring it is secure is "*Routine, highly practised, rapid task involving relatively low level of skill*" for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in *Table 2.2*. Since the task is solely focusing on checking whether the clamps are secured, the nature of the task is simpler than *Event 1.1.1* and less time-demanding as compared to the fastening and checking task described above. The EPC is therefore not applicable in this case but a conservative 1% *assessed proportion of effect* has been assumed.

Table 2.2 ***HEART Calculation***

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
Failure of independent check to detect insecure clamping	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	4.52E-2
		Low signal-to-noise ratio	10	0.1	1.9	
		Little or no intrinsic meaning in a task	1.4	0.05	1.02	
		Low workforce morale	1.2	0.3	1.06	

* Values obtained from Williams (1986)

† Proportions of effects lie in the range of 0 to 1

Based on the above estimates, the likelihood of failure to independently check for insecure clamping is **4.52E-2**.

Event 1.2: Failure to correct insecure clamping

Following the detection of insecure clamping of the load, the operator would fix the clamping arrangement such that the drum is properly secured. However, due to time pressure or assumed low workforce morale, it is possible that the insecure clamping may fail to be corrected.

The generic HEART task type taken to represent this corrective action task is *"Completely familiar, highly practised, routine task occurring several times per hour, but without the benefit of significant job aids"* for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in *Table 2.3*.

Table 2.3 HEART Calculation

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
Failure to correct insecure clamping	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	4.76E-4
		Little or no intrinsic meaning in a task	1.4	0.05	1.02	
		Low workforce morale	1.2	0.3	1.06	

* Values obtained from Williams (1986)

† Proportions of effects lie in the range of 0 to 1

Based on the above estimates, the likelihood of failure to correct the insecure clamping is **4.76E-4**.

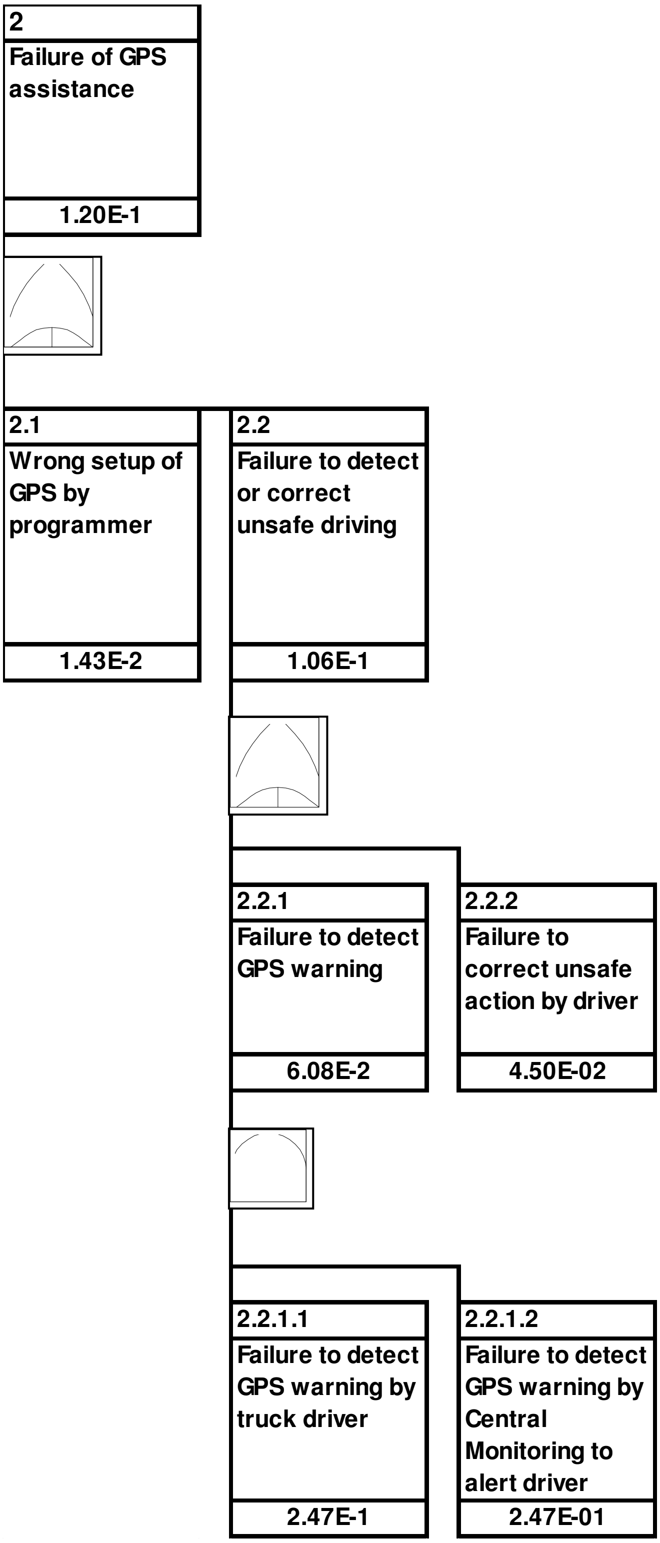
A12.10-3 GPS ASSISTANCE FOR DETECTION AND CORRECTION OF UNSAFE DRIVING

A12.10-3.1 EVENT 2: FAILURE TO DETECT OR CORRECT UNSAFE DRIVING WITH GPS ASSISTANCE

Based on the failure of some or all of the tasks analysed below, the overall probability of failure to detect or take corrective action for unsafe driving (e.g. speeding) which may lead to truck rollover or significant impact energies upon collision is **1.20E-1**.

Although HEART focuses on human error, it is noted that the GPS, similar to any other handheld sized electronic device, is subject to internal electrical failures. Industry failure rate data for CPU's used for safety applications fall in the range of 10^{-6} per hour to 10^{-5} per hour [(1)]. As a sensitivity check, assuming a conservative failure rate of once per year (comparable to manufacturers' warranty time-period) and utilising the exponential failure rate calculation based on the truck trip duration results in a chance a failure in the order of 10^{-4} per trip, which is significantly less than failure due to human error. Hence, internal failure of the GPS is not further considered.

[(1)] SINTEF, Reliability Data for Safety Instrumented Systems, 2010. Also refer to MTRC WIL e-dets, 2010.



A12.10-3.1.1 Event 2.1: Wrong Setup of GPS by Programmer

The overall probability of a wrong setup of the GPS by the programmer is **1.43E-2**, based on the failure of the tasks analysed below.

The generic HEART task type taken to represent this task is "*Restore or shift a system to original or new state following procedures, with some checking*" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in *Table 3.1*. The EPC of c*hannel capacity overload* was considered as a main contributing factor for error since multiple variables and custom safety-specific features may be required to be programmed and configured.

Table 3.1 *HEART Calculation*

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
Wrong setup of GPS	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	1.43E-2
		A mismatch between an operator's model of the world vs. designer	8	0.1	1.7	
		Channel capacity overload	6	0.3	2.5	
		Little or no independent checking	3	0.01	1.02	

* Values obtained from Williams (1986)

† Proportions of effects lie in the range of 0 to 1

Based on the above estimates, the likelihood of wrong setup of the GPS by the programmer is **1.43E-2**.

A12.10-3.1.2 Event 2.2: Failure to Detect or Correct Unsafe Driving by the Truck Driver

The overall probability of failure to detect or take corrective action for unsafe driving by the driver is **1.06E-1**, based on the failure of the tasks analysed below.

2.2.1.1 Failure to detect GPS warning by the truck driver

Upon detection of unsafe driving (speeding), an alarm and/or beacon warning will flash onboard the truck to notify the truck driver. However, the driver may be distracted and not notice the warning given by the GPS. The generic HEART task type taken to represent this task is "*Fairly simple task performed rapidly or given scant attention*" for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in *Table 3.2*.

Table 3.2 *HEART Calculation*

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
Failure to detect GPS warning by truck driver	0.09	Low signal-to-noise ratio	10	0.05	1.45	2.47E-1
		A means of suppressing or overriding information or	9	0.1	1.8	

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
		features				
		Channel capacity overload	6	0.01	1.05	

* Values obtained from Williams (1986)

† Proportions of effects lie in the range of 0 to 1

Based on the above estimates, the likelihood of failure to detect the GPS warning by the truck driver is **2.47E-1**.

2.2.1.2 Failure to detect GPS warning by Centralised Monitoring to radio the truck driver

In addition to the onboard GPS warning, the truck will also be tracked by centralised monitoring in which an operator would track unsafe driving or conditions and notify the truck driver via radio. However, due to low signal-to-noise ratio, lag time between communications, or channel capacity overload, the truck driver may fail to properly receive and acknowledge the warning.

The generic HEART task type taken to represent this corrective action task is "*Fairly simple task performed rapidly or given scant attention*" for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in *Table 3.3*.

Table 3.3 HEART Calculation

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
Failure to detect GPS warning from centralised monitoring to alert the driver by radio	0.09	Low signal-to-noise ratio	10	0.05	1.45	2.47E-1
		A means of suppressing or overriding information or features	9	0.1	1.8	
		Channel capacity overload	6	0.01	1.05	

* Values obtained from Williams (1986)

† Proportions of effects lie in the range of 0 to 1

Based on the above estimates, the likelihood of failure to detect the GPS warning by Central Monitoring and alert the operator via radio is **2.47E-1**.

2.2.2 Failure to correct unsafe driving by truck driver

Upon receiving a warning from the onboard GPS or by radio, the truck driver is expected to take corrective action. However, warnings may become suppressed by the driver if excessive spurious alerts arise or the driver may override the information with his own judgement. Certain driving habits may also take time and special training to correct.

The generic HEART task type taken to represent this corrective action task is "*Routine, highly practised, rapid task involving relatively low level of skill*" for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in *Table 3.4*.

Table 3.4 HEART Calculation

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
Failure to correct unsafe driving by driver	0.02	A means of suppressing or overriding information or features	9	0.1	1.8	4.50E-2
		A need to unlearn a technique	6	0.05	1.25	

* Values obtained from Williams (1986)

† Proportions of effects lie in the range of 0 to 1

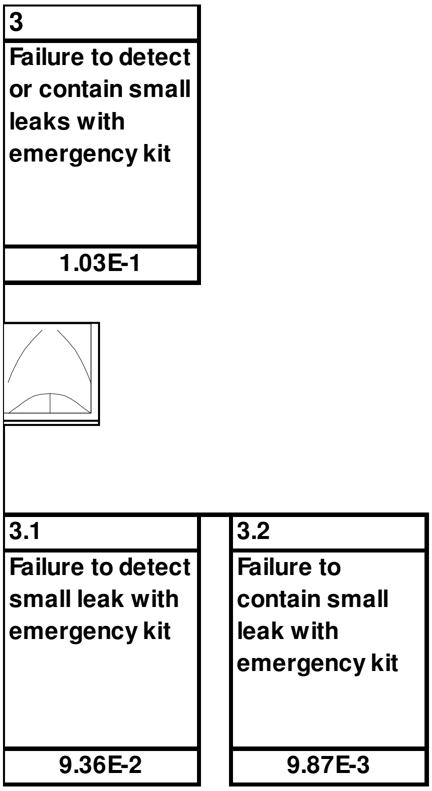
Based on the above estimates, the likelihood of failure to correct unsafe driving by the truck driver is **4.50E-2**.

A12.10-4 DETECTING AND CONTAINING SMALL LEAKS WITH EMERGENCY KIT

A12.10-4.1 EVENT 3: FAILURE TO DETECT OR CONTAIN SMALL LEAKS WITH EMERGENCY KIT

In the event of a load shed, it is expected that an operator would deploy the emergency kit to check for leaks of the drums, and upon detection of any small leaks, a mechanical capping technique would be applied to contain the leak. For medium leaks and larger, the emergency kit would be ineffective and no credit is taken in the analysis. This mitigation measure would not apply for leaks due to spontaneous failure in transit since the operators would not know that a leak has occurred.

Based on the failure of some or all of the tasks analysed below, the overall probability of failure to detect or contain a small leak with the emergency kit upon a load shedding scenario is **1.03E-1**.



Although HEART focuses on human error, the emergency kits may be subject to mechanical failures. However, the emergency kits do not bear any load and thus will not experience fatigue. They are also constructed from corrosion resistant materials. The kit shall be checked before transport of chlorine to ensure probability of failure on demand is negligible compared to human error. Hence, mechanical failure of the emergency kit is not considered further.

A12.10-4.1.1 *Event 3.1: Failure to detect a small leak with the emergency kit*

The overall probability of failure to detect a small leak with the emergency kit is **9.36E-2**, based on the failure of the tasks analysed below.

The generic HEART task type taken to represent this task is "*Routine, highly practised, rapid task involving relatively low level of skill*" for which the nominal unreliability is 0.02. It has been assumed that the operators deploying the emergency kit would be under levels of stress following a load shed scenario. The working environment would be chaotic and the operators' efforts would be frantic in checking for drum leaks, safety of the transport team, safety of the public, as well as damage to property. The EPCs and their impacts are shown in *Table 4.1*.

Table 4.1 HEART Calculation

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
Failure to detect small leak with emergency kit	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	9.36E-2
		Low signal-to-noise ratio	10	0.3	3.7	
		High-level emotional stress	1.3	0.5	1.15	

* Values obtained from Williams (1986)

† Proportions of effects lie in the range of 0 to 1

Based on the above estimates, the likelihood of failure to detect a small leak with the emergency kit upon a load shed scenario is **9.36E-2**.

A12.10-4.1.2 *Event 3.2: Failure to Contain a Small Leak with the Emergency Kit*

The overall probability of failure to contain a small leak with the emergency kit is **9.87E-3**, based on the failure of the tasks analysed below.

The generic HEART task type taken to represent this task is "*Restore or shift a system to original or new state following procedures, with some checking*" for which the nominal unreliability is 0.003. The effort required in containing the leak with the kit would vary depending on the way the drum has been damaged. Nevertheless, the task has been considered to be performed infrequently, and the operator may be unfamiliar with such a situation. The EPCs and their impacts are shown in *Table 4.1*.

Table 4.2 HEART Calculation

Task	Generic Task Unreliability*	EPCs	Multiplier*	Assessed Proportion of Effect†	Assessed Effect	Human Error Probability
Failure to detect small leak with emergency kit	0.003	Unfamiliarity with a situation which is potentially important but which only occurs infrequently	17	0.1	2.6	9.87E-3
		Shortage of time available for error detection & correction	11	0.01	1.1	
		High-level emotional stress	1.3	0.5	1.15	

* Values obtained from Williams (1986)

† Proportions of effects lie in the range of 0 to 1

Based on the above estimates, the likelihood of failure to contain a small leak with the emergency kit upon a load shed scenario is **9.87E-3**.