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The Concept of Human Reliability Assessment Tool CREAM and Its Suitability for Shipboard Operations Safety

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Abstract: Shipboard operations as a hazardous process require the human element to be aware of any operation risks. Since the concept of human error exposed to ample arguments, the introduction of human element concerns to practices rather than other means is essential because the provenance of accidents is human error. HRA (human reliability assessment) is a theoretical framework to assess the human actions for predicting the potential human error probability of a certain given task or operation scenario. Furthermore, surveillance of the human performance is through the task by steps and sub-steps. The CREAM (cognitive reliability and error analysis method) tool is the second generation of HRA which emphasizes the features of the context and utilized as retrospective and prospective tool. The paper illustrates the basic and extended version of CREAM and its suitability for critical shipboard operations safety assessment.

Key words: HRA, CREAM, CPCs, HEP, CFP.

1. Introduction

The maritime transport system is four times riskier than air transport. Over the last four decades, the shipping industry has concentrated on developing ship structure and the reliability of ship systems in order to decrease the rate of casualties and increase proficiency and productivity. It is important to mention that 67% of accidents in the mentioned period are related to human erroneous activities even there are dominant international conventions and codes, which entered into force such as STCW, ISM code, etc. [1].

The spine of a maritime system or any organization is the human element; in that human element is the operator anyway. As far as human operation is taking place in a difficult environment, errors will occur, and its possibility increases. Since the human factor is one of the main concerns of safety and total safety standards, HRA (human reliability assessment), could be applied to be the way to identify how reliable the operator to achieve a given action with estimation of the probability of human errors for a certain task or operation.

Since approximately 50 years, HRA concentrated on the human actions and involved to predict human error rate as hybrid techniques or tools. It falls inside the field of human factors and it has been defined as:

"The application of relevant information on human characteristics and behaviours to the design of objects, facilities, and environments that people use" [2].

HRA has three main purposes: recognizes human errors, predicts their probability, and minimizes the likelihood "if needed". The human reliability defined as:

"The probability that a person correctly performs an action required by the system at a required time and that he does not perform any extraneous activity that can degrade the system" [3].

The HRA framework frequently uses the concept of HEP (human error probability). It identifies errors and weaknesses in an operation by exploratory procedures

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of work including those who work in the operation. The primary of HRA tools was the first generation that developed to use by risk assessors in quantifying the probability of human error in different applications [4].

The widely used tools of the first generation were: THERP (technique for human error rate prediction), HEART (human error assessment and reduction technique), ASEP (accident sequence evaluation program), and SPAR-H (standard plant analysis risk HRA method). The tools of first generation emphasize quantification in term of (success or failure) of activities, but the first generation tools have less consideration to human behaviors, which are required in maritime operations [5].

Kirwan (1998) checked the validation of 38 HRA tools and categorized them into five classes taxonomic approaches psychology-based tools, cognitive modelling e.g. CREAM, cognitive simulations and reliability-oriented tools e.g. FMEA (failure mode and effect analysis) [4, 6].

The second generation of HRA tools has been established to recover the disadvantages and weak points of the first generation by utilizing the cognitive methods, denoted by HRA tool CREAM (cognitive reliability and error analysis method). CREAM is a second-generation HRA tool if compared to other tools; it takes another approach to human reliability assessment because the details of events in terms of success or failure (first generation tools) of actions are an oversimplification of human performance consequences [4].

2. CREAM

CREAM is one of the main examples of so-called second-generation human reliability method. It was designed to take a better form of context than the former first generation tools. It was initially established from the COCOM (cognitive control model), and offered applied approach to both performance assessment and errors likelihood. In addition, this tool offers reliable error classification system integrating all individual technological and organizational factors.

CREAM is retrospective analysis tool of a historical occurrence and a prospective analysis tool of a high-risk critical operation/task. It is different from old-style HRA tools, which emphasize the result binary actions, the CREAM inspects the environmental context in which humans operate and evaluate actions utilizing a difference between competence and control (competence discusses what a person can do, while control refers to how competence is applied). The CREAM tool, distinguishes between actions (phenotype) and possible causes (genotype) [8].

There are two versions of CREAM to calculate HEP basic version and extended version. Basic version offers a primary screening of human error, to realize the probability of error. While extended version uses the outcomes of basic version to obtain the detailed value of the probability of error [4].

CREAM introduced nine CPCs (common performance conditions) (Table 2). CPCs constructed the basis of identifying the condition of likely performance. The features of the different conditions were revealed by four control modes (Scrambled, Opportunistic, Tactical, and Strategic) (Fig. 1).

2.1 The Relation between CPCs and Control Modes

The assessors use Table 1 to find out the score of CPCs for a certain task by counting the number of reduce, not significant, and improve performance reliability which is stated by $\sum_{reduce}$, $\sum_{not\ significant}$, and $\sum_{improve}$. The CII (context influence index) which is equal to $\sum_{reduce}$ minus $\sum_{improve}$ of CPCs scores

$$CII = \sum_{reduce} - \sum_{improve} \quad (1)\ [7]$$

The values of CII indicate the control mode through using Fig. 1, if the score of CPCs is not significant, i.e., there is no effect upon human performance reliability, so it can be discounted and ignored [7, 8].

3. CREAM Basic Version

The basic version of CREAM is divided to three main steps:

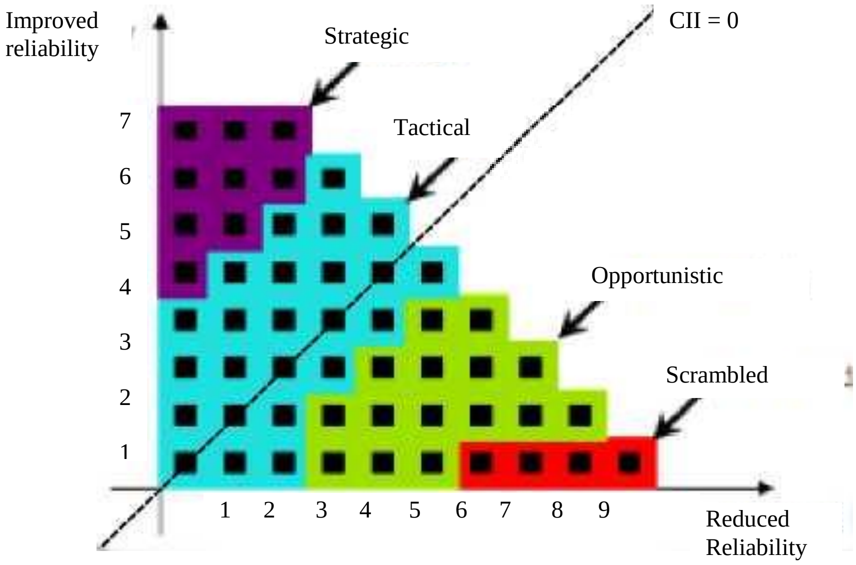

Fig. 1 The CPCs score and control modes [4, 8].

Table 1 CREAM control modes.

Control modes	HEP interval	CII values	Control modes descriptions
Strategic	0.00005 < HEP < 0.01	-7 to -3	Adequate time, practical, management and organizational support, are accessible to consider the actions.
Tactical	0.001 < HEP < 0.1	-3 to 1	Performance typically follows planned procedures although some specified deviations are probable.
Opportunistic	0.01 < HEP < 0.5	2 to 5	The next action is determined by shallow characteristics of the condition. "Situation is characterized by lack of planning".
Scrambled	0.1 < HEP < 1.0	6 to 9	The choice of the next action is unexpected or disorganized.

Source: Refs. [4, 8, 9].

- HTA (hierarchical tasks analysis)

This step is to identify the operation task in accordance with a scenario and break the task into steps and sup-steps under the HTA;

- CPCs evaluation

The objective of this step is to apply task steps to CPCs Table 2 in order to calculate the CII by utilizing Eq. (1). Expert's opinion is required to obtain the level of CPCs of certain task steps, by using "opinionnaire" then collect the results and use the means of results. The opinionnaire is performed according to the specifics organization structural conditions (creation of questions about CPCs, and transform the answers into numerical terms to achieve the level of the CPCs);

- Find the control mode error interval determination

The calculation CII and using Fig. 1, indicate the control mode, the interval of HEP, and the probability of the human error as a result. The HEP is an initial conclusion and screening of the human failure actions [8].

When the sum of reduced CPCs is equal to the sum of improved CPCs, the value of CII is zero, i.e. CFP in this case is considered as a basic value (Nominal Cognitive Failure Probability) and stated as (CPF_0). It is identified that the increase of CII value means the increase of the sum of reduced CPCs (Fig. 1) and the value of CFP as a result [7, 8].

There is a correlation between CFP and CII defined by the following equation:

$$\text{Log}\ (CFP/CFP_0) = k.CII \quad (2)$$

where, k is a constant coefficient.

The constant coefficient (k) is calculated as following:

$\text{Log}\ (CFP_{max}/CFP_0) = k.CII_{max}$

$\text{Log}\ (CFP_{min}/CFP_0) = k.CII_{min}$

i.e.

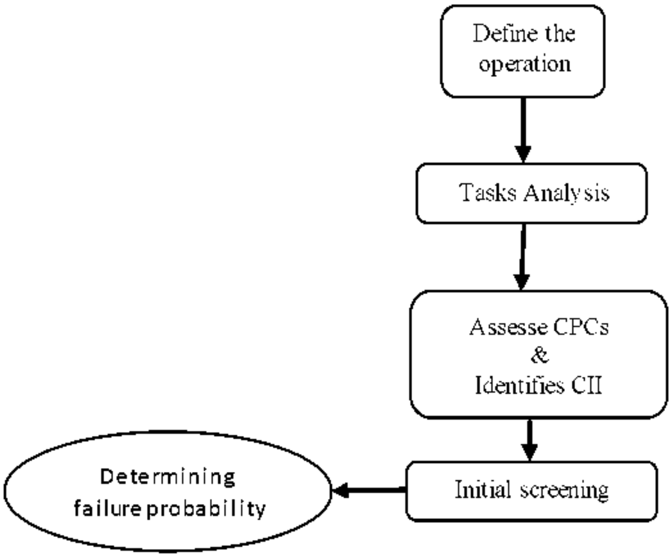

Fig. 2 CRAM basic version.

$$k = \text{Log}\ (CFP_{max}/CFP_{min})/(CII_{max} - CII_{min}) \quad (3)$$

$$CFP_0 = CFP_{max} / 10^{kCIImax} \quad (4) \quad [7, 8]$$

According to Table 2 the maximum sum of CPCs is nine (reduced) and the minimum is seven (improved) CII_{max} = 9 and CII_{min} = -7.

As per Table 1 CFP_{max} (maximum HEP) is 1.0000 and CFP_{min} (minimum HEP) is 0.00005 Then k = 0.26.

$$CFP = CFP_0 \times 10^{0.26.CII} \quad (5) \quad [7, 8]$$

Eq. (5) illustrates that performance reliability is the subjective of the overall combined score of CPCs through the basic version of CREAM tool.

The basic version as mentioned is a screening stage and qualitative classification of CPCs only, and it is not a quantification process. To perform a detailed reliability assessment the Performance Influence Index PII of CPCs that set by judgement of experts should be calculated. PII was used to calculate the quantitative effects of CPCs rather than qualitative effects, so CII in the extended version can be calculated by Eq. (6)

$$CII = \sum_{i=1}^{9} PII \quad (6) \quad [7, 8]$$

PII of CPCs, which must be adjusted by expert judgement, is listed in Table 2 for nine CPCs.

4. CREAM Extended Version

The extended CREAM version recognizes error modes of the four cognitive functions (observation, interpretation, planning, and execution) [10]. Extended version of CREAM is essential in cases where the general action probability of the basic method is unacceptably or when the uncertainty is large. In the extended version, the task requires to be divided into sub-tasks or sub-steps and each sub-step can be matched to one of 15 pre-specified cognitive activities (Table 5) and identify cognitive failure type (Table 4) for each sub-task, then use the Eqs. (5) and (6) to quantify it. The extended version includes the following steps:

- Cognitive profile construction

Find the values of PII, then construct a table including the CPCs and the values of PII for each main step of the task count on the results of the basic version before utilizing Eq. (6).

- Possible failure modes of cognitive functions

Identify the cognitive activities, generic failures type related to the cognitive functions, which are selected from a list of failures (Tables 4 and 5). CII for each main step of the task has been found, so using Eq. (5) CFP_0 to find the adjusted CFP. The main purpose of this step is to state the Cognitive Profile considering the dependences between cognitive activities and COCOM functions Table 5 [2].

- Finding human error probability

Table 2 CPCs and performance reliability.

CPCs	CPC levels/descriptors	Expected effects on performance reliability	PII
Adequacy of organization	Very efficient	Improved	-0.6
	Efficient	Not significant	0
	Inefficient	Reduced	0.6
	Deficient	Reduced	1.0
Working conditions	advantageous	Improved	-0.6
	compatible	Not significant	0
	Incompatible	Reduced	1.0
Adequacy of human-machine interaction and operational support	Supportive	Improved	-1.2
	Adequate	Not significant	-0.4
	Tolerable	Not significant	0
	Inappropriate	Reduced	1.4
Availability of the procedures/plans	Appropriate	Improved	-1.2
	Acceptable	Not significant	0
	Inappropriate	Reduced	1.4
Number of simultaneous goals	Fewer than capacity	Not significant	0
	Matching current capacity	Not significant	0
	More than capacity	Reduced	1.2
Available time	Adequate	Improved	-1.4
	Temporary inadequate	Not significant	1.0
	Continuously inadequate	Reduced	2.4
Time of day when the task is performed	Day time (adjusted)	Not significant	0
	Night time (unadjusted)	Reduced	0.6
Adequacy of training and preparation	Adequate high experience	Improved	-1.4
	Adequate low experience	Not significant	0
	Inadequate	Reduced	1.8
Level of cooperation and interaction among department staff or crew collaboration quality	Very efficient	Improved	-1.4
	Efficient	Not significant	0
	Inefficient	Not significant	0.4
	Deficient	Reduced	1.4

Source: Refs. [4, 10].

Table 3 The rule to find HEP of operation task by HEPs of sub-tasks.

Relation between sub-tasks	Dependence	HEP of task
Operation task failed if all sub-tasks fail (parallel)	High dependence	$HEP_{Task} \approx Min(HEP_{Sub\text{-}task\ i})$
	Low/no dependence	$HEP_{Task} = \prod(HEP_{Sub\text{-}task\ i})$
Operation task failed if one of sub-tasks fails (sequential or serial)	High dependence	$HEP_{Task} \approx Max(HEP_{Sub\text{-}task\ i})$
	Low/no dependence	$HEP_{Task} = 1 - \prod(1 - HEP_{Sub\text{-}task\ i}) \approx \sum HEP_{Sub\text{-}task\ i}$

Source: Refs. [4, 7, 8].

Assess the failure probabilities for the identified cognitive function failures. The nominal values of probabilities are presented in Table 4, and adjusted, it considers the effects of CPCs (identified in basic version). It will be beneficial to construct a table collecting the assessment task's sub-steps elements (sub-step—cognitive activity—cognitive function—generic failure type—nominal CPF or CPF_0—$CPF_{adjusted}$) of the extended version. To find HEP the operation task's sub-steps in HTA which included in the mentioned table should be reviewed and conducted. Moreover, check the dependence of the

Table 4 Generic cognitive function failures and their nominal probabilities.

Cognitive function	Potential generic failure types		Nominal CFP		
			Lower value	Basic	Upper value
Observation errors	O1	Observation of wrong object. A reaction is given to the wrong stimulus or event	$3.0\cdot10^{-4}$	$1.0\cdot10^{-3}$	$3.0\cdot10^{-3}$
	O2	Wrong identification made	$2.0\cdot10^{-2}$	$7.0\cdot10^{-2}$	$1.7\cdot10^{-2}$
	O3	Observation not made- overlooking a signal or measurement	$2.0\cdot10^{-2}$	$7.0\cdot10^{-2}$	$1.7\cdot10^{-2}$
Interpretation errors	I1	Faulty diagnosis,(either a wrong diagnosis or an incomplete diagnosis)	$9.0\cdot10^{-2}$	$2.0\cdot10^{-1}$	$6.0\cdot10^{-1}$
	I2	Decision error(not making a decision or making a wrong or incomplete decision)	$1.0\cdot10^{-3}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-1}$
	I3	Delayed interpretation, i.e., not made in time	$1.0\cdot10^{-3}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-1}$
Planning errors	P1	Priority error, as in selecting the wrong goal	$1.0\cdot10^{-3}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-1}$
	P2	Inadequate plan formulated or inadequate plan.	$1.0\cdot10^{-3}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-1}$
Execution errors	E1	Implementation of wrong type performed, with regard to force, distance, speed or direction	$1.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$9.0\cdot10^{-3}$
	E2	Action performed at wrong time, (too early or too late)	$1.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$9.0\cdot10^{-3}$
	E3	Action on wrong object (similar or unrelated)	$5.0\cdot10^{-5}$	$5.0\cdot10^{-4}$	$5.0\cdot10^{-3}$
	E4	Action performed out of sequence, such as repetitions, jumps, and reversals	$1.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$9.0\cdot10^{-3}$
	E5	Missed action, not performed	$2.5\cdot10^{-2}$	$3.0\cdot10^{-2}$	$4.0\cdot10^{-2}$

Source: Ref. [8].

Table 5 Matrix of cognitive activities for defining the HEPs of CREAM.

	Cognitive functions. Generic failure type (error modes) and its basic values COCOM functions												
	Observation			Interpretation			Planning		Execution				
Cognitive activities	O1	O2	O3	I1	I2	I3	P1	P2	E1	E2	E3	E4	E5
	1E-3	7E-2	7E-2	2E-1	1E-2	1E-2	1E-2	1E-2	3E-3	3E-3	5E-4	3E-3	3E-2
Coordinate													
Communicate													
Compare													
Diagnose													
Evaluate													
Execute													
Identify													
Maintain													
Monitor													
Observe													
Plan													
Record													
Regulate													
Scan													
Verify													

Source: Ref. [11].

sub-tasks according to the rule (Table 3) [12].

5. The Suitability of CREAM for the Shipboard Operations

Ships safety is a critical process, and vessel's crew is acting as a safety regulator through their performance on board ships for the safety process. Indeed safety depending on the human performance standards for decreasing the risk of human errors, not only the ships operations, but the maritime industry as general, the probability of human error should be assessed and evaluated particularly for critical operation tasks to reduce disastrous results. Since CREAM has two versions; screening (qualitative) then quantification phase (quantitative) to improve the safety considerations for any operation. Moreover, CREAM's taxonomy structure is detailed and comprehensive, as it is considering system and environmental reasons of error (sociotechnical) and the CREAM tool compensate the lack of data as CPCs leveled by experts' judgment. Furthermore, it depends on the cognitive behaviors of human element, so it can be applied to the shipboard operations particularly of the critical nature. The validation of CREAM model is confirmed by researches through an example of shipboard critical operation case [8].

6. Conclusion

Human element plays the main role in the achievement of safety measures on board ships. The absence of careful consideration of influences human performance and actions often result in deprived safety standards. Their roles and influences require supporting by evolving more progressive approaches for human performance assessment that deliberate more issues emphasizing the ways to assess human behaviours proficiently. The second-generation HRA tool CREAM is able to assess human reliability more efficiently due to its ability for representing the difficulty of assigning cognitive activity of human performance. IT was built on COCOM based on four control modes depending on time availability, and context of the condition. CREAM uses the grouping of Performance Shaping Factors called CPCs, these preserved as non-independent and expected to assess in an integrated manner in the context of particular actions (NEA, 2015), the core area of CREAM structure is the generic failure type through the selection of cognitive activity necessary for each task step. Dependency is explicit in CREAM basic version, but probabilistic dependency is hidden between the basic and extended version, as CPCs of different tasks are independent in the levels evaluation. Moreover, uncertainty in the resulting probability is obvious in the control mode interval in the basic version. The extended version gave values of CFP_0 with no explanation of its meaning but fuzzy measure will play an important role in compensating such disadvantage. CREAM is a fixable and promise tool of HRA able to use in different fields.

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