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Computer-Based Human Reliability Analysis Onboard Ships

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Abstract

Human performance monitoring has become a core matter of maritime industry since crew error ratios cannot be reduced to the desired level. This study develops an approach to conduct human reliability analysis (HRA) via knowledge-based system in order to minimize the operational problems that may arise from human errors on-board ships. The model base of the system takes the advantage of human error assessment and reduction technique (HEART) which is robust tool in reliability assessment. The main role of programming language in the system is to transform operational task scenarios in database into meaningful information to quantify two key parameters (i.e. GTT, EPC) sensitively. The system is expected to support shipboard organizations to monitor, identify, prioritize and implement the remedial measures to mitigate the human error in ship operational level. The aim of this article is to provide advance support through the WP#4 (Model Development) and WP#6 (Application Interface Design) of the research project entitled "Human Reliability Analysis and Monitoring System Proposal in Shipboard Operations (H-RAMS)" (Project no: 114M352) supported by the Scientific and Technological Research Council of Turkey (TUBITAK). In consequent, the study has both methodological and practical values in knowledge based systems and ship operations modeling.

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Keywords: Human Reliability Analysis; Ship Operations; Human Error, Knowledge Based System

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1. Introduction

Safety is one of the most important concerns in maritime transportation. It may affects human life, environment pollution and property at sea. There have been various regulatory authorities such as port state, flag state, classification society, etc. to enhance safety at sea. Although maritime authorities have adopted numerous regulations and rules under the control of IMO, safety has not raised to the desired level yet (Akyuz and Celik, 2015a). The safety practitioners have been attempting to extend the theoretical and practical proactive studies to mitigate hazards at sea in particular critical shipboard operations such as cargo loading, cargo discharging, bunkering, ballasting & de-ballasting, maneuvering, gas inerting, hold or tank cleaning and etc. In this context, human performance plays critical role since the statistics show that about eighty percent of marine accident are due to human errors (Fotland, 2004). A variety of technical or maintenance operations on-board ship have been performed by human/crew. It is clear that human behavior is often a root and critical contributing cause of system failure. Therefore, human reliability poses a crucial aspect as the adverse consequences may induce potential harm for human life and marine environment as well as cargo (Akyuz and Celik, 2015b). In the light of above, the aim of this study is to assess human reliability performance on-board ship based on a knowledge-based system in order to mitigate human errors during shipboard operations. Within this scope, the paper organized as follows; this part provides motivation concerning maritime safety. The next section deals with literature review upon HRA in maritime industry. Section three introduces methodology to establish a marine specific HRA. Section four defines how a knowledge-based system will be created for marine-specific HRA. The final section gives conclusion and discussion.

2. Literature Review

Human reliability assessment has always been a critical issue for safety and researchers, decision makers, safety engineers and practitioners. The reasons of that the HRA method are subjective and the data concerning human factor is impreciseness. Human reliability can be defined as human performance which shows how reliable the person/operator can perform the action correctly or how long the person/operator can perform without failure (Pyy, 2000). The first probabilistic HRA studies was performed after Second World War to assess weapon system feasibility (Swain, 1990). Thereafter, the technique has adopted to the different industries such as nuclear power plant (Zubair and Zhijian, 2013), engine system (Chang et al., 2010), electronic system (Liang and Wang, 1993) defense industry (Hausken, 2008), manufacturing (Bertolini et al., 2010), transportation (Calhoun et al., 2014; Guo et al., 2012) and etc.

There have been a variety of HRA techniques developed to assess human reliability. The most of techniques based on empirical studies such as THERP- technique for human error rate prediction (Swain and Guttmann, 1983), SLIM- success likelihood index methodology (Embrey et al.,1984), ATHEANA- a technique for human error analysis (Cooper et al., 1996), HEART- human error assessment and reduction technique (Williams, 1988), CREAM- cognitive reliability and error analysis method (Hollnagel, 1998), SPAR-H -simplified plant analysis risk human reliability assessment (Gertman et al.,2005) since human error data is scarce in the literature. Therefore, it is quite tough to apply stochastic models such as Bayesian Network (Almond, 1992) or Markov chain (Mennis et al., 2006) in order to predict human error probability (HEP).

In the context of human reliability assessment in marine industry, the researchers are quite limited. For instance, Yang et al. (2013) discussed a modified CREAM method by integrating Bayesian reasoning model. The method was demonstrated with an illustrative example of analysing an oil tanker cargo oil pump shut down scenario. Likewise, another study was conducted by Martins and Maturana (2013) as a marine-case in conjunction with HRA. In this paper, the authors introduced Bayesian belief networks (BBN) approach to evaluate human reliability during operation of a crude oil tanker while focusing on collision accidents. Furthermore, another original research was presented by Musharraf et al. (2013) in order to perform a quantitative HRA during emergency condition in an off-shore environment. The authors discussed the Bayesian Network (BN) approach to represent the dependency among the human factors and their associated actions. In addition, Vanem et al. (2008) discussed a generic high level risk assessment in LNG tanker ships. The paper provides a generic formal safety risk assessment upon LNG tanker ships. Furthermore, Akyuz and Celik (2015a) have recently presented a novel paper in which conducts an empirical HRA for tank cleaning process on-board chemical tanker ship by integrating HEART and AHP hybrid technique. Likewise, a study provides a quantified human reliability assessment towards cargo loading operation on-board LPG tanker ship by utilising CREAM approach has been adopted as a marine-specific case in recent time (Akyuz and Celik, 2015b). The marine-specific HRA approach namely called MAHRA (Maritime Human Reliability Analysis) has been introduced recently as a novel research to remedy the gap in literature (Akyuz, 2015). Considering the lack of maritime related studies in literature, this study provides a novel HRA approach based on knowledge-based system.

3. Methodology

The objective of this study is to build up an approach to conduct human reliability analysis (HRA) via knowledge-based system in order to mitigate the operational problems that may arise from human errors on-board ships. The next section introduces methodologies accordingly.

3.1. HEART approach

HEART (human error assessment and reduction technique) is a well-known modeling tool in safety and reliability analysis where critical operation is conducted. It is applicable to wide range of industries including nuclear power plant, railway, petrochemical, aviation, etc. Since the human error data is scarce in the literature, it is very difficult to apply stochastic models into marine industry to predict HEP value. Moreover, the current HRA techniques are limited to identify all of the significant aspects of human performance in marine industry such as uncertainty, insufficient data or subjectivity of expert judgment. Therefore, using the empirical method such as HEART seems more reasonable to support the consideration of human performance. The technique is quick and flexible requiring few researches. It was presented to assess human tasks with defined values for HEP calculation (William, 1988). The fundamental of technique is depend on two parameters; generic task type (GTT) and error-producing condition (EPC). The GT allows user to find suitable task under HRA and then define the generic error probability (GEP) value (also known as nominal human unreliability), while EPC defines the performance shaping factor of human which influence the probability of human error in the related task. This means that EPCs are expected to affect human performance negatively and leading to increase HEP associated with generic task (Akyuz and Celik, 2015a).

The effect of GEP and EPC value were generated by various researches of human factor performances for a long time. These data base includes a variety of HEP values derived from numerous industries such as nuclear power plant, petrochemical industry, offshore platforms, service industry, etc. (William, 1988). However, marine-specific HRA approach proposes a novel base technique deriving particular value for EPCs since internal and external factors increase the human error probability in marine industry.

The HEART method is easy to understand. The process starts selecting a generic task type in order to nominate GEP values as first parameter. As the GEP values are based on the nature of generic task to be performed and generic, they are regarded as the same value as adopted in HEART with given nominal likelihood within probabilistic limits. There are eight generic tasks associated with eight GEP values which gives the probability of human error occurred in perfect condition. The analysts have specific tasks that they need to quantify during HRA. Thereafter, EPC is selected by marine experts as a second parameter. The EPC is an external and internal factor such as time pressure, operator experience, familiarity, fatigue, noise level, age, etc. that might heavily affect the human performance and increase the probability of human error. There are thirty-eight different marine-specific EPCs assigned in MAHRA approach. They have substantial influence to HEP values (Akyuz, 2015). The marine-specific

EPC selection is based on scenario for the task being applied in critical shipboard operations. In this context, equation (1) gives the HEP value in MAHRA approach.

$$HEP = GEP_{value} \times [(W_i - 1) \times APOA_1 + 1] \times [(W_i - 1) \times APOA_2 + 1] \times \ldots \quad (1)$$

3.2. AHP Technique

The technique is widely recognized a multi-criteria decision making (MCDM) method. It was developed by Saaty (1980) to analyze complex decisions. The aim of the method is to calculate relative weight of nodes within the group. It first decomposes their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. Then, relative importance of alternatives are weighted respectively. In this paper, the AHP technique is adopted to prioritize proportion effect of EPC to get sensitive data. Since the AHP technique is robust tool to enable relevant weight for criteria, the first step is to construct a pair-wise comparison matrix (A) as presented by Saaty (1986). To accomplish this, Saaty's 1-9 linguistic importance scale, illustrated in Table 1, is used.

Table 1. Saaty's 1-9 linguistic scale.

Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Absolute extreme) importance
2,4,6,8	Intermediate values

The matrix A, provided in equation (2), introduces pair-wise comparison matrix where each a_{ij} *(i,j= 1,2,...,n)* has the relative importance of ith elements when compare to the jth. This shows a higher value of a_{ij} where indicates stronger preference of criteria a_i to a_j.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \qquad a_{ii} = 1,\ a_{ji} = 1/a_{ij},\ a_{ij} \neq 0 \quad (2)$$

After that, the priority weights of each criteria can be calculated with equation (3). In order to check whether the data inserted in AHP is consistent or not. The following equations are used sequentially (4), (5), (6). The consistency ratio (CR) value is equal or smaller than 0.10 otherwise the expert judgements will be revised to acquire consistent result. In this context, random index (RI) value is provided in Table 2 (Saaty, 1994).

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad (3)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

$$\sum_{j=1}^{n} a_{ij}\, w_j = \lambda_{max}\, w_i \quad (5)$$

$$CR = CI/RI \quad (6)$$

where ;
n : the order of the matrix
λ_{max} : the maximum matrix eigenvalue
λ_{max} can be found with equation (5) as proposed by Vargas (1982).

Table 2. Random index value

n	1	2	3	4	5	6	7	8	9	10
RI	***0***	***0***	***0.58***	***0.90***	***1.12***	***1.24***	***1.32***	***1.41***	***1.45***	***1.49***

3.3. System Design

The flow chart of marine-specific HRA approach (MAHRA) is depicted in Figure 1 where knowledge-based software to run the system on the principle of flow diagram. The software includes human reliability analysis and monitoring system which is practically used by the Master or shore-based manager. The aim of the software is to transform theoretical information into practice application by utilizing MAHRA approach framework. The process begins to define the relevant task in accordance with the scenario which involves main and sub-tasks on-board ship. This is provided in line of hierarchical task analysis (HTA) where main tasks are split up to the sub-tasks (Shepherd, 2001).Thereafter, a variety of scenarios representing in a broad sense are defined. These scenarios involve a wide range of conditions such as time pressure, operator experience, familiarity, fatigue, noise level, age, working environment, time of day, etc. Then, the related GTT is assigned by the software in accordance with defined scenario in the course of eight qualitative descriptions of actions (A to M) which is clearly defined by Williams (1988). Thus, quantitative GEP value for each sub-step is ascertained.

The next step provides users to select appropriate marine-specific EPC in accordance with the condition of operator. The user can be selected more than one marine-specific EPC. After having assigned relevant EPC, assessed proportion of affect (APOA) calculation is performed if there are more than one marine-specific EPC. The software builds up a comparison matrix for marine-specific EPCs and user is asked to compare each criteria with respect to Saaty's linguistic scale. Furthermore, a criteria weight of each marine-specific EPC is calculated. Thus, relative importance of each marine-specific EPC is ascertained respectively. In order to accomplish consistency through comparison matrix, the software is calculated CR values. If the CR values are found more than 0.10, the judgments inserted by user shall be re-considered and the pair-wise comparison matrix shall be re-inserted by user. The next step is to calculate HEP value in compliance with equation (1). In order to obtain final HEP value, the software is asked to define dependency among the sub-tasks in course of HTA PSA where serial or parallel system description is required. Accordingly, final HEP can be calculated.

The recovery proposal will be recommended to minimize HEP value in case of final HEP value is found higher than desired level. At this point, proper mitigation measures are taken for marine-specific EPC which may lead to increase HEP values. Prior to do that, risk matrix is used to verify if the final HEP value is within acceptable limit or not (DiMattia et al., 2005). Recovery proposal is needed to mitigate HEP into desired level (lower risk level-yellow blocks) if the final HEP value is clustered inside the red boxes in the risk matrix. In the light of above, error reduction measures are proposed to remove the impacts of relevant marine-specific EPCs. After having applied recovery measures, the last step is to re-calculate of final HEP value. In case re-calculated final HEP value is not decreased into desired level again (lower risk level- yellow blocks), the recovery measures needs to be revised and final HEP re-calculated one more time. If the final HEP is within the acceptable limits, then software allows user to perform task/operation.

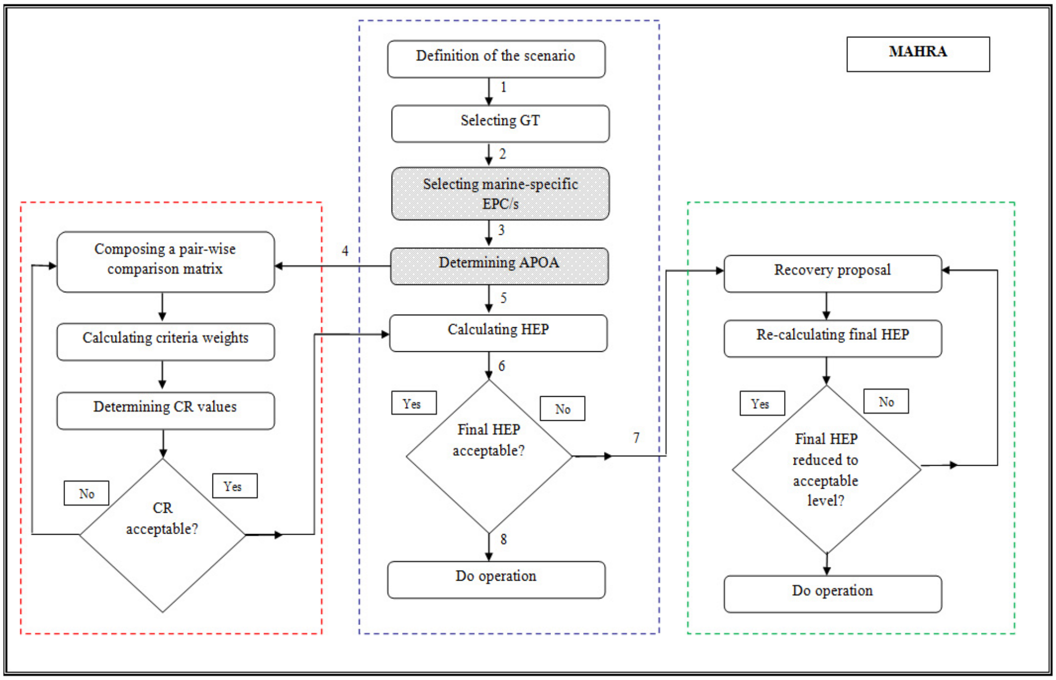

Fig. 1. System flow chart.

4. Knowledge-based system

A knowledge-based system is part of a computer programming which takes benefit of knowledge-based to solve comprehensive problems. It was generated by artificial intelligence researchers. In this paper, C# programming language, which is developed by using design component, is utilized to transform operational task scenarios in database into meaningful information to quantify two fundamental parameters sensitively. The software consists of two main design forms. The first design form requires the input data where iteration outcomes inserted. The second one runs the algorithm that has been provided in first design.

The first screen, illustrated in Figure 2, shows the GEP value in conjunction with GTT where the grid allows user to select one of them only. In the below of screen, the marine-specific EPC selection part can be seen. Since the user can choose more than one EPC, the grid allows multiple choices. In MAHRA concept, APOA calculation is performed by adopting AHP technique. Therefore, each EPC has corresponding APOA grid right next to the column. The software requests user to compare the each EPC in accordance with comparison matrix. In this part, Saaty's 1-9 linguistic scale is used. Thereafter, software calculates the HEP value for each sub-step, which is depicted in Figure 3, if the user clicks calculate button (upper left on the screen). When the user clicked calculate button, the software runs the algorithm and calculated the HEP according to the value of GTT object and EPC object which is weighted APOA grid.

The result screen appears right after calculation instruction. The result screen should be closed in order to calculate next HEP value. The software saves the each HEP value in case result screen is closed. When the whole

HEP calculation is completed for each sub-step, the system shows final HEP value with a graph result where user can see the fluctuation of HEP as well as values. It is illustrated in Figure 4

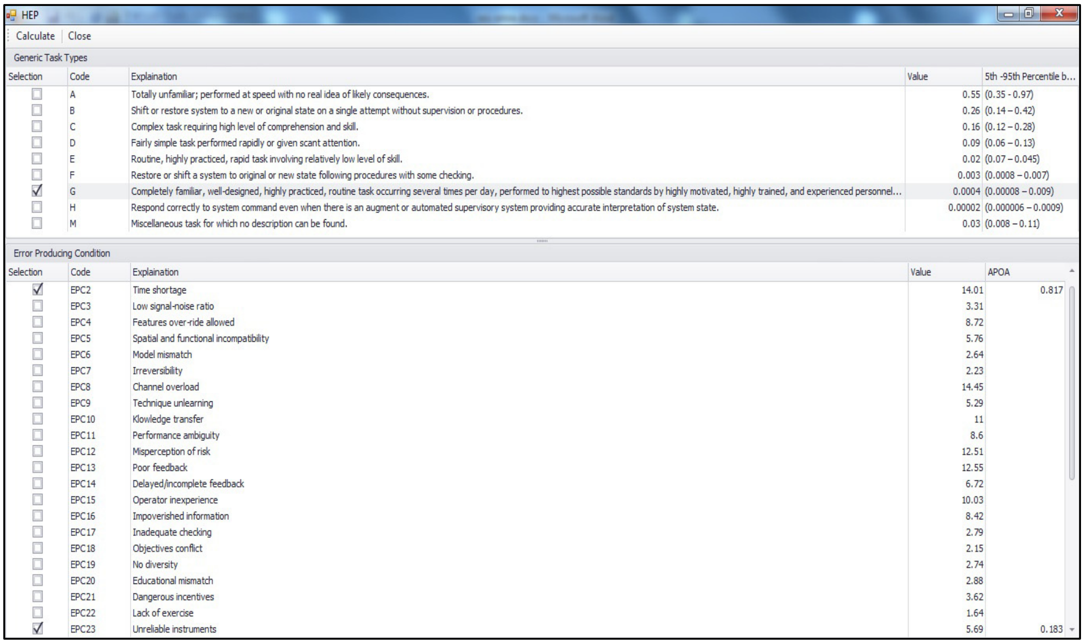

Fig. 2. Software user screen- GEP value in conjunction with GTT, EPC and APOA value.

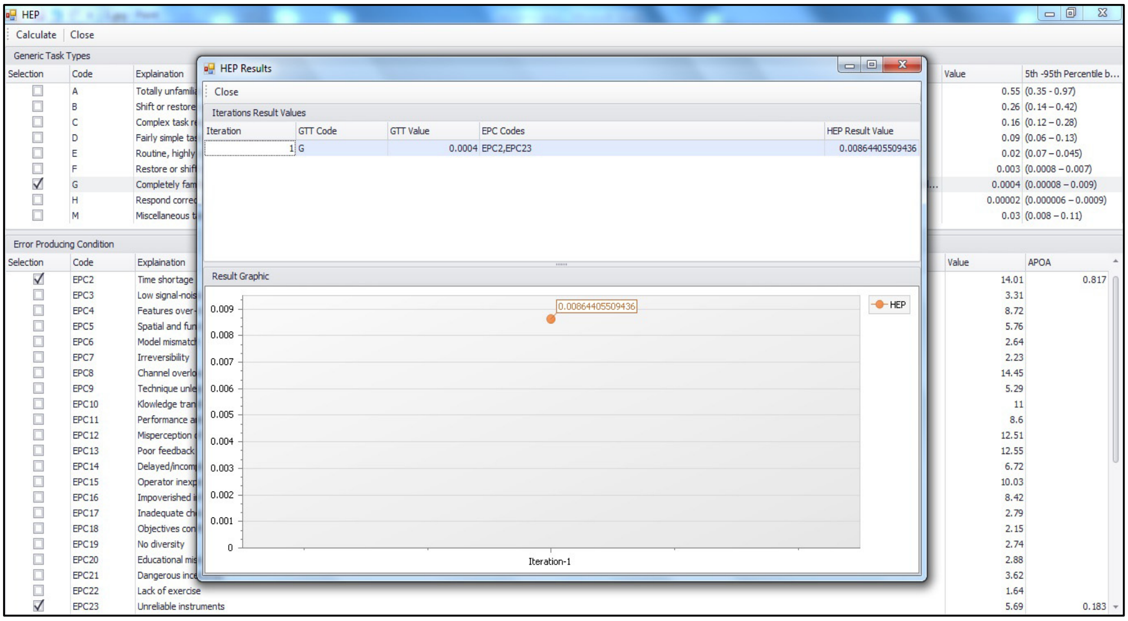

Fig. 3. Software user screen - Calculated HEP value for each sub-step

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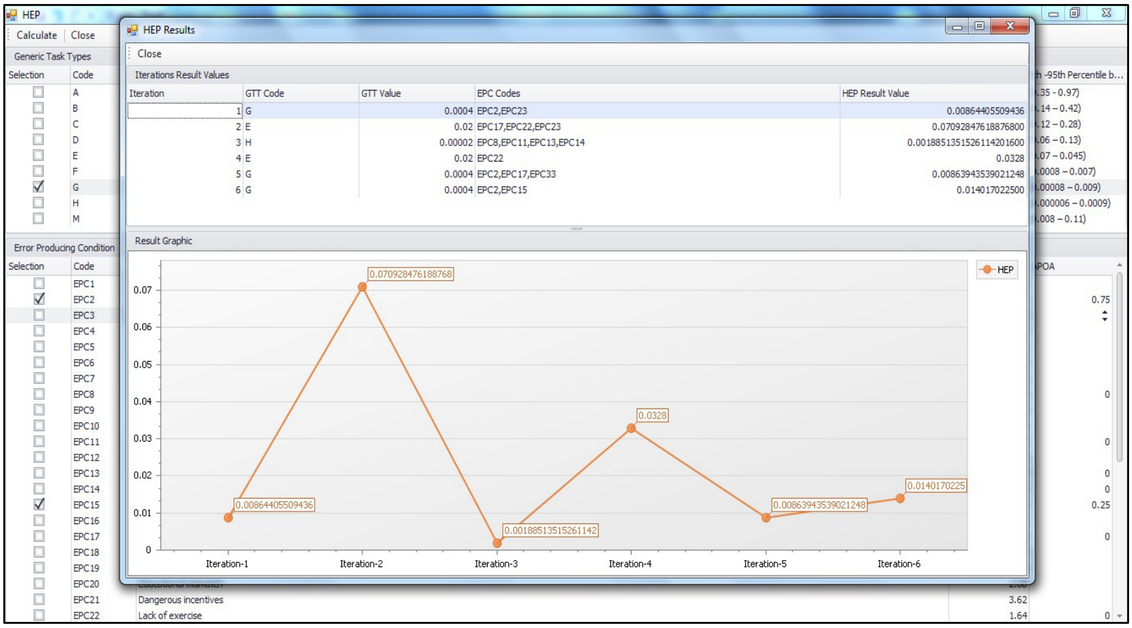

Fig. 4. Software user screen – Final HEP value and its graph for each sub-step

5. Conclusion

Human reliability assessment has always been a significant concern for safety researchers/practitioners in particular marine industry since human error may create life and environment threatening. Therefore, safety and risk researchers have strong tendency to seek proactive solution to prevent unexpected consequences in conjunction with human failures. At this point, this paper develops an alternative comprehensive solution by taking advantage of knowledge-based system in order to transform theoretical information into practical solution. The proposed approach enables to user a proactive user-friendly solution prior commencement of any critical shipboard operations. The system basically uses C # programming language, which is developed by using design component, is utilized to transform operational task scenarios in database into meaningful information to quantify two fundamental parameters sensitively Thus, the system is expected to encourage shipboard organization as well as shore-based managers by monitoring and identifying human error probability on-board ship. Respectively, remedial measures will be taken in advance to mitigate the human error and enhance human reliability simultaneously in ship operational level.

Consequently, the study not only makes a theoretical contribution in literature but also practical contribution in marine industry via knowledge based systems. The system is applicable to numerous critical shipboard operations such as system repair & maintenance, emergency preparedness, cargo loading & discharging operations, bunkering, cargo securing/lashing, hold or tank cleaning, gas freeing, gas inerting, crude oil washing (COW), cargo tank purging, cargo stripping, ballasting & de-ballasting, lightering, hot works etc. where risk of human error is relatively high.

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