Safety Science 110 (2018) 102–109

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

# Prediction of human error probabilities in a critical marine engineering operation on-board chemical tanker ship: The case of ship bunkering

Emre Akyuz[a,*], Metin Celik[b], Ilker Akgun[c], Kadir Cicek[b]

[a] Department of Maritime Transportation and Management Engineering, Istanbul Technical University, Tuzla 34940, Istanbul, Turkey
[b] Department of Marine Engineering, Istanbul Technical University, Tuzla 34940, Istanbul, Turkey
[c] Department of Business Administration, Marmara University, Bakirkoy, Istanbul, Turkey

ARTICLE INFO

*Keywords:*
Maritime safety
Human reliability
Bunkering operation
Chemical tanker ship
Decision-making

ABSTRACT

Ship bunkering, a safety critical operation in marine engineering, can cause drastic environmental damage at sea. Though bunkering presents high safety procedures, minor accidents also can pose potential harm for marine environment and human life. Indeed, it is well-known that numerous bunker accidents can be attributed to different types of human error. Therefore, control of human factor during bunkering operation plays critical role to enhance safety aboard and prevent environmental pollution at sea. This study presents a comprehensive human error prediction during bunkering operation demonstrated with a case study at chemical tanker platform. To achieve this purpose, a Shipboard Operation Human Reliability Analysis (SOHRA) method, which has been developed as a marine-specific approach to quantify human error, is employed. In the view of outcomes, human error reduction measures are recommended. In conclusion, the paper is expected to give practical contribution to the systematically prediction of human error for designated tasks, enhancement of safety control level in operational aspect and protection of the marine environment.

## 1. Introduction

Human factor is one of paramount topics in maritime industry since it may directly influence the operational performance. The majority of failures are attributed to the human factors which may cause serious consequences such as environment pollution. The findings show that most of maritime accidents are due to human errors (Akyuz, 2017; Corovic and Djurovic, 2013; Akyuz, 2015a). In order to minimize maritime accidents, it is essential to focus on the types of human errors (Abujaafar, 2012; Akyuz, 2016). The maritime authorities have been adopting a set of rules and regulations to minimize human error and enhance safety awareness such as SOLAS, STCW, ISM Code (Akyuz et al., 2016; Karahalios, 2014; Chauvin, 2013; Karahalios, 2011). On the other hand, maritime safety practitioners are also seeking creative solutions to reduce human error. However, human error prediction is quite onerous task in maritime transportation due to the uncertainty and inadequacy of quantitative human error data (Akyuz and Celik, 2018). To overcome these limitations, some scientific researches have been undertaken in the past decades. For instance, Macrae (2009) conducted an extensive study to identify potential human error in the event of two major types of marine accident: grounding and collision. A similar study has been performed in recent time to quantify human errors related to grounding and collision accidents at sea (Akyuz, 2017).

Furthermore, a couple of scientific research papers have been conducted through human error and system failure in maritime and offshore industries (Hou et al., 2017; Abbassi et al., 2015; Akyuz and Celik, 2015; Lavasani et al., 2015; Noroozi et al., 2014; Deacon et al., 2013; Abascal et al., 2010). The papers contributed guidelines to adopt various human error assessment techniques such as HEART (Human Error Assessment and Reduction Technique), SLIM (Success Likelihood Index Method) and THERP (Technique of Human Error Rate Prediction) in the application of numerous procedures on maritime and offshore industries in order to reduce human error and improve operational safety. Akyuz and Celik (2014) proposed a hybrid tool to analyse human error during maritime events. Another study was performed to systematically estimate human error probability towards the gas inerting process in crude oil tanker ships (Akyuz, 2015b).

Although a set of researches on human error prediction have been carried out in the past decade, those dedicated to critical shipboard operations in maritime transportation have remained very limited. The assessment of human error probability is a critical task to enhance safety. Bunkering, for example, is one of the critical shipboard operations under the ISM Code (SOLAS, 1974) since adverse consequences can pose potential harm to marine environment and human life.

* Corresponding author.
*E-mail addresses:* emreakyuz@hotmail.com.tr, eakyuz@itu.edu.tr (E. Akyuz).

https://doi.org/10.1016/j.ssci.2018.08.002
Received 17 October 2017; Received in revised form 25 June 2018; Accepted 3 August 2018

Bunkering operation is a critical shipboard process and also known as ship to ship transfer including fuel oil, diesel oil, etc. The operation requires utmost care to prevent any kind of oil spill or fire on-board chemical tanker ship. It may be conducted either in berth or at anchorage. The bunker barge come alongside of ship and secured properly prior to operation. All chemical tanker ships are governed by MARPOL Annex I and VI during bunkering operation. The statistics show that ship-sourced oil spill incidents are still a major source of oil pollution during bunkering operation. An extensive oil spill may spread out hundreds nautical miles from the source of accident and cause catastrophic pollution for marine environment. Since consequences of oil spill are severely damaging to marine environment, performance of ship crew become a critical concern during bunkering operation. Ship crew performance become a serious concern at this point. The ship crew must exercise particular caution when attending a bunkering operation. In this context, prediction of human error probabilities pose a major challenge to retain a high level of safety in the maritime industry.

The ship crew must perform utmost care during bunkering procedure. The operation follows a bunkering plan including agreed cargo quantity, pumping rate, time of completion and sampling. Master of ship carries out a safety meeting with all ship crew to discuss the operation and emergency response procedures. The bunkering operation is monitored by responsible ship crew in accordance with agreed bunkering plan. Watchkeeping during the entire operation is provided by engine and deck crew rating. All events are properly recorded to log books. The sampling of cargo is carefully carried out throughout the operation. Cargo intake quantity is calculated at the end of transfer.

In the literature, most of studies concerning the bunkering operations have focused on management strategies such optimal costs, ports, ship routes or contracts to minimize fuel-related costs (Zhen et al., 2016; Pedrielli et al., 2015; Wang et al., 2014) rather than focusing on operational aspect to enhance safety control level on-board ships. To remedy the gap, this paper aims at conducting a systematic human error prediction and assessment during bunkering operation in chemical tanker ship. The SOHRA (Shipboard Operation Human Reliability Analysis), a marine-specific human error prediction technique, is adopted to assess human error for designated tasks in bunkering operation. The human error probabilities are evaluated and necessary human error control measures are recommended to improve performance of ship crew. Within this context, the paper is organised as follows. Section 1 gives motivation and brief literature reviewing about human error prediction and bunkering operation in the maritime industry. Section 2 explains theoretical background of method. Section 3 demonstrates model application through bunkering operation at chemical tanker ships. Section 4 gives conclusion, contribution and future researches. A list of symbols and abbreviations, meantime, is provided in Table 1 for easy perusal of readers.

## 2. Methodology

### 2.1. Theoretical background of SOHRA

Shipboard Operation Human Reliability Analysis (SOHRA) was developed to quantify human error and predict human reliability in critical shipboard operations (Celik et al., 2014; Akyuz et al., 2016). The method introduces m- EPC (marine specific error producing condition) values which was validated by analysing a hundred of real-marine accident cases (Akyuz et al., 2016). The SOHRA is based on tailoring the basic principle of human error assessment and reduction technique (HEART) (Williams, 1988; Akyuz et al., 2018)· The method has a similar structure with HEART. It presents consistency of usage during assessed proportion of affect (APOA) calculation which is the key aspect of human error weighting in m-EPC calculation. Also, the SOHRA adopts the m-EPCs to define the performance shaping factors (PSF) of human beings for specific tasks in the maritime industry (Kirwan and Gibson, 2008; Kirwan, 1987).

**Table 1**
Nomenclature.

| | | | |
|---|---|---|---|
| *A* | Matrix | MARPOL | Maritime pollution prevention convention |
| $a_{ij}$ | Each criteria | MSDS | Material safety data sheet |
| A/B | Able seaman | *n* | Constant in Eq. (3) |
| AHP | Analytic hierarchy process | PSF | Performance shaping factor |
| APOA | Assessed proportion of affect | SLIM | Success likelihood index method |
| *CI* | Consistency index | SOHRA | Shipboard human reliability analysis |
| *CR* | Consistency ratio | SOPEP | Shipboard Oil Pollution Emergency Plan |
| EPC | Error-producing condition | SOLAS | Safety of life at sea |
| m-EPC | Marine-specific error producing condition | SPM | Single point mooring |
| GEP | Generic error probability | STCW | Standard training certification Watchkeeping |
| GTT | Generic task type | STS | Ship to ship |
| HEP | Human error probability | SMS | Safety Management System |
| HEART | Human error assessment and reduction technique | *RI* | Random index |
| HTA | Hierarchical task analysis | $w_i$ | Priority weight |
| HRA | Human reliability analysis | $\lambda_{max.}$ | Maximum matrix eigenvalue vector |
| *i* | Constant in Eq. (2) | THERP | Technique of human error rate prediction |
| *j* | Constant in Eq. (2) | | |

The SOHRA provides a consistent approach to quantify human error. It is quite applicable tool to calculate HEP in the critical shipboard operations such as cargo loading, discharging, berthing, unberthing, bunkering, ballasting, gas inerting, tank cleaning, hold cleaning, etc (Akyuz et al, 2018). The method is comprised of two fundamental parameters: generic task type (GTT) and m-EPC respectively (Akyuz et al., 2016). The GTT allows user to select appropriate task in perfect condition. The GTT is associated with generic error probability (GEP) which is provided in Table 2 (Williams, 1988).

The second parameter is the m-EPC which influences ship crew

**Table 2**
GTT and GEP values.

| Generic task type (GTT) | | Generic error probability (GEP) ($5^{th}$–95th percentile Bounds) |
|---|---|---|
| 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 practiced, rapid task involving relatively low level of skill | 0.02 (0.07–0.045) |
| 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 practiced, routine task occurring several times per day, performed to highest possible standards by highly motivated, highly trained, and experienced personnel, with time to correct potential error, but without the benefit of significant job aid. | 0.0004 (0.00008 – 0.009) |
| H | Respond correctly to system command even when there is an augment or automated supervisory system providing accurate interpretation of system state | 0.00002 (0.000006–0.0009) |
| M | Miscellaneous task for which no description can be found | 0.03 (0.008–0.11) |