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Analysis of Safety Requirements for Large Offshore Units Evacuation Systems. LSA safety function

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Abstract

The paper presents the problems related to the effectiveness of evacuation systems for large offshore installations. The analysis of safety requirements related to the complex evacuation, escape and rescue (EER) system elements has been carried out on the basis of the reports from the accidents of offshore drilling and production platforms. The safety function developed for life saving appliances (LSA) – the 6, 10 and 20 persons liferafts is presented as an example of a method for life saving appliances safety assessment.

1. Introduction

The offshore drilling and production platforms are the complex structures with the large number of personnel. They are exposed to the failures related to the technological process of oil and gas production, influence of harsh environment and supply vessels operation [2]. The reasons of the past accidents were the deficiencies in design, construction, organisational and technical aspects. The biggest tragedies of the Alexander Lange Kielland and Piper Alfa platforms arisen mainly due to the organisational reasons.

The Alexander L. Kielland platform operated as a floating hotel capsized in 1980 in the stormy weather because of the absence of command and lack of the organised evacuation which caused the time delay between the initial failure and final capsizing. 123 persons from 212 on board did not survive.

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In the disaster of Piper Alfa in 1988 due to the lack of alarming and leading of the evacuation action 168 persons lost their lives.

In the next catastrophes of the offshore platforms in 2001 and 2005 which were the explosion of Petrobras 36 platform and fire of Mumbai High North platform no more than several people lost their lives. The reason of the successful evacuation was mainly the good weather conditions during the evacuation.

In 2007 after the accident of Usumacinta platform 22 people were lost after launching the lifeboats because of not complying with the rescue procedures.

In the last catastrophe in 2010 of the Deepwater Horizon platform in the Gulf of Mexico all the personnel not killed during the explosion was rescued. 115 of the 126 crew members on board were evacuated. No casualties were reported as a result of the EER (escape, evacuation and rescue) operations. The reported causes of the successful evacuation were the good weather conditions, fast and effective evacuation and rescue procedures.

The findings from the post-accident investigations allow for the assessment of the EER system effectiveness and improvement of its availability, reliability, capacity, mobilisation time, functionality, vulnerability and personnel competence [6].

The following characteristics and parameters of the evacuation system should be considered [7]:

- parameters of the offshore installation (type of construction, floatability, dimensions, weight),
- function (drilling unit, production unit, transportation unit),
- number of persons on board,
- layout of evacuation routes,
- position of muster stations,
- kind of failure (explosion, fire, gas release, blow up of toxic gas, collision with a vessel, loss of stability due to ice, stormy weather, earth quake, construction and equipment failures),
- external conditions (wind, waves, visibility, ice, snow),
- units taking part in rescue action, emergency response rescue vessels (ERRV), other units operated close to the installation,
- lifesaving appliances and launching systems.

The analyses of the effectiveness in relation to the technical functional requirements for safety systems are carried out in relation to the risk analyses of escape, evacuation and rescue. The assessment of cost effectiveness is based on the selection of a desired performance level and choice of the option that achieves the desired level at the lowest cost.

The emergency preparedness analysis is based on the risk assessment. The vital result of this analysis is the following information:

- organisational and operational measures,
- time requirements,

– required capacity, effectiveness and protection of systems that form the emergency preparedness.

The paper presents the general approach to assessment of the effectiveness of EER system with respect to the safety requirements and detailed analysis of the liferafts safety. The liferafts are the semi-dry lifesaving appliances, making the last chance of escape and rescue for the personnel not able to participate in the organised evacuation. The proposed safety function for the liferafts allowed formulating the conclusions useful in design and operation of the EER systems.

2. Evacuation Systems for Large Offshore Installations

The evacuation and escape from a platform followed by the transfer of survivors from the lifeboats on board a rescue ship or rescue of persons in the liferafts and in the water are the successive stages of the emergency action [3].

The evacuation is a planned method of leaving the installation and its vicinity without directly entering the sea. As a result the survivors can be transferred from the installation on board a rescue vessel or to the onshore location.

The escape is the process of leaving a platform when the evacuation systems fail. The personnel on board make their way into the sea using the various means. In the worst situation it may be even by jumping into the sea from the installation.

The rescue is the process by which the escapes and men overboard are retrieved from the water to a safe place.

There are the following elements of evacuation system:
– commander of evacuation,
– rescue teams,
– alarm procedures,
– evacuation routes,
– muster stations, temporary safe rescue places,
– fire-fighting equipment,
– individual and collective lifesaving appliances.

The sequence of the evacuation phases starts at the initial incident after the decision to muster. The phases of evacuation are as follows:
– alarm activation,
– alarm detection,
– alarm identification,
– action to follow the announcement,
– making safe workplace,
– choice of egress route,
– movement along egress route,
– registering at the temporary safe rescue place,
– dressing in survival suites,
– lifeboat embarkation.

After the decision to abandon the installation the next steps of evacuation are launching the lifeboats and abandoning the dangerous platform zone.

The design and operational factors determine the proper performance of the alarm system, evacuation routes system, ventilation, emergency communication, auxiliary powering, auxiliary lighting, passive fire protection and escape routes marking system.

The escape routes lead from the working areas and living quarters to the temporary refuge areas and muster stations, lifeboats and liferafts-stations, boat landings, helicopter deck, floating hotel or other installations linked by the bridges and walk ways. The preferable methods of evacuation from the offshore installations are the helicopters and free-fall lifeboats.

For the platforms connected to the neighbouring installations the primary means of evacuation is the bridge between the platforms.

The semi-dry evacuation includes the evacuation by the davit launched liferafts, liferafts in combination with the slides or chutes and throw-over liferafts in which the people can float on reaching the sea.

3. Requirements for the EER Systems

There is the necessity of implementation of the proper safety criteria in the lifetime of the offshore installation: in design, construction, development, operation and operation during an accident. The catastrophes of platforms were the reasons of systematic investigations of EER systems. The conclusions from the investigations were included in the reports published by IMO (International Maritime Organisation) and institutions involved in safety [12]: Oil and Gas UK, Health and Safety Executive (HSE), Emergency Response and Rescue Vessel Association and The Step Change in Safety Group in Great Britain, Norwegian Petroleum Services Authority in Norway, Transport Canada in Canada and Mineral Management Services, Occupational Safety and Health Administration and Coast Guard in USA.

The analysis of the requirements for the alarm and evacuation systems including the most restrictive rules applied in the Norwegian offshore industry (NS) [7, 8, 9] along with the description of different systems functioning during the accidents is presented in table 1. The examples were taken from the reports of the accidents of Piper Alfa (PA) [10], Deepwater Horizon (DH) and Alexander L. Kielland (ALK) offshore installations [13].

The different requirements for the EER systems correspond with the operational practice. However the standards applied by the different companies are different and there is still a place for their improvements.

An example is the comprehensive IMO LSA code (Life Saving Appliances Code) with the requirements related to totally enclosed lifeboats and free fall lifeboats – basic lifesaving appliances during the mass evacuation:

Table 1

The analysis of the requirements for the EER system

<table>
<tr><th>Lp.</th><th>System functioning in case of the accident</th><th>System requirements</th></tr>
<tr><td>1</td><td>The alarm system did not work properly because the alarms in the living quarters were disabled to not awake and disturb the crew having a rest with the false alarms (DH).</td><td>The alarm and public address system should be installed in all platform areas in which the people work or rest.</td></tr>
<tr><td>2</td><td>The lack of auxiliary lifesaving appliances, the necessity of their complete embarkation before launching caused the long waiting time for the persons, who cannot get to the muster station.
In heavy seas the lifeboats launched from the platform could not release the hooks and capsized (ALK).</td><td>The minimum number of free-fall lifeboats in the main evacuation area should be equal to the number which aggregate capacity can accommodate the total number of persons on board and one auxiliary lifeboat (NS).</td></tr>
<tr><td>3</td><td rowspan="2">The auxiliary evacuation systems: ladders and evacuation chutes were necessary to make possible safe abandoning the installation in case the lifesaving appliances cannot be used.</td><td>The additional muster stations should be provided in case it is not possible to reach the main muster station (NS).</td></tr>
<tr><td>4</td><td>The Maritime Evacuation Systems should provide the evacuation of 100% people on board the installation (NS).</td></tr>
<tr><td>5</td><td>The use of liferafts in the weather conditions over the allowable conditions should be reduced to minimum, even if their use in MES (Maritime Evacuation System) and embarkation through the evacuation chutes can speed up the evacuation.</td><td>The number of places in the liferafts can be decreased on the basis of a preceding analysis (NS).</td></tr>
<tr><td>6</td><td>The persons escaping from the installation were in the water without the individual life saving appliances protecting against hypothermia and toxic substances (DH).</td><td>The immersion suites for no less than 50% of free fall lifeboats crew should be stored at the muster stations. (NS).</td></tr>
<tr><td>7</td><td>The wrong location of the radio station in the zone exposed to destruction in case of operational failures caused the lack of communication between the platform and rescue vessels (PA).</td><td>The emergency communication systems with other installations, helicopters, life boats and rescue boats, liferafts, rescue vessels and shore should be available on board offshore installation (NS).</td></tr>
<tr><td>8</td><td>The lack of emergency systems was the reason of the delay in taking over the on scene commander duties by the rescue vessel and delay in fire-fighting action (PA).</td><td>The emergency communication systems should stay active in case of failure, they cannot be a reason of an additional threat in the presence of inflammable gases. (NS).</td></tr>
<tr><td>9</td><td rowspan="2">The failure of powering, the lack of the emergency powering and communication were the reason the "abandon installation" alarm was not announced (PA).</td><td>Uninterruptible power supply devices should provide the energy in case of main and auxiliary generators failures for at least 30 minutes (NS).</td></tr>
<tr><td>10</td><td>The evacuation action should be planned in collaboration with all the parties taking part in the rescue action (NS).</td></tr>
</table>

cd Table 1

11	A part of the alarms did not function due to the failure of powering systems (DH).	The powering of the devices used only in case of the emergency should provide the energy for 4 hours. The use of batteries is permissible. The independent powering source, providing the energy for 18 hours could be the generator or electrical wire from the neighbouring installation (NS).
12	The wrong decisions and wrong assessment of the situation, the lack of the assigned second in command, purely trained in evacuation and rescue technics personnel, people jumped into the water from 60 m height installation, lack of the auxiliary lifesaving appliances, lack of the individual and collective lifesaving appliances inspections (PA).	The personnel should be trained in evacuation and rescue.
13	The localization of particular persons, finding the wounded persons was not possible, it delayed lifesaving appliances boarding and making decisions of launching the lifesaving appliances.	The electronic registration and identification systems Personnel Registration System PRS is proposed [14].

– The lifeboats and liferafts are designed for the assumed mass of a person equal to 75 kg, when according to the HSE circular "Big Persons in Lifeboats" the weight of a man employed on the platform is of average 98 kg and woman 77 kg [6].
– The requirements of IMO do not include the weather conditions in which the trials of life saving appliances should be conducted.
– In operation of the mass evacuation systems it is assumed that there are no weather limits. However the experience shows that there are the limits and they should be known. The weather conditions have the biggest influence on the boats launching operations:
– The basic difficulties are related to the possibility of release hooks in heavy seas, which can be the reason of boat hanging on one hook. According to the new requirements the hooks should be replaced by the "Release and Retrieval System" comprising the hook assembly and operating mechanism until June 2019.
– There are the serious difficulties in abandoning the dangerous zone by the lifeboat after launching due to the wave induced motions and difficulties in transport of the survivors from the lifeboat on board the rescue vessel.

The primary attribute of the operational system is the quality comprising effectiveness and reliability [3]. The effectiveness is the ability to function with the possibly low cost and suitability – the ability to function complying with the requirements of functionality, productivity, controllability, ergonomics and compatibility.

In relation to the functional requirements of the EER system the effectiveness is interpreted in a wide sense and includes availability, reliability, capacity, mobilisation time, functionality, vulnerability and personnel competence [8].

The assessment of the cost effectiveness is usually based on the selection of a desired performance level and choice of the option that achieves the desired level at the lowest cost. The obligatory effectiveness analysis of safety and emergency preparedness measures shall document the fulfilment of the functional requirements to safety and emergency preparedness [8]. The performance of technical emergency preparedness measures may be documented through the reliability or vulnerability studies. For the organisational or operational measures the results of training, experience from exercises, calculation of capacities and response times may be applicable [8].

Likely due to the political infeasibility of placing a valuation on human life the regulations give only the normative recommendations on the acceptance criteria and leave the specific acceptance criteria to be formulated by the individual oil companies. The individual risk criteria proposed for the ships [9] are as follows:

- maximum tolerable risk for the crew is equal to 10^{-3} fatal accidents per year,
- negligible risk is equal to 10^{-6} fatal accidents per year.

The effectiveness analyses in relation to the technical functional requirements for the safety systems are carried out in relation to the risk analyses [1]. The risk model in the form of the influence diagram of the event dependencies in the cause of the Piper Alfa accident scenario [10] is presented in figure 1. The random variables related to the EER system are placed in the dashed line rectangle: failure of public address system, no evacuation orders, exits cut off, survivor jump, rescue at sea, human casualties.

The random variable "rescue at sea" has the direct influence on the human casualties. It depends on the weather conditions and lifesaving appliances characteristics. Figure 2 presents the Bayesian network for prediction of the human casualties dependent on the random variables related to the rescue of survivors in liferafts and man overboard.

The conditional probabilities for survival of the man over board (MOB) can be determined on the basis of the time to rescue, MOB condition and external conditions [11].

The probability of surviving for the personnel in the life rafts can be determined using the proposed liferaft safety function [4, 5].

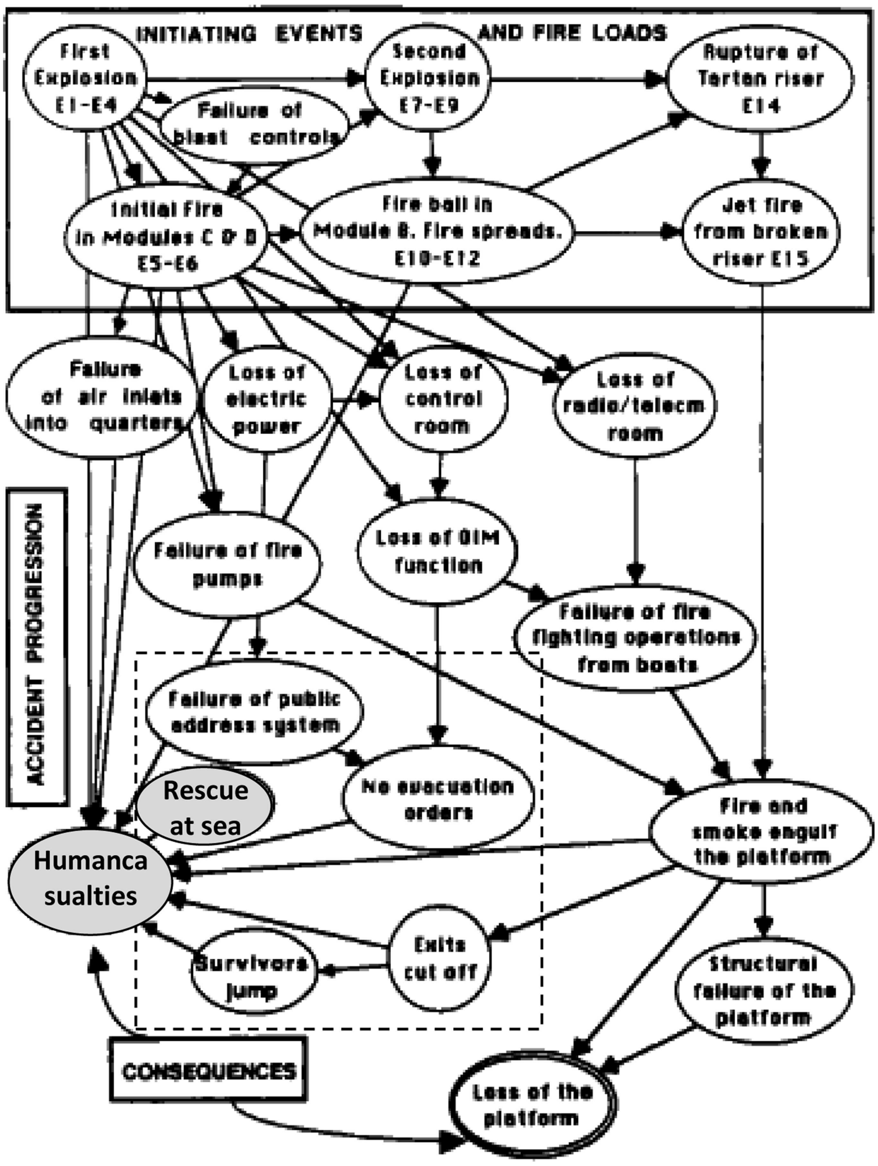

Fig. 1. Influence diagram of the event dependencies in the Piper Alfa accident scenario [10]. The random variables related to the EER system are placed in the dashed line rectangle: failure of public address system, no evacuation orders, exits cut off, survivor jump and rescue at sea

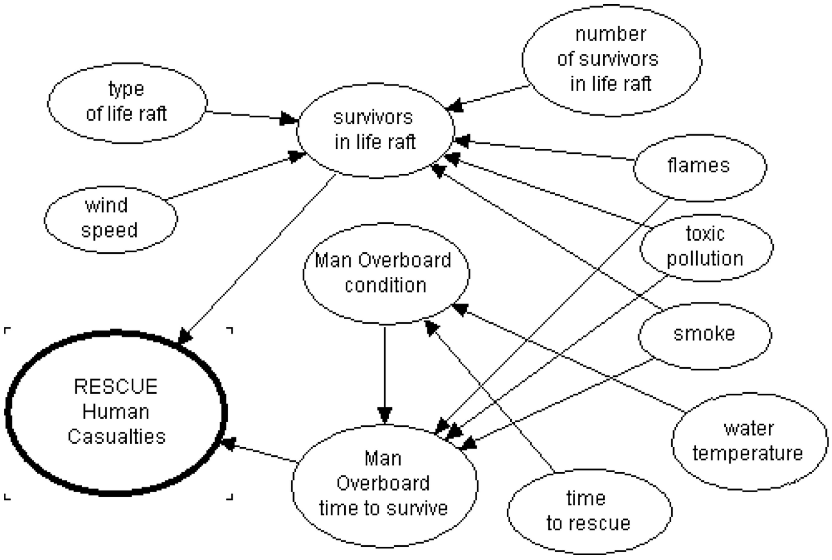

Fig. 2. Bayesian network for prediction of the human casualties due to rescue of survivors: men overboard and survivors in life rafts

4. LSA Safety Function

With respect to the LSA code the liferaft should survive in the sea conditions for 30 days [3,5].

$$R(t) = P(t_p \geq t_{30}) \tag{1}$$

where:
R – liferaft reliability,
t_p – time to failure.

In fact the operational characteristics of the liferafts used by the rescue services are available for the wind force no greater than 7° B (34 knots). The liferaft safety function presented in [5] was developed on the basis of investigations conducted for the wind speed up to 80 knots. It depends on the liferaft type, size, loading and wind velocity fluctuations. The reliability of 6, 10 and 20 persons liferafts has been determined.

The operational reliability of a liferaft is the characteristic informing whether it fulfils the consigned functions in the given hydro-meteorological conditions and assure safety to people on board. To define the reliability function for the random variable Z denoting "limiting safe" the wind velocity for the liferaft has been introduced.

The relation between the liferaft speed and wind velocity is the basis for formulation of the model which enables to find the function of the raft reliability as a function of the wind velocity.

$$y = -a\,x^3 + b\,x^2 + c, \quad x \in [0,\ x_1], \quad a > 0, \quad b > 0, \quad c > 0 \tag{2}$$

where x is the wind velocity and y is the numerical value of the raft speed, and parameters a, b are the average values of independent nonnegative random variables A and B. These values depend on a number of random factors, among others, on the liferaft type, size and loading as well as on the wind velocity fluctuation. Therefore a quantity:

$$Y = -A\,x^3 + Bx^2 + C \tag{3}$$

is a random process which value denotes the raft velocity and the parameter $x \in [0,\ x_1]$ denotes the wind velocity. It is assumed [5] that the random variables A and B have the gamma distribution $G(\alpha_1, \lambda_1), G(\alpha_2, \lambda_2)$ respectively and the random variable C is of one-point distribution. The probability density functions of A and B, expected values and variances are described by the formulas [5]:

$$f_A(u) = \frac{\lambda_1^{\alpha_1}}{\Gamma(\alpha_1)} u^{\alpha_1 - 1} e^{-\lambda_1 u}, \quad u > 0; \quad E(A) = \frac{\alpha_1}{\lambda_1}; \quad D^2(A) = \frac{\alpha_1}{\lambda_1^2} \tag{4}$$

$$f_B(w) = \frac{\lambda_2^{\alpha_2}}{\Gamma(\alpha_2)} w^{\alpha_2 - 1} e^{-\lambda_2 w}, \quad w > 0; \quad E(B) = \frac{\alpha_2}{\lambda_2}; \quad D^2(B) = \frac{\alpha_2}{\lambda_2^2} \tag{5}$$

A critical event for a liferaft is for the wind velocity where the stochastic process takes maximum value [5]:

$$x = Z = \frac{2B}{3A} \tag{6}$$

The value of the liferaft reliability function for the wind speed x is given by the formula (7) [5]:

$$\begin{aligned} R(x) = P(Z > x) &= 1 - \int_0^x f_Z(z)dz = \\ &= 1 - \frac{\lambda_1^{\alpha_1}\lambda_2^{\alpha_2}}{3^{\alpha_1} 2^{\alpha_2} B(\alpha_1,\ \alpha_2)} \int_0^x \frac{z^{\,\alpha_2 - 1}}{(\frac{\lambda_1}{3} + \frac{\lambda_2}{2} z)^{\alpha_1 + \alpha_2}} dz \quad z > 0 \end{aligned} \tag{7}$$

The expected value of the random variable Z can be described by formula (8):

$$E(Z) = \frac{\lambda_1^{\alpha_1}\lambda_2^{\alpha_2}}{3^{\alpha_1} 2^{\alpha_2} B(\alpha_1,\ \alpha_2)} \int_0^\infty \frac{z^{\,\alpha_2}}{(\frac{\lambda_1}{3} + \frac{\lambda_2}{2} z)^{\alpha_1 + \alpha_2}} dz \tag{8}$$

The results of computations allowed for formulating the following conclusions [5]:

– The reliability of a liferaft depends on a number of boarded persons; a fully loaded raft is more reliable than a partly loaded raft. The biggest difference between the reliability of the fully loaded raft and the raft boarded by 1 person is for a 6-person liferaft.
– 10-persons liferaft with the drogue boarded by 10 persons is the safest one; the second safest is the same liferaft without the drogues. The expectation of a 'limiting safe' wind velocity for the raft in this case is 63.903 knots.
– The smallest reliability has a 20-person raft boarded by 2 persons. The reliability (safety) functions for the liferafts with and without the drogue in this case are equal. Similarly, the expected values of the random variable denoting the 'limiting safe' wind speed are about 48.32 knots.

5. Conclusions

According to the requirements [8] the knowledge of the performance capabilities of the selected means of evacuation, including launching and clearing the dangerous area, should be incorporated into the operational planning, including the emergency response plans. There is still not enough information about the performance of life-saving appliances such as the scramble nets, ladders, or other individual means of entering the sea, as well as the inflatable throw-over life rafts, provided as a last means of leaving the installation when other planned means either fail or are unavailable. The emergency response plan should recognize that such the equipment is to be used only as a last resort [7], however the rescue procedures should include the recommendations related to the choice of this equipment and boarding procedures, based on the proposed safety functions, of which an example has been presented in the paper for 6, 10 and 20 person life rats.

The safety functions for the large 50 persons life rafts used in combination with the slides or chutes in the mass evacuation systems as well as the totally enclosed and free fall life boats are not known. There are only the post-accident reports conclusions which can be used as a source of information about the temporary measures to be implemented in their construction and evacuation procedures.

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