Development of a Risk Based Methodology to Consider Influence of Human Failure in Industrial Plants Operation

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Abstract: Human Failures are one of the most unexplored causes in industrial accidents. Since there is still lack of heeds to qualify as well as quantify Human Errors, in this paper the authors attempt to highlight the importance of paying attention to qualitative methods in implementing quantitative risk analyses mainly in the framework of estimating more accurate Human Error Probability (HEP). A key point in evaluating such a risk is considering non-linear socio-technical interaction in system to develop causal network for the accident scenario. An application of qualitative and quantitative Bayesian Network (BN) is therefore presented. The study shows that human performance has the most changes in the light of evidences. The developed methodology applied to a case study of an operation in field of Oil and Gas.

Keywords: Human Error Probability, Risk Assessment, Bayesian Network

1 Introduction

As it has been dramatically demonstrated in many cases, injuries and dangerous occurrences arising from lifting operations account for a significant proportion of the total of those occurring offshore. Many regulators found that it would be beneficial to look at the worldwide picture to review national initiatives and to share best practice in order to improve their effectiveness in regulating these risks; see for example (CAPP, 2013; DNV, 2014; HSE, 2007; OGP, 2006).

Human factors play a pivotal role in process industry. There is no specified, valid and determined on the statistical distribution of the causes to industries accidents owing to the different sort of accident analysis. However, the main group of causes are identified as human errors, technical and mechanical failures (Celik et al, 2009; Muhammad Juned Akhtar et al, 2014).

Human reliability, as defined by Swain et al, 1983, is "the probability that a person correctly performs system-required activities in a required time period (if time is a limiting factor)". Human reliability is one of the most substantial parts of human factors engineering major and involves the study of human Performance Shaping Factors (PSF) (Blackman et al, 2008). PSFs influence to improve or decrease the human performance. Different Human Reliability Analysis (HRA) techniques were developed by consideration and identification of the potential contributions of PSFs to accidents (Mashrura Musharraf et al, 2013).

UK Health and Safety Executive published several reports due to the importance of human factors in oil and gas offshore operations in which the inclusion of human factors in the offshore industry process were taken into account (Widdowson et al, 2002). An integration of human factors principles into offshore system design, development and operation were achieved in the result of these reports (Khan et al, 2006).

As it claimed in many research, on a regulatory basis there is not any clear definition for the inclusion of human error considerations in risk assessments (Khan et al, 2006). Without estimating Human Error Probability (HEP), the final Risk Priority Number (RPN) will not be plausible. Increasing emphasis is being placed on a comprehensive assessment of the human role in system safety following the occurrence of major disasters in the petrochemical industry such as Piper Alpha and other industries like Chernobyl where human errors were seen as direct or indirect causes. Zarei et al, (2015) investigated human error contribution in decision making of operators in the process industry. Furthermore, a better estimate of human reliability would help design more effective safety systems and evaluate more accurate risk assessments. The main focus of the paper is improving Human Reliability Assessment (HRA) method to have better estimation of HEP.

HEP assessment techniques preliminary have been a focus of the nuclear industry and have developed expert judgment techniques such as Successive Likelihood Index Method (SLIM), Technique for Human Error Rate Prediction (THERP), Justified Human Error Data Information (JHEDI), and Human Error Assessment and Reduction Technique (HEART) which are described sufficiently by researchers (Kirwan, 1997; Kirwan, 1998;

Kirwan et al, 1997). There have been a blaze of efforts to assess HEPs using the aforementioned methods (Miller et al, 1986; Raafat and Abdouni, 1987; Zamanali et al, 1992; DiMattia et al, 2005; Noroozi et al., 2013; Noroozi et al., 2014; Abbassi et al., 2015).

On the other hand, despite there are some researches in which the quantification of HEP were thought-out, only a few of these techniques would be pragmatic approaches (Embrey et al, 1984; Khan et al, 2006). A better comprehension of human error and its causes and consequences can be gained through the application of human error identification methods in the system. (DiMattia et al, 2005) Researchers have argued that linear approaches fail to represent the complex dynamics and interdependencies commonly observed in socio-technical systems (Dhillon et al, 2006; Herrera et al, 2010; Hollnagel et al, 2014). Also, establishing previous methods singly may result in focusing only on an identified accident model that occurred in operations mostly based on the energy-barrier event models, and not to pay attention to risk reducing measures and barriers in regard to decreasing the variabilities of activities (Torgauten, 2010). However, recently, some systemic models and methods have been proposed that consider safety as an emergent property of the socio-technical system as a whole (Herrera et al, 2010). One of the developed qualitative methods is Functional Resonance Accident Model (FRAM) (Hollnagel, 2015; Hollnagel et al, 2014). FRAM is based on resilience engineering method which is defining as "the ability to meet risk" (Hollnagel et al, 2014; Hollnagel, 2013). It provides a clear condition for monitoring risk and monitoring accident scenarios in a process, especially to describe what may happen due to resonance of potential variability (i.e., unexpected combinations of human, organization and technical errors) (Halseth, 2010; Sjölin, 2013; Torgauten, 2010). In present paper FRAM is implemented as a qualitative technique to achieve deep insight into process and estimate human error as a part of risk assessment.

Recently, BN is used exclusively in a wide range of studies including medical, engineering, economics, business, etc., however implementing HEP in terms of modern-stage probabilistic studies still is not considered as it deserves. Expressing HEP in connection with probabilistic network such as BN will lead up to work out cause and effect interaction between each sub-activities of human performance in more details. Almost all previous methods are based on mutually exclusive assumption without any attention being taken into account on the part of human interactions with technical and organization issues quantitatively. Although, FRAM is supposed to find out these reciprocal interaction qualitatively and consider the flexibility of system to overcome failure conditions based on resilient engineering, still it is derived from a suitable quantitative part to give a reasonable number to each resonance scenarios. BN itself is quantitative and qualitative based probabilistic method with introducing acyclic directed graph for the whole system. Probabilistic network graph oblige risk assessor to couple BN and FRAM. It means Directed Acyclic Graph (DAG) could be constructed by using FRAM qualitative analysis which itself introducing resonance on system.

The objective of this paper is to present a methodology for developing HRA and risk analysis, using qualitative to quantitative risk-based approach for modeling the risk of an operation in oil and gas operation in marine. The methodology applied in this study is described in section 2 and illustrated concisely in Figure 1. A short overview on the case study is given in section 3. Section 4 is devoted to conducting FRAM network while applying methodology to estimate HEP is presented in section 5. Finally in section 6 the conclusion is presented.

2 Risk-based approach

A risk-based methodology is developed to assess the risk of studied operation as illustrated in Figure 1, including qualitative and quantitative risk analysis. These main parts are presented by FRAM and BN. FRAM is applied to analysis human error interacting with different parts of system as well as providing resonance on network to work out an accident scenario qualitatively. Finally, as a beneficial point of executing BN, in the light of new evidence, the influence of variables on each other are investigated.

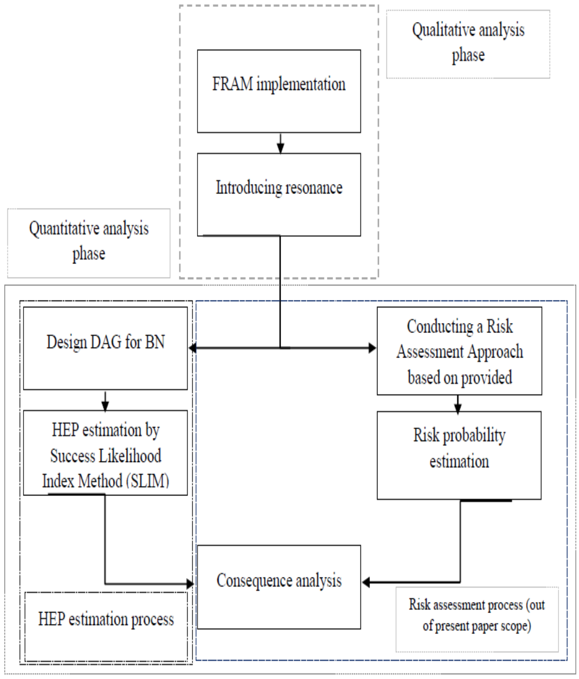

Figure 1: Risk based methodology for qualitative to quantitative analysis

3 Application of methodology: Case study

To apply the methodology, a practical case study of support structure lifting operation in the South Pars gas field of Iran is considered. In shallow water depth, it is common to use steel or concrete support structure at crossing point of two or more different pipe line directions to overcome the problem of intersection between pipes.

The main sub-activities in brief are that, (a) vessel is positioned in correct coordinate, (b) Ultra Short Base Line System (USBL) is used for positioning under the water and under water gyro system will be used for object orientation. (c) Beacons and under water gyro is transferring the transitional position of the object to the survey room on board, (d) lifting equipment consists of sling, belt, spreader bar, is ready for lifting support, (e) carne ready for lifting, (f) object lowered down by crane up to 1 m above seabed and checking its orientation by survey team and Remote Operating Vehicle (ROV), (g) ROV supervisor check the operation by monitor and take fix point to validate the position of Support installation on seabed and releasing the object on seabed.

4 Functional Resonance Analysis Method (FRAM)

The Functional Resonance Accident Model (FRAM; Hollnagel, 2004) are systemic models and methods that consider safety as an emergent property of the socio-technical system as a whole. In this approach functions and performances of functions are the units of analysis, rather than physical components and sequences of events. It is a risk model reviewing non-linear interactions and it is reviewing everyday activity when things are working as they should do. By describing operations when they are functioning you can find out how and why something go wrong in the system. A function may be defined as "a set of actions that a system performs or is used for, which are valuable for the achievement of a set of goals" (Woltjer, 2009).

The FRAM network of studied operation is presented in Figure 2. This network is a basis for quantitative analysis of HEP estimation. In the FRAM network of present case study functions with green color are background function which provide a support for foreground function. The functions with blue color are foreground function. Foreground function directly can lead to a failure in lifting process. As it is obvious from FRAM network the process has 14 functions, 7 background and 7 foreground. The functions are coupled with each other via their common aspects. There are some functions with barrier goal such as quality control, winch control and connecting wire/belts and inspection of connection. Lack of functional barriers make some functions of the operation such as under water gyro/beacon, USBL system, lifting support by crane, vulnerable against unpredictable variabilities.

It should be noted that since all operation are assumed to be performed at same time, it is not possible to consider the variability and resonance of all functions in an entire accident scenario. Hence, the HEP estimation is conducted for an operation as a specific resonance in the FRAM network. This resonance is based on variabilities of the functions (it is specified by numbers). The resonance is a detectable signal that emerges from the unintended interaction of the variabilities of many functions that together may combine in unexpected ways, leading to consequence that are disproportionally large (Herrera, 2010).

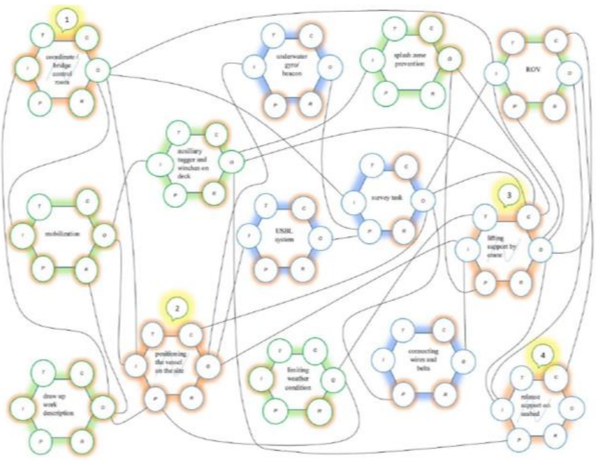

Figure 2: Resonance of human error in the process of fixing the sea fastening of derrick on the vessel. Note: T = Time, C=Control, P=Precondition, R=Requirement, I=Input, O=Outcome

5 Applied methodology for HEP estimation

Human error consideration as a part of risk analysis is inevitable if one wants accuracy to be achieved in the process of risk assessment. In present paper a developed methodology is proposed for HEP estimation. In order to implement the idea of developing HEP a novel methodology presented in 4 parts: 1) Converting FRAM networks into BN, 2) Including provided resonance of FRAM into BN, 3) Computing HEP in each function, 4) Compile BN based on HEP, evidence and max-propagation.

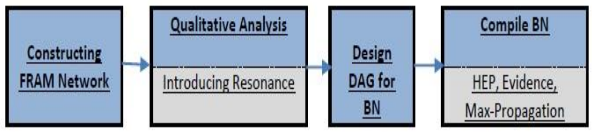

Figure 3: quantitative analysis based on qualitative analysis

5.1 Converting FRAM network into BN

BN is a graph with a set of probabilities. A Combination of probability theory and graph theory and based on a well-defined Bayes theorem, BN are demonstrated by a DAG, contains nodes representing random variables, arcs as joints among nodes, and Conditional Probability Tables (CPTs) (Tung-Tsan Chen et al., 2014; Majeed Abimbola et al., 2015)

BN provide an elegant mathematical structure for modeling complicated relationships among random variables and inferring the probability of a cause when its effect is observed. It allows scientists to combine new data with their existing knowledge or expertise.

BNs are based on the Bayes theorem, that is, inference of the posterior probability of a hypothesis according to some evidence. Mathematically, the Bayes' rule states,

$$posterior = \frac{likelihood.prior\ probability}{evidence} \quad (1)$$

$$P(\theta|x) = \frac{p(x|\theta)\, p(\theta)}{p(x)}$$

Where $P(\theta|x)$ denotes the probability that random variable "θ" with specific value given the evidence "x".

One of the most constructive and widespread criticism associated with traditional approach towards HEP assessment is inability to update. BN is applied in proposed methodology mainly thanks to:

- Recognizing that Total HEP is affected by what functions more than the others. In the other words, according to provided resonance in FRAM network, human error in each function has specific impact on total HEP and implementing BN contributed to find out more in details about the influence of each function on HEP.
- Updating HEP in the light of new evidence.

5.2 Including provided resonance of FRAM into BN

There are just two functions that have no impact on the resonance (under water gyro and USBL system) and subsequently there is not any variable related to these function in the BN. Four variables are defined as a resonance in the BN; one, two, three and four (Fig.4.). Related functions of these variable in the FRAM network are coordinate bridge/control room, positioning the vessels on the site, lifting support by crane and release support on seabed respectively.

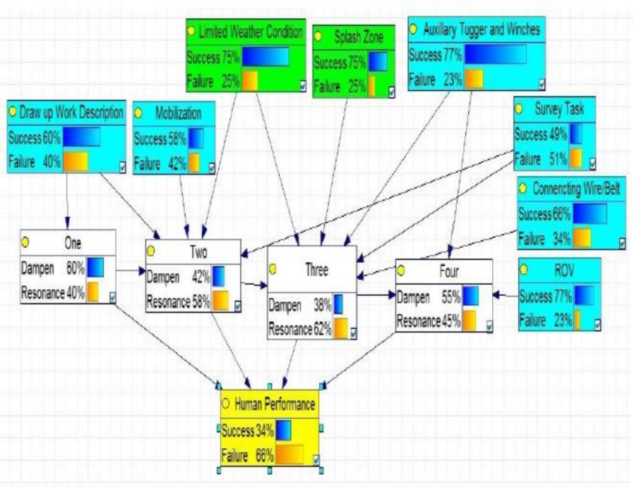

Figure 4: Bayesian Network based on provided resonance through functions 1 to 4 in qualitative FRAM network

Each arc in the network is based on both linear and non-linear interactions between variables according to provided resonance. Without considering any resonance there is not any relationship between variables in the BN and as a result human error would be the common and exclusive descendent node of all functions.

5.3 Computing HEP in each function

After mapping the operation into BN based on FRAM, it is needed to find the probability of error for each human related lifting activity. If significant human contributors to the likelihood of major occurring accidents be omitted, then the probability of the occurring event may be seriously underestimated. Conversely, the role of human in enhancing the reliability of a system needs to be taken into account. Although dozens of Quantitative Risk Assessment (QRA) techniques are employed today, most of them suffer from lack of calculation of human error likelihood.

The SLIM integrates various Performance Shaping Factors (PSFs) relevant to a task into a single number called a success likelihood index (SLI). The SLI is calculated by the following formula (see Eq.(2)). For numerous sub-activities for each task then SLI should be calculated for each sub-activity separately and consequently the related HEP should be calculated by Eq. (3) in which, "n" is the number of sub-activity and "m" is the number of PSFs to find related SLI for task jth, besides, R and W are the Rate and Weight of each PSF respectively.

$$SLI = \sum_{i=1}^{m} R_i W_i \tag{2}$$

$$SLI_j = \sum_{j=1}^{n} \sum_{i=1}^{m} R_{ij} W_i \tag{3}$$

For a given SLI, the human-error probability (HEP) for a task is estimated by using the Eq. (4):

$$\log(HEP) = a \times SLI + b \tag{4}$$

$$HEP = 10^{a \times SLI + b} \tag{5}$$

Where a and b are constants determined from two or more tasks for which HEPs are known. In this study a and b are considered as -1.95 and 10 E-04, respectively.

Identifying PSFs is a substantial step of presenting the SLIM. The first step of Human Reliability Assessment is to focus on human behavior and identify a set of human factors believed to be related to performance. These PSFs are then employed to estimate the probability of human error in a given situation (Mashrura Musharraf et al, 2013).

5.3.1 Identification PSFs

Performance shaping factor is provided basis for considering potential influences on human performance and systematically considering them in quantification of Human Error Probabilities (HEPs). PSFs often characterized as internal and external. Internal PSFs are influences that the individual brings to the situation such as mood, fitness, stress level, etc. External PSFs are influences in the situation or environment that affect the individual such as temperature, noise, work practices, etc. Currently there is no standard set of PSFs used in HRA methods, but most sets use PSFs identified in human performance literature. Personal factors include, attention, attitude, personality, fatigue, knowledge, experience, motivation. Additional factors include communication, teams, leadership, safety culture, ergonomics, training, environment, management, time and workload. PSFs are used to meet multiple goals in HRA and the study of human performance. PSFs are used to pin-point positive or negative influences on human performance and to predict conditions that lead to human errors. Several HRA methods use the state (level of influence) of the PSFs to estimate HEPs or to gain qualitative insight about the scenario. PSF states are defined on different scales depending on the selected method, but they generally range from low to high influence.

5.3.2 PSFs assessment

Determining the weight of PSFs to estimate the SLIs is one of the most pivotal steps. Human performance data with greater detail is difficult to find in real world situations, which requires the use of expert judgment techniques (Mashrura Musharraf et al, 2013). In this assessment, the PSFs with highest ranks are taken into account as the related PSFs, listed in Table 1 . The number in the second column denotes the normalized importance (weight Wi) of a particular PSF for the task under consideration, as determined by experts.

Table 1: Rank and weight of PSFs

PSF	Rank	Weight
Experience	10	0.21
Skill	9	0.19
Motivation	8	0.17
Stress Level	7	0.15
Work Memory	7	0.15
Time Pressure	6	0.13

Rating the PSFs is another important step in the SLIM procedure. Participant experts such as technical engineers select rating R, from 0 to 1 for each of PSFs. Each PSF rating has an ideal value of 1 at which human performance is judged to be optimal. These ratings are based on six PSFs demonstrated in Table 1 as the most important ones in lifting of light structures. It is necessary to mentioned that, Human Error assessment are faced up with uncertainty, especially in any modern and novel industry like offshore industry. In these technologies, the problem of Minimum field data in regard to major component is inevitable. The main reason of uncertainty in such technologies is the lack of knowledge with regard to inappropriate or missing experimental and operational data. As a result, a combination of qualitative and quantitative risk assessment with expert judgment could result in a better interpretation of system based on epistemic knowledge and subsequently a better ability to cope with scarce in operational experience and uncertainty.

By applying Eq. (3) SLI were obtained for each activity. Afterward, Eq. (4) and Eq. (5) are used to calculate the HEP of each task. Human Error Probability of activities is presented in Table 2.

the probability of human error, HEPT, for light structure's lifting in the offshore industry can be calculated using Eq. (6)

$$HEP_T = 1 - \prod_{j=1}^{n}\left(1 - HEP_j\right) \qquad (6)$$

5.4 compile BN based on HEP, evidence and Max-propagation

The application of BNs are climbed gradually based on probabilistic and uncertain knowledge specially in the major of risk and reliability engineering (Khakzad et al, 2011). Using probabilistic network such as BN to represent HEP will result in finding cause and effect interaction between each sub-activities of human performance in more details. The CPTs determined to the nodes restate how the linked nodes have impact on each other (Toledano JG et al, 1998; Khakzad et al, 2011).

In order to find out that how BN help to have better interpretation about relationship between nodes, the evidence are set on two variable; survey task failure, human performance failure. Also, the results from BN are depicted in Fig.5 and Fig.6. BN illustrated that what variables work most effectively on the others when evidences are set. The maximum changes in both types of Max-propagation analysis for human error, are related to second resonance (two) and third resonance (three) nodes.

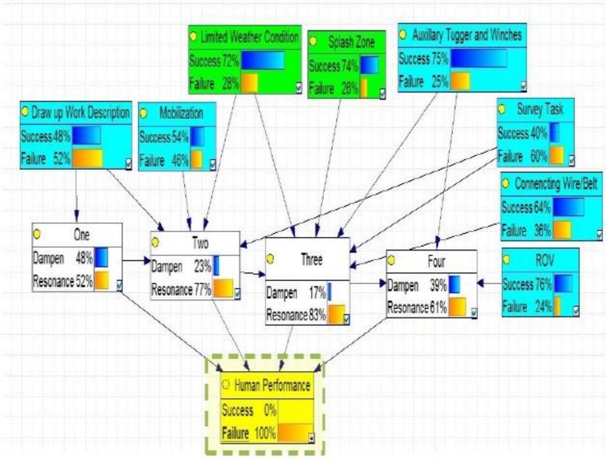

Figure 5: Max-Propagation analysis for human errors based on evidence on Human Performance

In the light of mentioned evidence the CPTs were changed and shown separately in Table 3. As it has been mentioned previously, the primary HEP value are based on SLIM and subsequently the update process using NOGM are made according to these rates. The differences of methodologies are appeared in probability of resonance nodes (see Table 2). It is necessary to say that two variables in the BN (Splash zone and Limited weather) do not have any value in primary HEP estimation. The reasons are that firstly, mentioned variables are not within the scope of human performance and control and secondly, HEP estimation was carried out based on PSFs, using SLIM.

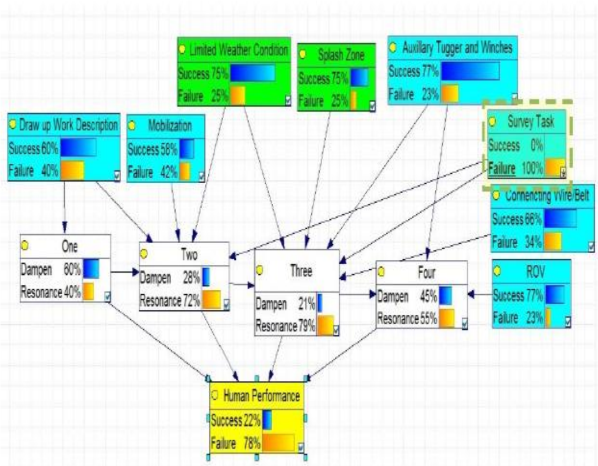

Figure 6: Max-Propagation analysis for human errors based on evidence on Survey Task

6 Conclusion

A method was developed to estimate HEP accurately and provide good understanding of the events that lead to human errors. It also illustrated that coupling FRAM and BN will result in better HEP estimation.

The First half of the paper was devoted to qualitative analysis of considered case study where FRAM network were drawn and build on this network the BN were conducted qualitatively. The second half of the paper discussed quantitatively in which HEP estimation for each function were assigned. Finally, in the light of new information and to figure out the impact of failure in each nodes on the other nodes, two evidences were set.

The application of the developed methodology to a case study depicted that the proposed coupling of FRAM and BN has made the application of risk assessment more reliable. It is highly recommended to have interdisciplinary studies based on HRA and statistical method to find accurate estimation of human error in terms of hidden cause effects and time dependence. Including the time element in HEP estimation, gives more accurate results. Besides, "Hidden causes effect gap" plays a prominent rule in understanding the accuracy of prior estimation of human error. Since, it means a hidden cause individually contributes to a major means of error, but it could not be realized in reality.

Table 2: Human error (failures) probability comparison of different sub activity using SLIM and BN

Variables	SLIM	BN (Fig. 4)	BN (Fig. 5) Evidence on Human Performance	BN (Fig. 6) Evidence on Survey Task
Draw up work description	40.07%	40.07%	51.85%	40.07%
Mobilization	42.33%	42.33%	46.19%	42.33%
Limited weather	-	25%	27.9%	25%
Splash zone	-	25%	26.49%	25%
Auxiliary tugger and winches	23.03%	23.03%	25.22%	23.03%
Survey task	50.6%	50.6%	60.19%	100 %
Connecting wire and belts	33.59%	33.59%	36.11%	33.59%
ROV	23.11%	23.11%	24.12%	23.11%
First resonance	28.33%	40.07%	51.85%	40.07%
Second resonance	10.5%	57.61%	77.04%	72.07%
Third resonance	47.63%	61.53%	82.66%	78.6%
Forth resonance	13.6%	44.91%	60.89%	54.59%
Human Performance	86%	65.82%	100 %	78.29%

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