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Analysis of Human Error Probability at Shipyard Using Human Error Assessment and Reduction Technique (HEART)

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***Abstract*—In shipyards, human error is a serious problem that can compromise operational effectiveness, productivity, and safety. The effectiveness of shipyard operations still largely depends on human participation, despite the quick advances in automation and technology. In shipyards, human error can result in mishaps, monetary losses, and reputational harm. Finding workable solutions is therefore essential to lowering the possibility of human error. The possibility of human error in shipyards is investigated in this article by first determining the variables that may lead to errors and then estimating the likelihood that they will occur. The Human Error Assessment and Reduction Technique (HEART) is the methodology employed. A technique called HEART is used to assess the degree of human error in a system, which helps to analyze how human errors affect a system's performance. The analysis's findings show that bending and pressing plates are two fieldwork tasks that have a high risk of human error. This study also makes it clear that management's engagement in resolving human error issues must be proactive. Hands-on training, ongoing safety policy formulation, and encouragement of a happy workplace are just a few ways that management can help lower the possibility of human error.**

Keywords—*Human Error, Human Error Probability, HEART*

I. Introduction

Human error refers to actions or decisions that deviate from the expected or desired outcome. It can involve mistakes in thinking, planning, decision-making, or task execution. Human error can occur in various contexts and situations, including the workplace, transportation, healthcare, and everyday activities. [1]

Human error is often caused by factors such as fatigue, lack of training, time pressure, task complexity, or a lack of attention to detail. While humans always have the potential to make errors, understanding the origins and characteristics of human error is the first step in designing strategies to reduce the risk and impact of these errors. [2][3]

A shipyard is a pivotal center in the maritime industry where ships are built, repaired, and maintained. Serving as a hub of technical expertise, shipyards play a key role in supporting the sustainability of global maritime transportation. The processes in a shipyard involve a series of complex technical and construction tasks that require a variety of skills and technologies.

Workplace accidents in shipyards are a primary concern in efforts to maintain the safety and well-being of workers and ensure operational sustainability. Shipyards, as centers of technical and construction activities, involve various complex and often high-risk tasks that initiate the accident. Numerous investigations have been conducted to identify and assess different factors that contribute to the occurrence of accidents in shipyards [4]. The cause of accidents and crucial risk incidents in shipyards are primarily ascribed to adverse environmental conditions, human-related factors, and organizational elements. Environmental factors encompass various on-site conditions like weather, atmosphere, and the availability of hardware or technical equipment in shipyards. Celebi et al. [5] and Krstev et al. [6] extensively identified adverse environmental conditions by scrutinizing the operational processes in shipyards.

As per Seker et al. [7], human-related elements are mainly manifested in personal skills, sociological, psychological, and physiological aspects. Barlas and Izci [8], through a statistical examination of shipyard accidents, identified that factors associated with human actions, including inadequate education and training, fatigue, extended working hours, and similar aspects, stood out as the principal contributors to accidents in shipyards.

Efe [9] similarly presented results indicating that the primary reason for accidents involving falls from heights is the lack of safety belts or seat belts during operations. Additionally, the incorporation of insights derived from accident analysis into the safety management system is heavily influenced by organizational factors [10][11]. Crispim et al. [12] emphasized in their study that the major contributors to risk events in military shipbuilding can be traced back to human and organizational elements.

However, a comprehensive examination of human-related factors linked to shipyard accidents has not been conducted. While numerous scholars have recognized the importance of human-related factors in contributing to shipyard accidents, there is a scarcity of literature exploring the influencing pathways and mechanisms of these factors, as observed by researchers such as Barlas and Izci [8], Efe [9], and Crispim et al. [12].

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The scarcity of these studies can be ascribed to the intricate and uncertain nature of human-related activities in shipyards. Shipyard operations entail multiple stakeholders, especially in ship repair endeavors, encompassing ship crews, shipyard workers, ship surveyors, and technical engineers from various suppliers.

These stakeholders collaborate temporarily to execute ship repair tasks in accordance with the work agreement. Furthermore, overseeing the behaviors of individuals engaged in shipyard operations proves to be a significant challenge.

As highlighted in the review conducted by Qiao et al. [13], analysis models concentrating on human-related factors can be classified into four types, each integrating various technologies, whether quantitative or qualitative. Significantly, qualitative approaches or models play a pivotal role in furnishing analytical frameworks. Examples encompass the Human Factors Analysis and Classification System (HFACS) [14], System Theoretic Process Analysis (STPA) [15], Human Error Assessment and Reduction Technique (HEART) [16], Cognitive Reliability and Error Analysis Methods (CREAMs) [17], and System Theoretic Accident Model and Process (STAMP) [18].

In the shipyard environment, the role of humans as the primary performers in various technical and complex tasks significantly determines operational success. Despite the rapid advancements of technology and automation in the maritime industry, human involvement remains a vital element influencing various aspects, ranging from safety to operational efficiency.

Human error, or mistakes made by individuals, refers to actions or decisions that deviate from expectations or desired goals. In shipyards, human error can lead to serious consequences, including accidents, financial losses, and threats to the company's reputation. Despite continuous efforts to improve technology and automation processes, understanding and addressing human error remain integral parts of maintaining operational sustainability.

It is crucial to define and comprehend human error in the shipyard context to design effective mitigation strategies. Therefore, this study examines the probability of human error in shipyards by identifying potential factors that cause human mistakes and then calculating the probability of errors occurring.

II. Method

To identify the probability of human factors, two main steps should be generated. First, calculate the human reliability using the Human Reliability Assessment (HTA). Second, calculating the human error probability using the Human Error Assessment and Reduction Technique (HEART) [19]. In this study, some following works activities in the shipyard i.e. cutting process, pipe, and valve pressing, deck machinery assembling process, and sheet metal forming or bending were chosen to be examined by using the HTA and HEART. The explanation of each step is described as follows:

A. Human Reliability Assessment (HRA)

Human Reliability Assessment (HRA) is an approach used for knowing the level of human reliability to become a member of a system. Human reliability is defined as the probability that a person's performance will be free from errors over a certain period. Human Reliability can also be defined as the probability that an activity carried out by humans is successful in following its objectives in an operating system.

The goal of HRA is to identify areas of high risk, quantify the overall risk, and indicate where and how improvements should be made to the system. Bell et al. [20] states that to assess HRA human reliability, qualitative and quantitative methods can be used. With this method, an assessment can be made regarding human contribution to risk. There are many and varied methods available for HRA. High-risk industries have developed their methods, keeping in mind their very specific risks. In this study, the HTA process is illustrated as shown in **Figure 1**.

To identify human error, we must simplify the list of work processes into a structured diagram using Hierarchical Task Analysis (HTA). HTA in the production process in each work process in the Shipyard i.e. i.e. cutting process, pipe, and valve pressing, deck machinery dismantling process, and sheet metal forming or bending is shown in **Figure 2-5**.

B. Human Error Assessment and Reduction Technique (HEART)

In the subsequent stage, the likelihood of an error occurring was assessed using the HEART method. The HEART method is a technique employed in the realm of human reliability assessment (HRA) to gauge the likelihood of human error during the execution of a specific task.

The HEART method operates on the premise that every time a task is executed, there exists a potential for failure, and this probability is influenced by one or more Error Producing Conditions (EPCs), such as distractions, fatigue, cramped conditions, and others. Factors with a substantial impact on performance are identified by the highest Human Error Probability (HEP) values. These conditions are then applied to an "ideal scenario" estimate of the failure probability under optimal conditions to derive the final error opportunity.

This figure helps in communicating possible errors with the broader risk analysis or safety case. With EPCs in mind, the HEART method also has the indirect effect of providing various suggestions on how reliability can be improved from an ergonomic point of view. The HEART method is based on several things, namely:

- The fundamental human reliability is contingent upon the inherent characteristics of the task at hand.
- Under ideal circumstances, the reliability level is expected to be consistently achieved within the nominal probability provided, falling within probabilistic limits.
- Recognizing the absence of perfect conditions in all scenarios, human reliability can foreseeably diminish based on the degree to which identified Error Producing Conditions (EPCs) are applicable.

In research using the HEART method, the role of experts is very important. The experts involved in this research are the Head of Occupational Health and Safety who has worked at PT. XYZ for 11 years. The following are the stages carried out in calculating Human Error Probability (HEP) using the HEART:

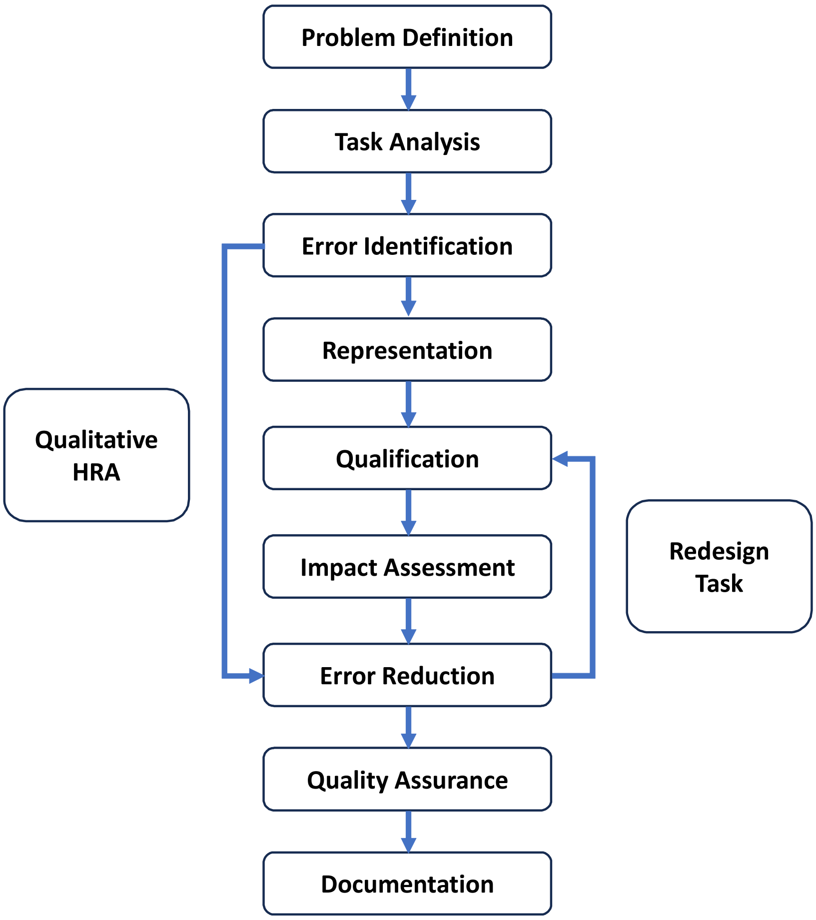

Figure 1. Human Reliability Assessment (HRA) Process

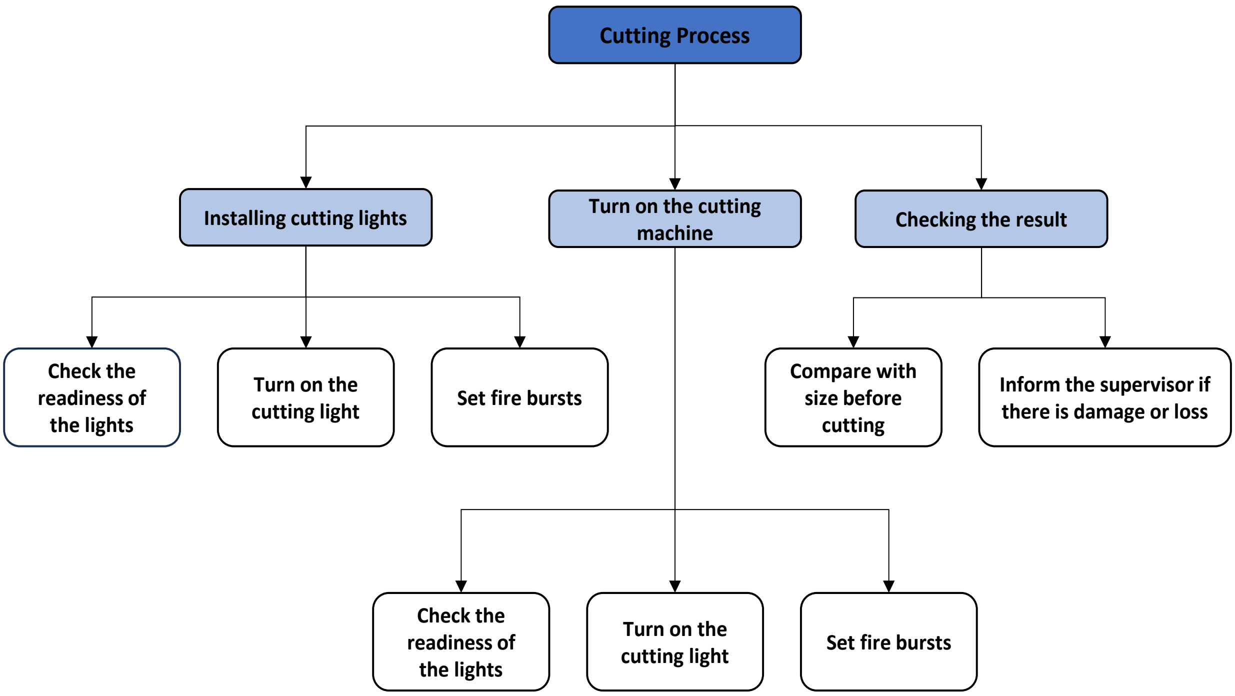

Figure 2. Hierarchical Task Analysis (HTA) of Cutting Process

Stage 1. Determine the Nominal Human Error Probability by using the Generic Task Type (GTT). At this point, the goal was to discover any inaccuracies that

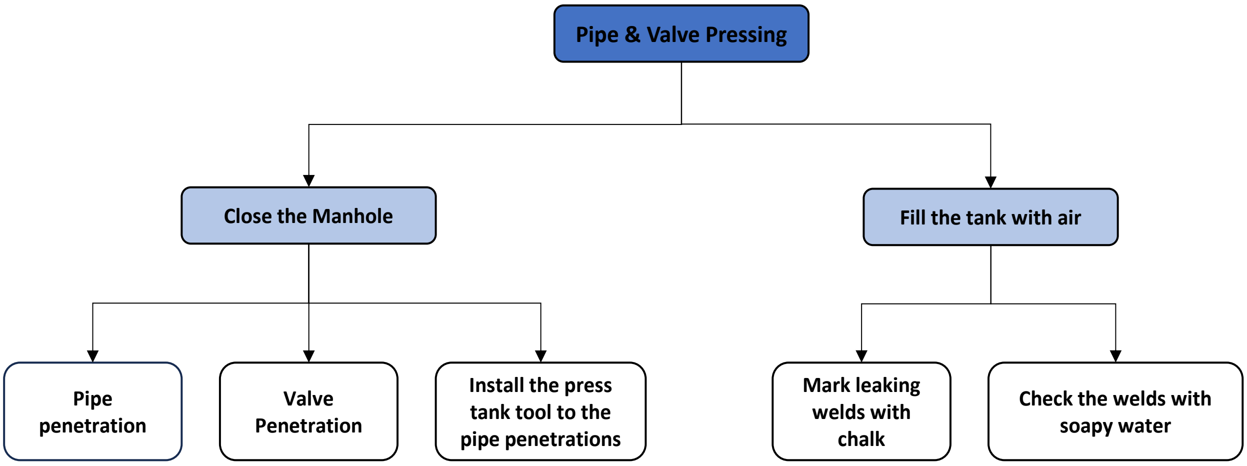

Figure 3. Hierarchical Task Analysis (HTA) of Pipe and Valve Pressing

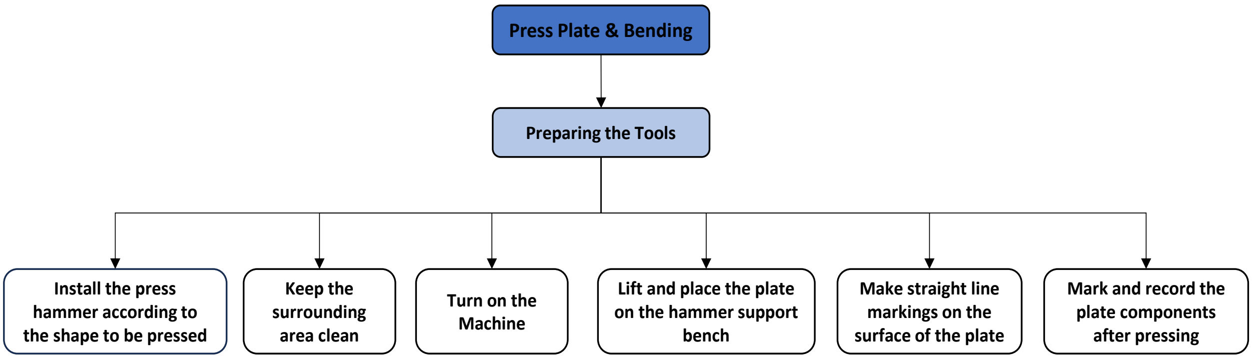

Figure 4. Hierarchical Task Analysis (HTA) of Press Plate and Bending

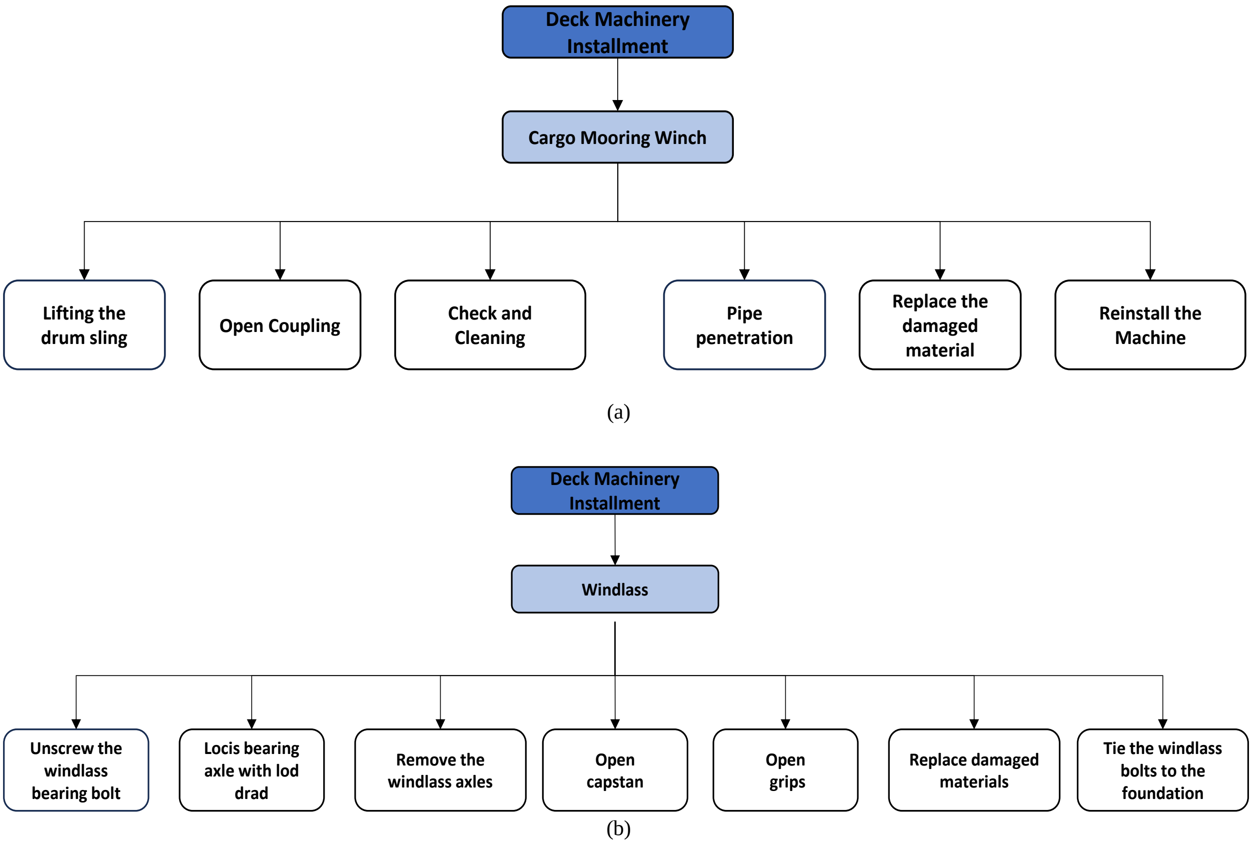

Figure 5. Hierarchical Task Analysis (HTA) of Deck Machinery Installment (a) Cargo Mooring, (b) Windlass

TABLE 1.
GENERIC TASK TYPE

Type	Generic Task Type	Nominal Human Error Probability	Range
A	Work/tasks that are completely unfamiliar/unmastered, done at a speed without clear consequences	0.55	(0.35 - 0.97)
B	Changing or returning a system to a new or initial state with a single effort without supervision or procedures	0.26	(0.14 - 0.42)
C	The work is complex and requires a high level of understanding and skill	0.16	(0.12 - 0.28)
D	A fairly simple job, done quickly or requiring little attention	0.09	(0.06 - 0.13)
E	Work that is routine, skilled, and requires a low level of skill	0.02	(0.007 - 0.045)
F	Restore or shift the system to its initial or new condition by following procedures, with several checks	0.003	(0.0008 - 0.007)
G	Familiar, well-designed, routine tasks occurring several times per hour, performed to very high standards by trained and experienced personnel with time to correct potential errors	0.0004	(0.00008 - 0.09)
H	Responding correctly to system commands there is even an additional automated monitoring system that provides accurate interpretation	0.00002	(0.000006 - 0.009)
M	There are no circumstances like the above	0.03	(0.008 - 0.11)

TABLE 2.
ERROR PRODUCING CONDITION

No	Error Producing Conditions (EPSs)	Maximum Effect Value affect HEP
Category I		
1	Unusual (rare or new) but important conditions	17
2	Lack of time available for operators to detect and repair failures	11
3	Lack of signs identifies warning signs of disruption in work	10
4	There are efforts to suppress or prioritize information or the existence of equipment that makes it easier to access information	9
5	There is no suggestion to convey special and functional information to operators in a format that operators can easily understand	8
6	There is a discrepancy between the model available to the operator and that imagined by the designer	8
7	There are no clear procedures for correcting unintentional work errors	8
8	The information received is excessive	6
9	It requires a different technique (method) than usual to do the job	6
10	There needs to be a transfer of certain knowledge in every job carried out, but without any information being reduced or lost	5.5
11	Ambiguity in the performance standards provided (performance standard boundaries are not clear)	5
12	There is a mismatch between the perception of risk and the actual risk that occurs	4
13	Feedback from the system is bad, ambiguous, or not as expected	4
14	Actions intended to control the work being done are unclear and late	4
15	Inexperienced operators (operators who have met the requirements to carry out their work, but are not yet considered experts)	3
16	The appropriateness of the desired information conveyed in procedures and interactions between workers is poor	3
17	Independent checks on the output (results) are few or may not be checked	3
Category II		
18	There is a conflict regarding short-term goals and long-term goals	2.5
19	The information received is not uniform, making the inspection process difficult	2.5
20	The operator's education level does not match the work requirements	2
21	There are incentives for operators to carry out other, more dangerous work procedures	2
22	Little time is given to train the mind and body when doing work	1.8
23	Unreliable equipment (by direct assessment)	1.6
24	It requires more skilled personnel than the operators who usually do their work	1.6
25	Allocation of duties and responsibilities is unclear	1.6
26	There is no clear way to maintain or increase supervision during work	1.4

might have been retrieved from the HEART Generic Categories table. Following the establishment of a hierarchy through the examination of current tasks, the nominal value of the chance of human error is ascertained by contrasting the nature of the task with the task categories found in HEART Categories and consulting with specialists using **Table 1**.

Stage 2. Identify the Error Producing Conditions (EPSs). To identify the EPCs, at this point, experts are consulted to identify EPCs that may result in errors for the job under analysis. The EPC is then assessed to determine the likelihood that errors or failures may result from it; its process is shown in **Table 2** below**.**

Stage 3. Determining the Assessed Proportion of Effect (APOE) and calculating the Assessed Effect (AE) Value of Each Identified EPC. The value of APOE is referred to in Table 3.

TABLE 3.
ASSESSED PROPORTION

Assessed Proportion	Description
0	EPC has no effect on HEP
0,1	Can affect HEP if EPC occurs frequently (frequency > 5 times per shift) and is accompanied by at least 3 other EPCs
0,2	Can affect HEP if EPC occurs frequently (frequency > 5 times per shift) and is accompanied by at least 2 other EPCs
0,3	Can affect HEP if EPC occurs frequently (frequency > 5 times per shift) and is accompanied by at least 1 other EPC
0,4	It can affect HEP if EPC occurs frequently (frequency > 5 times per shift) and without anything else
0,5	Can affect HEP if EPC occurs infrequently (frequency = 2-5 times per shift) and is accompanied by at least 2 other EPCs
0,6	Can affect HEP if EPC occurs infrequently (frequency = 2-5 times per shift) and is accompanied by at least 1 other EPC
0,7	Can affect HEP if EPC occurs infrequently (frequency = 2-5 times per shift) and is accompanied by others
0,8	It can directly affect HEP if one EPC occurs and is accompanied by at least 2 other EPCs
0,9	It can directly affect HEP if a single EPC occurs and is accompanied by at least 1 other EPC
1	It can directly affect HEP if a single EPC occurs without being accompanied by at least 1 other EPC

III. DISCUSSION

A. Identification of Potential Error Result

As the first stage to identify the Human Error Probability (HEP), the potential error of each job task in the Shipyard especially for the cutting process, pipe and valve pressing process, deck machinery assembly, sheet metal forming or bending process was identified. The identification of potential error for each task and NHEP value is shown in Table 4-7. Based on the analysis it can understand the potential error based on the expert's point of view and the worker's point of view.

TABLE 4.
POTENTIAL ERROR OF CUTTING PROCESS

Task	TASK ANALYSIS	POTENTIAL ERROR
Cutting Process	Check the readiness of the lights	The operator did not prepare the cutting light readiness
		The cutting light is not working
		The operator did not clean the nozzle
	Turn on the cutting machine	Cutting machine not working
		The operator did not attempt to direct the cutting machine
		The operator did not test the cutting machine
	Check the cut results	The operator did not pay attention to the cable hose
		The operator does not check the cutting results
		The operator does not compare the cut results

TABLE 5.
POTENTIAL ERROR OF PIPE AND VALVE PRESSING PROCESS

Task	TASK ANALYSIS	POTENTIAL ERROR
Pipe and Valve Pressing Process	Close manholes	Pipes leaks and air comes out because the pipe connection is not tight when the pressure test were executed
		The connection of the pipes is not tight, causing a gap so that it leaks because the valve installation is not tight
		The pipe cannot be penetrated so you don't know which part is leaking because you forgot to install the press tool
	Fill the tank with Air	When checking, we didn't know which parts had to be replaced and re-welded because the operator didn't mark the leaking welds
		Don't know which parts need to be repaired/rewelded because they didn't check the pipe for leaks

TABLE 6.
POTENTIAL ERROR OF SHEET METAL FORMING

Task	TASK ANALYSIS	POTENTIAL ERROR
Sheet Metal Forming	Install the hammer press according to the shape to be processed	The resulting plate did not match the shape requested by OS because installing the press hammer did not match the desired shape
	Maintain cleanliness around the location	The engine is exposed to oil droplets from oil and other objects because it is not kept clean
	Turn on the press machine	The operator buttons do not work properly, the hammer lowers and raises do not run smoothly because they do not check and note that all related equipment is functioning
	Lift and place the plate on the hammer support bench	Improper machine operation results in the hammer's position being inaccurate with the plate because the machine operator and plate worker are not focused
	Make straight line markings on the surface of the plate	The resulting curved or round shape is not precise because the marking lines are not straight with the pressure point of the hammer plate
	Note the plate components that have been processed	There is no work report data on parts and materials that have been completed because the components are not recorded

B. Result of Human Error Probability (HEP) Analysis

HEP were organized into an HEP Calculation Table. The HEP Calculation Table of the cutting process task 1 and task 2 were taken as an example as shown in Table 8. The compilation results of HEP for the cutting process, pipe, and valve pressing, deck machinery assembling process, and sheet metal forming or bending process is shown in Table 9-12.

TABLE 7.
POTENTIAL ERROR OF DECK MACHINERY ASSEMBLY

Task	TASK ANALYSIS	POTENTIAL ERROR
Deck Machinery Assembly	Lift the drum sling/mooring rope	Workers were scratched and pinched because they did not pay attention to the sling rotation and were in a hurry and did not use auxiliary lifting equipment
	Open coupling	The work process did not run optimally because a good wrench was not used
	Check and clean	New materials become dirty and cause them to wear out quickly because they are not checked for cleanliness
	Dismantle the gooseneck	The gooseneck was crushed because he didn't use a lifting tool/corkscrew
	Replace damaged materials	Data reports and repair prices do not match the agreement because they do not replace materials according to the OS list
	Put it back	The material becomes damaged quickly and does not function properly because the material is installed incorrectly according to the regulations
	Unscrew the windlass bearing bolt	The bolt installation process did not run optimally because the bolt position was not paid attention to
	Locis bearing axle with lod drad	The material becomes scratched quickly and wears out quickly because installation is not precise
	Remove the windlass axle	Damage to the material due to opening the axle not according to procedures
	Open capstan	Work results are not optimal due to negligence and not focusing while working
	Open grips	The grip becomes difficult to remove, the material becomes scratched because it does not provide grease when opening the grip
	Open the Grispy bush	The grips bush becomes difficult to remove, the material slips/gets stuck because it doesn't provide grease when opening the gypsy bush
	Replace damaged materials	Data reports and repair prices do not match the agreement because they do not replace materials according to the OS list
	Fasten the windlass bolts to the foundation	The windlass foundation is not strong and precise because it is not tight when installing the bolts

The human error probability value is defined by multiplying the Nominal Human Error Probability (NHEP), the total HEART effect (EPC), and the Assessed Proportion of Effect (APOE). To simplify the calculation of HEP, the identification, and calculation of

TABLE 8.
HUMAN ERROR PROBABILITY (HEP) CALCULATION

CUTTING PROCESS			
Check the readiness of the lights			
Potential Human Error	The operator did not prepare the cutting light readiness		
Generic Task Types (GTTs)	The work is complex and requires a high level of understanding and skill		
Nominal Human Error Probability (r)	**0.16**		
Error Producing Condition (EPCs)	**Total HEARTH Effect**	**Assessed Proportion**	**Assessed Effect**
	f_i	p_i	$AE= [p_i (f_i-1) + 1]$
No. 7	8	0.2	2.4
No. 20	2	0.2	1.2
No. 23	1.6	0.2	1.12
Human Error Probability (HEP) **$[rx\Pi p_i (f_i-1) + 1]$**	0.516096		
Potential Human Error	The cutting light is not working		
Generic Task Types (GTTs)	Work that is routine, skilled, and requires a low level of skill		
Nominal Human Error Probability (r)	**0.02**		
Error Producing Condition (EPCs)	**Total HEARTH Effect**	**Assessed Proportion**	**Assessed Effect**
	f_i	p_i	$AE= [p_i (f_i-1) + 1]$
No. 2	11	0.2	3
No. 7	8	0.2	2.4
No. 23	1.6	0.2	1.12
Human Error Probability (HEP) **$[rx\Pi p_i (f_i-1) + 1]$**	0.16128		

TABLE 9.
HUMAN ERROR PROBABILITY (HEP) CALCULATION OF CUTTING PROCESS

Process	Task Number	Generic Task Types (GTTs)	Nominal Human Error Probability	Total Assessed Proportion (AE)	Human Error Probability (HEP)
Cutting	No. 1	C	0.16	4.72	0.516
	No. 2	E	0.02	5.4	0.161
	No. 3	F	0.003	2.6	0.042
	No. 4	C	0.16	2.3	0.211
	No. 5	C	0.16	2.4	0.229
	No. 6	B	0.26	1.06	0.276
	No. 7	C	0.16	2.9	0.333
	No. 8	C	0.16	2.9	0.333
	No. 9	C	0.16	1.6	0.256

TABLE 10.
HUMAN ERROR PROBABILITY (HEP) CALCULATION OF PIPE AND VALVE PRESSING PROCESS

Process	Task Number	Generic Task Types (GTTs)	Nominal Human Error Probability	Total Assessed Proportion (AE)	Human Error Probability (HEP)
Pipe and Valve Pressing Process	No. 1	H	0.00002	4.72	0.516
	No. 2	H	0.00002	5.4	0.161
	No. 3	E	0.02	2.6	0.042
	No. 4	E	0.02	2.3	0.211
	No. 5	E	0.02	2.4	0.229

TABLE 11.
HUMAN ERROR PROBABILITY (HEP) CALCULATION OF SHEET METAL FORMING PROCESS

Process	Task Number	Generic Task Types (GTTs)	Nominal Human Error Probability	Total Assessed Proportion (AE)	Human Error Probability (HEP)
Sheet Metal Forming	No. 1	C	0.16	5.8	0.936
	No. 2	E	0.02	11.8	0.702
	No. 3	C	0.16	2.9	0.320
	No. 4	F	0.003	7.3	0.026
	No. 5	C	0.16	5.8	0.936
	No. 6	H	0.00002	4	0.00004

TABLE 12.
HUMAN ERROR PROBABILITY (HEP) CALCULATION OF DECK MACHINERY ASSEMBLY PROCESS

Process	Task Number	Generic Task Types (GTTs)	Nominal Human Error Probability	Total Assessed Proportion (AE)	Human Error Probability (HEP)
Deck Machinery Assembly	No. 1	C	0.16	5.7	0.864
	No. 2	E	0.02	6.5	0.18
	No. 3	C	0.16	3.5	0.48
	No. 4	F	0.003	5.8	0.01755
	No. 5	C	0.16	1.3	0.208
	No. 6	H	0.00002	3.5	0.00006
	No. 7	C	0.16	2.8	0.312
	No. 8	E	0.02	10.5	0.54
	No. 9	C	0.16	2	0.32
	No. 10	F	0.003	5.8	0.01755
	No. 11	C	0.16	1.3	0.208
	No. 12	H	0.00002	3.5	0.00004
	No. 13	C	0.16	1.3	0.208
	No. 14	H	0.00002	1.5	0.00002

As shown by the HEP analysis above, it can be seen that the sheet metal forming process had the highest HEP for task number 1 and number 5 with HEP = 0.936, followed by the deck machinery assembly process for task number 1 with HEP = 0.864.

IV. CONCLUSION

Based on the HEP result it can be concluded that the work process that is classified as critical is the press plate and bending frame process and deck machinery assembly process which is this process mostly causes defects in the production process at the shipyard. To minimize the defects in production,

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