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Probability Analysis of Human Error on Container Crane Operation Using SPAR-H Method

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Abstract

Container service company is one of the companies that carry out logistic activities. Where in these activities there are activities with marine terminal facilities which include loading and unloading equipment, warehouse, and dock. The company has container cranes as the main operational tool used for loading and unloading activities at the dock. Container crane operation is the highest accident rate viewed from accident data based on the equipment used. Most accidents are caused by human error. This study aims to analyze the probability of human error in container crane operation. This research is aim to analyze the probability of human error in container crane operation in this study with the Standardized Plant Analysis Risk Human Reliability Analysis Method (SPAR-H). SPAR-H was a method used to determine the results of HEP values and dependency factors. The highest HEP value is 0,315 which is found in the stage of container crane operation both in loading and unloading activities, containers, gantry movement, and open or close hatches.

Keywords*: human reliability assessmen, human error, SPAR-H*

1. Pendahuluan

Most of the logistic activities in Indonesia are carried out by 25 strategic ports located in 21 provinces in Indonesia. The container service company is one of the companies that carry out the logistic activities by providing container terminal facilities. Based on the Indonesian Central Statistics Agency which stated that there was an increase in loading and unloading activities of shipping both domestically and abroad in the 2005-2019 period, the provision of container terminal services at container service companies also increased. This affects the use of loading and unloading aids used by container service companies, namely container cranes. Container crane is the main operational tool for container service companies that are used for loading and unloading containers from ships to docks and so from docks to ships [1]. This can pose a potential danger that causes work accidents.

The operation of loading and unloading facilities has a potential hazard that will cause work accidents [2]. Data on work accidents in 2018-2020 involving loading and unloading equipment at the company, the incidence of accidents on container crane equipment has the highest percentage of 42%. Work accidents can occur due to several influencing factors including environmental factors, equipment or machinery factors, and human factors [3]. Based on preliminary research studies to classify the causative factors of work accidents in container crane operations, it was produced that most of the factors causing accidents came from human factors with 161 accidents. Meanwhile, the accidents with a factor of equipment of 31 events and environmental factors were 19 events. Human resources are the most important element in operating all resources in the company [4].

Two-thirds of accidents are caused by human error [5]. Also, operator ability is a factor causing a high human error [6]. Human error is an inappropriate human decision or behavior that can potentially reduce the effectiveness, safety, or performance of the system [7]. There are 3 types of errors that must be considered in conducting human error analysis, including omission error, extraneous act, and action error [8]. According to Heinrich, human error is the main cause of work accidents [9]. Several factors cause human error including lack of knowledge, information, violation of regulations, and poor communication [10]. Therefore, it is necessary to analyze to prevent accidents due to human error by identifying human error probability.

This study uses the SPAR-H method to analyze the probability of human error in container crane operating work. SPAR-H method has advantages and disadvantages. It has been described in a review conducted on HRA methods [11].The advantages possessed by SPAR-H are the 8 PSF covers many situations where a more detailed analysis is required and dependency models

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such as THERAPY can be used to handle event-sequence dependencies. The SPAR-H method has advantages as a method that can be applied more widely and is easy to use [12]. While the weakness of SPAR-H is no explicit guide for more PSFs if needed.

The SPAR-H method is a method that can be used to calculate the probability of human error. This method uses several factors such as time availability, stress, complexity, experience, and training, fitness, ergonomics, work procedures, and processes. From these factors, it can be known the factors that cause the highest probability of human error so that the right solution can be known.

2. Methods

This research was conducted at a container service company which is engaged in loading and unloading activity of goods. This research is directed at taking action that aims to solve the problem of work accidents caused by human error in the work of container crane operation. The method used in this study is the SPAR-H (Standardized Plant Analysis Risk Human Reliability Analysis Method). The SPAR-H method is used to determine the probability value of human error as the cause of the accident. There are several stages in this research, including preliminary research, data collection, data processing, analyzing data processing, and concluding the final results of the study.

Data processing stage begins with compiling a Hierarchical Task Analysis (HTA), where the HTA is compiled using work instruction data for container crane operating work. Furthermore, data processing using the SPAR-H method is as follows:

1. Determination of action/diagnosis activities
2. Determination of the value of 8 Performance Shaping Factors (PSF)

Table 1. The Performance Shaping Factors Value

PSF	PSF Level	Multipliers
Time Availability	Inadequate time	P (failure) = 1,0
	Barely enough time	10
	Nominal	1
	Time available ≥ 5x time required	0,1
	Time available ≥50x time required	0,01
	Not enough information	1
Stress	Extreme	5
	High	2
	Nominal	1
	Not enough information	1
Complexity	High complexity	5
	Moderate complexity	2
	Nominal	1
	Clear diagnosis	0,1
	Not enough information	1
Experience/ training	Low	10
	Nominal	1
	High	0,5
	Not enough information	1
Cue	Not available	50
	Incomplete	20
	Available, but poor	5
	Nominal	1
	Diagnosis oriented	0,5
	Not enough information	1
Ergonomic	Misleading	50
	Poor	10
	Nominal	1
	Good	0,5
	Not enough information	1

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Fitness for duty	Poor Relegated fitness Nominal Not enough information	P (failure) = 0,1 5 1 1
Work process	Poor Nominal Good Not enough information	2 1 0,8 1

Based on Table 1, there are 8 Performance Shaping Factors (PSF), namely time availability, stress, complexity, experience/training, cue, ergonomic, fitness for duty, and work process.

3. Calculation of the value of Human Error Probability (HEP)

HEP calculation can be done after calculating the composite PSF value. Composite PSF value can be generated by multiplying the values in each PSF. After that, the value of HEP diagnosis and action can be calculated based on the type of work. If the activity is classified as action and diagnosis, then the combined HEP is calculated.

$$HEP(Diagnosis) = \frac{NHEP\ x\ PSF\ Composite}{NHEP\ x\ (PSFComposite - 1) + 1} \quad (1)$$

Where:
NHEP(Diagnosis) = 0,01

$$HEP(Action) = \frac{NHEP\ x\ PSF\ Composite}{NHEP\ x\ (PSFComposite - 1) + 1} \quad (2)$$

Where:
NHEP(Action) = 0,001

$$HEP(Total) = HEP(Action) + HEP(Diagnosis) - [HEP(Action) \times HEP(Diagnosis)] \quad (3)$$

4. Determination of the value of the dependency factor

Table 2. The Dependency Factor

Condition	**Crew (s/d)**	**Time (c/nc)**	**Location (s/d)**	**Cue (a/na)**	**Dependency**
1	s	c	s	na	complete
2				a	complete
3			d	na	high
4				a	high
5		nc	s	na	high
6				a	moderate
7			d	na	moderate
8				a	low
9	d	c	s	na	moderate
10				a	moderate
11			d	na	moderate
12				a	moderate
13		nc	s	na	low
14				a	low
15			d	na	low
16				a	low

Based on Table 2, there are 4 criteria of dependency factor. The dependency factor assesses whether stages 1 and 2 are carried out by the same person (s) or different (d), whether the distances for working on stages 1 and 2 are close (c) or far apart (nc), whether the location for carrying out the stages of work is a different location (d) or same location (s), as well as whether there is container crane operation cue (a) or not (na). For complete dependency has a probability of failure with value of 1. For high dependency, it can calculate the probability of failure.

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$$\frac{(1+\frac{Pw}{Od})}{2} \quad (4)$$

Where:

Pw/od = HEP(Action)+ HEP(Diagnosis)

For moderate dependency can calculate the probability of failure.

$$\frac{[1+\left(6x\frac{Pw}{od}\right)]}{7} \quad (5)$$

Where:

Pw/od = HEP(Action)+ HEP(Diagnosis)

For low dependency can calculate the probability of failure.

$$\frac{[1+\left(6x\frac{Pw}{od}\right)]}{20} \quad (6)$$

Pw

Where:

Pw/od = HEP(Action)+ HEP(Diagnosis)

3. Methods

3.1 Hierarchical Task Analysis (HTA)

This research was carried out in the preparation of HTA. Where HTA is compiled based on work instructions for operating container cranes. HTA is created based on conditions that existed in the field when the work was carried out. HTA is a human relationship with work equipment in a work process, so that it can be seen in the stages of work carried out by humans.

Container crane operation has 6 main tasks. Task 1 covers general operator preparation which consists of 4 subtasks, task 2 covers operator preparation before operation which consists of 9 sub-tasks, task 3 covers unload and load container which consists of 12 sub tasks, task 4 covers gantry moving which consists of 6 sub-tasks, task 5 covers open or close activity of hatch cover which consists of 6 sub-tasks, and task 6 covers container crane operation completion which consists of 3 sub-tasks.

3.2 SPAR-H Method

a. Diagnosis or Action Activity

Container crane operation work process is included in diagnosis and action activities. Based on interviews with expert judgment, container crane operation is said to be a diagnostic activity because it requires knowledge and experience of the container crane operator in planning and determining appropriate movement such as host up or hoist down, gantry, also boom up and down movements. Meanwhile, it is said to be an action activity because the operation of a container crane consists of stages that require the knowledge and experience of the container crane operator; it uses written instructions in the form of work instructions for container crane operation.

b. Performance Shaping Factors (PSF)

PSF values consist of available time, stress, complexity, experience, procedure, ergonomic, work process, and fitness. In the available time factor, container crane operation there are 2 variations of values 1 and 10. Value 1 means nominal which is enough time to do the work stages and value 10 means barely enough time to do the work stages. The stress factor has 2 values, there are 1 which is nominal, and 2 which is the stress experienced by workers is quite high.

The level of time availability for sub tasks 1.1 to 6.3 stated nominally with a value of 1 in several sub-tasks and stated time to do work is almost inadequate with a value of 10 in several other sub-task such as sub-task 2.9. the stages are declared nominal, meaning that the available time is slightly greater than the time needed to do the work or the time to carry out the stages of work is adequate so that there is no shortage of time. Meanwhile, it is stated that the time is almost inadequate, because the available time is almost the same as the time needed to do the work. So that the time to do the work is almost inadequate. Stages of work with a value of 10 relate to the coordination process of workers and checking by the operator requires a little more time.

The stress level in sub tasks 1.1 to 6.3 is declared nominal with a value of 1, except for several other sub tasks such as subtask 3.3 which is stated to be high with a value of 2. Sub tasks which are declared nominal mean that the stress experienced by the operator is still conductive, which means the operator does not feel their mental burn so as not to affect the work of the container crane operation. Meanwhile, it is stated as high, because the stress level at that stage is higher than nominal. The stages are declared to have a high level of stress because the operating work is quite influenced by the work target.

The level of complexity in sub-tasks 1.1 to 6.3 is stated as nominal with a value of 1, except for some sub-tasks such as 3.7 which is stated to be moderate complexity with a value of 2. The level of complexity is stated as nominal because the work is not difficult to do. While the sub-task is considered moderate complexity because the stages of work require planning in the form of a vessel plan and planning carried out by the operator before carrying out the hoist down movement.

The experience factor in sub tasks 1.1 to 6.3 is stated to be high with a value of 0,5, because the operator has years of experience in container crane operation work. The cue in subtasks 1.1 to 6.3 is declared nominal with a value of 1, because the container crane operation procedure in the form of work instruction is available and can be implemented by the operator. Ergonomic or human-machine interface in 1.1 to 6.3 is declared good with a value of 0,5. The sub task is considered good because the equipment, layout, or operator interaction with the equipment is good. Making it easy for the operator to carry out the stages of work.

Fitness for duty for 1.1 to 6.3 is declared as graded fitness with a value of 5. Graded fitness is assessed because container crane operators can do work and are provided with a place to rest before work starts or after work is finished. But based on interviews with expert judgment, almost the cause of accidents are the fatigue condition of the operator which affects performance in operating the container crane.

The work process in sub-tasks 1.1 to 6.3 is declared good with a value of 0,8 because performance is not affected by the work process. This means that the performance of the container crane operator is adequate and information related to the work process is available. For example, changing shifts between operators accompanied by good communication and a shift team leader operator and operators. For procedure factor, container crane operation has a work instruction as a procedure. So the value is 1 which is nominal.

c. Human Error Probability (HEP) Value

HEP value calculation is based on the results of determining PSF factors. When it comes to determining the value of PSF, each expert judgment does not always have the same opinion regarding PSF. Based on the guideline, if there is a difference in determination of the value then the PSF is taken which is the lowest [13]. The calculation of the HEP value can be exemplified in sub task 1.1 with a PSF Composite value of 1. Then calculate the value of the HEP action and HEP diagnosis which resulted in a value of 0,001 and 0,01. The last is to calculate the combined HEP value that resulted in a value of 0,011.The result of the HEP calculation can be seen in Table 3.

Table 3. The Result Of Calculation Hep Value

Sub Task	PSF Composite	HEP_{Action}	$HEP_{Diagnosis}$	HEP Total
1.1	1	0,001	0,01	0,011
1.2	1	0,001	0,01	0,011
1.3	1	0,001	0,01	0,011
1.4	1	0,001	0,01	0,011
2.1	1	0,001	0,01	0,011
2.2	1	0,001	0,01	0,011
2.3	1	0,001	0,01	0,011
2.4	1	0,001	0,01	0,011
2.5	1	0,001	0,01	0,011
2.6	1	0,001	0,01	0,011
2.7	1	0,001	0,01	0,011
2.8	1	0,001	0,01	0,011
2.9	10	0,01	0,092	0,101
3.1	10	0,01	0,092	0,101

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Sub Task	PSF Composite	HEP $_{Action}$	HEP$_{Diagnosis}$	HEP Total
3.2	1	0,001	0,01	0,011
3.3	2	0,002	0,02	0,022
3.4	10	0,01	0,092	0,101
3.5	10	0,01	0,092	0,101
3.6	10	0,01	0,092	0,101
3.7	2	0,002	0,02	0,022
3.8	40	0,038	0,288	0,315
3.9	2	0,002	0,02	0,022
3.10	40	0,038	0,092	0,315
3.11	1	0,001	0,01	0,011
3.12	10	0,01	0,092	0,101
4.1	1	0,001	0,01	0,011
4.2	40	0,038	0,288	0,315
4.3	40	0,038	0,288	0,315
4.4	1	0,001	0,01	0,011
4.5	2	0,002	0,02	0,022
4.6	2	0,002	0,02	0,022
5.1	40	0,038	0,288	0,315
5.2	2	0,002	0,02	0,022
5.3	1	0,001	0,01	0,011
5.4	4	0,038	0,039	0,043
5.5	1	0,001	0,01	0,011
5.6	10	0,01	0,092	0,101
6.1	1	0,001	0,01	0,011
6.2	1	0,001	0,01	0,011
6.3	1	0,001	0,01	0,011

Based on Table III above, it shows that the highest HEP value is located in 5 sub-tasks with a HEP value of 0.315. It means that the probability of human error is 31,5%. The five sub-tasks are the stages of container crane operation, both in loading or unloading containers, gantry movement, and open or close hatches. The sub-task has the highest HEP value due to factors of time availability, stress, ergonomics, and fitness. The stage of work is a coordination stage that requires more operator attention so that it takes a little more time to complete the work. In addition, ergonomic factors in the form of communication equipment are judged to be lacking by expert judgment and vehicle traffic often causes the operator's concentration to be disturbed. Furthermore, the determination of dependency factors can be carried out as follows.

The lowest HEP value is in most of the sub tasks with an HEP value of 0,011 or the probability of human error is 1,1%. The stages with the lowest HEP are mostly found in the general operator preparation stage, operator preparation before the operation, and the container crane completion stage. This stage has a low probability of human error because it is a stage of work that is quite easy for operators to complete. The higher the PSF value, the higher the HEP value produced [14].

Value of HEP can be high if there is no availability of time to carry out stages of work and complexity work that requires more energy which can cause work fatigue and stress to the operator. In addition, it can be caused by operators who do not have experience or training as well as other factors such as work ergonomics and poor work processes. Also work procedures do not exist or are difficult to implement. Otherwise, the HEP value can be low value if there is sufficient time available and the work is not complicated. That it does not require a lot of free thought and effort. In addition, work procedures that are available and easy to apply, experience or operator training as well as good ergonomics and work processes are factors in the low HEP score.

d. Dependency Factor

The dependency factor is an error relationship on a job. Determination of the value of dependency is determined by discussing with an expert judgment regarding 4 criteria of dependency factors, namely worker, time, location, and cue when operating the container crane. The calculation of the HEP value can be exemplified in sub task 1.4. Determination of 4

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dependency factors in sub task 1.4 considering the stages before and after, namely 1.3 and 2.1.Worker on sub tasks 1.3, 1.4, 2.1 are carried out by the same person (s), namely the container crane operator.

The time factor in sub task 1.4 is considered close (c), because even though sub tasks 1.3, 1.4, 2.1 have a pause, the pause does not take a long time. Location between sub tasks 1.3, 1.4, and 2.1 performed at different locations (d). The procedure for sub task 1.4 is available (a) as a container crane operator guide. Based on the description, sub task 1.4 includes dependency high criteria with the failure probability value of 0,505. The result of determining the dependency factor can be seen in Table 4.

Table 4. The Result Of Dependency Factor

Sub Task	**Criteria**	**Dependency Value**
1.1	Complete	1
1.2	Complete	1
1.3	Complete	1
1.4	High	0,505
2.1	High	0,505
2.2	Complete	1
2.3	Complete	1
2.4	Complete	1
2.5	Complete	1
2.6	Complete	1
2.7	Complete	1
2.8	Complete	1
2.9	Complete	1
3.1	Complete	1
3.2	Complete	1
3.3	Complete	1
3.4	Complete	1
3.5	Complete	1
3.6	Complete	1
3.7	Complete	1
3.8	Complete	1
3.9	Complete	1
3.10	Complete	1
3.11	Complete	1
3.12	Complete	1
4.1	Complete	1
4.2	Complete	1
4.3	Complete	1
4.4	Complete	1
4.5	Complete	1
4.6	Complete	1
5.1	Complete	1
5.2	Complete	1
5.3	Complete	1
5.4	Complete	1
5.5	Complete	1
5.6	Complete	1
6.1	Complete	1
6.2	Complete	1
6.3	Complete	1

Based on Table IV above, it shows 2 variations of dependency values, namely complete dependency, and high dependency. Sub tasks that have a complete dependency category because the workers at that stage are the same, the time with the stages after or before is the same, the location of the work is the same, and there are procedures at that stage of work. While the sub-task with the high dependency category because the worker at that stage is the same, the time with the stage

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after and before the same, there is a procedure at that stage, but the location of the work is different from the location at the previous stage of work.

Sub task 1.4 and 2.1 belongs to dependency high criteria. The dependency value is amount of success or failure in sub task that affects the next sub-task. Based on the above calculation, sub task 1.4 and 2.1 have a high dependency value of 0,505. This means that this subtask has an effect of approximately 50,5% on the success or failure of the next subtask. Sub-task with high dependency value have the second highest dependency level after complete dependency, which means sub-tasks with high dependency have a fairly high influence. It is adjusted to the dependency calculation value that has been obtained.

4. Conclusion

The result of determining the probability value of human error using the SPAR-H method obtained 5 variations of the HEP value. Where the highest HEP value is on the 5 stages of container crane operation work, which is 0,315. This is due to the availability of time to complete work, stress experienced by workers, poor ergonomics, and graded fitness. While the lowest HEP value is found in most stages of preparation and completion of container crane operation 0,011.

Value of dependency container crane operation resulted in 2 dependency criteria, namely complete with value is 1 and high dependency with value is 0,505. High dependency criteria are obtained in sub- task 1.4 and 2.1 because one of the criteria is the location between stages of work before and before being different. The criteria of worker, time, and procedure have the same criteria as other stages, namely the stages of work carried out by the same worker. The time between is close and the procedure in work operation of container crane is existing. To prevent accidents due to human error, it is recommended to carry out refresher training activities according to the law number 1 1970 chapter 9.

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