Human error probability analysis of overhead crane operation in steel fabrication company using SLIM-DEMATEL-ANP method

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Abstract. The accident record from a steel fabrication company in 2014-2017 shows that the most frequent accidents take place in overhead crane operation with a percentage of 42%. The overhead crane operation has the greatest potential of accidents with human error as the main cause. The purpose of this study is to determine what factors affect the occurrence of errors, to know how much HEPs, and to determine recommendations. The method used in this research is Success Likelihood Index Method (SLIM) with qualitative development using Decision Making Trial and Evaluation Laboratory (DEMATEL) which aims to establish the relationship among PSFs to be an easily comprehensible structured model by considering expert judgements and to solve dependency in a set of criteria. Analytic Network Process (ANP) is used to overcome the inconsistency of expert judgements and difficulty in selection and weighting. The calculation and analysis reveal that the highest Human Error Probability (HEP) value is shown by the task to handling or lifting with the value 0.000485. Impact assessment using the HEP value to determine probability and consequence is performed by expert judgements. Improvement recommendations are prioritized for high rating error tasks using Error Reduction Analysis.

1 Introduction

This research was conducted in a steel fabrication company with a high accident rate for the past four years. Of the total 31 accidents, 13 of them were overhead crane accidents. Most of the accidents were caused by human error. One example is as follows: An operator was ordered to handle a material and adjust its weight specification, but in fact he did not perform one of the steps correctly as work instruction described. The material weight

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specification was not adjusted with the overhead crane capacity and caused it to fall to the ground. Thus, it is necessary to evaluate this kind of accident by using Human Reliability Assessment (HRA). HRA involves the use of qualitative and quantitative methods to assess the human contribution to risk [1]. HRA can also enhance the profitability and availability of systems via human error reduction / avoidance, though the main drive for development and application of HRA techniques has so far come from the risk assessment and reduction domain. According to [1], 17 of the 35 HRA methods were applied to the safety field. The HRA method chosen and at least includes the consideration of five from the total of six HRA experts is THERP and SLIM [2]. According to [2], SLIM is the most flexible method compared to other HRA methods.

Previous research [3] developed a new method of AHP-SLIM to solve the subjectivity of expert judgments by quantification and affirmation of consistency, but the integration of AHP and SLIM methods performed assumed to be independent and research aimed to know HEP. In the study[4], developing a SLIM method is limited to know the value of HEP. The SLIM method has drawbacks such as difficulties in PSF selection and also its weighting difficulties [2]. Prior to that, ANP and DEMATEL had been applied to production economics, engineering management, computers and industrial engineering [5 - 10]. The application of both methods has not been integrated, but is limited to the application of ANP for selection of product, a potentially valuable method to support the selection of projects in a research and development environment. The integration of ANP and DEMATEL in decision making has not been applied in the field of HRA. This research integration of SLIM-DEMATEL-ANP method to solve the human error problem on the work of overhead crane operators. Assessment of relationships between PSFs is identified through the Decision Making Trial and Evaluation Laboratory (DEMATEL). Therefore it requires precautionary and controlling steps with one HRA method that is approach of SLIM-DEMATEL-ANP. The Assessment identification of the relationship between PSF and DEMATEL to establish relationships between PSFs to be easily understood structured models taking into account expert input in identifying the relationship assessment between PSFs. Then ANP is chosen because of the inconsistency of the expert judgment, difficulty in selection or weighting, and overcoming the dependency problem between PSF. In this study, an impact assessment was conducted with the objective of the impact assessment function to reduce the risk level and focus on main factors causing the accident, then the Error Reduction Analysis stage applied to provide improvement recommendations [2].

The purpose of this study is to determine what factors affect the occurrence of errors on the work overhead crane operation in steel fabrication companies, to know how much the probability of human error on the work overhead crane operation in steel fabrication companies with SLIM-DEMATEL-ANP approach, and to determine recommendations to reduce the probability of human error in overhead crane operation work in steel fabrication companies.

2. Method

2.1 Success Likelihood Index Method (SLIM)

SLIM, one of the technique used in the field of HRA, aims to analyze the possibility of human error which occurs in a system and can provide improvements in all levels of safety [2]. Steps in applying SLIM method of [11] are as follows:

1. Identify the problem, predict the errors qualitatively, and represent them
2. Determine the suitable PSF
3. Rate each PSF on each task
4. Determine the right value
5. Calculate the SLI

$$SLI_J = \sum R_{ij} W_i \quad (1)$$

6. Convert SLI into HEP

$$Log\,(POS) = aSLI + b \tag{2}$$

$$HEP = 1 - POS \tag{3}$$

2.2 Decision Making Trial and Evaluation Laboratory (DEMATEL)

DEMATEL is a comprehensive method for building and analyzing a structural model involving causal relationship between complex factors [9]. Based on [9], the five main stages in applying DEMATEL are as follows:

1. Generate the direct-relation matrix
2. Normalize the direct-relation matrix

$$X = k \times A \tag{4}$$

$$k = \frac{1}{\underset{1 \le i \le n \Sigma j = 1 aij}{Max}\ i, j = 1,2,..,n} \tag{5}$$

3. Attain the total relationing matrix

$$T = X\left(I - X\right)^{-1} \tag{6}$$

4. Produce causal diagram

$$T = [tij]_{n \times n'}\ i, j = 1,2,...,n \tag{7}$$

$$D = \left[\Sigma^{n}_{j=1} tij\right]_{n \times 1} = [ti]_{n \times 1} \tag{8}$$

$$\kappa = \left[\Sigma^{n}_{j=1} tij\right]_{1 \times n} = [tj]_{n \times 1} \tag{9}$$

5. Obtain the inner dependence matrix and impact diagraph

2.3 Analytic Network Procces (ANP)

The Analytic Network Process (ANP) is a new theory that extends the AHP to cases of dependence and feedback and generalizes on the supermatrix approach[12]. It allows interactions and feedback within clusters (inner dependence) and between clusters (outer dependence). It is implemented in the SuperDecisions software.

3. Data Analysis and Discussion

3.1 Human Error Identification

In this research three experts were selected and interviewed. They are from overhead crane operator, HSE inspector, and engine and mechanical supervisor. Based on the literature study and expert judgments, 10 PSFs which affected the occurrence of the error were determined. These factors are procedure, physical condition, workplace condition, complexity, mental state, skills, training, experience, workload, and cooperation.

3.2 Relationship among PSFs

Based on the PSF determination, an assessment of the relationship among 10 PSFs were conducted by expert judgments along with DEMATELs questionnaires and ANPs pairwise comparison which were filled out in a group discussion. The calculations uses formula 4 – 9 of 2.9 subsections. Factors that affect each other can be seen in Table 1 below.

Table 1. Total value matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1		0.842	0.762		0.783		0.762			0.808
F2	0.783	0.827	0.871	0.823	0.868	0.817	0.871		0.778	0.895
F3		0.793								0.784
F4		0.820								0.762
F5	0.766	0.911	0.827	0.781		0.798	0.852		0.785	0.874
F6		0.842	0.762				0.762			0.783
F7		0.886	0.850	0.779	0.846	0.796		0.765	0.784	0.872
F8		0.889	0.832	0.787	0.827	0.802	0.831			0.828
F9		0.819								0.761
F10		0.866	0.812		0.783		0.811			

Table 2. Priority value and variable influence of other variables.

	Dij	Rij	D - R	D + R		Dij	Rij	D - R	D + R
F1	7.380	6.953	0.427	14.333	**F6**	7.380	7.559	-0.179	14.939
F2	8.293	8.495	-0.202	16.788	**F7**	8.061	7.859	0.202	15.920
F3	7.136	7.859	-0.724	14.995	**F8**	7.858	6.958	0.900	14.816
F4	7.160	7.374	-0.214	14.534	**F9**	7.154	7.154	-0.001	14.308
F5	8.079	7.829	0.250	15.908	**F10**	7.631	8.092	-0.460	15.723

The notation factor of PSFs at Table 1 are (Procedure) F1, (Physical condition) F2, (Workplace condition) F3, (Complexity) F4, (Experience) F5, (Mental state) F6, (Skills) F7, (Workload) F8, (Training) F9, (Cooperation) F10. The Table 1 shows the matrix values that exceed the threshold value 0.761 which are called the inner dependence matrix. From Table 2, calculation (D+R) shows that the most important PSF is physical condition. The highest PSF which giving highest effect to others is workload with the (D-R) values 0.900. The PSF which accepting the highest effect is workplace condition. So, the conclusion from DEMATEL calculation are value (D-R) positive is a cause and value (D-R) negative is effect. The total value matrix is then used to input in the ANP method.The total value matrix is then used to input in the ANP method.

3.3 Weighting PSF

The weight value of the PSF with ANP with super decisions software which affects the human error occurrence in overhead crane operation can be seen in the following Table 2 from the highest weight.

Table 3. Weighting PSF.

PSF	Normalization Weight	PSF	Normalization Weight
Skills	0.32283	Experience	0.08582
Workload	0.18498	Complexity	0.04044
Physical condition	0.15768	Procedure	0.02849
Cooperation	0.11755	Workplace condition	0.02349

PSF	Normalization Weight	PSF	Normalization Weight
Mental state	0.02823	Training	0.01050

From Table 2, the highest weight is skills. The description of skills are lack of skill in preparing documents and lifting. Skills have the highest weight due to influence from procedure, mental state, cooperation, workload, experience, and physical condition based on total matrix value.

3.4 PSF Rating, SLI Calculation, POS, and HEP

After performing assessment, calculation of SLI by formula 1, POS by formula 2, and HEP by formula 3 on the 23 subtasks of overhead crane operation, the task that have the highest HEP value can be seen in Table 3 below.

Table 4. SLI, POS, HEP.

No	Task	PSF Rating										SLI value	POS	HEP
		Experience	conditionPhysical	conditionWork place	stateMental	Procedure	Complexity	Workload	Skills	Training	Cooperation			
												4.9859	0.99951	0.000485
7.2	Ensure the lifting team is coordinated	5	7	5	6	7	4	6	5	6	4			

From Table 3, the highest HEPs value is 0.000485. HEPs value got influence that experience, skills, cooperation, and poor understanding in complexity. Lack of experience can affect workers in completing work. Workers become less skilled because they feel the job is complicated, thus requiring good support and team coordination to get things done right and not making any mistakes. Task 7.2 in the work instruction has explained that prior to handling or lifting, the worker must ensure that the lifting team is coordinated. Procedurally, task 7.2 already exist in the company's work instruction. Dependency among PSF giving influence of the successful task.

3.5 Impact Assessment

Furthermore, an impact assessment is done through error identification, risk assessment, and error reduction analysis.

Table 5. Impact assessment.

No	Task	Possible Error	Impact	HEP	Likelihood	Consequence	Risk Rating
7.2	Ensure the lifting team is coordinated	No team coordination	No supervision, No checks before lifting process, workers injured by collision and falling objects	0.000485	3	4	H

From Table 5, the possible consequence of task 7.2 are no supervision, no checks before lifting process before lifting process, and workers injured by collision and falling objects. The recovery points is ensure the completeness of team members. So, recommendation of the remedial actions are increasing competent with conducting internal training to the overhead crane operation team, performance shaping factors – based error reduction with tasks divison in accordance with the jobdesk of the team members and perform regular team evaluation.

4. Conclusion

A company should assessing human factors which caused accident especially a company with high human operation in manufacture process. Many factors of accident have dependency one to other so it will develop an accident tragedy. In this study, factors that identified with DEMATEL methods which affected each other and caused human error are experience, physical condition, workplace condition, mental state, procedure, complexity, workload, skills, training, and cooperation. The highest HEPs value is in task before handling or lifting, the workers make sure the team is coordinated with the HEP value 0.000485. HEPs value indicate that the task is the most error which develop the overhead crane operation accident. Then, priority recommendations are given based on error reduction analysis in tasks with the highest rating, as follows:

a. Performance shaping factors – based error reduction aims to decide the possibility of error reduction measures that can be used to reduce the impact of PSF on work performance.
b. Increasing competent aims to improve the operator's competence in controlling errors through training.

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