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ORIGINAL ARTICLE

The Use of Accident Indicators for Risk Assessment Monitoring in Design and Construction Phase of Pelletizing Project, 2016-2017

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ABSTRACT

To preserve workforce and reduce accidents, requirement in industrial HSE management system relies on prevention before occurrence. The aim of this study was to evaluate the safety conflicts by preliminary hazard analysis (PHA) method and monitoring of subjective risk assessment by safety performance indicators. This descriptive–analytical study was carried out on 30 jobs in the Yazd pelletizing project in the 2016-2017. After classifying risks in Preliminary Hazard List (PHL), severity and probability of the risk and the initial risk assessment code (RAC1) were calculated. Acceptance risks were eliminated of the PH L, and the remainder for corrective actions was recorded in the form of PHA and then the secondary risk assessment code (RAC2) was determined. Annual safety performance indicators were also calculated for these jobs and finally, statistical analysis was conducted on the relationship between mentioned indicators and the results of risk assessment. In order to determine the relationship between RAC1 and safety performance indicators (AFR, ASR, and FSI), a Pearson correlation coefficient was calculated. Among different occupations, the highest accident frequency rate and risk related to welding jobs. The relationship between RAC1 and RAC2 showed a significant difference between risk assessment code before and after corrective action. Our result was an indicative of the effectiveness of corrective actions. Regarding the monitoring of risk assessment by accident indicators and significant relationship between them, subjective risk assessment research can be used for further safety in working environments.

KEYWORDS: *Monitoring of risk assessment, PHA, Accident indicator*

INTRODUCTION

Preliminary Hazard Analysis (PHA) was first used in the 1950s in the US for the analysis of Liquid-propellant rocket where it proved to be successful indicator of the risk factors. PHA was applied in various industries, e.g. chemical industry and nuclear industry [1] . The PHA is an analysis, and evaluation of the generic hazard groups in a system and recommendations for their control during design and construction phase of a system life cycle [2- 3].

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"PHA is one of the most widespread methods for identification and qualitative or semi-qualitative risk analysis. It may take a variety of different forms to be suited to different forms of activity" [4]. The PHA has been applied for assessing and documenting the risks of new or altered systems [6].

PHA can be adopted as a comprehensive method for risk assessment in partly simple and small systems [5]. In exact and detailed analyses like Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA), the PHA method acts as a prerequisite for the analysis [7].

If potential risks and consequences are correctly identified, PHA shows a risk rate very close to actual risk in environment [8].

In a study, the relation between mortality and injuries has been investigated by using risk analysis in changing process; the risk of possible losses and injuries in involved activity is acceptable. Conducting a development plan did not show a significant effect on the society's risk [9].

Many other studies have presented a beneficial effect of implemented PHA method of risk assessment in altered systems [10-13].

Providing Preliminary Hazard List (PHL) precedes PHA. The PHL is an analysis technique to identify and list potential

hazards and mishaps in a system. The PHL is performed during conceptual or

preliminary design and is considered as a starting point for all subsequent hazard analyses. PHL can be designed based on checklists and reports of accidents and events [1,6,14].

In a study in peaking power plant, implementing PHL was leads to better identification of hazards risk factors. Using new approach 17 hazards were reported in their study [15].

PHL was designed by system security team consisting of a group of engineers, security experts, users (operators and consumers) and the manager. The risk was categorized based on the security state of system activity into low, medium and high risks [6].

The existing risks were analyzed in a diary in Wisconsin and after identifying hazards. Considering severity and possibility using PHA method, risks were prioritized as high risk, low risk, and medium risk. High-risk hazards included accidents leading from slipping, stumbling and falling down, lack of mechanical shield and machinery and invisibility of holes and areas covered with bushes. Security policies in this diary are appropriate and consequently decrease the accident rate [16].

The comparative risk assessment of remote control locomotive operations versus conventional yard switching operations and was studied calculated 19 risk scenarios; furthermore, the total risk score of remote control locomotive operations was compared with that of current criteria which showed a significant difference between risk score and its mean and current security criteria [17].

In this study, monitoring of risk assessment was performed by using data from accident indicators. These indicators included Accident Frequency Rate (AFR), Accident Severity Rate (ASR) and Frequency-Severity Indicator (FSI).

Exact date relating to accidents provides a criterion to gauge past mistakes that had led to faults. Besides, the data was used to make comparisons in time intervals or between two organizations [6, 18].

PHA provide a summary of the loads and hazards of system for the consideration of preventive measures or specialized analyses. “The preliminary job hazard analysis comprises different types of loads and hazards as such. Therefore, the items cover most common hazards and loading factors and the number of items was kept as small as possible” [19].

Investigating the relationship between these indicators and risk scores shed light on the congruity of risk assessment and accident indicators, i.e. to what extent one can rely on the researcher's risk assessment. The risk and its indicators were not calculated in many mines in Iran. Description and classification of risk hazards in pelletizing process may lead to better understanding of hazardous parameters and increases the safety level.

We aimed to identify existing hazards, determine accident indicators and investigate the relation between the risk score and accident indicators and this study can be considered to improve safety in working environment. The aim of this article was monitoring of subjective risk assessment by safety performance indicators.

MATERIALS AND METHODS

This study is explaining a descriptive-analytic research covering 30 jobs in the construction project of Yazd pelletizing company in the 2016-2017. The pelletizing is a process that uses fine particles, added with binders or other products to form pellets, briquettes or nodules (sinter).

This project was in the design and construction phase. As this research project addresses operations in design stage, fabrication, framework and montage, it used PHA method, from among other methods, for risk assessment [20].

Variables used in the study were annual working time, annual working days lost, AFR, ASR, FSI, Risk Assessment Code 1 (RAC1) and Risk Assessment Code 2 (RAC2). RAC was defined as code for quantitative determination of risk factors and includes the potential outcomes of possible hazard on the environment, workers, material, and equipment. For the calculation of RAC, the severity and possibility of occurrence were calculated. RAC1 and Rac2 represented the risk value before and after considering corrected action.

Generally, PHA has four main stages, which include:

1. PHA prerequisites (determining PHA team, defining and describing the system to be analyzed, gathering data related to former

similar systems);
2. Identifying the hazards;
3. Determining the effects of the hazards and the probability that an accident will be caused by a hazard.
4. Classifying the risks and follow-up actions [5].

First, the data related to the process was gathered and then the PHL was provided by inspecting all the data. After that, the hazards were identified using checklists, description of facilities, investigating records of similar jobs and reviewing past reports. Having identified potential hazards, the possible effects of each hazard like fire, poisoning, bone fracture and suchlike, which affect persons' security, were recorded. In the later stage, factors involved in producing danger were identified.

For the better assessment of the risk, controlling processes on the site were also analyzed. In subsequent stages, risk severity rate and its probability were specified using criterion tables (Tables 1 and 2). These tables were adopted from AS/NZS 4360:2004 Risk Management, published jointly by Councils of Standards Australia and New Zealand. It introduces a 7-stage-process for risk management that includes management of potential profits and losses [21].

Table 1. Qualitative Measures of Probability [21]

Event	Likelihood	Description	Probability
A	Almost Certain	Happens often	More than 1 event per month
B	Likely	Could easily happen	More than 1 event per year
C	Possible	Could happen and has occurred elsewhere	1 event per 1 to 10 yr
D	Unlikely	Hasn't happened yet but could	1 event per 10 to 100 yr
E	Rare	Conceivable, but only in extreme circumstances	Less than 1 event per 100 yr

Table 2. Qualitative Measures of Maximum Reasonable Consequence [21]

	People	Environment	Asset/Production
1	Multiple fatalities	Extreme environmental harm (e.g. widespread catastrophic impact on environmental values of an area)	More than $500k loss or production delay
2	Permanent total disabilities, single fatality	Major environmental harm (e.g. widespread substantial impact on environmental values of an area)	$100 to $500k loss or production delay
3	Major injury or health effects (e.g. major lost workday case/permanent disability)	Serious environmental harm (e.g. widespread and significant impact on environmental values of an area)	$50 to $100k loss or production delay
4	Minor injury or health effects (e.g. restricted work or minor lost workday case)	Material environmental harm (e.g. localized and significant impact on environmental values of an area)	$5 to $50k loss or production delay
5	Slight injury or health effects (e.g. first aid/minor medical treatment level)	Minimal environmental harm (e.g. interference or likely interference to environmental values)	Less than $5k loss or production delay

By multiplying the numbers of severity (S) and probability (P), RAC was obtained and risk prioritization was calculated as described for the risk number. The first step to correct hazards is to categorize them for the better identification. A risk ranking table was prepared which shows the risk plus the probability of risk factor in each group based on previously published results [21,22] [Table 3].

Table 3. Risk Ranking Table

Consequence		**Probability**				
		A	**B**	**C**	**D**	**E**
	1	1 (H)	2 (H)	4 (H)	7 (M)	11 (M)
	2	3 (H)	5 (H)	8 (M)	12 (M)	16 (L)
	3	6 (H)	9 (M)	13 (M)	17 (L)	20 (L)
	4	10 (M)	14 (M)	18 (L)	21 (L)	23 (L)
	5	15 (M)	19 (L)	22 (L)	24 (L)	25 (L)

Notes: L – Low, M – Moderate, H – High
Rank numbering: 1 – highest risk; 25 – lowest risk

Legend – Risk level:

Yellow	Tolerable
Orange	ALARP – As low as reasonably practicable
Red	Intolerable

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All these stages were listed in PHL. In fact, all PHA parameters were included in the PHL; this was done through recognition of additional hazards, analysis of known hazards, providing recommendations to control hazards and determining risk level after control measurements [6].

When the PHL form was completed, minor hazards, i.e. those with the RACs of 16 to 25, were omitted and the rest were listed in PHA form. Having specified the corrective measure, a risk assessment was repeated and RAC2 was obtained. Corrective measures were taken in accordance with scientific and technological potentials, facilities and finances; they were prioritized in 6 areas as follow: safely designing machines and tools, minimizing hazards, fencing, posting warning signs, special instruction and training and personal protection equipment.

The smaller was the RAC, the higher would be the risk and clearly, RAC2 values (after corrective measure) will be greater than those of RAC1 [Table 3].

After risk assessment, accident indicators in pelletizing project during the past year were addressed. For this purpose, information related to all accidents happened during past year, annual working days lost, man – working days and annual working time were gathered and recorded using statistical techniques for project control. Afterwards, accident indicators including AFR, ASR, FSI were calculated according to OSHA standard and other formulas mentioned below [23,24].

(Equation 1):

$$AFR = \frac{\text{Number of Accident} \times 200000}{\text{Number of Employee Labor Hour Worked}}$$

(Equation 2):

$$\text{ASR} = \frac{\text{Total numberlost work days} \times 200000}{\text{Number of Employee Labor Hour Worked}}$$

(Equation 3):

$$\text{FSI} = \sqrt{\frac{\text{AFR} \times \text{ASR}}{1000}}$$

As safety performance indicator cannot be determined just by AFR and ASR, a combination of these two rates, namely FSI, was taken into consideration.

In the last step, data were entered into SPSS software (Chicago, IL, USA) and the relationship between these variables was analyzed by Pearson correlation coefficient and linear regression. The significance between two groups was calculated by the use of directional student t-test.

RESULTS

After investigating examined variables, a general description of these variables in 30 analyzed jobs was developed as shown in Table 4. In this project, the mean and the standard deviation of accidents were 5.36±10.22 and the number of working days lost is 34.46±63.02 days. Additionally, the mean and the standard deviation of AFR, ASR and FSI were 29.66±31.97, 185.32±213.73 and 2.2±2.3, respectively.

The resulted mean and the standard deviation values for RAC1 and RAC2 were 7.93±1.53 and 13.78±1.89, respectively.

The variables was shown different values in different jobs. In 23 jobs among 30 investigated jobs between 2016 and 2017, there have been accidents and 7 jobs, namely safety officers, firefighters, ambulance driver, operators of loader, tractor, mixer and crawler excavator, no accident had occurred.

Welding is more prone to accident; it had the highest values of AFR and FSI and the lowest RAC1 (Table 5). Building installers had the most working days lost among all different jobs in Table 5. Cutters, building installers, and electricians were the jobs that had the highest values of AFR; the lowest AFR values belong to those 7 jobs in which no accidents had occurred. The lowest values of ASR and FSI were also assigned to these jobs.

Cutting and Bending the armature, welders, building installer and electricians possess the highest values of ASR respectively. The highest value of FSI goes to welders after whom were building installers, cutters, electricians, benders and armature cutters. Building installation had the most workers and the working hours and crawler excavator had the least workers and the least working hours.

Analysis of RAC1 in different jobs showed that the highest rate of risk respectively relates to welders, building installers, cutters, and electricians. Topographers and firefighters' jobs had the highest values of RAC1 that mean they are less exposed to risks. After a reanalysis of risk and obtaining the amount of RAC2, scaffold installers and cutters were more exposed to risk and restaurant workers, benders and armature cutters had the least rate of risks.

Table 4. Descriptive statistics of analyzed variables in 30 jobs involved in the construction project of a pelletizing company

Variable	Mean± SD	Min	Max
Person-work day	2289.43±2557.39	60.00	10009.00
Annual working hours	22894.33±25573.9	600.00	100090.00
Lost work days	34.46±63.02	0.00	299.00
Accident Frequency	5.36±10.22	0.00	42.00
AFR (Accident Frequency Rate)	29.66±31.97	0.00	137.50
ASR (Accident Severity Rate)	185.32±213.73	0.00	605.30
FSI (Frequency-Severity Indicator)	2.20±2.30	0.00	8.20
RAC1 (Primary Risk Assessment Code)	7.93±1.53	5.37	10.47
RAC2 (Secondary Risk Assessment Code)	13.78±1.89	11.40	19.11

Table 5. The frequency table of existing variables in pelletizing project in 2016-2017

Job	Person-work day	Annual working hours	Accident Frequency	Lost work days	AFR	ASR	FSI	RAC_1	RAC_2
Welder	6109	61090	42	150	137.5	491.1	8.2	5.37	12.62
Building installer	10009	100090	30	299	59.9	597.5	6.0	5.6	12.13
Cutter	5605	56050	29	91	103.5	324.7	5.8	6.04	11.75
Electricians	1050	10500	3	30	57.1	571.4	5.7	6.09	13.45
Bending and cutting the armature	1520	15200	4	46	52.6	605.3	5.6	6.33	18.47
Painting and sandblasting work	2018	20180	4	55	39.6	545.1	4.6	6.23	12.23
Armature installers	5591	55910	13	106	46.5	379.2	4.2	6.37	14.42
Sandwich panel Installer	1895	18950	3	47	31.7	496	4.0	6.96	12.58
Montage	6207	62070	11	91	35.4	293.2	3.2	7.12	13.53

Therefore, understanding the difference between accident-prone jobs (group 1) and those with accidents (group 2), a series of statistical tests were needed. Using standard *t*-test, there was a significant difference between groups 1 and 2 in respect to workforce and working hours ($P<0.001$) (Table 6).

Besides, analysis of RAC1 in each group showed that there was no meaningful difference between these groups.

In the next stage, paired t-test was adopted to analyze risk assessment code before and after the corrective measures (RAC1 and RAC2) in job groups 1 and 2; the results showed a meaningful difference between these groups ($P<0.001$).

In addition, the relation between RAC1 and RAC2 was examined without distinguishing between jobs with or without accidents using paired t-test; this analysis proved that there was a significant difference between RAC before and after corrective measure ($P<0.001$).

The subsequent step was to determine the relation between RAC1 and safety performance indicators (i.e. AFR, ASR and FSI). By using a Pearson correlation coefficient, a reverse and meaningful relation between RAC1 and safety performance indicators were observed ($P<0.001$). In other words, an increase in RAC1 or a decrease in risk rate resulted in a decrease in accident indicators and vice versa.

Additionally, accident indicators were predicted based on RAC1 values (decreased risk) by linear regression. Accordingly, a 1-unit increase in RAC1 leads to a decrease in AFR, ASR, and FSI by 14.9, 110.37 and 1.24, respectively.

Table 6. Analysis of variables of man – working days, working hours and RAC1 in group 1 (jobs with accidents) and group 2 (jobs without accidents)

Variable	Job groups	Mean± (SD)	*P*-value
Person-work day	group 1	2903 (2629.70)	$P<0.001$
	group 2	273.42 (280.15)	
Working hours	group 1	29030 (29292.72)	$P<0.001$
	group 2	2734.28 (2801.51)	
RAC1	group 1	7.64 (1.57)	$P=0.06$
	group 2	8.87 (0.97)	

Table 7. The relation between RAC1 and accident indicators (safety performance indicators)

Accident indicators	Pearson correlation coefficient	*P*-value
AFR	- 0.71	*P*<0.001
ASR	- 0.79	*P*<0.001
FSI	- 0.82	*P*<0.001

DISCUSSION

Among different jobs, construction activities suffer from a high percentage of accidents. For example, a previous study in Yazd Province (2012) showed construction industry to be the most accident-prone job [25-28].

In this study, the biggest number of work-related accidents (i.e. the highest value of AFR and FSI and the lowest value of RAC1) related to welders; this was in complete concordance with previously published data, which introduces welding to be the most hazardous job [29]. Another study conducted in Kerman Province showed that most of the injured workers are welders [30]. These results partly were consistent with a study in Kerman [31].

One of the known risks in welding and cutting is eye damage, which happens when workers are not wearing safety glasses and protective equipment. In a study on the prevalence of eye damage and its reasons in Mashhad industrial workhouses, a reluctance to wear safety glasses accounts for the most of accidents occurred for workers [32]. Three-quarters of injured welders did not use appropriate eye protection [33-34]. Two-thirds of those who suffered from eye injuries at work had not used safety glasses [35]. However, one-third of those who used safety glasses still suffered eye injuries, caused by incorrect use of the safety glasses or because the glasses had not been optimally designed. Consistent use of safety glasses and development of more effective glasses would reduce the risk of eye injuries [29].

In this study, relationship between RAC1 and safety performance indicators (i.e. AFR, ASR, and FSI) showed that there was a reverse and meaningful relation between RAC1 and safety performance indicators. Therefore, monitoring of risk assessment by assessor can be trusted.

In other words, an increase in RAC1 (decrease in risk rate) will result in a decrease in accident indicators and vice versa. Thus, regarding the relationship between risk scores and accident indicators, determine the role of risk assessment and enhancing safety in decreasing accident indicators. The role of safety control in preventing possible accidents was emphasized and detecting hazardous points [36]. Based on the results of PHA form, 38% of jobs, among welders, building installers, electricians, and cutters, were in high-risk zone (red zone) and considered unacceptable according to risk criteria in AS/NZS 4360:2004 standard. Therefore, some corrective measures had to be taken in regard to these jobs. The remaining jobs were in ALARP (As Low as Reasonably Possible) zone. In a study, 32% of hazards were also in this zone. According to ALARP principle, those in charge should take action to reduce the risks unless it was reasonably impractical. Risk acceptance in a work environment depends on some factors like the environment in which there is risk, the nature of system in respect to necessity and benefits, workers, understanding of the nature of risks and the cost of risk reduction [37].

In a risk assessment in Sydney Water Corporation using PHA method, all the hazards were reduced such that they were included in ALARP zone [11]. Most of the accidents result from carelessness to hazards in ALARP zone (orange zone). A similar attention is paid to the risks in this zone [38].

There was a meaningful difference between RAC before and after the corrective measures, that shows the effectiveness of these measures. Decrease in a certain sort of risk factor will decrease other risks. Nevertheless, it is necessary to study risk scores after taking measures. This can be helpful for both monitorings the effectiveness of those measures and detect any change in indicators of other risks connected with the enhanced risk [39-40].

Linear regression showed that a 1-unit increase in RAC1 leads to a decrease in accident indicators. In other words, when a work environment is kept safe and hazardous factors are minimized, there will obviously be fewer accidents and less working days lost. In a study, the concurrent relationship between unsafe activities and accidents was examined using logistic regression analysis and showed that 1% increase in unsafe activities can three times increase the accidents [41].

According to the results, there was a meaningful difference between group 1 (jobs with accidents) and group 2 (jobs without accidents) in respect to man - working day and working hours. The low number of working day and working hours may account for the fact that no accident had occurred in-group 2. There is the possibility that a rise in these factors may lead to accidents. In a research by International Association of Oil & Gas Producers in 2011, a 5% decrease in working hours caused a 9% decrease in lethal accidents and total injuries were reduced to 4% [42]. Besides, in correspondence with the results of the present research, other studies have shown that working hours beyond the standard limit increase possible accidents [43].

One of the limitations of this study was due to the nature of the construction project; there were different groups' affixed-term contract workers in different months. Therefore, information for man – working day needed to be extracted from project control forms. Furthermore, the information was not without ambiguity because form processors had not been trained. Hence, for having access to exact information, in some case, we either contact or visit the injured workers. These processes were time-consuming. Therefore, a comprehensive accident recording software or integrated administrative system is used in such projects.

CONCLUSION

Given the high rate of hazards and unacceptable risks associated with pelletizing project, safety officers and supervisors inspect closely and quickly safety deviations and try to resolve them; they should minimize accidents and control hazards using suggested corrective measures.

Applying a preventive plan to reduce the risks of these pitfalls is very necessary for the industry. Safety planning is one of the most important factors in preventing accidents in work environment. Such a plan not only specifies individuals' duties (including executive managers, supervisors, inspectors, and contractors) but also enhances their responsibilities toward safety issues. Therefore, all the jobs, equipment, machinery and personnel's behaviors are analyzed by novel methods of assessment. In addition, determining a new RAC is needed after a change in work process that has to be followed by adopting corrective measures.

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