THE EVALUATION OF FACTORS INFLUENCING SAFETY PERFORMANCE: A CASE IN AN INDUSTRIAL GAS MANUFACTURING COMPANY (GHANA)

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ABSTRACT

Safety has become a very important element in firms and organisations especially in Ghana. The impact of safety factors on a firm's 3E's (Employee, Environment and Equipment) can improve or deteriorate firm's public image. This paper identified the key safety indicators and also provided a set of core factors that contribute meaningful in promoting safety performance in an Industrial Gas producer in Ghana using the Analytic Hierarchy Process. Organisational, Human, Technical and Environmental factors were identified as the safety indicators in relation to the study area. The studies revealed that organisational factor is the most important factor or criterion that could facilitate a better safety performance of the Industrial Gas Company. In addition, employees was identified the best safety alternative, whilst environment and equipment followed sequentially.

KEYWORDS

Occupational safety, Performance, Indicator, MCDM, Analytic Hierarchy Process (AHP).

1. INTRODUCTION

Recent research in occupational safety in business world is attracting public interest due to the increasing societal awareness of the importance of safety at work places and its valuable outcome on firms, societies and economy in general. Safety management is a very important element within effective manufacturing firms. Managing occupational risk enhances firms to maintain and develop intellectual capital that is paramount in organizational development [1].

Measuring occupational safety exactly and objectively using safety indicators could be problematic and could differ across industry types. The author in [2] proposed the following safety indicators including historical, psychological, economical, technical, organizational, procedural, and environmental issues are linked to safety at construction sites. The author in [1], presented four general safety indicators including Organizational, Human, Technical and Environmental indicators.

Even though evaluation of safety factors has been difficult and inaccurate in the past, the adoption of AHP as a tool to evaluate safety factors by many pervious research [1, 2, 3] has been useful. AHP has been used for forward and backward planning in transportation problems and also road safety and accident prevention as well as for a typical cost-benefit analysis [4]. The authors in [5, 6] also used AHP to solve engineering problems and Information security policy implementation respectively. However, to our knowledge no Multi-criteria decision making techniques has not been used to evaluate safety performance of any manufacturing firm in Ghana. Most firms in

Ghana measure safety performance based on managerial decisions. Hence, by adopting AHP as decision making tool and organizational, human, technical and Environmental as safety indicators as proposed in [1], this paper measures the influence of these safety indicators on safety performance of an industrial gas manufacturing company. This company is well known for the production Oxygen, medical oxygen, acetylene, nitrogen, carbon dioxide, dry ice, and argon to serve industries such as mining, oil and gas, medical consumables, naval, construction, firefighting, food and pharmacy among others in Ghana and abroad.

This research contributes in two major folds. First it adds to literature of safety indicators and safety performance in Ghana. Secondly, the results in this paper will educate Managers and decision makers on factors that highly influence safety performance in industrial gas companies and thereby aiding them to strategize sound accident preventive mechanism to increase safety at their work places.

The paper is organized as follows: the subsequent section presents an overview of literature related works. Section 3 explains the methodology of AHP, the AHP of safety performance in an Industrial gas manufacturing company is illustrated in section 4. Discussion of the results is presented in section 5 followed by conclusion in section 6.

2. RELATED WORK

A short near-term investment in safety can potentially prevent larger future costs in workers compensation, lost-time work, and or huge legal cost. Also, a firm's reputation could be damaged if the incident was significant and thus, the possibility to hurt a company in the marketplace [6]. Safety cultures, which include prevention and detection programs, can increase employee awareness and reduce costs associated with injuries [7].

According to the authors in [1], there is a positive relationship between the safety of an organization as its important performance and the effectiveness of safety of occupational safety. Safety performance indicator is the measure of changes in the level of safety over time, which results from action taken to reduce appropriate risks [8]. Safety indicators has been defined by [9] as direct and indirect indicators. Whilst direct indicators use experience data, indirect data measure the performance of functional units with and organization such as engineering support, operations maintenance and training.

The AHP was first proposed by Thomas L. Saaty [10] to solve multi-criteria decision making problems. Analytic Hierarchy Process (AHP) has been used by the Specialist Committee on Safety of High-Speed Marine Vehicles of the ITTC as early as 1999 [11]. On the other hand, researchers have used MCDM models on safety problems in other fields. As part of their decision making tool, authors in [12] used MCDA (multi-criteria decision aid) in order to support a decision in a nuclear-engineering application. A typical multiple criteria evaluation problem focuses on a set of feasible alternatives and considers more than one criterion to determine a priority ranking for alternative implementation. Completeness, operational, decomposable, non-redundancy, and minimum size are principles to be considered when criteria are being formulated [13].

3. METHODOLOGY

This research began by reviewing literature on the relevance of occupational safety, safety indicators, in academic journals. This was followed by exploratory interviews with three safety managers, a production manager and five production workers. Explorative interview discussion were centered of the causes of accidents, attitude of workers at the workplace, available safety materials provided by company and safety prevention measures that they have in place.

Secondly, Analytic Hierarchy Process (AHP) proposed by Saaty [10], is one of the most popular multi-criteria decision making (MCDM), and has been applied to practical decision making problems. The AHP applied to the safety performance involve of the following steps:

Step 1: Establishing decision goal for evaluating safety performance. The goal of this paper is to identify the key safety factors that improves the Safety Performance in the company.

Step 2: Alternatives formulation

This paper considered 3 E's as the alternatives for safety performance which includes;

1. Employees: They are people who have been employed to work within the company.
2. Environment: The infrastructure and natural resources within which a firm operate.
3. Equipment: The plants and machines used in the manufacturing process.

Step 3: Criteria Identification (Four criteria were identified)

1. Organizational factor includes the safety measures put in place by management to reduce industrial accidents. Safety culture and safety polices are the key measures used to control the working environment thereby increasing the safety performance.
2. Human factor includes working experiences and motivation of employees to comply with safety rules and regulations of firm within the company.
3. Technical factor includes plant and equipment design, plant and equipment control and plant and equipment location with regards to high safety performance.
4. Environmental factor includes how political, technological, social and economic factors affect safety performance in firms.

The above definitions are presented in figure 1 and in table 1 below.

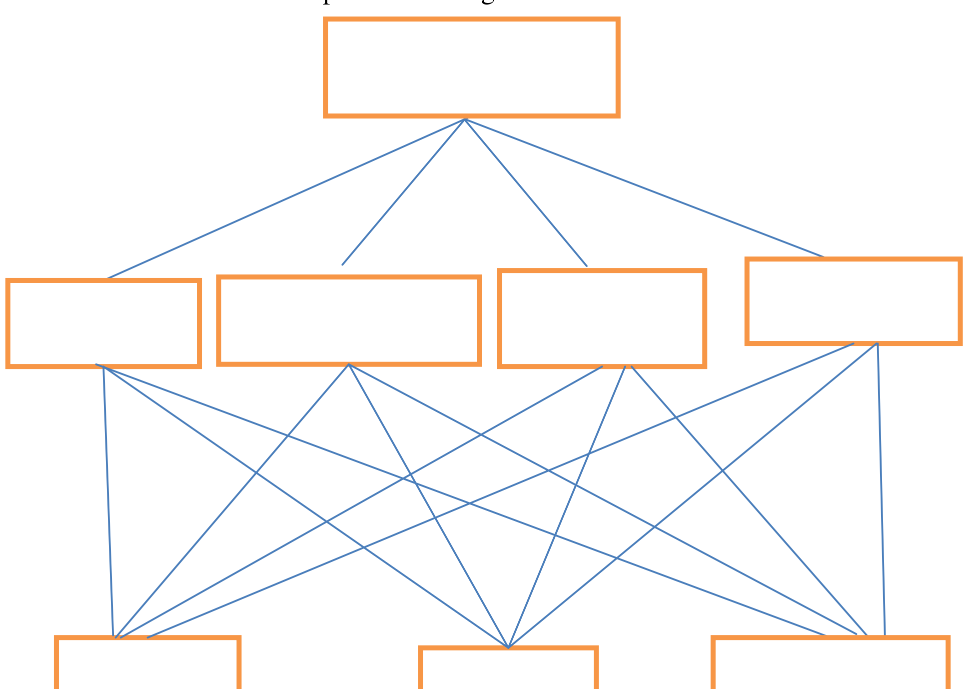

Figure 1. Safety Performance Model

Table 1. The Decision Matrix.

	CRITERIA				
		C_1	C_2	C_3	C_4
Alternatives	Weights	W_1	W_2	W_3	W_4
	A1	a_{11}	a_{12}	a_{13}	a_{14}
	A2	a_{21}	a_{22}	a_{23}	a_{24}
	A3	a_{31}	a_{32}	a_{33}	a_{34}

In the above decision matrix:

let C_i (for i = 1, 2, 3. 4) be the decision criteria.
let A_j (for j= 1,2,3,4) be the decision alternatives.
let W_k (for k = 1, 2,3,4) be the weight of criterion C_i.
let a_{ij} be the performance of alternative Aj.

Step 4. Criteria scores

Even though there are many measurement scales that could be used to quantify managerial judgments, the 9-point scale in Table 2 is the standard used for AHP. The scores of criteria and the alternatives were given based on managerial judgments using the AHP scale.

Table 2. 9-point scale for pairwise comparison in AHP

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two criteria/ sub criteria contribute equally to the level immidiately above.
3	Moderate Importance	Judgement slightly favors one criterion / sub criterion over another
5	Strong Importance	Judgement strongly favors one criterion /sub criterion
7	Very Strong Importance	One Criterion/ sub criterion is favored strongly over the another
9	Absolute / Extreme Importance	There is evidence affirming that one criterion / sub criterion is favored over another
2,4.6,8	Immidiate values between above scale values	Absolute Judgement cannot be given and a compromise is required
Reciprocals of the above	If element i has one of the none zero numbers assignment whent compared with activity j. j has the reciprocal value when compared to i	A reasonable assumption

Source : Saaty 1980

Table 3. Criteria weight pairwise comparison matrix

	Organizational	Human	Technical	Environmental
Organizational	1	1	4	4
Human		1	2	4
Technical			1	5
Environmental				1

Pairwise comparisons defines the relative importance of one item to the other in meeting the decision goal. $\frac{n^2 - n}{2}$, where n=4 results in six (6) judgemental comparisons are needed and n^2 =16 cells in the decision matrix.

Step 5: Normalization of the weights.

Step 6: Determining weights of criteria.

Step 7: Determination of Alternative Preference Order.

Step 8: Ranking of Criteria and Alternatives from the Computed Weight.

4. AN ILLUSTRATIVE EXAMPLE (CASE STUDY)

The scope of this illustrative example is to show the most important factors to improving safety performance in the industrial gas company using AHP.

Original Matrix

$$\begin{bmatrix} 1 & 1 & 4 & 4 \\ 1/1 & 1 & 2 & 4 \\ 1/4 & 1/2 & 1 & 5 \\ 1/4 & 1/4 & 1/5 & 1 \end{bmatrix} * \begin{bmatrix} 1.00 & 1.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ 0.25 & 0.5 & 1 & 5.00 \\ 0.25 & 0.25 & 0.20 & 1 \end{bmatrix} = \begin{bmatrix} 43.38\% \\ 32.08\% \\ 18.22\% \\ 6.32\% \end{bmatrix}$$

The data in the matrix above has been used to generate the percentage weights of the decision criteria. From the above results, organizational factor had the highest percentage of 43.38%. The weights of human, technical and environmental factors are 32.08%, 18.22% and 6.32% respectively. The results are presented in Figure 2. The percentages of these criteria represent the measure of relative importance of each criterion. The higher the percentage, the greater the impact on safety performance. Therefore, organizational factor is the most important factor to improving safety performance since it has the highest percentage of 43.38%.

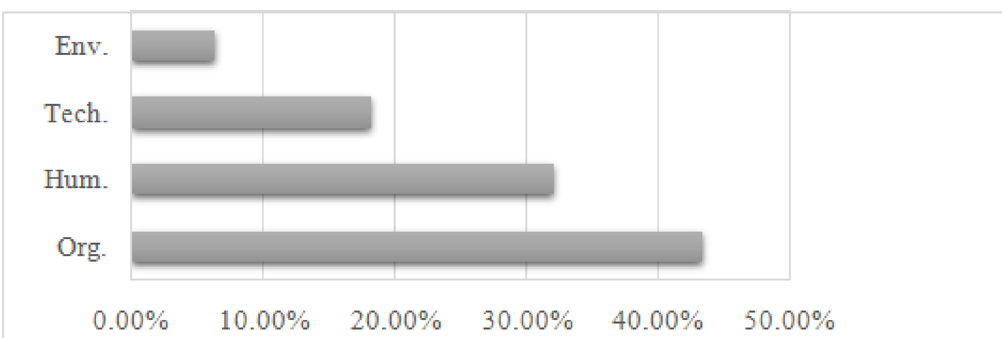

Figure 2. Percentages (%) of weights of Criteria

The original matrix has been augmented in table 4. The first and second weight is calculated in Table 4 and Table 5 to give the relative ranking of the Criteria. The process was iterated until the weight was not so different from the previous one.

Table 4. Augmented Matrix (Computation the first weight)

	O	H	T	E	Weight
O	4	5	10.8	32	0.4338
H	3.5	4	8.8	22	0.3208
T	2.25	25	4	13	0.1822
E	0.8	0.85	1.90	4	0.0632

Table 5. Computation of the second weight.

	O	H	T	E	Weight
O	83.8	94.2	191.2	506.4	0.4163
H	65.4	66.55	150	402.4	0.3255
T	37.15	42.30	87	231	0.1890
E	13.65	15.55	31.32	85	0.0692

Computation of the difference of the first and the second weights.

$$\begin{bmatrix}0.4338\\0.3208\\0.1822\\0.0632\end{bmatrix} - \begin{bmatrix}0.4163\\0.3255\\0.1890\\0.0692\end{bmatrix} = \begin{bmatrix}0.175\\-0.0049\\-0.0068\\-0.0060\end{bmatrix}$$

$$\text{Weight (Criteria)} = \begin{bmatrix}O\\H\\T\\E\end{bmatrix} = \begin{bmatrix}0.4163\\0.3255\\0.1890\\0.0692\end{bmatrix}$$

The decision maker compared each pair of safety alternatives including employee, environment and equipment with respect to organizational, human, technical and environmental factors. The weight of these matrices is shown in Table 6, 7, 8 and 9. The overall weights of the alternatives in relation to each criterion is presented in Table 10.

Table 6. Evaluation in context of organizational factor

	Employees	Environment	Equipment	Alternative (Org.)	Weight
Employees	1	6	4	100	0.6993
Environment	1/6	1	3	13.24	0.1939
Equipment	1/4	1/3	1	31.51	0.1067

Table 7. Evaluation in context of human factor

	Employees	Environment	Equipment	Alternative (Hum.)	Weight
Employees	1	9	5	100	0.7906
Environment	1/9	1	5	55.56	0.1517
Equipment	1/5	1/5	1	55.56	0.0577

Table 8. Evaluation in context of technical factor

	Employees	Environment	Equipment	Alternative (Env.)	Weight
Employees	1	3	5	60	0.66069
Environment	1/3	1	1	100	0.184333
Equipment	1/5	1	1	20	0.154976

Table 9. Evaluation in context of environmental factor

	Employees	Environment	Equipment	Alternative (Env.)	Weight
Employees	1	3	5	60	0.66069
Environment	1/3	1	1	100	0.184333
Equipment	1/5	1	1	20	0.154976

Table 10. Computation of alternative weights in relation to safety criteria.

	Organizational	Human	Technical	Environmental	Weights
Employees	(.4163)(.7199) +	(.3255)(.7906) +	(.1890)(.6377) +	(.0692)(.6607) =	0.7232
Environment	(.4163)(.1828) +	(.3255)(.1517) +	(.1890)(.2699) +	(.0692)(.1843) =	0.1893
Equipment	(.4163)(.0973) +	(.3255)(.0577) +	(.1890)(.0924) +	(.0692)(.1550) =	0.0875

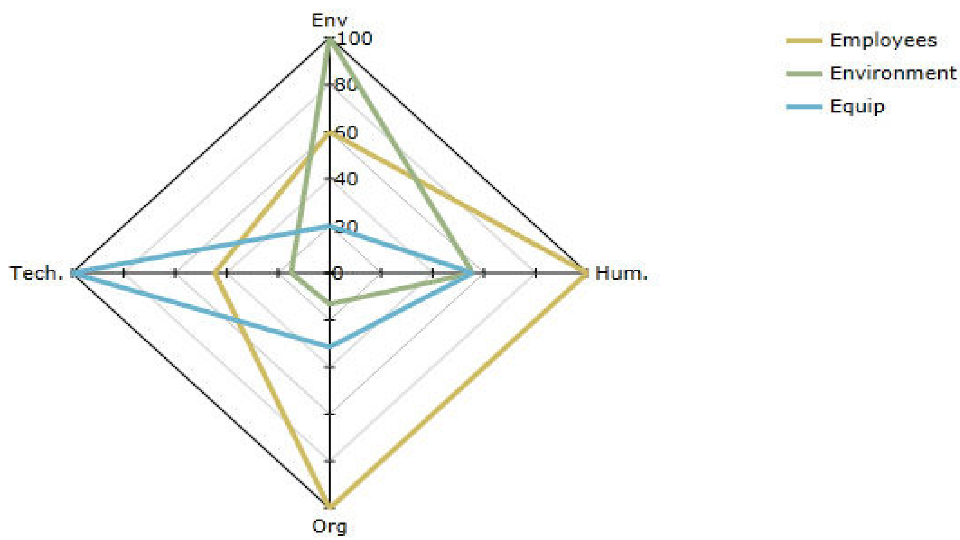

Figure 3. Ranking in Context of Safety factor.

5. DISCUSSION

In the AHP methodology, organizational factor was found to be the most important criterion with the overall priority weight of 0.4163 as presented in Table 5. Human, Technical and Environmental factors followed with a weight of 0.3255, 0.1890 and 0.0692 respectively. The overall weight of employees, environment and equipment in relation to organizational, human, technical and environmental factors are 0.7232, 0.1893 and 0.0875 respectively in table 10. The overall weights of the alternatives in the context of criteria of the safety performance is presented in Figure 3.

Results indicate that safety performance of the company is significantly affected by organizational factor because it had the highest weight and it is identified as the most important factor. Management has the responsibility of using organizational factors to improve the safety performance of the company. Hence, safety policies, safety orientation and safety culture in the company should be strengthened. The other key indicators as presented in this paper cannot be totally ignored since they collectively contribute to safety performance.

In addition, employee is the best alternative to be used to measure the safety performance within the company. This indicates that employee is the key ingredient for a successful safety performance in the company. This implies that the impact of the safety indicators on employees is more critical in the company.

6. CONCLUSION

The paper has contributed to the field by applying Analytic Hierarchy Process in an industrial gas manufacturing company in Ghana. Although AHP is not the only best method for solving complex decision making problems, it is recognized as a tool to provide reasonable solution. The AHP was used as a basis to formalize the evaluation of tradeoffs between conflicting safety performance criteria and its alternatives. In this study, the work safety issue is studied through the analytic hierarchy process (AHP) approach which allows both multi-criteria and simultaneous evaluation.

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