Prioritization of Occupational Safety Parameters in Small Scale Manufacturing Industry- Analytical Hierarchy Process

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Abstract

The objective of this study is to identify and prioritize the factors related to occupational safety of workers in the Small-Scale Manufacturing Industry (SSMI), where usually safety standards are placed at the last. Due to this, chance of accidents becomes eminent which not only becomes loss to individual or workers but also harness to SSMI. Questionnaire has been framed for conducting the study which is evident using analytic hierarchy process (AHP). Experienced experts have been consulted for questionnaire survey. Total of nine main and twenty-two sub-factors have been considered after due consideration from various norms and experts. The study revealed that first priority should be personal protective equipment's, which is having maximum Eigen vector i.e. 30.6% followed by fire prevention 22.8% and organizational attributes 14.0%. Consistency of all the factors and sub-factors is less than 10%. This paper provides a tool by which SSMI can be advantageous without off setting considerable cost. This technique not only helps the SSI to empower their safety standards but also prioritization of factors considering due weight-age are of great importance.

Keywords- Analytical hierarchy process (AHP), Manufacturing industry, Occupational safety, Small scale industry

Introduction

Responsible factors that can be helpful to industry for marking and prioritize the safety standards which not only help the workers but also has an advantage to industry in-sense that unnecessary finances are being taken care. To empower this, multi criteria decision approach should be employed. The AHP approach was framed by Saaty in 1977. The approach used is a composite of mathematics and interaction of the intended work (Viswanadhan *et al.,* 2009; Wang *et al.,* 2010). The application becomes useful and effective in prioritizing the factors that can be successfully taken to industries to mitigate unforeseen accidents, which engulf the funds that is actually not allocated (Akarte *et al.,* 2001; Al-Harbi *et al.,* 2001; Badri *et al.,* 2001). By implementing the prioritized factors, industry have to encore minimal cost thereby savings on unallocated funds. Industries can grow by such eminent tool (Singh *et al.,* 2016; Mudavanhu *et al.,* 2013). As per the data provided by Directorate General, Factory Advice and Labor Institutes (DGFASLI), in the year 2012, there are 1383 fatal injuries (causing death) and 28441 non-fatal injuries occur in Indian industries. According to ILO, in each year around 43,000 people die in India due to work related problems (Sharma *et al.,* 2013). The increase in some operational accidents can be attributed to carelessness or lack of knowledge (about safety parameters) among workers and owners of these industries (Marais *et al.,* 2004). The direct or indirect losses due to work related mortality and morbidity of employees have made this problem a major issue of vital importance among these industries. There are many industrial accidents occurring in India. The Bhopal Gas Heartbreak (1984) is the whirling opinion in the antiquity of safety in India (Singh *et al.,* 2016). The number of occupational accidents is increasing day by day. In Punjab, as the number of factories increases, the number of accidents is also increased (Rafiq *et al.,* 2012).

Application of AHP encompasses various organizations such as integrated manufacturing, in layout design [2], in assessment of technology asset decisions by Boucher [3] in flexible type industrialized systems and in many other engineering related fields (Arbel *et al.,* 1990; Armacost *et al.,* 1994; Ashraf *et al.,* 2001; Cambron *et al.,* 1991; Das *et al.,* 2012; Thomas L.Saaty, 1990). AHP works on an Eigen value approach which is based on pair-wise comparisons (Thomas L.Saaty, 1990; Bayazit *et al.,* 2005; Bouche *et al.,* 1991). Qualitative and quantitative analyses can be performed and calibration can be done with the help of suitable numeric scale. The range of the scale can be from 1/9 (minimum value) to 9 for (maximum value importance), which covers the entire comparison (Bouzon *et al.,* 2016; Forgionne *et al.,* 2002; Forman *et al.,* 1998). AHP has varied applications which have impact on production and software development etc. can improve the safety features for motor vehicles, evaluate the qualitative approach for research and development proposal (Ye *et al.,* 2010; Hafeez *et al.,* 2002; Bouzon *et al.,* 2016; Azis *et al.,* 1990). Last to last can be used to estimate the cost and schedule for material requirement and planning (Arbel *et al.,* 1990; Angelis *et al.,* 1996).

Research gaps and need of the present work

This study is focused to prioritise the occupational safety parameter related to SSMI of Punjab region, using AHP. Very less literature has been found related to safety culture of Punjab especially for SSMI. Therefore, it assumes that this study covers all the factors related to the occupational safety of workers as per factory act, Punjab rules and OSHA norms. It also provides the hierarchy of safety parameters for implementation in the industry which will help to provide a platform or has scope of improvement in future scenario of occupational safety of workers.

Methodology

AHP is a decision criteria technique which is used in various areas's to identify and prioritize the factors due to which the concern industry can be benefitted (Armacost *et al.,* 1994; Armacost *et al.,* 1998; Badri *et al.,* 2001; Bayazit *et al.,* 2005). AHP is employed on this study where factors have been identified after rigorous literature review. Proficient and experienced expert's have been asked to complete the questionnaire framed by factors after due weightage. The methodology has been depicted in figure 1. Various steps have been highlighted wherein the processes such as identification, selection, feedback and consistency test. Every step is being scrutinized with ample care.

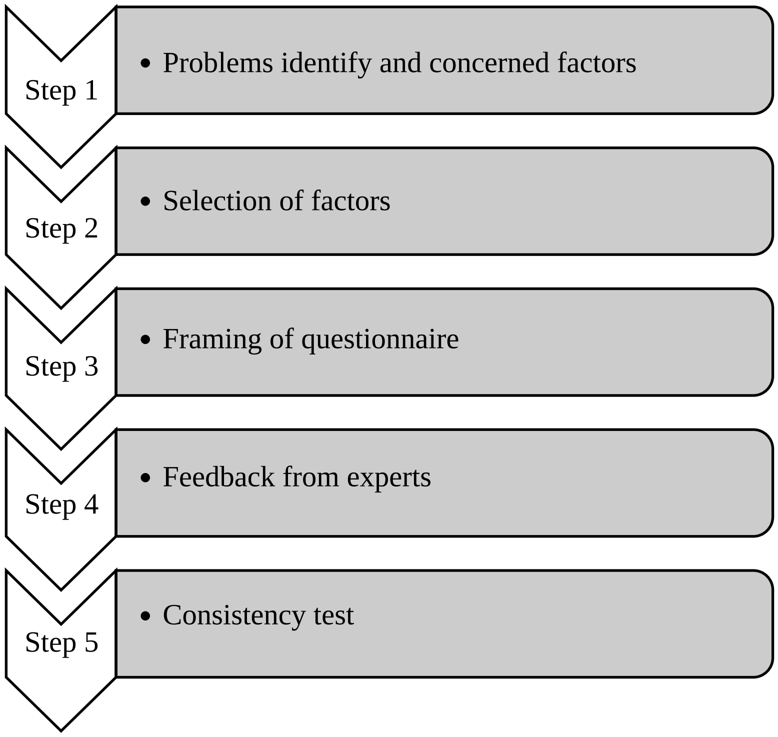

Figure 1: Represents the methodology for AHP

The data is collected in questionnaire form for different possible factors with pair wise comparison. AHP 9-point scale is used and presented in table 1.

Table 1: 9-point scale of AHP

Relative Importance	Definition
1	Equally important
3	Moderate importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8.	Intermediate values between the two neighbouring scales.

For the working of model, framing of questionnaire and optimization of the factors responsible, this all is ensured by the calculated value of CR. When the value of CR is below or nearly equal to 10%, then the questionnaire is considered best fit and when the CR is above10%, the questionnaire should be revised as it might not be catering the possible factors. Random index (RI) tabulated in table 2 (Thomas L.Saaty.1990; Traintaphyllou *et al.*, 1995).

Table 2: Value for Random Index

No. of factors (n)	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

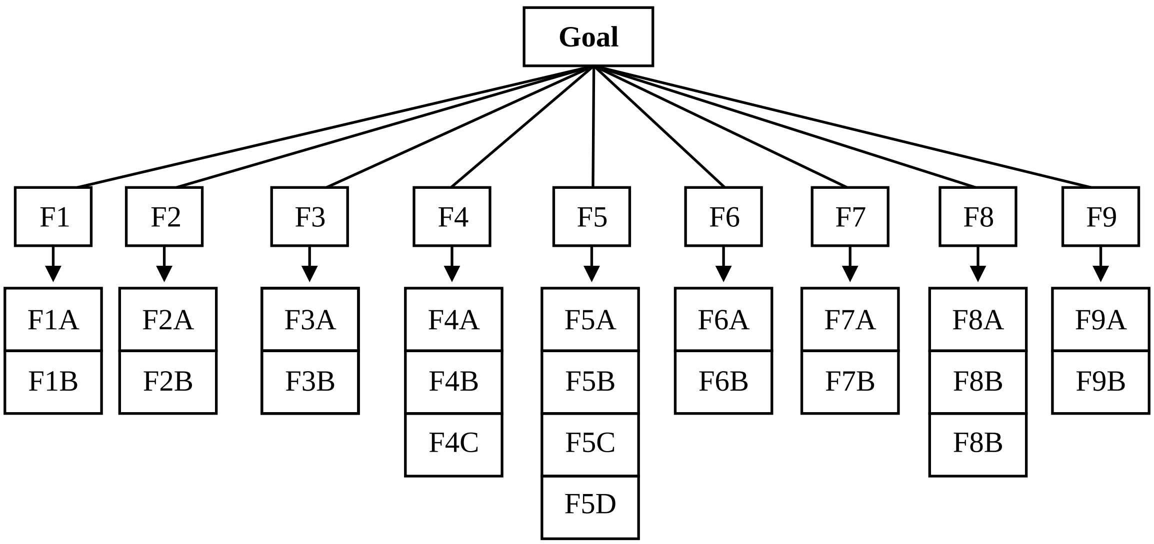

Figure 2: AHP hierarchy model

Pair-wise comparison of sub factors under first main factor (F4)
F4A. Need of periodic inspection (PI)
F4B. Availability of proper machine guards (APMG)
F4C. Training programs for hand-tools and equipment use (TPFHT)

PI	9	7	5	3	1	3	5	7	9	APMG
PI	9	7	5	3	1	3	5	7	9	PTPHT
APMG	9	7	5	3	1	3	5	7	9	PTPHT

For model calculation, we considered forth factor and its sub-factors. Pair –wise comparison has been carried out with expert's opinion. In this 3 order matrix has been made and the diagonally positioned elements having their value equal to unity and the upper triangular part of the matrix is entered as follows:

1. If judgemental value lies in left hand side of 1, then there is no change and entered as shown in first matrix.
2. If judgemental value lies in right hand side of 1, then the reciprocal of value will be entered in matrix (Thomas L.Saaty,1990; Traintaphyllou *et al.*, 1995).

$$A = \begin{array}{c} \\ PI \\ APMG \\ PTPHT \end{array} \begin{array}{c} \begin{array}{ccc} PI & APMG & PTPHT \end{array} \\ \begin{pmatrix} 1 & 1/7 & 1/3 \\ 7 & 1 & 3 \\ 3 & 1/3 & 1 \end{pmatrix} \end{array} \qquad \text{.........................} \quad (1)$$

Upper triangulation matrix is prepared wherein the element chosen by expert while marking relativeness, if it falls on the left hand side of neutral value i.e. 1 then same is to be taken. Of the value chosen falls on right hand side, the reciprocal of the element is to be taken. Once the upper triangulation matrix is completed, the lower triangulation to be taken as reciprocal of element mirroring in upper triangulation.

$$A = \begin{array}{c} \\ PI \\ APMG \\ PTPHT \end{array} \begin{array}{c} \begin{array}{ccc} PI & APMG & PTPHT \end{array} \\ \begin{pmatrix} 1 & 1/7 & 1/3 \\ 7 & 1 & 3 \\ 3 & 1/3 & 1 \end{pmatrix} \end{array} \qquad \text{.........................} \quad (2)$$

Matrix labelled as 2 is the final matrix upon which further operations as per technique are to be employed. Always positive values are being taken in the matrix to prevent miscalculation. Eigen value and eigen vector are to be calculated.

$$A = \begin{array}{c} \\ PI \\ APMG \\ PTPHT \\ \\ \end{array} \begin{array}{c} \begin{array}{ccc} PI & APMG & PTPHT \end{array} \\ \begin{pmatrix} 1 & 1/7 & 1/3 \\ 7 & 1 & 3 \\ 3 & 1/3 & 1 \\ 11 & 31/21 & 13/3 \end{pmatrix} \end{array} \qquad \text{.........................} \quad (3)$$

Each column in matrix 3 is to be summed as shown. Each element of the matrix 3 is to be divided by the summation of the respective column. Matrix 4 is generated after the operations employed as stated above. To ensure the technique performed, the sum of the columns should be unity.

$$A = \begin{array}{c} PI \\ APMG \\ PTPHT \\ Sum \end{array} \begin{array}{c} \begin{pmatrix} 0.090 & 0.096 & 0.076 \\ 0.636 & 0.677 & 0.69 \\ 0.272 & 0.225 & 0.230 \end{pmatrix} \\ \begin{array}{ccc} 1 & \quad 1 & \quad 1 \end{array} \end{array} \qquad \text{.........................} \quad (4)$$

Normalized principal Eigen vector (Priority vector) is computed by arithmetic mean of respective rows of matrix 5.

$$W = 1/3 \begin{pmatrix} 0.090 & 0.096 & 0.076 \\ 0.636 & 0.677 & 0.69 \\ 0.272 & 0.225 & 0.230 \end{pmatrix} = \begin{pmatrix} 0.088 \\ 0.669 \\ 0.243 \end{pmatrix} \qquad \text{.........................} \quad (5)$$

Table 3: Category wise priority of sub-factors from online software

Category		Priority	Rank
1	PI	8.8%	3
2	APMG	66.9%	1
3	PTPHT	24.3%	2

W is computed in equation 5 which shows the prioritization of factors among their relative importance. According to this the APMG is followed by PTPHT followed by PI. The relative ranking of the factors from highest are 66.9%, 24.3% and 8.8%.

$$\lambda max = 11(0.088)+31/21(0.669)+13/3(0.243) \quad \text{.................... (6)}$$

Eigen value is calculated wherein the summation of the reciprocal of elements from diagonal position in matrix 5 is being multiplied by respective principle Eigen vector. Consistency Index (CI) is being evaluated using expression 7.

$$CI= \frac{\lambda max - n}{n - 1} \quad \text{....................... (7)}$$

CI = 3.75

Consistency ration (CR) is to find out to ensure the effectiveness of AHP. CR is calculated using expression 8.

CR = CI/RI .... (8)

CR= 3.75/0.58= 6.4 %

Where RI is random index, taken the value from table 2 as 0.58 for n, number of comparison are 3. CR obtained is 6.4% which is less than 10%, which means the framework is accepted. If CR is more than 10%, shows inconsistence and need to be revise the subjective judgement.

The whole technique is illustrated with one framework comprising comparisons of three factors. The same is employed over other framework and the result is presented in table no 4.

Results and Discussion

Using AHP for various frameworks, respective Eigen vector, Eigen value, CI and CR are computed and tabulated as table 4. The prioritization of factors within various frameworks are completed and prioritized. In all the cases, consistency ratio is well below acceptable value i.e. less than 10% which evident subjective judgement of experts is rationale.

Table 4: Calculation of Eigen vector, priority and Consistency ratio

Main Factors	Sub-factors	Eigen Vector	Priority	Consistency Ratio
Organizational Attributes	Requirement of written Safety policy	75.0%	1	0%
	Requirement of safety department/division/committee	25.0%	2	

Occupational S Services/doc.	Provision of first aid services (box/doctor/physician)	83.3%	1	0%
	Records of accident and injury	16.7%	2	
Workplace Layout and Housekeeping	Adequate and smooth material flow	75.0%	1	0%
	Neat and clean floors, walls and ceilings	25.0%	2	
Equipment & Hand ols Safety and Machine Guarding	Need of periodic inspection	10.5%	3	6.4%
	Availability of proper machine guards	63.7%	1	
	Provision of training programs for hand tools and equipment use	25.8%	2	
Fire Prevention, fire fighting and electrical safety	Provision of fire detection system	38.6%	1	2.9%
	Need of fire fighting training and emergency plan	10.9%	4	
	Provision of emergency Exit and exit signs	13.8%	3	
	Proper electrical wiring	36.6%	2	
Material Handling and Storage	Need of inspection schedule	66.7%	1	0%
	Provision of safe storage and stacking	33.3%	2	
Occupational Exposures	Exposure to high thermal conditions	66.7%	1	0%
	Monitoring of occupational exposures	33.3%	2	
Personal Protective Equipment	Adequate provision of PPE	73.1%	1	6.8%
	Proper maintenance of PPE	18.8%	2	
	Adequate training on PPE usage	8.1%	3	
Hygiene Factors	Availability of safe drinking water	25.0%	2	0%
	Provision of proper lighting and ventilation	75.0%	1	

The major factors are also prioritized using AHP and it has been observed that the most critical factor is PPE which needs to be taken care at first priority so as to avoid unnecessary loss of life and cost. Some part of cost should be utilized for training programs effectively which will lead more towards worker's safety and awareness. Following the same path the other factors have been listed in table 5 are to be taken care. From table 5 the factor PPE is 1.34 times important than factor 2 i.e. fire prevention, fire fighting and electrical safety, 2.19 times than organizational attributes. Likewise factor 2 is 1.63 times factor 3 and 2.26 times factor 4 i.e. equipment & hand Tools Safety and machine guarding. Factor 1 i.e. PPE is 12.24 times significant than factor at 9 position i.e. Workplace Layout and Housekeeping.

Table 5: Calculation of Eigen vector and priority of main factors

Main Factors	Eigen Vector	Priority
Organizational Attributes	14.0%	3
Occupational Safety Services/documentation	7.6%	5
Workplace Layout and Housekeeping	2.5%	9

Equipment & Hand Tools Safety and Machine Guarding	10.1%	4
Fire Prevention, fire fighting and electrical safety	22.8%	2
Mat erial Handling and Storage	4.6%	7
Occupational Exposures	4.7%	6
Personal Protective Equipment	30.6%	1
Hygiene Factors	3.0%	8

Within nine frameworks the factors are also prioritized which will lead considerable saving of cost that can be offset for worker well fare. Say first priority factor is PPE wherein three sub-factors are further prioritized as 1, 2 and 3. Adequate provision of PPE factor is 3.89 times essential than maintenance of PPE and 9.02 time's essential than training on PPE usage. Now SSI can take the benefit means industry needs to think for adequate provision for PPE, maintenance and training program can be subsidiary than adequate provision thereby industry can uplift workers safety and meagre cost should be employed over training program.

Conclusion

Study of this paper is an effective tool to SSI in building safety standards and to avoid mishaps which needlessly incur loss of life and cost. AHP works well to prioritize complicated factors using mathematical modeling and analytical analysis with the aid of experienced experts from concerned area. Because of AHP only, industry can take extra ordinary benefits taking care of these prioritized factors according to their size. This technique not only helps the SSMI to empower their safety standards but also prioritization of factors considering due weight-age are of great importance. It has been concluded that adequate provision of PPE, maintenance are the prime factors which needs utmost care and should be supported by training programs time to time with marginal cost that can prevent the accidents happened to a worker leading disturbance of mind and work.

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