STRATEGIC ENHANCEMENT OF WORKPLACE SAFETY IN SMALL SCALE MANUFACTURING INDUSTRIES USING AHP APPROACH

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ABSTRACT

Despite progress in technology, workplace safety in small scale manufacturing industries (SSMIs) still lacks the required attention. Occupational safety of workers is one of the major concerns for organizations as it involves a number of factors that affect many direct and indirect costs of the industry. To this end, the current study was conducted in order to determine the key factors that affect workplace safety. A total of nine main factors and twenty-two sub-factors were identified and then prioritized using the Analytic Hierarchy Process (AHP). Opinions from experienced and proficient experts were recorded on a framed questionnaire for all the above factors. The effectiveness of the study was ensured by maintaining a consistency ratio of less than 10% for the factors and sub-factors. The factor personal protective equipment was found to have the highest Eigen vector of 27.4%, and therefore the highest priority. Organizational attributes and hygiene are the factors that demand the next level of priority, whereas, equipment and hand tools safety and machine guarding, and material handling are the factors requiring the least priority. The outcome of this analysis enables the small scale manufacturing industries to effectively implement safety measures by giving priority to the factors in the order specified by the study. This would empower the organizational safety standards and benefit not only the employees but also the employers without considerable costs.

Keywords: Analytical Hierarchy Process (AHP); small scale manufacturing industry (SSMI); workplace safety; safety factors

1. Introduction

Small scale industries have played a vital role in the development of India, and industrial growth has contributed greatly to the development of the Indian economy

(Wani et al., 2004). It is well-known that industrial production can be enhanced considerably by providing better safety aspects at the workplace (Singh et al., 2009). Occupational safety is concerned with protecting the safety and welfare of people engaged in work or employment. The goal of any occupational safety program is to develop a safe and healthy work environment which follows a set of laws that have been made to protect people while they work. Safety programs also protect, directly or indirectly, the co-workers, family members, employers, customers and many others who might be affected by the workplace environment as they are all related to the employee/worker.

Safety is a major concern for individuals as well as organizations, as it is a substantial cause of direct and indirect costs (Andersson & Menckel, 1995). Every year, a large number of employees are injured in small scale manufacturing industries because of workplace accidents due to improper implementation or sometimes the absence of safety norms (Takala et al., 2014). Occupational accidents and injuries not only lead to permanent disabilities or deaths and/or economic losses, but they also affect the efficiency of the victim and other workers (Singh, 2018). In this way, occupational accidents result in economic losses for the employee as well as the employer. Occupational safety is the prime responsibility of an organization because the workers are the soul of any progressive organization. Safety is of great importance in industrial development and productivity of small scale manufacturing industries. Therefore, there is a strong necessity to implement necessary safety measures in industrial organizations, as well-organized occupational safety management is the key to any successful industrial establishment. The utmost attention needs to be given to maintaining safety standards at the workplace of SSMIs and the employer needs to reasonably ensure the practical safety of an employee from injuries and health risks at the workplace (Marhavilas et al., 2011).

The growth of small and medium scale manufacturing industries have a large contribution to the economic development of a nation (Wani et al., 2004). However, with an increase in the number of small and medium enterprises, occupational injuries have also increased (Bhagwat & Sharma, 2007; Singh et al., 2009). The reason for the increase is primarily due to lack of awareness and training regarding occupational safety, improper workplace design, unstructured jobs, a mismatch between worker abilities and job demands, an adverse working environment and inappropriate management programs (Saiyed & Tiwari, 2004; Shikdar &Sawaqed, 2003). It is well-known that the production rate can be enhanced by providing better safety aspects at the workplace (Singh et al., 2009). In order to develop a good safety culture, the attitude of workers needs to be reoriented by adopting best practices such as hazard measurement, training, good housekeeping and use of better personal protective equipment (Wilson & Corlett, 2005; Feyer and Williamson, 1991). An employee's perception reflects the value of safety in the organization. Management is not only responsible for the development of safety oriented policies and procedures, but is also accountable for the implementation of safety enhancing systems (Vredenburgh, 2002). Therefore, it is imperative to identify and prioritize the underlying causes of workplace accidents in small scale manufacturing industries so that effective safety interventions can be designed and implemented.

A number of studies demonstrate the effectiveness of workplace safety and health administration in successful business performance (Kwon & Kim, 2013). Training and enforcement of safety practices impact worker behavior and help prevent accidents on the work floor (Atsumbe et al., 2012). Improvements in engineering controls, personal protective equipment, safer machinery and processes and

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adherence to regulations and labor inspections have proved to be the key role parameters (Brauer, 2016). Regardless of the nature of the work, workers should be able to carry out their responsibilities in a safe and secure environment that is free from hazards. Occupational safety and health (OSH) is generally defined as the science of anticipation, recognition, evaluation and control of hazards arising in or from the workplace that could harm the health and well-being of workers (Zwetsloot & Leka, 2010). Even though the importance of OSH has remained the same, the working environment and the overall conditions in society are always in a state of change (Peterson, 2005). Moreover, a wide range of new issues are constantly being added to OSH due to the rapid development of science and technology in industries. Studies on safety factors in medium scale industries were reported by Singh et al. (2016). These types of studies are essential for small scale manufacturing industries to increase the level of workplace safety, reduce the rate of accidents and increase the production rate. Hence, the present study seeks to prioritize the key factors affecting occupational safety in SSMIs. Therefore, the Analytic Hierarchy Process (AHP) is utilized to prioritize all the factors along with their respective sub-factors related to workplace safety in SSMIs. A questionnaire is developed for conducting the study and the opinions of experienced and proficient experts is recorded for different factors and sub-factors with pair-wise comparison.

2. AHP for prioritization of safety factors

The Analytical Hierarchy Process (AHP), developed by Saaty (1990), is a combination of mathematics and interaction of the intended work (Viswanadhan, 2005; Wang & Wang, 2010). AHP is one of the most successful techniques for solving decision making problems involving goals, alternatives for reaching the goals and criteria for evaluating the alternatives (Harker & Vargas, 1987). AHP is successfully implemented in various organizations such as integrated manufacturing, layout design (Al-Harbi, 2001), assessment of technology asset decisions (Boucher & MacStravic, 1991), flexible industrialized systems and in many other engineering related fields (Arbel & Orgler, 1990; Armacost et al., 1994; Cambron & Evans, 1991; Das et al., 2012; Saaty, 1990; Shikdar & Al-Araimi, 2001). AHP is effective in prioritizing the factors to mitigate unforeseen accidents in industries, and the implementation of prioritized factors saves unallocated funds (Akarte et al., 2001; Al-Harbi, 2001; Badri, 2001). Effective implementation of AHP can increase the growth of SMEs in many aspects (Mudavanhu et al., 2013; Singh et al., 2016).

The approach is based on the ability of mathematical structure of consistent matrices and the associated Eigen vectors to generate true or approximate weights. AHP works on an Eigen value which is based on pairwise comparisons (Bayazit, 2005; Boucher & Mac Stravic, 1991; Saaty, 1990). Qualitative and quantitative analyses can be performed simultaneously and calibration can be done using the suitable numeric scale (Saaty, 1985). The following steps give a detailed procedure for carrying out the AHP analysis (Saaty, 1985; Saaty, 1990).

Step-1: Hierarchical structuring of a decision problem and selection of criteria. At the topmost level, this is comprised of a goal or focus. At the intermediate and lower levels, the approach deals with criteria or sub-criteria and the available alternatives, respectively.

Step-2: Construction of a pairwise comparison matrix for each level with respect to higher levels. In this step, the relative importance of different alternatives with

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respect to the immediately above sub-criteria is determined. This is followed by rating the relative priority of the criteria by assigning a weight between 1 (equal importance) and 9 (extreme importance) to the more important criterion. In contrast, the reciprocal of this value is assigned to the other criterion in the pair.
Step-3: Application of Eigen vector methods to calculate the relative weight for the pairwise comparison of options on each criterion.

Step-4: Check the consistency associated with the comparison matrix. This is achieved using the consistency ratio (CR) of consistency index (CI) with the appropriate value of the random index (RI).

Step-5: Repeat the above steps for all levels in the hierarchy.

Step-6: Evaluate the overall relative value by linear addition function.

3. AHP methodology

The methodology of AHP involves five key steps as shown in Figure 1. At first, the problem and the concerned factors that affect the problem are identified and selected. Then, feedback is recorded from field experts on a developed questionnaire and a consistency test is performed. Every step is scrutinized with ample care. The ranking of different factors is based on the 9-point AHP scale shown in Table 1. Increasing rank indicates the growing importance of the factor for which that rank is given.

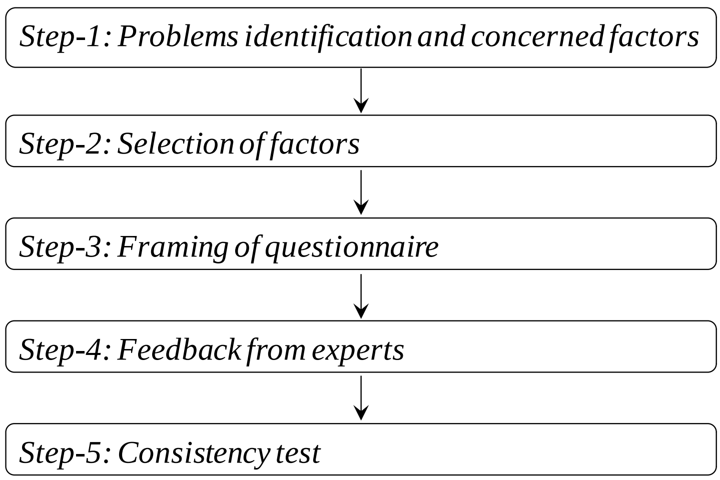

Figure 1 Methodology for Analytic Hierarchy Process (AHP)

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Table 1
9-point scale of Analytic Hierarchy Process 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.

It is ensured that the consistency ratio (CR), the ratio between CI and RI, is less than 10%, after the pairwise comparison is completed because only then is the questionnaire considered adequate. If the CR is above 10%, the questionnaire needs to be revised because it might not accommodate the possible factors. Accordingly, the random index (RI) is obtained for a different number of factors considered for this study (Saaty, 1990; Triantaphyllou & Mann, 1995) (Table 2).

Table 2
Values for random index (RI) for different number of factors considered

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

4. AHP hierarchy model for SSMIs

Based on the above discussions, a hierarchy model for SSMIs is presented in Figure 2 in the form of nine main factors and 22 sub-factors. The detailed procedure for the AHP method with pairwise comparisons based on the experts' opinion has been discussed here for one of the main factors f_5 *and its sub-factors* f_{51},f_{52},f_{53}*and* f_{54} *(Figure 3). These four sub-factors refer to:* f_{51}*: Provision of fire detection system (PFDS);* f_{52}*: Need of fire-fighting training and emergency plan (NFT);* f_{53}*:Provision of emergency exit, exit signs and other relevant safety signs (PEE) and* f_{54}*: Proper electrical wiring (PEW). As part of the questionnaire, the rating given by experts for these four sub-factors is highlighted in Figure 3.*

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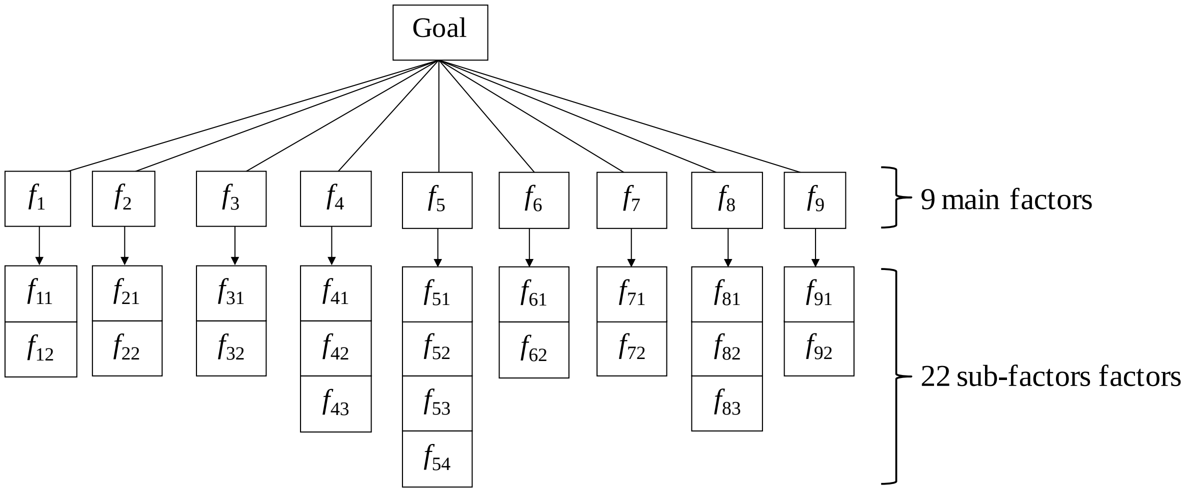

Figure 1 AHP hierarchical model for SSMIs

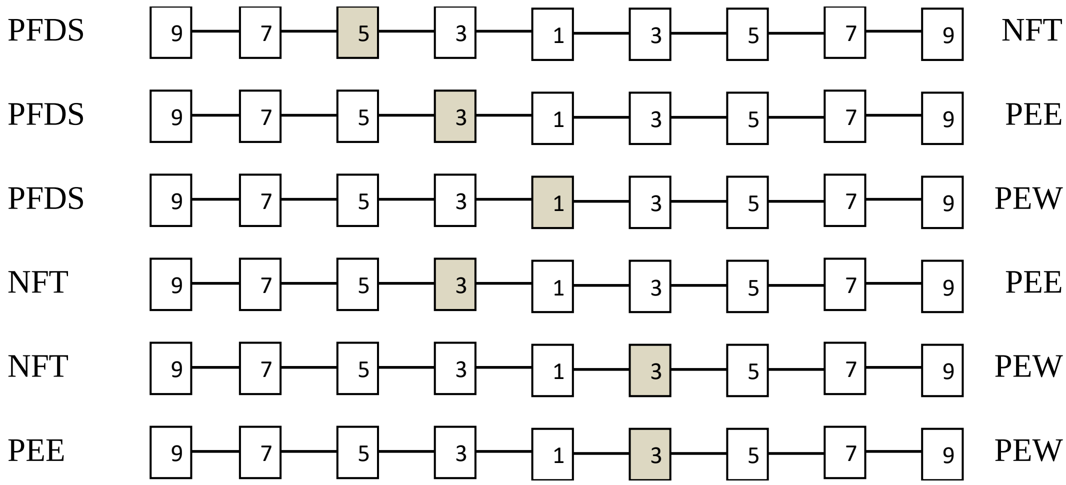

Figure 2 Rating given by experts for the sub-factors f_{51},f_{52},f_{53}, f_{54} of the main factor f_5: Fire prevention, fire-fighting and electrical safety

The fourth order matrix [A] for the pairwise comparison was prepared and represented by matrix (1), in which the diagonally positioned elements are unity, while the upper triangular part of the matrix is filled as described in the following two steps.

- *Step 1.* If the judgemental value given by the expert lies on left hand side of 1, then the value is entered as it is in the matrix.

- *Step 2.* If the judgemental value given by the expert lies on right hand side of 1, then the reciprocal of that value is entered in the matrix (Saaty, 1985).

$$[A] = \begin{array}{c} \\ PFDS \\ NFT \\ PEE \\ PEW \end{array} \begin{array}{c} \begin{array}{cccc} PFDS & NFT & PEE & PEW \end{array} \\ \begin{bmatrix} 1 & 5 & 3 & 1 \\ 1/5 & 1 & 3 & 1/3 \\ 1/3 & 1/3 & 1 & 1/3 \\ 1 & 3 & 3 & 1 \end{bmatrix} \end{array} \tag{1}$$

Once the upper triangular matrix is completed, the lower triangular matrix is filled by taking the reciprocal of the values mirroring the diagonal of the matrix in the upper triangular matrix. It is worthwhile to note that only positive values are entered in the matrix in order to prevent miscalculation. Next, the Eigen values and Eigen vector need to be calculated. For this, each element of matrix (1) is divided by its respective column summation to obtain matrix (2). As a check, the sum of each column in the newly generated matrix (2) must be unity.

$$[A] = \begin{array}{c} \\ PFDS \\ NFT \\ PEE \\ PEW \end{array} \begin{array}{c} \begin{array}{cccc} PFDS & NFT & PEE & PEW \end{array} \\ \begin{bmatrix} 0.3947 & 0.535 & 0.3 & 0.3751 \\ 0.078 & 0.107 & 0.3 & 0.124 \\ 0.131 & 0.036 & 0.1 & 0.124 \\ 0.394 & 0.322 & 0.3 & 0.375 \end{bmatrix} \end{array} \tag{2}$$

Afterwards, the normalized principal Eigen vector $\{W\}$, also known as the priority vector, is computed from the arithmetic mean of the respective rows of matrix (2). The vector $\{W\}$ is shown as matrix (3) below.

$$\{W\} = \begin{Bmatrix} 0.401 \\ 0.154 \\ 0.098 \\ 0.347 \end{Bmatrix} \tag{3}$$

The values in vector $\{W\}$ indicate the relative importance of the four sub-factors f_{51}: PFDS, f_{52}: NFT,f_{53}: PEE and f_{54}: PEW of the main factors f_5. Therefore, the highest priority is given to PFDS (0.401), followed by PEW (0.347), and then NFT (0.154). With a value of W=0.098, the factor PEE is given the least priority. Hence, based on priority matrix $\{W\}$, the relative ranking of factors PFDS, PEW, NFT, PEE is 40.1%, 34.7%, 15.4%, and 9.8%, respectively. Using Equation 4, the Eigen value of factor f_5 is evaluated by taking the sum of the product of column summations of matrix (1) with the respective principle Eigen vector element in matrix (3). This is followed by the calculation of consistency index (CI) using Equation 5.

$$\lambda_{\max} = \frac{38}{15}(0.401) + \frac{28}{3}(0.154) + 10(0.098) + \frac{8}{3}(0.347) = 4.2783 \tag{4}$$

$$CI = \frac{\lambda_{\max} - n}{n} = \frac{4.2783 - 4}{4} = 0.069575 \tag{5}$$

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Since, the number of factors considered in this particular problem are n = 4, (f_{51}, f_{52}, f_{53}, f_{54}), we will use the random index RI = 0.90 corresponding to n = 4 in Table 2. The consistency ratio (CR) is then evaluated as the ratio of consistency index and random index which is $CR = CI/RI = 7.73\%$.

Since the CR is 7.73%, which is less than 10%, this means the framework is accepted. This has illustrated the AHP technique with one framework comprised of comparisons of four sub-factors f_{51}, f_{52}, f_{53} and f_{54}. In the same manner, an AHP analysis was carried out over other frameworks considering the remaining factors and the results are presented in Table 3. This table gives the respective Eigen vector, priority, and consistency ratio after applying AHP on the sub-factors of the remaining main factors. The prioritization of sub-factors within different frameworks was completed and prioritized. In all the cases, the consistency ratio is well below the acceptable value of 10%, which is evidence of the fact that the judgment of experts is rational.

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Table 3
Eigen vector (*W*), priority and consistency ratio (CR) for the various sub-factors considered for SSMIs

***f_x*: Main factor**	***f_{xj}*: Sub-factor**	***W***	***Priority***	***CR***
f_1: Organizational attributes	f_{11}: Existence of safety policy	75.0%	1	0%
	f_{12}: Functioning of safety department	25.0%	2	
f_2: Occupational safety service	f_{21}: Provision of first aid services	83.3%	1	0%
	f_{22}: Records of accident and injury	16.7%	2	
f_3: Work place layout and housekeeping	f_{31}: Adequate and smooth material flow	75.0%	1	0%
	f_{32}: Provision of proper disposal of waste	25.0%	2	
f_4: Equipment and hand tools safety and machine guarding	f_{41}: Need of periodic inspection	10.5%	3	6.4%
	f_{42}: Availability of proper machine guards	63.7%	1	
	f_{43}: Provision of training programs for hand tools and equipment use	25.8%	2	
f_5: Fire prevention, firefighting and electrical safety	f_{51}: Provision of fire detection system	40.1%	1	7.7%
	f_{52}: Need of fire-fighting training and emergency plan	15.4%	4	
	f_{53}: Provision of emergency Exit, exit signs and other relevant safety signs	9.8%	3	
	f_{54}: Proper electrical wiring	34.7%	2	
f_6: Material handling and storage	f_{61}: Need of inspection schedule	66.7%	1	0%
	f_{62}: Provision of safe storage and stacking	33.3%	2	
f_7: Occupational exposures	f_{71}: Exposure to high thermal conditions	66.7%	1	0%
	f_{72}: Monitoring of occupational exposures	33.3%	2	
f_8: Personal protective equipment	f_{81}: Adequate provision of PPE	73.1%	1	6.8%
	f_{82}: Proper maintenance of PPE	18.8%	2	
	f_{83}: Adequate training on PPE usage	8.1%	3	
f_9: Hygiene factors	f_{91}: Availability of safe drinking water	25.0%	2	0%
	f_{92}: Provision of proper lighting and ventilation	75.0%	1	

5. Results and discussion

In a similar way, the main factors are also prioritized using AHP and the priority level is tabulated in Table 4. With an Eigen vector W = 27.4%, factor f_8 (personal protective equipment) is highly prioritized, followed by f_1 (organizational attributes) with W=16.8% and f_9 (hygiene factors) with W =11.4%. However, prioritization of only the main factors is not enough; there is a strong need to prioritize the sub-factors of each of the main factors as well. Without proper prioritization of the sub-factors, the least prioritized factor might be given more importance while the essential factor is missed. This could result in a delay in the progress of workplace safety and in the worst circumstances may further degrade the safety at SSMIs.

Accordingly, the sub-factors of all the main factors have been prioritized based on the Analytical Hierarchy Process. For the first main priority factor f_8, it is observed that the sub-factor *f_{81}: adequate provision of PPE* is almost 4 times more essential than *f_{82}: proper maintenance of PPE*. This implies that while implementing the required safety measures to improve PPE at the workplace, the most importance must be given to adequate provisions of PPE, followed by proper maintenance of PPE and finally training on PPE. The prioritization of main factors along with their sub-factors helps management make efficient decisions about safety implementation in SSMIs. Eventually, this will lead to considerable savings in time and cost that can be offset for worker welfare.

The next three main factors with an intermediate priority of W = 10.1%, 8.4%, 7% are f_5 (fire prevention, fire-fighting, and electrical safety), f_2 (occupational safety services/documentation), and f_3 (workplace layout and housekeeping), respectively. Again, the advantage of AHP is to segregate the least prioritized factors from the important ones, which can be established from the prioritization of the four sub-factors of factor f_5. It should be noted, that among all the main factors considered in this study, factor f_5 has the highest number of sub-factors which is four. Now, in the absence of any prioritization of these four sub-factors: f_{51}, f_{52}, f_{53}, f_{54}, it would be a complex task for the management to distribute the necessary equipment, money and time required by each factor. From Table 3, it is observed that the provision of a fire detection system $\left(W_{f_{51}} = 38.6\%\right)$ is the most important parameter to improve fire prevention, fire-fighting and electrical safety at workplace. Moreover, to fully develop the fire prevention, fire-fighting and electrical safety at workplace proper electrical wiring $\left(W_{f_{54}} = 36.6\%\right)$, provision of an emergency exit, exit signs and other relevant safety signs $\left(W_{f_{53}} = 13.8\%\right)$ and need of fire-fighting training and an emergency plan $\left(W_{f_{52}} = 10.9\%\right)$ are the next three key factors to be taken care of in the same order as they are presented here.

Finally, the factors: f_7 (occupational exposures), f_4 (equipment and hand tools safety and machine guarding) and f_6 (material handling and storage) have a minimum Eigen vector of $W_{f7} = 6.5\%$, $W_{f4} = 6.4\%$ and $W_{f6} = 5.9\%$, respectively and hence need the least attention from the management of SSMIs.

Based on the results, the SSMIs should focus on personal protective equipment (PPE) and organizational attributes and hygiene of the workers as these are the three most critical factors that need immediate attention to avoid loss of life and cost at the

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workplace. Considering the outcome of this study, it is highly recommended that SSMIs follow this hierarchy while implementing the safety measures on the workplace.

Table 4
Eigen vector (*W*) and priority for various main factors of SSMIs

Main Factor	***W***	***Priority***
f_1: Organizational Attributes	16.8%	2
f_2: Occupational Safety Services/documentation	8.4%	5
f_3: Workplace Layout and Housekeeping	7.0%	6
f_4: Equipment and Hand Tools Safety and Machine Guarding	6.4%	8
f_5: Fire Prevention, fire-fighting and electrical safety	10.1%	4
f_6: Material Handling and Storage	5.9%	9
f_7: Occupational Exposures	6.5%	7
f_8: Personal Protective Equipment	27.4%	1
f_9: Hygiene Factors	11.4%	3

6. Conclusion

The Analytical Hierarchy Process is used to prioritize the nine main factors and twenty-two sub-factors of occupational safety associated with SSMIs. Based on the AHP analysis, it is observed that personal protective equipment has the highest priority, followed by organizational attributes and hygiene factors to improve workplace safety. Further, it is important to individually prioritize sub-factors of each main factor as well as the main factors in order to effectively enhance workplace safety. The SSMIs should follow the hierarchy presented in this work while implementing safety measures and the industry should also give the highest priority to the factors at the top of the ranking list and conduct necessary training programs in order to prevent workplace accidents. It is envisaged that by employing the hierarchy developed in this study, any newly established SSMI can become capable of saving effort, time and money and can also build a safer working environment.

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