

# Hazard Identification & Risk Assessment with Human Error Analysis Method in Automotive Industry

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**ABSTRACT:** Hazard Identification and Risk Assessment (HIRA) is a safety tool used in most automotive industries to identify the hazards and assess the risks in the plant. The primary purpose of the HIRA tool is to assess the risks and prioritize the risks in order to eliminate the hazards in the prioritized order. Human error analysis method (HEA) is one of most recent and effective human error identification techniques which assesses the human error probability and is chosen as the tool to integrate with the HIRA method in this paper. The impetus for the thesis stems from the idea that the HIRA method overlooks one of the root causes of the accidents/incidents in the workplace, which is, the unsafe acts or human error. Thus, in order to make it more efficient towards the proactive approach of accident prevention in workplace, HIRA method has to consider human error assessment in the workplace which can be achieved through Human Error Analysis method (HEA). Also, the integration of HIRA with HEA will result in giving an additional dimension in prioritizing the hazards identified and assessed and thus, making HIRA, a more effective and proactive tool for safety supervision in an industry. Myunghwa Automotive India, a leading international automotive manufacturing corporation, was chosen as a case study for the thesis where the upgraded HIRA was implemented by which the hazards in the Knuckle Spindle Rough & Finish machining line in the plant were identified and prioritized for the control measures.

**KEYWORDS:** HIRA – Hazard Identification and Risk Assessment, HEA – Human Error Analysis

## I. INTRODUCTION

HIRA is the primary tool used in most industries to prevent accidents as a proactive approach of safety system. The impetus for the paper stems from the idea that the HIRA method overlooks one of the root causes of the accidents/incidents in the workplace, which is, the unsafe acts or human error. Thus, in order to make it more efficient towards the proactive approach of prevention of accidents in workplace, HIRA method has to consider the human error assessment in the workplace which can be achieved through the integration of HIRA with HEA.

### 1.1 RELATED WORKS

HIRA is a widely used safety tool for the maintenance of safety in an organization. Researchers have reported several data related to HIRA study and human error assessment in an organization. In general, it is accepted that low ergonomics value would result in injuries and loss of man days. But, very few researches have been done to study the integration of HIRA with a human error assessment method in automotive industries. Thus, the thesis is expected to study the integration of HIRA with a human error assessment method in automotive industries. Some of the important research works considered are summarized as follows. Russell A. Matthews et al (2010) evaluated five dimensions

related to unsafe acts which are, Self-involvement, Knowledge Base, Managerial Support, Employee Supportiveness, and Strain related to ergonomic changes, with the study on 407 participants. Self-involvement, Knowledge Base, and Managerial Support were all positively related to reports of upward safety communication, and all three were negatively related to perceived likelihood of being injured on the job. Similarly, Employee Supportiveness was also positively related to upward safety communication. In the case of reports of Strain related to ergonomic changes, individuals reporting more strain were more likely to report that they would be hurt on the job, and less likely to report feeling comfortable discussing safety issues with their supervisor. In addition, Strain related to ergonomic changes was positively related to the number of injuries reported by participants. Participants reported higher frequencies of work-related injuries in relation to strain due to ergonomic changes.

The performance of Health, Safety, and Environment (HSE) study integrated with ergonomics system was studied by Azadeh A. et al (2008). HSE at the operational level will strive to eliminate injuries, adverse health effects and damage to the environment. Effective application of ergonomics in work system design can achieve a balance between worker characteristics and task demands. This can enhance worker productivity, provide improved worker safety (physical and mental) and job satisfaction. Several studies have shown positive effects of applying ergonomic principles to the workplace including machine, job and environmental design. Studies in ergonomics have also produced data and guidelines for industrial applications. The main concern of work system design in context of ergonomics is improvement of machines and tools. Lack of utilization of the ergonomic principles could bring inefficiency to the workplace. Moreover, an ergonomically deficient workplace can cause physical and emotional stress, low productivity and poor quality of work conditions. It is believed that ergonomic deficiencies in industry are root cause of workplace health hazards, low levels of safety and reduced workers productivity. By considering health, safety, environment and ergonomics (HSEE), an organization manages its operations in a manner that places safety and health first. It encourages employees to adopt a healthy and safe life-style.

Julie bell & Justin Holyard (2009) investigated a total of 35 human reliability analysis methods and have summarized about the scope, approach, and information on the underlying models of the methods, the advantages and disadvantages of the methods, the suitability of the methods in their application, a comment on the validity of the methods and a note of the resources required for the use of the methods.

Mats Eklof et al (2004) highlighted the importance of participative ergonomics in better working environment and health. This study examined cross-sectional and prospective associations among (1) worker participation (and empowerment) in efforts to improve the working environment, (2) integration of ergonomics and core organizational concerns (i.e., work organization, quality, and productivity), and (3) working environment and health indicators. A sample of 40 groups of white-collar visual display unit users from 11 private and public Swedish organizations was studied. In conclusion, the results indicated that participation and integration in efforts to improve the working environment were consistently associated with psychological demands (-), stress (-), and social support (+).

The Probabilistic risk assessment of highway tunnels was studied by Ondrej Nyvlt et al (2011). He studied the concept of adjusted probabilistic risk assessment into the framework of advanced risk analysis and enables incorporation into risk management process.

Zhaoyang Tan et al (2014) studied the risk assessment and countermeasures of gas accidents in the sensitive areas under control during the Olympic Games in Beijing. They came to conclusion that Risk assessment of gas accident is a dynamic and continuous process, and in accordance with the workflow of risk assessment, timely tracking, communication and feedback, as well as regular update of the results are needed.

The Integrated risk assessment for LNG terminals was analyzed by Aneziris O.N. et al (2014). He outlined the major sequence of steps that should be undertaken as follows: hazard identification, accident sequence modeling, data acquisition and parameter estimation, accident sequence quantification, consequence assessment, and integration of results where individual risk is assessed for any person who might be near the terminals. Probabilistic methods for risk assessment have extensively been used in the literature for toxic and flammable substances.

## II. SCOPE OF THE PROJECT

The objectives of the thesis are the following:

- ❖ To improve HIRA with the integration of HEA in automotive industry, thereby, making HIRA a complete tool for the proactive approach of safety management in the organization. To implement the new improved HIRA tool in Myunghwa, Singadivakkam.
- ❖ To suggest control measures based on the HIRA.
- ❖ To enhance the worker productivity, provide improved worker safety (physical and mental) and job satisfaction as a result of implementing the new improved HIRA.

### 1.1 ACCIDENT THEORY

Accidents are defined as unplanned occurrences which result in injuries, fatalities, loss of production or damage to property and assets. Preventing accidents is extremely difficult in the absence of an understanding of the causes of accidents. Many attempts have been made to develop a prediction theory of accident causation, but so far none has been universally accepted. Researchers from different fields of science and engineering have been trying to develop a theory of accident causation which will help to identify, isolate and ultimately remove the factors that contribute to or cause accidents. According to W.H. Heinrich (1931), who developed the so-called domino theory, 88% of all accidents are caused by unsafe acts of people, 10% by unsafe conditions and 2% by “acts of God” as illustrated in figure 2.1. The definitions of incidents, accidents, unsafe acts and unsafe conditions are as follows.

❖ **Incidents:**

Incidents represent situations which have occurred and that had the potential to cause harm to a person or damage equipment or property. A vessel pressurized to a point nearing rupture is an example for incident.

❖ **Accidents:**

Accidents are incidents which occur and result in harm to a person or damage to equipment or property. Trips or falls causing injury are an example of accidents.

❖ **Unsafe Act:**

Performance of a task or other activity that is conducted in a manner that may threaten the health and/or safety of workers. Use of tools for other than their intended purpose is an example of unsafe act.

❖ **Unsafe Condition:**

A condition in the work place that is likely to cause property damage or injury. Defective tools, equipment, or supplies are the examples of unsafe condition.

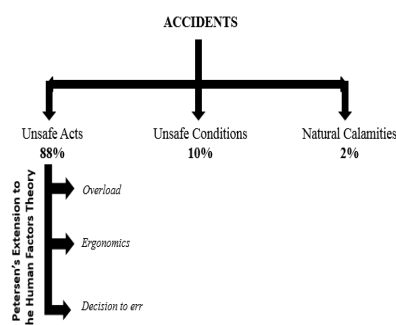


Figure 2.1 Heinrich Theory of Accidents

### 2.2 PROBLEM IDENTIFICATION

The methodology of the research, is explained as following: The Hazard Identification & Risk Assessment (HIRA) was carried out in the 25Ton Knuckle machining at line 4, Myunghwa, Singadivakkam. The Human Error Probability (HEP) for the Human Error analysis (HEA) method was calculated for all the activities considered in the HIRA. The results of the HIRA and HEP values were compared and analyzed for highlighting the importance of the integration of the human error assessment in HIRA method. The introduction of human error assessment in the HIRA method was achieved through HEA technique with the help of the mean value of HEP value calculated for the

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accidents which occurred during the period 2011, 2012, and 2013 in Myunghwa, Singadivakkam. The mean value of HEP for the accidents were calculated using normal distribution method and also, the goodness of fit was tested using chi-squared test to ensure the credibility of the mean value calculated. The formula for the proposed method of integrated HIRA was formulated and the proposed method was carried out in the cylinder head rough machining line in Myunghwa, Singadivakkam. The control measures were suggested for the most hazardous risk, prioritized by the upgraded HIRA, in accordance with the hierarchy of controls

**2.3PROCEDURE**

**1. Identify Hazards**

Identify all potentially hazardous things or situations that may cause harm in consultation with workers. In general, hazards are likely to be found in the physical work environment, equipment, materials or substances used, work tasks and how they are performed, work design and management.

**2. Assess Risks**

Risk assessment involves considering the possible results of someone being exposed to a hazard and the likelihood of this occurring. A risk assessment assists in determining how severe a risk is, whether existing control measures are effective, what action should be taken to control a risk, and how urgently action needs to be taken. The process of assessing the risk is undertaken by reviewing any available information about the hazard and by using personal work experience about what sort of harm, the hazard could create and how likely this would be to happen. The risks are assessed by calculating the Risk Priority Number (RPN). The RPN is calculated by multiplying the severity and likelihood values of the hazard which are referred from the tables 2.1 and 2.2 respectively (NEBOSH, 2011). After assigning the values of likelihood (P), and severity (S) from the appropriate grids, the Risk Priority Number (RPN) is calculated with the use of equation 2.1.

$$\text{Risk Priority Number (RPN)} = \{Likelihood (P)\} * \{Severity (S)\} \text{ [Equation 2.1]}$$

**3. Controlling Risks**

After calculating the RPN value, the requirement of corrective action is assessed by the prioritization grid such as low, medium, high, and urgent which is given in the table 2.3.

Table 2.1 Severity Rating

NATURE OF SEVERITY	VALUE
There is no injury but only property damage (<Rs 5000/-).	1
There is a minor injury, first aid injury like laceration; Property damage > Rs 5000/- but less than Rs 20,000/-).	2
There is a serious injury, like reportable injury, property damage > Rs 20000/- < 50,000/-	3
There is major injury which may lead to a Permanent Disability or property damage beyond repair.	4
There is a fatal injury, loss of limb, loss of property and damage to a total plant, equipment or machinery etc.	5

Table 2.2 Likelihood Rating

PROBABILITY / LIKELIHOOD	VALUE
Almost Impossible or very unlikely of the occurrence.	1
Unlikely or the occurrence is less than once per year.	2
Possible or the occurrence is once or twice per year.	3

Probable or the occurrence is once or twice per month.	4
Very likely or the occurrence is on a weekly frequency.	5

Table 2.3 Prioritization index

Action Levels	RPN	Priority
Tolerable Risk-safe to Work	1-5	Low
Tolerable Risk – Control Measures required	6-12	Medium
Intolerable Risk – Safe Under Supervision/Safe Job Procedures/Permits etc required	13-16	High
Urgent Actions to – Reduce the Risk to Manageable Level – Activity may be stopped until tolerable level is achieved.	17-25	Urgent

NOTE:

If severity level alone is 5: The Action level becomes “Urgent”.

If legal concern is present: The Action Required becomes “High”.

#### 4. Implement additional risk controls

Having identified the hazards in the workplace, assessed their risks and reviewed the existing controls, all hazards must be managed before people are hurt, become ill or there is damage to plant, property or the environment. The management of risks in the workplace requires eliminating risks so far as reasonably practicable in the first instance. Where elimination is not possible, then risks should be minimized, so far as reasonably practicable. All hazards that have been assessed should be dealt with in order of priority. The most effective control option/s should be selected to eliminate or minimize risks. The hierarchy of controls (figure 2.2) ranks control options from highest level of protection and reliability to lowest. This should be used to determine the most effective control/s.

#### 5. Monitor and Review

Hazard identification, risk assessment and control are an on-going process. Therefore, the effectiveness of hazard assessment and control measures should be regularly reviewed. When there is a change to the workplace, work systems, tools, machinery or equipment change, the HIRA should be carried out.

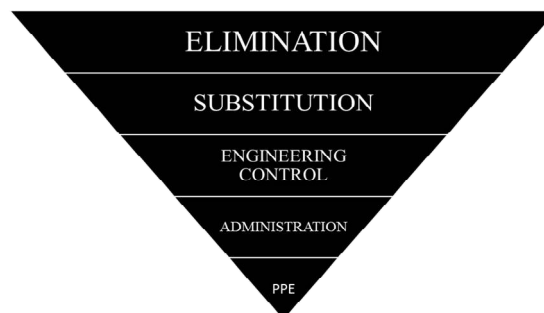


Figure 2.2 Hierarchy of Controls

### III. PROPOSED METHOD

The HIRA method was integrated with a human error assessment technique, HEA by the use of the mean value of HEP of the accidents which occurred in Myunghwa, Singadivakkam during the period 2011, 2012 and 2013, calculated using the normal distribution method which is detailed in the section 3.4.1.

#### 3.1 Calculation of Mean HEP Value

The accident reports for the previous three years, 2011, 2012 and 2013, for all the shops in Myunghwa, Singadivakkam were collected and the cause for the accidents were analyzed and grouped into two categories, namely,

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unsafe conditions, and unsafe acts. The accidents caused by the unsafe conditions were filtered out and only the accidents caused by unsafe acts were considered for the study. Thereby, a total of 52 out of 81 accidents were found to be caused by unsafe acts and measured for HEP value contributing to the accidents. The HEP values for the activities in which the 52 accidents occurred was measured carefully and listed in the table 3.4. The data's are fitted with a normal distribution and the mean and variance were calculated with the help of the table 3.2.

Table 3.1 HEP Data for Accidents

Acc. No.	HEP	Acc. No.	HEP
1	0.0385	2	0.02
3	0.07414	4	0.04766
5	0.091	6	0.0385
7	0.04766	8	0.091
9	0.06	10	0.04766
11	0.02	12	0.07414
13	0.04	14	0.05
15	0.025	16	0.06
17	0.91	18	0.04
19	0.02	20	0.0385
21	0.06	22	0.07414
23	0.025	24	0.07414
25	0.04	26	0.07414
27	0.1	28	0.04766
29	0.07414	30	0.091
31	0.06	32	0.138
33	0.04766	34	0.02
35	0.0385	36	0.05
37	0.07414	38	0.06
39	0.05	40	0.04
41	0.07414	42	0.1
43	0.04766	44	0.04
45	0.02	46	0.1
47	0.07414	48	0.0385
49	0.05	50	0.04766
51	0.06	52	0.0385

The interval, C was taken as 0.01475 and the frequency, F and the value, X was obtained from the accident's data. A was assumed to be 0.0716 as it is the mid value of the range taken in the table 3.2. The mean and variance values were calculated by the equation 3.1 and equation 3.2 by substituting the values obtained from the table 3.2.

Table 3.2 Normal Distribution

Range	X	F	$D = \frac{(X-A)}{C}$	$D^2$	F * D	F * D <sup>2</sup>
0.02 – 0.03475	0.0274	7	-3	9	-21	63
0.03475 – 0.0495	0.0421	18	-2	4	-36	72

0.0495 – 0.06425	0.0569	10	-1	1	-10	10
0.06425 – 0.079	0.0716	9	0	0	0	0
0.079 – 0.09375	0.0864	4	1	1	4	4
0.09375 – 0.1085	0.1011	3	2	4	6	12
0.1085 – 0.12325	0.1159	0	3	9	0	0
0.12325 – 0.138	0.1306	1	4	16	4	16
		$\sum F = 52$			$\sum(F*D) = -53$	$\sum(F*D^2) = 177$

$$\text{Mean, } \mu = [A + \{(C/N) * \sum(F*D)\}] \quad \text{[Equation 3.1]}$$

$$\gg \mu = [0.0716 + \{(0.01475/52) * (-53)\}]$$

$$\gg \boxed{\text{Mean, } \mu = 0.0566}$$

$$\text{Standard deviation, } \sigma^2 = [C^2\{(\sum(F*D^2) / N) - ((\sum(F*D) / N)^2)\}] \quad \text{[Equation 3.2]}$$

$$\gg \sigma^2 = [(0.01475)^2\{ (177 / 52) - (((-53) / 52)^2)\}]$$

$$\gg \sigma^2 = 5.145 * 10^{(-4)}$$

$$\gg \boxed{\text{Variance, } \sigma = 0.023}$$

The goodness of fit for the fitted data with the normal distribution is tested with the Chi-squared test with the level of significance, 2.5%. The mean and the variance were found out with the normal distribution method and the hypothesis was taken as 'the data fitted using the normal distribution is a good fit'. If the hypothesis is true, then it signifies that the normal distribution is a good fit to the data's collected and the mean value calculated is credible.

Null Hypothesis,  $H_0$ : The data fitted using normal distribution is a good fit.

Alternative Hypothesis,  $H_1$ : The data fitted using normal distribution is not a good fit.

**Step 1:** The probability for the limits defined are calculated.

Probability for the limits is calculated by the equation 3.6.

$$P[a < X < b] = P\left[\frac{(a - \mu)}{\sigma} < Z < \frac{(b - \mu)}{\sigma}\right] \quad \text{[Equation 3.3]}$$

Where,  $P[X]$  is the probability distribution,  $a$  and  $b$  are limits,  $\mu$  is the mean and  $\sigma$  is the variance. Therefore, the probability distribution for the value of  $X$  within the limits 0.02 to 0.03475 is,

$$P[0.02 < X < 0.03475] = P\left[\frac{(0.02 - \mu)}{\sigma} < Z < \frac{(0.03475 - \mu)}{\sigma}\right]$$

Substituting the values of mean,  $\mu = 0.0566$  and variance,  $\sigma = 0.023$ ,

$$\begin{aligned} \gg P [0.02 < X < 0.03475] &= P \left\{ \frac{(0.02 - 0.0566)}{0.023} < Z < \frac{(0.03475 - 0.0566)}{0.023} \right\} \\ &= P \{-1.59 < Z < -0.95\} \\ &= P \{-\infty < Z < -0.95\} - P \{-\infty < Z < -1.59\} \end{aligned}$$

From the Z table of normal distribution, the values for  $Z = -0.95$  and  $Z = -1.59$  were found and substituted as follows,

$$\begin{aligned} \gg P [0.02 < X < 0.03475] &= 0.1711 - 0.0559 \\ \gg P [0.02 < X < 0.03475] &= 0.1152 \end{aligned}$$

Similarly, the probability for the other limits is calculated and given as follows:

$$\begin{aligned} P [0.03475 < X < 0.04950] &= 0.2072 \\ P [0.04950 < X < 0.06425] &= 0.2510 \\ P [0.06425 < X < 0.07900] &= 0.2047 \\ P [0.07900 < X < 0.09375] &= 0.1134 \\ P [0.09375 < X < 0.10850] &= 0.0407 \\ P [0.10850 < X < 0.12325] &= 0.0100 \\ P [0.12325 < X < 0.13800] &= 0.0100 \end{aligned}$$

**Step 2:** The theoretical frequency distribution using probability distribution is calculated.

The theoretical frequency distribution was calculated by the equation 3.4.

$$F_t (a < X < b) = \sum F * P[a < X < b] \quad [\text{Equation 3.4}]$$

Where,  $F_t (a < X < b)$  is the theoretical frequency,  $\sum F$  is the total frequency and  $P[a < X < b]$  is the probability distribution. Therefore, the theoretical frequency,  $F_t$  for the value of  $X$  within the limits 0.02 to 0.03475 is,

$$F_t (0.02 < X < 0.03475) = \sum F * P[0.02 < X < 0.03475]$$

Substituting the values of  $\sum F = 52$  and  $P [0.02 < X < 0.03475] = 0.1152$ ,

$$\begin{aligned} \gg F_t (0.02 < X < 0.03475) &= 52 * 0.1152 \\ \gg F_t (0.02000 < X < 0.03475) &= 5.99 \approx 6 \end{aligned}$$

Similarly, the theoretical frequency for the other limits is calculated and given as follows:

$$\begin{aligned} F_t (0.03475 < X < 0.04950) &= 10.77 \approx 11 \\ F_t (0.04950 < X < 0.06425) &= 13.12 \approx 14 \\ F_t (0.06425 < X < 0.07900) &= 10.67 \approx 11 \\ F_t (0.07900 < X < 0.09375) &= 5.89 \approx 6 \\ F_t (0.09375 < X < 0.10850) &= 2.12 \approx 3 \\ F_t (0.10850 < X < 0.12325) &= 0.52 \approx 1 \\ F_t (0.12325 < X < 0.13800) &= 0.088 \approx 0 \end{aligned}$$

**Step 3:** The goodness of fit with 2.5% level of significance using Chi-squared test is tested.

The value chi-square,  $\chi^2$  is found by the equation 3.5.

$$\chi^2 = \sum [(F - F_t)^2 / F_t] \quad [\text{Equation 3.5}]$$



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Where, F is the experimental frequency and  $F_t$  is the theoretical frequency. The values of the experimental frequency, F and theoretical frequency,  $F_t$  are tabulated in the table 3.6.

The conditions for validity of chi-squared test are as follows:

1. Sample observation should be independent.
2. Constraints on the cell frequencies must be linear,  $\sum F = \sum F_t$
3. N- the total number of frequency should be reasonably large (<50).
4. No theoretical cell frequency should be less than '5'. If so, it is pooled with the succeeding or preceding, so that, the pooled frequency is more than '5'.

All the above conditions were verified for the data used and were found to be fulfilling the conditions of validity for chi-squared test. In chi-squared test, the values of frequencies have to be equal to or above 5. Therefore, the values of the theoretical frequency,  $F_t$  and the experimental frequency, F are tabulated after adjusting the values of frequencies to be equal to or above 5 by adding the respective rows.

Table 3.3 Frequency Data

Experimental frequency, F	Theoretical frequency, $F_t$
7	6
18	11
10	14
9	11
4	6
3	3
0	1
1	0

In order to satisfy this condition, the following function was applied in the table 3.6 to obtain the table 3.7,

$$\gg R_6 \rightarrow R_6 + R_7 + R_8 + R_9$$

Table 3.4 Chi-Square

Experimental frequency, F	Theoretical frequency, $F_t$	$(F - F_t)^2 / F_t$
7	6	0.166
18	11	4.45
10	14	1.42
9	11	0.363
8	10	0.4

The values obtained from the table 3.4 were substituted in the equation 3.8 and the value of the calculated chi-square,  $\chi^2_{cal}$  was obtained as follows.

$$\chi^2_{cal} = \sum [(F - F_t)^2 / F_t] = 0.166 + 4.45 + 1.42 + 0.363 + 0.4$$

$$\chi^2_{cal} = \mathbf{6.521}$$

The degrees of freedom, D, to calculate the value of chi-square,  $\chi^2_{0.025}$  was calculated by the following formula,

$$\mathbf{D = n - k}$$

Where,

Number of rows, n = 5

Constraint, k for normal distribution = 3

Substituting the above values,

Degrees of freedom, D = 5 - 3 = 2

The chi-square,  $\chi^2$  for the degrees of freedom, D = 2 and 2.5% level of significance was derived from the chi-square table and is given as follows:

$$\chi^2_{0.025}(2) = \mathbf{7.378}$$

$$\gg \chi^2_{cal} < \chi^2_{0.025}(2)$$

Therefore, the calculated chi-square,  $\chi^2_{cal}$  value is less than the acceptance chi-square,  $\chi^2_{0.025}$  value. This implies, the null hypothesis is accepted.

$\gg$  **H<sub>0</sub> is accepted; H<sub>1</sub> is rejected.**

Thus, the normal distribution was found to be tested for goodness for fit with chi-square test and the mean value was calculated as 0.0566.

<b>Mean, <math>\mu = 0.0566</math></b>
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### 3.2 Procedure for the Proposed Method

The integrated approach of HIRA with SPAR-H method is carried out by first carrying out HIRA method by identifying the hazards in the operation, and calculating the RPN value for the hazards following the procedure as explained in the section 3.1 referring the tables 3.1 and 3.2. The prioritization of the hazards alone differs from the prevalent HIRA method as the proposed HIRA takes into account of the HEP value also as a dimension to prioritize the hazards. The modified prioritization table is formulated and illustrated in the table 3.5. Then, the HEP of the operation considered, is calculated by the SPAR-H method as explained in the section 3.3. The mean value of HEP for the accidents during the period 2011, 2012 and 2013, calculated as 0.0566, is fixed as a benchmark for the prioritization of the hazards.

The hazards are then, prioritized according to the table 3.5, where the prioritization order is Low1(L1) < Low2(L2) < Medium1(M1) < Medium2(M2) < High1(H1) < High2(H2) < Urgent1(U1) < Urgent2(U2) in which L1 is given the least priority and U2 is given the highest priority. Finally, the identified hazards should be analyzed for the control measures in their prioritized order.

Table 3.5 Prioritization Index for the Proposed Method

RPN	HEP	PRIORITY
1-5	<b>&lt;0.0566</b>	<b>LOW1 (L1) - Safe to Work</b>
	<b>≥0.0566</b>	<b>LOW2 (L2) – Measures are required to reduce the HEP to as low as reasonably possible.</b>

6-12	<0.0566	<b>MEDIUM1 (M1)</b> – Control Measures are required
	≥0.0566	<b>MEDIUM2 (M2)</b> – Control Measures required to eliminate hazard and also to reduce the HEP to as low as reasonably possible.
13-16	<0.0566	<b>HIGH1 (H1)</b> – Safe Under Supervision/Safe Job Procedures/Permits etc., are required
	≥0.0566	<b>HIGH2 (H2)</b> – Safe Under Supervision/Safe Job Procedures/Permits etc., are required and with reduction of HEP to as low as reasonably possible.
17-25	<0.0566	<b>URGENT1 (U1)</b> – Reduce the Risk to Manageable Level – Activity may be stopped until tolerable level (RPN number less than 12) is achieved.
	≥0.0566	<b>URGENT2 (U2)</b> – Reduce the Risk to Manageable Level – Activity may be stopped until tolerable level (RPN number less than 12 & HEP less than 0.0566) is achieved. Also, measures are required to reduce the HEP to as low as reasonably possible.

#### IV. RESULTS AND DISCUSSION

All the hazards in the 25T Knuckle machining line in Myunghwa, Singadivakkam were identified by using the tools, What If analysis and Checklist analysis. The hazards identified are listed in the table 4.1. The hazard identified for the activity “Loading of component from pallet to conveyor by using Electric hoist” in the first operation “Facing & Centering” was fall of component. The component is cylinder head which weighs 25 kg. The component is lifted at a height of 1.8 m from the ground level using an electric hoist and thus, severity of hazard as referred from the table 3.1 is “4” as the fall of the component from the height of 1.8 m is believed to have the potential to cause a major injury to the employee. The frequency of the hazard happening in plant was found to be once per month, thus from the table 3.2, the likelihood of the hazard is “4”. Thus, RPN was calculated by multiplying the value of severity and likelihood which is 16.

Then, the HEP value is calculated for the first operation “Machining of 25Ton Knuckle” through HRA technique which is explained as follows. The activities involved in the first operation “Facing & Centering” are to operate a electric hoist to lift a 25 kg component to a height of 1.8 m and aligning the component precisely on the conveyor, followed by pushing the component along the conveyor to the butting area, auto loading of the component to the fixture and auto unloading of the component to the conveyor and finally, pushing the component to the turn over table (TOT). Thus, the first operation is categorized as an action task as it is a task where each activity is done by following a written procedure and thereby, the  $N_{HEP}$  is assigned as 0.001. The eight PSF’s for the activity were assigned a value accordingly and multiplied to obtain the  $PSF_{composite}$  value which is 4 [1(Available time) x 2(Stress) x 2(Complexity) x 1(Training) x 1(Procedure) x 1(Ergonomics) x 1(Fitness for duty) x 1(Work process)]. HEP was calculated by substituting the values of  $N_{HEP}$  and  $PSF_{composite}$  in the equation 3.2 as there were only two negative values of PSF which are stress and complexity in the operation. Thus, the calculated HEP value was found to be 0.004.

Similarly, the RPN and HEP values were found for each of the other 11 operations in the 25Ton Knuckle machining line of the automotive industry and were tabulated in the table 4.1. While calculating the HEP value, the operations are considered as a whole and not necessarily divided into separate activities as each operation is performed by a single worker. The hazards are then prioritized according to the table 3.5, where the hazard in the activity

“Loading of component from pallet to conveyor by using Electric hoist” of the operation “Facing & Centering” had a RPN value of 16 and HEP value of 0.004, which according to the table 3.5, is prioritized as High1 (H1) risk. Similarly, all the hazards are prioritized according to the table 3.8 and the hazards are reduced or eliminated in the order of the prioritization where the Urgent2 (U2) risk is analyzed for the control measures first and subsequently to Low1 (L1) risk.

Table 4.1 Integrated HIRA with HEA

\*LC – Legal Concern; S – Severity; P – Likelihood; RPN – Risk Priority Number

S. No	Activity	Hazard identified	LC *	S*	P*	RP N*	HEP	RISK LEVEL
			Y/ N	0- 5	0- 5	S*P		L1/L2/M1/ M2/H1/H2 /U1/U2
<b>1</b>	<b>Facing &amp; Centering</b>						0.004	
	Loading of component from pallet to conveyor by using Electric hoist	Fall of component	N	4	4	16		<b>H1</b>
	Push the component to the butting area	slipping of hand	N	2	3	6		<b>M1</b>
	Auto loading of the component to the fixture	Auto cycle is running	N	2	3	6		<b>M1</b>
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6		<b>M1</b>
	Cleaning the fixture using air gun	Flying of burr chip	N	3	3	9		<b>M1</b>
	Push the component to the turn over table (TOT)	slipping of hand	N	2	3	6		<b>M1</b>
<b>2</b>	<b>Spindle rough turning</b>						0.0001	
	Pull the Component from TOT and push it to the butting face	slipping of hand	N	2	3	6		<b>M1</b>
	Auto loading of the component to the fixture	Auto cycle is running	N	2	3	6		<b>M1</b>
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6		<b>M1</b>
	Cleaning the fixture using air gun	Flying of burr chip	N	3	4	12		<b>M1</b>
	Push the component to the TOT	slipping of hand	N	2	3	6		<b>M1</b>
<b>3</b>	<b>Drilling, Tapping &amp; Facing</b>						0.0001	
	Pull the Component from TOT and push it to the butting face	slipping of hand	N	2	3	6		<b>M1</b>
	Auto loading of the component to the fixture	Auto cycle is running	N	2	3	6		<b>M1</b>
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6		<b>M1</b>

	Cleaning the fixture using air gun	Flying of burr chip	N	3	4	12		<b>M1</b>
	Push the component to the TOT	slipping of hand	N	2	3	6		<b>M1</b>
<b>4</b>	<b>Rough Gang milling</b>							
	Pull the Component from TOT and push it to the butting face	slipping of hand	N	2	3	6	0.0001	<b>M1</b>
	Auto loading of the component to the fixture	Auto cycle is running	N	2	3	6		<b>M1</b>
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6		<b>M1</b>
	Cleaning the fixture using air gun	Flying of burr chip	N	3	3	9		<b>M1</b>
	Push the component to the lifting conveyor.	Fall of Component	N	3	3	9		<b>M1</b>
<b>5</b>	<b>Spindle finish turning</b>							
	Push the component to the loading area	slipping of hand	N	2	3	6	0.0001	<b>M1</b>
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6		<b>M1</b>
	Push the component to the lifting conveyor.	Fall of component	N	3	3	9		<b>M1</b>
	Push the component to the TOT	slipping of hand	N	2	3	6		<b>M1</b>
	Cleaning the fixture using air gun	Flying of burr chip	N	3	3	9		<b>M1</b>
<b>6</b>	<b>King pin rough boring</b>							
	Pull the component from TOT and push it to the butting face	slipping of hand	N	2	3	6	0.0001	<b>M1</b>
	Auto loading of the component to the fixture	Auto cycle is running	N	2	3	6		<b>M1</b>
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6		<b>M</b>
	Cleaning the fixture using air gun	Flying of burr chip	N	3	3	9		<b>M1</b>
	Push the component to the TOT	slipping of hand	N	2	3	6		<b>M1</b>
<b>7</b>	<b>King pin finish boring &amp; grooving</b>							
	Pull the component from TOT and push it to the butting face	slipping of hand	N	2	3	6	0.0001	<b>M1</b>
	Auto loading of the component to the fixture	Auto cycle is running	N	2	3	6		<b>M1</b>
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6		<b>M1</b>

	Cleaning the fixture using air gun	Flying of burr chip	N	2	2	4		<b>L1</b>
	Push the component to the TOT	slipping of hand	N	2	3	6		<b>M1</b>
	Pull component from TOT and push it to another TOT	slipping of hand	N	2	3	6		<b>M1</b>
<b>8</b>	<b>Drilling, Tapping &amp; Keyway machining</b>							
	Pull the component from TOT and push it to the butting face	slipping of hand	N	2	3	6	0.0001	<b>M1</b>
	Auto loading of the component to the fixture	Auto cycle is running	N	2	3	6		<b>M1</b>
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6		<b>M1</b>
	Cleaning the fixture using air gun	Flying of burr chip	N	2	2	4		<b>L1</b>
	Push the component to the TOT	slipping of hand	N	2	3	6		<b>M1</b>
<b>9</b>	<b>Bush pressing</b>							0.00005
	Pull component from TOT and push it to the loader area	slipping of hand	N	2	3	6	<b>M1</b>	
	Auto loading of the component to the Machine	Auto cycle is running	N	2	3	6	<b>M1</b>	
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6	<b>M1</b>	
	Component is pushed up in the conveyor	Fall of Component	N	3	3	9	<b>M1</b>	
<b>10</b>	<b>Finish gang milling</b>						0.00005	
	Push component to the loading area	slipping of hand	N	2	3	6		<b>M1</b>
	Auto loading of the component to the Machine	Auto cycle is running	N	2	3	6		<b>M1</b>
	Auto unloading of the component to the conveyor	Auto cycle is running	N	2	3	6		<b>M1</b>
	Cleaning the fixture using air gun	Flying of burr chip	N	2	2	4		<b>L1</b>
<b>11</b>	<b>Spindle OD grinding</b>						0.0001	
	Pull the component from the unloader area and push it to the loader area	slipping of hand	N	2	3	6		<b>M1</b>
	Loading of the component to the machine	Slipping of hand	N	2	3	6		<b>M1</b>
	Unloading of the component to the conveyor	Slipping of hand	N	2	3	6		<b>M1</b>
	Cleaning the fixture using air gun	Flying of burr chip	N	3	3	9		<b>M1</b>

<b>A</b>	<b>Tool change</b>	Fall of component	N	4	4	16	0.07414	<b>H2</b>
<b>B</b>	<b>Shop floor maintenance</b>	Slip and trip hazard	N	2	2	4	0.005	<b>L1</b>

## V. CONCLUSION

The Hazard Identification and Risk Assessment (HIRA) method was successfully integrated with HEA, and thus, adding an extra dimension of human error assessment while evaluating the risk of the hazards identified and thereby, making HIRA, a complete method for proactive approach in accident prevention. The mean value of the human error probability (HEP) in the HEA method was calculated as 0.0566 for the accidents in an automotive plant during the period 2011, 2012 and 2013 using normal distribution method. Also, the data fitted with normal distribution was tested for goodness of fit using chi-squared test with the level of significance 2.5%, thereby, verifying the credibility of the mean value calculated. The mean value of 0.0566 was kept as a pivot value for the HEP consideration in the activities while prioritizing the hazards.

Also, the lack of human error consideration in the existing HIRA method was highlighted by the comparison of the RPN values and HEP values of two activities which showed that although the RPN value which is the only index on which the existing HIRA was based on for prioritization of the hazards, was same but on the other hand, the two activities had vast difference in their HEP values. The “tool change” operation was found to be the most prior hazard as a result of carrying out the integrated method in cylinder head rough machining line, with a priority level of High2 (H2). Further, the control measures for the tool change operation was suggested, which on implementation was expected to reduce the RPN value from 16 to 4 and the HEP value from 0.07414 to 0.004, thereby, reducing the risk level of the hazard in the tool change operation to Low1 (L1) which is as low as reasonably practicable level.

The scope for future work includes the suggestion of control measures for the other operations in the cylinder head rough machining line of the chosen automotive plant, in the order of the prioritization in the proposed method where the HEP value and RPN values should be reduced to as low as reasonably practicable (ALARP) level.

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