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# ERGONOMIC RISK ASSESSMENT OF MAINTENANCE JOB IN A GAS POWER STATION

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*SUMMARY: This study conducted ergonomic risk factors assessment of maintenance job in a gas generating power station with a capacity of 8.4 MW (1.4 MW x 6 units) and 12 maintenance staff. The ergonomic risk factors present in the maintenance job were identified as task, personal and environmental. The potential severity of all the recognized risk factors and probability of occurrence were assessed on a scale of 1 to 5. The risk index was determined as the product of probability of occurrence and potential severity of all the risk parameters. The relative weights of the parameters of the risk factors were determined by dividing each cumulative risk index by the total cumulative risk index. The relative weights of the ergonomic risk factors were determined by dividing the cumulative risk index for each factor by the total of the cumulative risk indexes. The total risk index for each factor was calculated by summing up the product of the relative weights and the risk indexes of the parameters that make up the factor. The Work Severity Index (WSI) was determined by summing up the product of the relative weights and the risk indexes of the ergonomic risk factors. The risk values were categorized into three classes of low, medium and high risk. Using the personal and environmental factors, the average risk values were 3.03 ± 0.42 and 3.00 ± 0.00 respectively signifying that the job was a low risk one. The value of the average Work Severity Index was 5.03 ± 1. 62 which showed that the maintenance job as it was practised in the power station under study was of low risk.*

**Key words:** *Ergonomics, Risk, Work, Severity, Index, Disorders*

## INTRODUCTION

Risk factors are sources/situations which have the potential to cause injury or lead to the development of a disease *(Oladeinde et al., 2012)*.

Ergonomics risk factors are factors that bring about risk of musculoskeletal injuries which are found in jobs requiring repetitive, forceful, or prolonged exertions of the hands: frequent or heavy lifting, pushing, pulling, or carrying of heavy objects; and prolonged awkward postures. Li and Buckle *(1999)* stated some risk factors that could result in occupationally related musculoskeletal disorders as force/load, posture, frequency of movement and vibration. High workload is a major risk factor in the development of musculoskeletal disorders *(Roman-Liu, 2014)*. The two main factors influencing workload are working posture and exerted force *(Brandl et al., 2017)*.

Occupational Health and Safety Act (OHS) (2004) emphasized the relationship between the working populations and the jobs itself. Meanwhile, maintenance in a power plant entails the use of manual handling tools to get the job done.

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There is always a challenge in matching or fitting the task to the task responsible, as most of the time, the use of wrong tools, poor maintenance planning, individual factors, environmental factors and or organizational factors create limitations that would induce discomfort while doing the job. Thermal power plant in all its entire process stages caused environmental consequence as stated by Kumar et al. *(2015)* resulting into various occupational diseases and injuries with major effect on economy due to loss of productive hour, man-power losses and compensation to concerned workers. However, for safety reasons, musculoskeletal injuries must be thoroughly avoided and equipment usage must be kept under control. In a nutshell, ergonomics or human factors' risk assessment will control all musculoskeletal disorder during maintenance in power station of any kind if they are properly administered. The main aim of this study was to develop a model that can analyze the ergonomics risks involved in maintaining power plant.

Musculoskeletal disorders associated with manual tasks are a common cause of injury across a number of industries according to Lynas and Burgess-Limerick *(2013)*. Almost three-quarters of all serious workers' compensation claims in 2010 -2011 across all Australian industries were the result of injury, with sprains and strains accounting for 42% of all serious claims. Kim et al. *(2010)* reported that work related low back disorders account for between 26% and 50% of the total number of reported cases of occupational musculoskeletal disorders. Mechanisms involving muscular stress while handling objects resulted in 32% of all serious injuries. These injuries are often complex with multiple contributing factors including the environment, task characteristics, and individual factors influencing the mechanism of injury. However, not all manual tasks are high risk, effective manual task risk management requires identification of hazardous tasks followed by assessment of the degree and source of risk associated with the task before effective controls can be implemented to either eliminate or reduce the risk.

Risk assessment is the careful examination and evaluation of what could cause harm to life and properties with a view to coming up with precautions that will arrest the menace. Occupational Health and Safety Act (OHS Act); *(2004)* presented a process that shows the essential Risk Assessment and Risk Control components as (i) Hazard (ii) Risk Identification/Assessment (iii) Risk Control (iv) Review/ Results Evaluation.

While carrying out a routine check in the workplace, risk factors or hazards are identified; hazard identification provides information that can be used to manage risks that could have the potential of causing injury. The basic principles of risk assessment involve looking at the extent of exposure to assess how great the risk is. Extent of exposure includes magnitude (how much), duration (how long), and frequency (how often, how fast). Risk control is the process of identifying the underlying cause of hazards and risk factors and putting measures in place to prevent a recurrence of the risk, attention are on the most urgent hazard and prioritizing those hazards using the risk management matrix, understanding that some methods are more effective than others. Moreover, the use of hierarchy of hazard controls to establish the most appropriate control measure is highly effective. It should be remembered that elimination of hazard is the most effective control. The use of the highest-ranked control that is reasonably practicable is good for controlling risk, while the lower-ranked control is good as a last resort or until a more effective way of controlling risk can be used. More than one control measure can be used to reduce the exposure to hazards. These are levels for hierarchy of hazard control which includes eliminate, substitute the hazard with a safer alternative, isolate the hazard, engineering controls, administrative controls and personal protective equipment (PPE).

There are a number of ergonomics exposure techniques that are used for ergonomics investigations of risk factors. A wide range of methods that have conventionally been used by earlier researchers to investigate risk factors and are categorized under the three headings of self-reports, observational methods and direct measurements *(David, 2005)*.

Some of the widely used methods are: OWAS (Ovako Working Posture Assessment System) *(Karhu et al., 1977)*; RULA (Rapid Upper Limbs Assessment); *(McAtamney and Corlett, 1993)*; Revised NIOSH Lifting Equation Revised NIOSH Lifting Equation *(Waters et al., 1998)*; PLIBEL (Plan

for Identifiering av Belastingsfaktorer); REBA (Rapid Entire body assessment)-entire body postures and force assessment for dynamic tasks *(Hignett and McAtamney, 2000)*. However, most of these methods either address the task (Revised NIOSH) or the worker (RULA, REBA, OWAS etc.). There is, therefore, the need to develop a risk assessment model that will combine task factors, workers' characteristics and environmental factors. This study developed a work severity risk index for the maintenance activities in a power generation plant.

## METHODOLOGY

The analysis and evaluation of ergonomics risk assessment in jobs are divided into four stages:

- **Stage 1: Dividing Jobs into units**

The maintenance jobs in the power plant were examined and classified into six units, with mechanical, electrical and general work given attention in each of the unit.

- **Stage 2: Identifying Ergonomics Risk Factors in each of the unit**

This stage makes use of questionnaire, checklists, physical inspections, workers interview and record checking for near misses, accident and musculoskeletal injuries in identifying inherent hazard and risk in the power station.

The musculoskeletal injury factors that could contribute to the risk for each of those jobs were divided into three:

- Job or task factors (Factor A)
- Personnel or personal factors (Factor B)
- Environmental factors (Factor C)

Each of the factors has component parts or parameters that are responsible for the power plant maintenance ergonomics problems as it becomes difficult to fit or match the worker with the job.

- **Stage 3: Assigning Values to Ergonomics Risk Factors**

These are the assessment of all the possible risk factors that have been identified in stage 2 based on the extent of exposure to magnitude (how much), duration (how long), and frequency (how often, how fast) and with respect to each of the maintenance unit. The assessment was done based on the potential severity of impact (generally a negative impact, such as damage or loss) and to the probability of occurrence.

- **Stage 4: Computation of Risk Index**

Risk Index is the Rate (or probability) of occurrence multiplied by the impact of the event. This is expressed as:

- Risk Index = Impact of Risk event × Probability of Occurrence or
- Risk Index = Severity/Consequent × Rate of Occurrence/Likelihood of event.

The impact of the risk event could be called severity or consequences of event and is assessed on a scale of 1 to 5, where 1 and 5 represent the minimum and maximum possible impact of an occurrence of a risk respectively.

The probability of occurrence is likewise assessed on a scale from 1 to 5, where 1 represents a very low probability of the risk event actually occurring while 5 represents a very high probability of occurrence. These axes are expressed in mathematical terms and the Risk Index ranging from 1 through 25 were divided into three sub-ranges of 1-8, 9-15 and 16-25 representing Low, Medium and high values respectively.

### Ergonomics Risk Factor Identification

The risk identification was conducted with a good knowledge of the work process and the risk factors; however, since it is not practical to identify ergonomics risk factors associated with all jobs at one time, an approach was adopted by listing the jobs in order of decreasing risk and establishes a plan in order of priority. To determine which job was at a higher risk for ergonomics factors and should be given priority, the history of musculoskeletal disorder hazards, near misses, incidents, and accidents for risk identification was examined.

**Instructions used in Assessing the Ergonomics Risk Factor on the Job**

STEP 1: Use of ergonomics checklists to identify those risk factors present in the task

STEP 2: Identify those risk parameters present in each of the risk factor.

STEP 3: Compute the probability of occurrence for all the risk parameters present using a scale of 1 to 5.

STEP 4: Compute the potential severity for all the risk parameters present using a scale of 1 to 5.

STEP 5: Compute the risk index for all the risk factors.

**Determination of Ergonomics Risk Factors and Probabilities of Occurrences**

***Task Factors***

Factor A which is task or job factor include the following parameters: weight of object, hand coupling, work posture and duration.

Due to the safe weight of lift established by Ismaila and Charles-Owaba (2012) as 6.6 kg, scales were distributed as follows for weight of object to be lifted: 1 for 0 to 6. 6 kg; 2 for 6.7 to 13.3 kg; 3 for 13.4 to 20 kg; 4 for 20.1 to 26.7 kg and 5 for greater than 26.7 kg.

The presence of hand coupling on the load to be carried was assigned a scale of 1 while its absence was assigned a scale of 5. A scale of 1 was assigned to working in the sagittal plane whereas a scale of 5 was assigned to any deviation from this plane. Based on the study of Dembe et al. *(2005)* that the number of hours of work was positively associated with an increasing risk of injury, a scale of 1 was assigned for 0 to 8 hrs of work; 2 for 9 to 10 hrs; 3 for 11 to 12 hrs; 4 for 13 to 14 hrs and 5 for greater than 14 hrs.

***Personal Factors***

Factor B is called the personal factor and the parameters include: experience (Number of years and skill acquired on the job regarded as experience); Body Mass Index (BMI); and age.

The risk of injuries in the work place decreases with experience on the job *(Bena et al., 2013)*; a scale of 1 was assigned for workers with an experience of 20 years and above; 2 for 16 to 19 years; 3 for 11 to 15 years; 4 for 6 to 10 years and 5 for 0 to 5 years.

Overweight and obese workers are more likely to be injured if they are compared to normal weight workers *(Gu et al., 2016)*. The scores for BMI were: 1 for 0 to 18 kg/m$^2$; 2 for 18. 5 to 24.9 kg/m$^2$; 3 for 25.0 to 29.9 kg/m$^2$; 4 for 30.0 to 34.9 kg/m$^2$ and 5 for more than 34.9 kg/m$^2$. According to Mitchell (1988), the risk of injuries positively and significantly correlated with age. Thus, scores were assigned as follows: 1 for less than 25 years; 2 for 26 to 35 years; 3 for 36 to 45 years; 4 for 46 to 55 years and 5 for more than 55 years.

***Environmental Factors***

Factor C is called the environmental factor and the parameters include: ambient temperature; standing or sitting on vibrating surfaces; noise level and ventilation.

High ambient temperature is a risk factor for work related injuries/accidents *(Morabito et al., 2006)* necessitating the assignment of scores for ambient temperature as follows: 1 for 25.7°C and less; 2 for 25.8 to 28.6°C; 3 for 28.7 to 31.7°C; 4 for 31.8 to 34.8°C and 5 for more than 34.8°C. Whole body vibration that is greater than the ISO limit can affect the workers adversely *(Seidel and Heide, 1986)*, the ISO 2631-5: 2004 value of the vibration in the workplace is 0.80 m/s$^2$. The scores for vibrating were as follows: 1 for up to 0.20 m/s$^2$; 2 for 0.21 to 0.40 m/s$^2$; 3 for 0.41 to 0.60 m/s$^2$; 4 for 0. 61 to 0.80 m/s$^2$ and 5 for more 0.80 m/s$^2$. Noise may also interfere with vigilance of workers and other risk factors for accidents and thus may lead to accidents *(Deshaies et al., 2015)*, the scores for noise levels in the workplace were assigned as: 1 for 0 to 49 dB; 2 for 50 to 70 dB; 3 for 71 to 89 dB; 4 for 90 to 95 dB and 5 for more than 95 dB.

## DEVELOPMENT OF A MODEL FOR WORK SEVERITY RISK INDEX

PO = Probability of Occurrence

PS = Potential Severity

RI = Risk Index
$i$ = Number of subjects
$j$ = Number of parameters
$n$ = Number of Participating Parameters
T = Total Number of parameters
$RI_i$ = Risk index for each subject
$RI_j$ = Risk Index for each parameter
$CRI_n$ = Cumulative Risk Index
$RW_j$ = Relative Weight of each parameter
RS = Risk Score
RC = Risk Code
TRI = Total Risk Index
PF = Personal Factor
EF = Environmental Factor
TF = Task Factor
WSI = Work Severity Index

Since $PO \times PS = RI$ [1]

Summing the subjects' risk indexes (RIs) for individual risk factor parameters give their Cumulative Risk Indexes (CRIs)

$$CRI_n = \sum_{i=1}^{n} RI_i \quad [2]$$

where $i$ is the number of subjects

$$CRI_T = \sum_{j=1}^{n} CRI_j \quad [3]$$

where $j$ is the number of parameters

The relative weights for individual risk factors parameters are given as:

$$RW_{j\ \text{personal factor}} = CRI_j / CRI_{T\ personal\ factor} \quad [4]$$

$$RW_{j\ environmental\ factor} = CRI_j / CRI_{T\ environmental\ factor} \quad [5]$$

$$RW_{j\ task\ factor} = CRI_j / CRI_{T\ task\ factor} \quad [6]$$

Equations 7 to 9 determine the total risk indices (TRIs).

$$\mathbf{TRI}_{\textbf{\textit{personal factor}}} = (RW_{work\ experience} \times RI_{work\ experience}) + (RW_{BMI} \times RI_{BMI}) + (RW_{age} \times RI_{age}) \quad [7]$$

$$\mathbf{TRI}_{\textbf{\textit{environmental factor}}} = (RW_{ambient\ temperature} \times RI_{ambient\ temperature}) + (RW_{noise\ level} \times RI_{noise\ level}) + (RW_{vibration\ level} \times RI_{vibration\ level}) \quad [8]$$

$$\mathbf{TRI}_{\textbf{\textit{task factor}}} = (RW_{weight\ of\ object} \times RI_{weight\ of\ object}) + (RW_{coupling} \times RI_{coupling}) + (RW_{work\ posture} \times RI_{work\ posture}) + (RW_{duration} \times RI_{duration}) \quad [9]$$

The probability of occurrence and potential severities for the personal; environmental and task factors using the literature as guides are presented in Tables 1 and 2 respectively *(Cox, 2008)*.

**Table 1. Probability of Occurrence**
**Tablica 1. Vjerojatnost pojave**

| Rate of Occurrence | Rating | Comment |
|---|---|---|
| Certain | 5 | Almost certain to occur in most circumstance |
| Likely | 4 | Likely to occur frequently |
| Possible | 3 | Possible and likely to occur at some time |
| Unlikely | 2 | Unlikely to occur but could happen |
| Rare | 1 | May occur but only in rare and exceptional circumstances |

**Table 2. Potential Severities and Consequence**
**Tablica 2. Potencijalne opasnosti i posljedice**

| Severity | Rating | Comment |
|---|---|---|
| Catastrophic | 5 | Death, permanent disability e.g. loss of hand |
| Major | 4 | Extensive permanent injury e.g. loss of fingers |
| Moderate | 3 | Significant non-permanent injury |
| Minor | 2 | Medical help needed |
| Insignificant | 1 | First Aid and in-house treatment |

### *Personal factors*

The obtained data from the workers are presented in Table 3.

**Table 3. The Parameters Obtained from the Assessed Workers**

**Tablica 3. Parametri dobiveni od radnika**

| Subject | Duration (Hours) | Age (Year) | Weight (Kg) | Height (M) | Body Mass Index (Kgm-2) | Experience (Year) | Designation |
|---|---|---|---|---|---|---|---|
| Subject 1 | 9 | 49 | 70 | 1.77 | 22.35 | 20 | Technologist |
| Subject 2 | 9 | 32 | 76 | 1.62 | 28.96 | 6 | Field Engineer |
| Subject 3 | 9 | 30 | 80 | 1.77 | 25.54 | 4 | Field Engineer |
| Subject 4 | 9 | 44 | 65 | 1.58 | 26.04 | 16 | Engineer Mech. |
| Subject 5 | 9 | 48 | 64 | 1.57 | 25.96 | 22 | Engineer Elect. |
| Subject 6 | 9 | 60 | 65 | 1.60 | 25.39 | 30 | Engineer Project |
| Subject 7 | 9 | 33 | 77 | 1.75 | 25.14 | 5 | Field Engineer |
| Subject 8 | 9 | 29 | 74 | 1.78 | 23.35 | 3 | Field Engineer |
| Subject 9 | 9 | 31 | 66 | 1.57 | 26.77 | 4 | Field Engineer |
| Subject 10 | 9 | 28 | 76 | 1.66 | 27.57 | 1 | Trainee Engineer |

Sum the entire subjects risk index for individual risk factor parameters to give their Cumulative Risk Index

$$\mathrm{CRI}_n = \sum_{i=1}^{n} RI_i$$

where *i* is the number of subjects

For work experience (Table 4),

$$\mathrm{CRI}_{10} = \mathrm{RI}_1 + \mathrm{RI}_2 + \mathrm{RI}_3 + \mathrm{RI}_4 + \mathrm{RI}_5 + \mathrm{RI}_6 + \mathrm{RI}_7 + \mathrm{RI}_8 + \mathrm{RI}_9 + \mathrm{RI}_{10} = 1 + 4 + 5 + 2 + 1 + 1 + 5 + 5 + 5 + 5 = 34$$

The cumulative risk indices for personal factors are presented in Table 4.

The same was repeated for BMI and age as presented in Table 4.

$$\mathrm{CRI}_T = \sum_{j=1}^{T} CRI_j$$

where *j* is the number of parameters for personal factors (Work experience, BMI, etc.)

$$\mathrm{CRI}_{\mathrm{Tpersonal\ factor}} = \mathrm{CRI}_{\mathrm{work\ experience}} + \mathrm{CRI}_{\mathrm{BMI}} + \mathrm{CRI}_{\mathrm{age}} = 34 + 28 + 28 = 90$$

The relative weights for individual risk factors parameters are given as:

$$\mathrm{RW}_{\mathrm{j\ personal\ factor}} = \frac{\mathrm{CRI}_j}{\mathrm{CRI}_{Tpersonal\ factor}} \qquad [4]$$

**Table 4. Cumulative Risk Indices for Personal Factors**

**Tablica 4. Indeksi kumulativnog rizika za osobne čimbenike**

| | Work Experience | | | | Body Mass Index | | | | Age | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SUBJECT | PO | PS | RI | CRI | PO | PS | RI | CRI | PO | PS | RI | CRI |
| Subject 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 4 | 1 | 4 | 4 |
| Subject 2 | 4 | 1 | 4 | 5 | 3 | 1 | 3 | 5 | 2 | 1 | 2 | 6 |
| Subject 3 | 5 | 1 | 5 | 10 | 3 | 1 | 3 | 8 | 2 | 1 | 2 | 8 |
| Subject 4 | 2 | 1 | 2 | 12 | 3 | 1 | 3 | 11 | 3 | 1 | 3 | 11 |
| Subject 5 | 1 | 1 | 1 | 13 | 3 | 1 | 3 | 14 | 4 | 1 | 4 | 15 |
| Subject 6 | 1 | 1 | 1 | 14 | 3 | 1 | 3 | 17 | 5 | 1 | 5 | 20 |
| Subject 7 | 5 | 1 | 5 | 19 | 3 | 1 | 3 | 20 | 2 | 1 | 2 | 22 |
| Subject 8 | 5 | 1 | 5 | 24 | 2 | 1 | 2 | 22 | 2 | 1 | 2 | 24 |
| Subject 9 | 5 | 1 | 5 | 29 | 3 | 1 | 3 | 25 | 2 | 1 | 2 | 26 |
| Subject 10 | 5 | 1 | 5 | 34 | 3 | 1 | 3 | 28 | 2 | 1 | 2 | 28 |

$$RW_{\text{personal factor (work experience)}} = \frac{CRI_{work\ experience}}{CRI_{Tpersonal\ factor}} = \frac{34}{90} = 0.38$$

$$RW_{\text{personal factor (BMI)}} = \frac{CRI_{BMI}}{CRI_{Tpersonal\ factor}} = \frac{28}{90} = 0.31$$

$$RW_{\text{personal factor (age)}} = CRI_{age} / CRI_{\text{Tpersonal factor}} = \frac{28}{90} = 0.31$$

This Equation gives their relative risk values.

$$TRI_{\text{personal factor}} = (RW_{\text{work experience}} \times RI_{\text{work experience}}) + (RW_{BMI} \times RI_{BMI}) + (RW_{age} \times RI_{age}) \quad [7]$$

$$TRI_{\text{personal factor}} = (0.38 \times RI_{\text{work experience}}) + (0.31 \times RI_{BMI}) + (0.31 \times RI_{age}) \quad [7]$$

### *Environmental factors*

The environmental factors obtained during the maintenance activities as presented in Table 5

**Table 5. The Environmental Factors Obtained during the Maintenance Activities**

**Tablica 5. Čimbenici okoliša utvrđeni tijekom održavanja**

| Parameter | Value (Hours) | Unit |
|---|---|---|
| Ambient temperature | 27 | °C |
| Vibration | 0.27 | m/s² |
| Noise level | 92 | dB |
| Duration | 9 | Hrs |

$CRI_n = \sum_{i=1}^{n} RI_i$, where *i* is the number of subjects

$$CRI_{10} = RI_1 + RI_2 + RI_3 + RI_4 + RI_5 + RI_6 + RI_7 + RI_8 + RI_9 + RI_{10}$$

$$CRI_T = \sum_{j=1}^{T} CRI_j,$$

where *j* is the number of parameters for Environmental factors

The cumulative risk indices for environmental factors are presented in Table 6.

$$CRI_{\text{T. environmental factor}} = CRI_{\text{ambient temperature}} + CRI_{\text{noise level}} + CRI_{\text{vibration}} = 20 + 40 + 20 = 80$$

The relative weights for individual risk factors parameters are given as:

$$RW_{\text{j environmental factor}} = \frac{CRI_j}{CRI_{Tenvironmental}} \quad [5]$$

$$RW_{\text{1 environmental factor}} = \frac{CRI_{ambient\ temperature}}{CRI_{Tenvironmental}} = 20/80 = 0.25$$

$$RW_{\text{2 environmental factor}} = \frac{CRI_{noise\ level}}{CRI_{Tenvironmental}} = 40/80 = 0.50$$

$$RW_{\text{3 environmental factor}} = \frac{CRI_{vibration}}{CRI_{Tenvironmental}} = 20/80 = 0.25$$

This Equation gives their relative risk values.

$$TRI_{\text{environmental factor}} = (RW_{\text{ambient temperature}} \times RI_{\text{ambient temperature}}) + (RW_{\text{noise level}} \times RI_{\text{noise level}}) + (RW_{\text{vibration}} \times RI_{\text{vibration}}) \quad [8]$$

**Table 6. Cumulative Risk Indices for Environmental Factors**

**Tablica 6. Indeksi kumulativnog rizika za čimbenike okoliša**

| | Ambient Temperature | | | | Noise Level | | | | Vibrating Surface | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SUBJECT | PO | PS | RI | CRI | PO | PS | RI | CRI | PO | PS | RI | CRI |
| Subject 1 | 2 | 1 | 2 | 2 | 4 | 1 | 4 | 4 | 2 | 1 | 2 | 2 |
| Subject 2 | 2 | 1 | 2 | 4 | 4 | 1 | 4 | 8 | 2 | 1 | 2 | 4 |
| Subject 3 | 2 | 1 | 2 | 6 | 4 | 1 | 4 | 12 | 2 | 1 | 2 | 6 |
| Subject 4 | 2 | 1 | 2 | 8 | 4 | 1 | 4 | 16 | 2 | 1 | 2 | 8 |
| Subject 5 | 2 | 1 | 2 | 10 | 4 | 1 | 4 | 20 | 2 | 1 | 2 | 10 |
| Subject 6 | 2 | 1 | 2 | 12 | 4 | 1 | 4 | 24 | 2 | 1 | 2 | 12 |
| Subject 7 | 2 | 1 | 2 | 14 | 4 | 1 | 4 | 28 | 2 | 1 | 2 | 14 |
| Subject 8 | 2 | 1 | 2 | 16 | 4 | 1 | 4 | 32 | 2 | 1 | 2 | 16 |
| Subject 9 | 2 | 1 | 2 | 18 | 4 | 1 | 4 | 36 | 2 | 1 | 2 | 18 |
| Subject 10 | 2 | 1 | 2 | 20 | 4 | 1 | 4 | 40 | 2 | 1 | 2 | 20 |

Substituting the calculated relative weight into respective equations of PF, EF and TF

$$TRI_{environmental\ factor} = (0.25 \times RI_{ambient\ temperature}) + (0.50 \times RI_{noise\ level}) + (0.25 \times RI_{vibration}) \quad [8]$$

$CRI_n = \sum_{i=1}^{n} RI_i$, where $i$ is the number of subjects

$$CRI_{10} = RI_1 + RI_2 + RI_3 + RI_4 + RI_5 + RI_6 + RI_7 + RI_8 + RI_9 + RI_{10}$$

The cumulative risk indices for task factors of the workers are presented in Table 7.

$$CRI_T = \sum_{j=1}^{T} CRI_j,$$

where $j$ is the number of parameters for Task factors

$$CRI_{Ttask\ factor} = CRI_{weight\ of\ object} + CRI_{work\ posture} + CRI_{coupling} + CRI_{duration}$$

$$CRI_{Ttask\ factor} = 74 + 31 + 73 + 20 = 198$$

Then calculate their relative weight for individual risk factors parameters. Given as:

$$RW_{j\ task\ factor} = \frac{CRI_j}{CRI_{Ttask}} \quad [6]$$

$$RW_{weight\ of\ object} = \frac{CRI_{weight\ of\ object}}{CRI_{Ttask}} = 74/198 = 0.37$$

$$RW_{work\ posture} = \frac{CRI_{work\ posture}}{CRI_{Ttask}} = 31/198 = 0.16$$

$$RW_{coupling} = \frac{CRI_{coupling}}{CRI_{Ttask}} = 73/198 = 0.37$$

$$RW_{duration} = \frac{CRI_{duration}}{CRI_{Ttask}} = 20/198 = 0.10$$

This Equation gives their relative risk values.

$$TRI_{task\ factor} = (RW_{weight\ of\ object} \times RI_{weight\ of\ object}) + (RW_{work\ posture} \times RI_{work\ posture}) + (RW_{coupling} \times RI_{coupling}) + (RW_{duration} \times RI_{duration}) \quad [9]$$

$$TRI_{task\ factor} = (0.37 \times RI_{weight\ of\ object}) + (0.16 \times RI_{work\ posture}) + (0.37 \times RI_{coupling}) + (0.10 \times RI_{duration})$$

$$\text{Work Severity Index (WSI)} = X_1PF + X_2EF + X_3TF \quad [13]$$

$$CRI_{T\ personal\ factor} = 34 + 28 + 28 = 90$$

$$CRI_{T\ environmental\ factor} = 20 + 40 + 20 = 80$$

$$CRI_{T\ task\ factor} = 74 + 31 + 73 + 20 = 198$$

$$\text{Total Risk Index (TRI)} = CRI_{Tpf.} + CRI_{Tef} + CRI_{Ttf}$$

$$\text{Total Risk Index (TRI)} = 90 + 80 + 198 = 368$$

Where

$$X_1 = CRI_{Tpersonal\ factor.}/(CRI_{Tpersonal\ factor} + CRI_{Tenvironmental\ factor} + CRI_{Ttask\ factor}) = 90/368 = 0.24 \quad [10]$$

**Table 7. Cumulative Risk Indices for Task Factors**

**Tablica 7. Indeksi kumulativog rizika za čimbenike zadataka**

| | Weight of object | | | | Work posture | | | | Presence of coupling | | | | Duration | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SUBJECT | PO | PS | RI | CRI | PO | PS | RI | CRI | PO | PS | RI | CRI | PO | PS | RI | CRI |
| Subject 1 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 |
| Subject 2 | 5 | 2 | 10 | 12 | 1 | 1 | 1 | 2 | 5 | 2 | 10 | 11 | 2 | 1 | 2 | 4 |
| Subject 3 | 5 | 1 | 5 | 17 | 1 | 1 | 1 | 3 | 5 | 2 | 10 | 21 | 2 | 1 | 2 | 6 |
| Subject 4 | 2 | 2 | 4 | 21 | 1 | 1 | 1 | 4 | 5 | 2 | 10 | 31 | 2 | 1 | 2 | 8 |
| Subject 5 | 2 | 2 | 4 | 25 | 1 | 1 | 1 | 5 | 1 | 1 | 1 | 32 | 2 | 1 | 2 | 10 |
| Subject 6 | 2 | 2 | 4 | 29 | 1 | 1 | 1 | 6 | 1 | 1 | 1 | 33 | 2 | 1 | 2 | 12 |
| Subject 7 | 5 | 2 | 10 | 39 | 5 | 1 | 5 | 11 | 5 | 2 | 10 | 43 | 2 | 1 | 2 | 14 |
| Subject 8 | 5 | 2 | 10 | 49 | 5 | 1 | 5 | 16 | 5 | 2 | 10 | 53 | 2 | 1 | 2 | 16 |
| Subject 9 | 5 | 2 | 10 | 59 | 5 | 1 | 5 | 21 | 5 | 2 | 10 | 63 | 2 | 1 | 2 | 18 |
| Subject 10 | 5 | 3 | 15 | 74 | 5 | 2 | 10 | 31 | 5 | 2 | 10 | 73 | 2 | 1 | 2 | 20 |

Where

$$X_2 = CRI_{Tenvironmental\ factor} / (CRI_{Tpersonal\ factor} + CRI_{Tenvironmental\ factor} + CRI_{Ttask\ factor}) = 80 / 368 = 0.22 \quad [11]$$

Where

$$X_3 = CRI_{Ttask\ factor} / (CRI_{Tpersonal\ factor} + CRI_{Tenvironmental\ factor} + CRI_{Ttask\ factor}) = 198 / 368 = 0.54 \quad [12]$$

$$\text{Work Severity Index (WSI)} = (X_1 \times TRI_{personal\ factor}) + (X_2 \times TRI_{environmental\ factor}) + (X_3 \times TRI_{task\ factor})$$

$$\text{Work Severity Index (WSI)} = (0.24 \times TRI_{personal\ factor}) + (0.22 \times TRI_{environmental\ factor}) + (0.54 \times TRI_{task\ factor}) \quad [13]$$

Table 8 presents the interpretation of the risk values obtained from the developed model. Category 1, 2 and 3 indicated low, medium and high risks respectively

Risk scores were categorized into 3 as presented in Table 8.

**Table 8. Categorization of Work Severity Index**

**Tablica 8. Kategorizacija indeksa opasnosti na radu (WSI)**

| Risk Score | Categorization of Work Severity Index |
|---|---|
| 1 – 8 | Low risk |
| 9 – 15 | Medium risk |
| 16 – 25 | High risk |

## RESULTS AND DISCUSSION

The mean WSI was 5.03 1. 62 signifying that the maintenance activities were carried out in the plant had a low risk.

In this research, the use of questionnaire and ergonomics checklist has revealed the risk factors and parameters that are eminent in the risk assessment of maintenance job in the power station. The risk assessment examined the extent of exposure to magnitude (how much), duration (how long) and frequency (how often) of risk factors and parameters. This assessment has revealed how to reduce musculoskeletal problems by managing the multiple risk factors presents. The management of risk factors includes risk factors identifi-

**Table 9. Presents the Work Severity Indices for the Assessed Workers**

**Tablica 9. Indeksi opasnosti na radu kod promatranih radnika**

| Subject | Total Risk Index for personal factor ($TRI_{personal\ factor}$) | Total Risk Index for personal factor ($TRI_{environmental\ factor}$) | Total Risk Index for personal factor ($TRI_{task\ factor}$) | Work Severity Index (WSI) |
|---|---|---|---|---|
| 1 | 2.24 | 3 | 1.47 | 1.99 |
| 2 | 3.07 | 3 | 7.76 | 5.59 |
| 3 | 3.42 | 3 | 5.91 | 4.67 |
| 4 | 2.62 | 3 | 5.54 | 4.28 |
| 5 | 2.55 | 3 | 2.21 | 2.47 |
| 6 | 2.86 | 3 | 8.4 | 5.88 |
| 7 | 3.45 | 3 | 8.4 | 6.02 |
| 8 | 3.14 | 3 | 8.4 | 5.95 |
| 9 | 3.45 | 3 | 8.4 | 6.02 |
| 10 | 3.45 | 3 | 11.05 | 7.46 |
| *Mean* | 3.03 | 3 | 6.75 | 5.03 |
| *SD* | 0.42 | 0 | 2.85 | 1.62 |

cation, risk assessment, risk control and risk results evaluation. This method makes it simpler to assess personnel and the jobs in power station maintenance. Once the risk factors are managed and a reduction in musculoskeletal injury becomes obvious, then automatically it will reflect in reducing overhead cost due to ill health in the organization.

The method applied, 5×5 risk matrix is used by authors and researcher such as Federal Highway Administration of U.S. Department of Transportation *(2006)* and Federal Aviation Administration of U.S. Department of Transportation *(2007)*.

The mathematical fundamental of analyzing the assessment is derived from a generally believed equation by ergonomics experts that the risk index is the multiplication of the probability of occurrence and its potential severity. The probability of occurrence and potential severity were computed on a scale of 1 to 5. Authors such as Cox *(2008)* and Occupational Health and Safety Act (OHS Act); *(2004)*, used this expression and in combination to produce risk assessment matrix (RAM), which is accepted as one of essential tools in solving ergonomic musculoskeletal problems.

The personal factor results showed that all the subjects have an average risk value of 7 (±1.13) signifying that the job was a low risk one. All subjects have risk values below 9 with subjects 1, 6, and 10 having risk values of 8.56, 8.53 and 8.25, and the least value is 5.34 obtained by subject 7. Similarly, environmental factors had an average risk value of 6.62 (±0.68) which also signified that the job was a low risk one and the least risk value was 5.99, obtained by four subjects (subject 3, 8, 9 and 10) while subjects 1 and 6 had risk values of 7.74 and 7.65. Furthermore, after considering the personal risk factor assessed, people of above 55 years of age should be re-assigned to another responsibility while the obese among them should be encouraged to embrace daily physical exercise pending the time their service will no longer be required by the company.

For the task factor, two of the subjects had risk values above 9 which showed that the job was of a medium risk while subjects 4, 5, and 6 had risk values of 4.05, 4.58, and 4.83 respectively. The WSI showed that the average risk value was 7 (± 1.37) and that the job was a low risk one. Urgent control measures are required for those factors with risk values above 9.

The economy of the work schedule to various subject and their work recovery cycle were good. Likewise, the work rate was moderate and tools were readily available to execute the maintenance work.

Five factors were considered for assessment under personal factor and these include work experience, body mass index, age bracket, duration, and exposure pattern. Work experience has a lot of contributing effect on the subjects. Subjects 8 and 10 have increased risk level due to their minimal experience level in maintenance job whereas, subjects 4, 5 and 6 were highly experienced both on the job and with safety procedure, therefore it means that risk score for these experienced workers will be low. However, it is still debatable that workers of higher experience level get involved in shabby practices that compromise safety which later leads to serious and fatal injury.

Body mass index is another personal factor of concern where subjects 2, 6, 9, and 10 were exposed to high risk because of their obese nature compared with the remaining subjects with less than 24.9 kg/m2. The way obese subjects will carry themselves in maintenance work will be different from the way the other subject of low BMI will conduct themselves in the same job just because of the comfortable nature for subjects of low BMI to do so and which will make the job convenient with adequate reduced risk.

The experience level of subject 6 with 60 years of age and 30 years' experience could be needed in overhauling and maintenance job. However, because of the nature of the work which involves manual handling of tools and physical strength, age could be a great disadvantage that will trigger a lot of musculoskeletal injuries and thereby worsen his situation. Likewise, this scenario is similar to subject 1 with 49 years, subject 4 and 5 with 44 years and 48 years respectively. The other subjects may not really be affected, except for their inexperience which may be questioned.

Work duration for supervisors and technical specialist like subjects 2, 4, 5 and 6 could be longer than the shift personnel because they are obli-

gated to stay longer as when required. All other factors like forces, work posture, local contact, exposure pattern and fatigue are factors that have a lot to do with the duration of the entire subject as to whether the score will be low, moderate or high.

The reason for the exposure of subjects 1, 3, 7, 8, 9, and 10 to musculoskeletal injuries more than subjects 2, 4, 5, and 6 was that they were the ones that carried out the task with their physical energy which involved manual handling activities. Therefore, subject 10 with one year of experience needs adequate knowledge of the job and safety practices for the maintenance job. All other factors including the noise level in the environment which was 85 dB, the ambient temperature, ventilation, force that are required to carry pull or push, work posture, local contact, and fatigue are factors that have a lot to do with the exposure to the job. Since everybody is exposed to the same environmental factor, WSI parameters will largely depend on individual and task factors which will suggest whether the risk will be low moderate or high.

The engine is enclosed in a 40 feet sound attenuated container so as to reduce the noise level into the environment and major maintenance are done in that confined space, though the container is having two doors and two extraction fans, yet ventilation within the confined engine space is poor.

The ambient temperature and the temperature of the object were within the acceptable values. The ambient temperature of the working environment was between 25°C and 31°C while the object temperature was between 24°C and 27°C. These temperature ranges were comfortable for the workers during maintenance work in the power station. The noise level was below 85 dB and there were dampers to cushioning the vibrating effect of the system.

All the risk parameters under task factor were measured against the duration of the job, the frequency and pattern of exposure. The identified factors that could compromise safety and cause musculoskeletal injuries include: weight of the object, asymmetry, forces, local contact and work posture. Subjects 4, 5 and 6 only provided managerial responsibility with little or no manual handling processes; thereby limiting their exposure and reducing their risk levels.

Cox *(2008)* explored mathematical and logical scope as risk management tools to solve the problem of priority setting and decision making by using 2×2 risk matrix, though this is the simplest. However, this research used a 5×5 risk matrix with additional mathematical expressions to answer the same question of priority setting and ranking risk to high, medium and low. Cox *(2008)* had a matrix with a quantitative risk value boundary of between 0 and 1 inclusive (where 0 = minimal adverse consequence and 1 = maximum adverse consequence). However, this research design had a quantitative risk value boundary between 1= (minimum) and 25 = (maximum) which could also be based on their relative weight by dividing 1 and 25 by 25 to give 0.04 and 1.00 as its own boundary.

Michalopoulos et al. *(2008)* analyzed a technique for identifying, characterizing and evaluating hazards which consist of two entities: a qualitative step of identifying, characterizing and ranking hazards; and a quantitative step of risk evaluation similar to this work. However, Michalopoulos et al. *(2008)* worked on systems or subsystems and event failure while this research established a relation between risk factors or parameters and the personnel.

## CONCLUSIONS

Task and personal factors generated high musculoskeletal injury for workers during maintenance job due to their increased total risk score and their relative weight. Therefore, this risk assessment technique may reduce the possibility of lost time injury, medical injury, first aid injury and fatality. It may maximize resources and uphold best practices of safety management in industries. However, the assessed risk parameters for environmental and organizational factors were minor and they will rarely cause musculoskeletal injuries because their estimated risk score and relative weight were below 0.5. This means that the company has little to spend on injuries caused by these two factors during manual handling job. The implication of these results is that control

measures are required for those factors of relative weight above 0.50. The modified and developed risk assessment worksheet covers virtually the entire maintenance job of a typical Otto engine, therefore the worksheet become relevant. Prioritizing the identified environmental, personal and task factors will necessitate proper proactive control measures that will mitigate the risk of musculoskeletal injuries during maintenance activities in a power station.

The consequences of organizational factor in this research are extremely not felt, therefore further research is recommended in this direction so as to reveal possible impeding factors and parameters that could affect ergonomics of maintenance jobs in power stations.

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## *PROCJENA ERGONOMSKIH RIZIKA NA POSLOVIMA ODRŽAVANJA PLINSKE ELEKTRANE*

*SAŽETAK: Studija procjenjuje čimbenike ergonomskih rizika na poslovima održavanja plinske elektrane kapaciteta 8.4 MW (1.4 MW x 6 jedinica) u kojoj na održavanju radi 12 osoba. Čimbenici ergonomskih rizika mogu se podijeliti na one povezane sa zadatkom, te osobne i okolišne. Potencijalna ozbiljnost svih utvrđenih čimbenika rizika i vjerojatnost da se ostvare prikazana je na ljestvici 1-5. Indeks rizika izračunat je kao umnožak vjerojatnosti pojave rizika i potencijalne ozbiljnosti svih parametara rizika. Relativne težine parametara čimbenika rizika utvrđene su dijeljenjem svakog indeksa kumulativnog rizika s ukupnim indeksom kumulativnog rizika. Relativne težine čimbenika ergonomskih rizika utvrđene su dijeljenjem indeksa kumulativnih rizika svakog čimbenika s ukupnim indeksima kumulativnog rizika. Ukupan indeks rizika za svaki čimbenik izračunat je zbrajanjem umnoška relativnih težina i indeksa rizika parametara koji čine taj čimbenik. Indeks opasnosti na radu (WSI) utvrđen je zbrajanjem umnoška relativnih težina i indeksa rizika čimbenika ergonomskih čimbenika. Vrijednosti rizika kategorizirane su u tri razreda: nizak, srednji i visok rizik. Koristeći osobne i okolišne čimbenike, prosječne vrijednosti rizika iznosile su 3.03 ± 0.42 i 3.00 ± 0.00 iz čega proizlazi da je posao niskog rizika. Vrijednost indeksa opasnosti na radu (WSI) iznosila je 5.03 ± 1.62 što je pokazatelj da posao održavanja na način kako se obavlja u promatranoj elektrani predstavlja nizak rizik.*

**Ključne riječi:** *ergonomija, rizik, posao, opasnost, indeks, poremećaji*

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