Chapter 3

Methodology

3.1 Introduction

The chapter explains the method of proposed research work. The process flow chart shows the directions of the research work. Experimental setup and instrumentation WBV measurement is also explained. The development of questionnaire is discussed in detail. The role of various contributing factors affecting WBV and statistical analysis used in this thesis are also discussed.

3.2 Development of Methodology

The occupational hazard of WBV is one of the most serious problems faced by the HEMM operators throughout the world. Vibration affects the human being both locally through HAV as well as the entire body of the exposed person, known as WBV. As already explained in Chapter 2, If a person is in contact with a vibrating surface, he experiences WBV, which affects all the parts of the body, though they are not in contact with it. Vibration syndrome has spread to a large number of operators in various industries including mining, agriculture, forestry, and manufacturing. WBV has an impact on the efficiency and physiology of the person depending on the nature of vibration and time of exposure [1]. Exposure to WBV lead to health hazards, mostly as lower back pain who operate HEMM as a part of their occupation. In mines, the operators of the HEMMs like dumpers, dozers, surface miners, and shovels are the worst sufferers from WBV syndrome. Risk of WBV related syndrome including lumber spine disorder as well as nervous system if the exposure continuous for years or decades [1].

A flow process chart of the methodology of the proposed work is depicted in Figure 3.1. This flow chart shows how the three streams of this research work is progressed to fulfill the objectives.

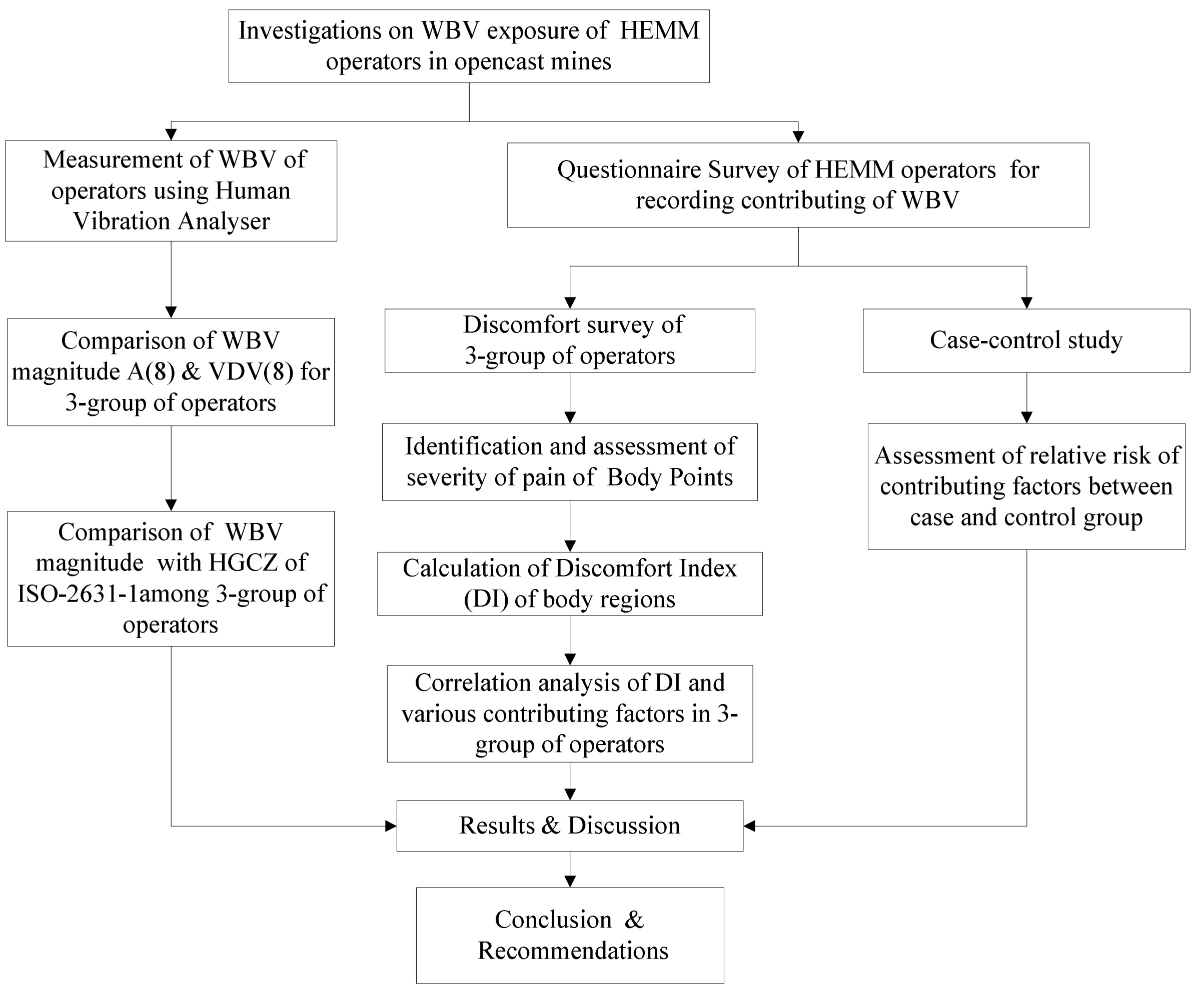

Figure 3.1 Flowchart of the research work

3.3 Measurement of WBV Using Human Vibration Analyzer

In order to measure the vibration magnitude, a Human Vibration Analyzer Type 4447 made by Bruel & Kjaer has been used for the study (Figure 3.2). The Vibration analyzer type 4447 is compact and handy also for studying safety and health of working persons. It is easy to carry for assessing the vibration level of the worker. A tri-axial accelerometer measures the impact along three orthogonal axes. Desired sensitivity level for the use of HAV study is 1.0 mV/(m/s^2) and that for WBV is 10.0 mV/(m/s^2). The satisfies both the requirements of EU Directive 2002/44/EC and ISO 8041:2005.

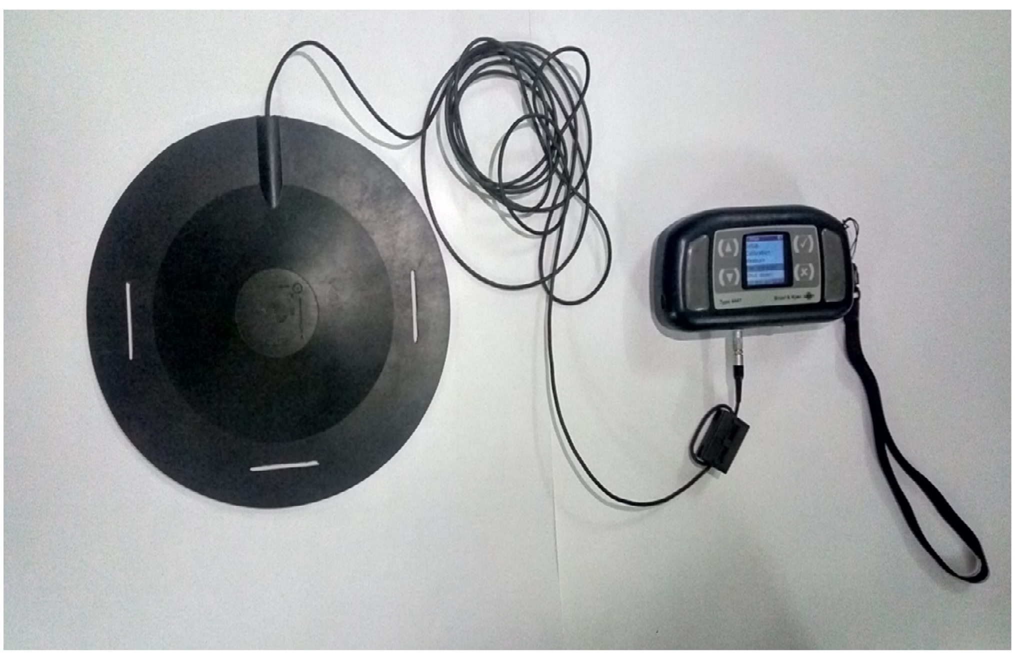

Figure 3.2 Human vibration analyzer, Type 4447

Three groups of HEMM operators were considered in this study for vibration measurement followed by questionnaire survey. HEMM operators such as dumper, shovel and drill machine operators are subjects of this study. Positioning of seat pad accelerometer on dumper operator's seat in the field is depicted in Figure 3.3. WBV exposure measurements were recorded following the ISO 2631-1:1997 standards [30], which are applicable to the vibration in the frequency range of 0.5 Hz to 80 Hz. Measurements were carried out at the operator–seat interface with a tri-axial seat pad accelerometer in combination with a control panel which records the vibrational exposure in the form of signals called vibration analyzer type 4447 [80].

Figure 3.3 Positioning of seatpad accelerometer on dumper operator's seat

The accelerometer is mounted on the seat of the operator where operators used to sit while operating the machine. Temporary adhesive tape was used to keep the seat pad accelerometer fixed onto the operator's seat during measurement. The accelerometer measured vibration in three translational axes with reference to the human basi-centric axes, namely, fore-and-aft (*x*-axis), lateral (*y*-axis), and vertical (*z*-axis) axes. Appropriate frequency-weighting curves were selected in all three axes during measurement such as W_d for *x*-axis, W_d for *y*-axis, and W_k for *z*-axis. WBVs were measured for a cycle of each task on machines as a representative sample of exposure, which varied from 5 to 20 min according to the mine layout and equipment capacity. For elimination of artifacts influences on measurement results, the entire cycle of operation for each activity, namely, drilling, dumping and shovelling by the HEMM operators was recorded. In any cycle of activity, vibration measurements were taken from the starting of the activity till its end – thus eliminating the measurement errors caused due to the idle time between two consecutive cycles. Since temporary adhesive tape was used for keeping the seat pad accelerometer fixed onto the operator's seat, possibility of displacement of the accelerometer due to nominal movements of the operator and the consequent measurement error was minimized.

The vibration measurement results are compared to ISO 2631-1: 1997. The detailed WBV measurement and its possible health impacts is discussed in Chapter 5.

3.4 Development of Questionnaire

Design of questionnaire is based on Nordic [81] and Stuart-Buttle questionnaires [82]. Nordic Standardized questionnaires for the analysis of musculoskeletal symptoms in an ergonomic or occupational health context were presented. The questions were either self-administered or used in interviews. They focused on symptoms frequently encountered in an occupational setting. The frequency of responses to the questionnaires reflected specific characteristics of work strain in their job.

Stuart-Buttle [82] did discomfort survey in a poultry-processing plant to prioritize areas for ergonomics intervention and to determine whether regions of discomfort relate to types of task performed. In ergonomics, the relationship of musculoskeletal pain and discomfort due to workforces, awkward work postures, over-use, and static loading is widely accepted as an indicator of poor job design.

The present research questionnaire consists of four factors: personal factors of operators, machine related factors, working condition-related factors and health-related factors. For the assessment of health impacts, the scores were scaled from 1 to 5. The subjective quantification scales have been rated as: *never = 1, rarely = 2, occasional = 3, often = 4, and always =5.*

3.5 Contributing Factors Affecting Whole-Body Vibration

There are five contributing factors affecting whole-body vibration. These factors have several contributing parameters as tabulated in Table 3.1.

Table 3.1 Factors and contributing parameters

Factors	Contributing parameters
Personal factors	Age, gender, weight, height, BMI, level of education, smoking and drinking habit, experience
Machine related factors	Make and model of the machine, age of the machine in hours, type of seat provided
Working condition related factors	Temperature, rotation policy, rest period, road condition

3.5.1 Personal factors

The personal factors of HEMM operators and control group operators are collected through questionnaire. The questions asked to operators/workers contain the factors such as age, experience, height, weight,pain in different parts of body. The research works conducted on these factors are presented in Table 3.2.

Table 3.2 Parsonal factors of operators exposed to WBV

Factors	Study	Inference
Age	Mani et al. [36], 'Chaudhary et al.' [3]	Age of operator is a potential predictor of WBV exposure. Older operators were more effected by WBV.
Weight	Mani et al. [36],	Body mass is significantly associated with quad bike induced WBV. Heavy equipment operators were more effected by WBV.
Body mass index	Mani et al. [36],	No association between WBV, BMI and low back pain in professional drivers
Experience	Ozkaya et al. [35]	Lower levels of WBV with more experienced vehicle operators

3.5.2 Health-related factors

The summary on the findings of health-related factors of WBV is given in Table 3.3

Table 3.3 Health-related factors of equipment operators exposed to WBV.

Factors	Study	Inference
Lumbar disk degeneration	Kellgren and Lawrence [83]	Lumbar disk degeneration significantly increased in the miners and attributed to mechanical stress
LBP	Atal et al. [51], Mandal & Srivastava [47], Mandal et al. [13], Kumar et al. [49], Jeripotula et al. [15]	• Bayesian Network analysis showed that the probability of LBP was found to be 52.6% [51]. • Observed that the problem of low back pain was significantly higher (85%) in the exposed population as compared to controls (20%) [49]. • Exposure time of dozer operators is associated with an increased risk of work-related LBP [15].
Pain in ankle	Mandal & Srivastava [47]	• 37.83% population who were having pain in the ankle were exposed to WBV.
Pain in shoulder	Mandal & Srivastava [47]	• 30% population who were having pain in shoulder were exposed to WBV.
Pain in neck	Mandal & Srivastava [47]	• 37.5% population who were having pain in neck were exposed to WBV.

3.5.3 Machine related factors

Machine operators while operating their machine are in direct contact with their physical body. The machine conditions may affect the exposure to WBV and health of operators. However, some of the factors of HEMM that may influence the impact of WBV on operators, like frequency of inspection and adoption of suitable maintenance, are not considered as a part of the present investigation.

Table 3.4 Machine related factors

Factors	Study	Inference
Manufacturer	Cann et al. [37]	Operators of newer transport trucks supplied by manufacturer B are exposed to significantly greater levels of WBV as compared to trucks supplied by manufacturer B.
Seat type	Mayton et al. [84]	NIOSH designed seats performed better than existing seats for both shuttle car models.
Suspension	Nishiyama et al. [39]	Air spring suspensions in general produced lower levels of WBV and low back pain than steel spring suspension systems.
Age of Equipment	Chaudhary et al. [3]	Age of equipment is not a significant factor.
	Bovenzi [23]	Older buses to be associated with greater levels of WBV
Cab design	McPhee et al. [85]	Poor cab design increased operator's complaints of discomfort.

Moreover, certain ergonomic features of the machine, e.g., 'seat type' will give the knowledge of the comfort level of operator while operating the vehicle, 'suspension' obsorbs the vibration and jerks, age of equipment shows the running condition of the vehicle, and cab design considers the approach of operator to the different equipments on vehicle.

Quantification of these factors may provide better understanding of the impacts of WBV on equipment operators. Various studies related to machine factors responsible for WBV is summarized in Table 3.4.

3.6 Questionnaire for Discomfort Survey

The purpose of the questionnaire survey is to collect the data related to the personal factors of the operators, self-reported health related MSD symptoms and work environmental factors to achieve the objectives of the research work. A total of 150 HEMM operators – 110 dumper, 20 drill and 20 shovel operators – were taken as subjects for the discomfort survey. Operator's five body regions and 11 body points were considered in the survey. The details of discomfort survey is presented in chapter 6.

3.7 Questionnaire for Case–Control Study

Case–control study included 220 subjects. Out of these, 110 were dumper operators exposed to vibration and referred as the case group. Remaining 110 subjects were different types of workers who were not exposed to machine vibration but working in similar mining environment. They are referred as the control group. Various personal, health-related and machine related factors were considered in the questionnaire for case–control study. The detailed case–control study is discussed in Chapter 7.

3.8 Statistical Methods

General regression has been limited to those situations in which the independent variable is a continuous variable such as age, weight, etc. In health-related research, the relationship between independent variables and a dependent (or outcome) variable is mainly discrete. Most of the time, circumstances are in which the outcome variable is dichotomous. A variable is dichotomous when it assumes only one of the two possible mutually exclusive values. These values are usually coded as Y=1 for a true and Y= 0 for a false. Dichotomous variables include two possible mutually exclusive values such as success – failure; died-live; cured – not cured; disease occurred – disease did not occur; and smoker–nonsmoker. Logistic regression is the type of regression analysis which is usually employed when the dependent variable is dichotomous.

3.8.1 Case–control study

The relative risk of subjects has been assessed through the case–control study designed via logistic regression model.

A linear regression analysis involves only two variables. The simple linear regression model is expressed by the Eq. (3.1):

$$\boldsymbol{y = \beta_0 + \beta_1 x + \varepsilon} \tag{3.1}$$

where *y* is the continuous dependent variable, β is coefficient, *x* is independent variable and ϵ is a constant (difference between observed Y and the regression line). When the dependent variable Y is $\mu_{y/x}$, the mean of a subpopulation of Y values for a given value of X, the constant ϵ is zero. Thus, the Eq. (3.1) can be written as:

$$\boldsymbol{\mu_{y/x} = \beta_0 + \beta_1 x} \tag{3.2}$$

which may also be written as:

$$\mathbf{E(Y/X)} = \boldsymbol{\beta_0 + \beta_1 x} \tag{3.3}$$

Generally, the right-hand side of Eqs. (3.1) to (3.3) may assume any value between minus infinity to plus infinity.

When Y is a dichotomous variable, the simple linear regression model is not appropriate because the expected value (or mean) of Y is the probability, and therefore, it is limited to the range 0 to 1. Eq. (3.1) to (3.3) then are incompatible with the reality of the situation.

If p = P(Y=1), then the ratio p/(1-p) can take on values between zero and plus infinity. Furthermore, the natural logarithm (ln) of $p/(1-p)$ can take on values between minus infinity and plus infinity just as can the right-hand side of Eq. (3.1) to (3.3). Therefore, it may be written as:

$$\boldsymbol{ln\left[\frac{p}{1-p}\right] = \beta_0 + \beta_1 x} \tag{3.4}$$

Eq. (3.4) is called the logistic regression model and the transformation of $\mu_{y/x}$ to $\ln[p/(1-p)]$ is called the logit transformation. Eq. (3.4) may also be written as:

$$\boldsymbol{p = \frac{e^{\beta_0+\beta_1 x}}{1 + e^{\beta_0+\beta_1 x}}} \tag{3.5}$$

The simplest example of logistic regression is one in which both the dependent and independent variables are dichotomous. The value of the dependent (or outcome) variable usually indicate whether or not a subject acquired a disease. The value of the independent variable shows the status of the subject relative to the presence or absence of some risk factor. Assume that the dichotomous of the two variables are coded 0 and 1. In this way the variables can be presented in contingency table that contains two rows and two columns. The cells of the table contain the frequency of occurrence of all possible pairs of values of the two variables: (1,1), (1,0), (0,1) and (0,0).

Table 3.5: Contingency table of dichotomous variables with coding 0 and 1

Dependent variable (Y)	Independent variable (X)	
	Case group (1)	Control group (0)
Exposed to vibration (1)	$N_{1,1}$	$N_{1,0}$
Non-exposed to vibration (0)	$N_{0,1}$	$N_{0,0}$

An objective of the analysis of data that meet these criteria is a statistic known as *odds ratio* (OR). Odds of an event can be defined as the ratio of the number of ways the event can occur to the number of ways the event cannot occur. In probability terminology, the odds for success is the ratio of the probability of success (p) to the probability of failure ($1 - p$), i.e.,

$$\textbf{Odds of success} = \frac{\textbf{probability of success}}{\textbf{probability of failure}} \tag{3.6}$$

In other words,

$$\textbf{Odds ratio} = \frac{p}{1-p} \tag{3.7}$$

The odds ratio is a measure of how much greater (or less) the odds are for subjects possessing the risk factor to experience a particular outcome.

$$\textbf{OR} = \frac{\textbf{odds that a case was exposed}}{\textbf{odds that a control was exposed}} \tag{3.8}$$

Computer software packages that perform logistic regression provide output estimate as β and odds ratio as exp(β).

Interpreting the Odds Ratio

If odds ratio is equal to one then there is no difference between case and control group in other words, they are as if the same population group. If odds ratio is greater than 1, case group is positively related to MSD. If odds ratio is less than 1, case group is negatively related to MSD, i.e.,

OR > 1 : case group is liable to develop MSD

OR < 1 : case group may have caring effect on MSD

OR = 1 : no difference in case and control groups, in other words , they are as if the same population group.

In the study, there are 11 variables are taken in the analysis, namely age, experience, smoking, alcoholic, BMI, neck, hand, upper back, lower back and leg. To apply logistic regression analysis, Eq. (3.4) can be expanded as

$$\boldsymbol{ln\left[\frac{p}{1-p}\right] = \beta_0 + \beta_1 age + \beta_2 experience + \beta_3 smoking + \beta_4\, alcoholic + \beta_5 BMI + \beta_6 neck + \beta_7 hand + \beta_8 lowerback + \beta_9 lowerback + \beta_{10} leg + \beta_{11} mine}$$
(3.9)

3.8.2 Correlation

After the discomfort survey and questionnaire assessment, correlation between the 10 prominent variables for the three groups of operators exposed to vibration was analyzed. Separate correlation tables for each group of operators is presented in Chapter 6.

3.9 Summary

This chapter depicted the methodology of the research work. Development of the has been presented from the principle. Process flow chart shows the three directions of the research work. The Human Vibration Analyzer Type 4447 has been discussed. The WBV measurement using its constructional features of has been explained. The developed questionnaire consists of four factors: personal factors of operators, machine-related factors, working condition-related factors and health-related factors. Contributing factors affecting WBV also been discussed. Statistical methods of odds ratio and logarithmic regression model have also been discussed. The next chapter describes the location, mechanisation and machine availability in the case study mines selected for WBV measurement and questionnaire survey. The subjects of the study are also explained.