# Whole-body Vibration Exposure of Opencast HEMM Operators –Development of a Conceptual Structural Equation Model

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***Abstract***

**In the mining industry, HEMM (Heavy Earth Moving Machinery) operators usually suffer from Whole Body Vibration (WBV) exposure. The vibrations generated from machinery sources during operation are transmitted to the human body. There are several undesirable health hazards arises due to WBV exposure in opencast mines, which includes deterioration of 'nervous system', 'circulatory system', 'digestive system', and 'low back pain'. This paper is anticipated to examine how machine condition, haul road condition, operational culture and work time exposure affect vibration exposure of mine operators in an opencast mine. In this context, a conceptual model is developed by means of path-analysis through Structural Equation Modelling (SEM). As there are no statutory guidelines and standardized threshold limit available for WBV with Indian mine operators, relevant clauses of International Organization for Standardization are followed for monitoring WBV.**

***Keywords: Whole Body Vibration (WBV), opencast mines, conceptual model, SEM, ISO 2631-1(1997), ISO 2631-5(2004)***

## I. INTRODUCTION

Mining is an essential operation for sustainability of Indian power sector and economic environment. As mining is the backbone of Indian power sector and economy, we must continue mining uninterruptedly. It is very known fact that the mining operation involves many challenges with respect to safety of mine workers. Various agencies have been conducting a significant number of scientific investigations on the methodological and behavioral characteristics of mine safety, miner's health and mine based occupational diseases. However, the multifaceted mechanisms that lie beneath the contributory associations of safety perceptions and mine injuries are still not entirely explored [1]. "In recent years, researchers have been trying to comprehend the hidden structures, including environmental, organizational and socio-technical factors that potentially lead to accidents and fatalities in mining complexes" [1-4]. Although health hazards like dust, noise and noxious fumes etc. engrossed researchers' attention, health problems arise due to exposure of whole-body vibration remained dormant for several years. The human body parts most prone to have an effect due to WBV depend on the "magnitude of vibration, the frequency of vibration, distribution of the motion within the body, body postures, and, direction, and duration of vibration"[5]. There is physically powerful evidence that work-related exposure to WBV is allied with an augmented risk of "Low Back Pain (LBP), sciatic pain, and degenerative changes in the spinal system including lumbar inter-vertebral disc disorders and chronic pain etc."[6]. the diseases encountered due to WBV can increase sick leave, minor-disabilities, and man day's loss etc.

Operators of HEMM deployed in open cast mines viz. motor grader, dozer, crane, rock breaker, dumper, excavators, and large diameter drill are exposed to high level of WBV and if they are exposed to vibration more than threshold limits (As given in ISO) for long time, than they may start suffering from many diseases and physical problems which may turn into serious if not taken care of properly [7-12]. In Indian mining scenario, vibration is not considered as major aspect till date, therefore proper management actions should be introduced in Indian mines for fighting against vibration related diseases. Design and implementation of proactive WBV management plan are required, so that the effect of WBV can be assessed and diagnosed properly.

This paper is anticipated to examine how machine condition, haul road condition, operational culture and work time exposure affect vibration exposure of mine HEMM operators in an opencast mine. In this context, a conceptual model is developed by means of path-analysis through Structural Equation Modelling (SEM). Structural equation modelling (SEM) has been recurrently applied in mine accident analysis, safety management, and other fields [13]. Complex

*IEECP'22, July 21-22, 2022, Oxford, United Kingdom*

***DAI : https://sci-index.com/DAI/2022.99101/IEECP/20220218***

associations between exogenous latent variables and endogenous variables are generally investigated by using SEM [13]. SEM essentially comprises a measurement model and a latent variable model (path analysis) that demarcate the relations among latent variables [14].

## A. Whole-body Vibration Standards

ISO technical committee submitted the first draft proposal, "Classification of the Influence of Mechanical Vibration of Man", in June 1964 was tabled. After getting green signal and consent from 19 countries (UK and USSR not given consent) the finalized provisions of standard were enforced and made available. The standard was amended in 1978, 1982 and 1985 respectively.

### *a) ISO 2631-1(1997)*

Comprehensive modification of ISO 2631 was commenced in 1979 and the new standard was finally published in 1997 in association with BS 6841. The appraisal methods comprise the fourth power VDV (Vibration Dose Value) and a running RMS (Root Mean Square) method with one-second time constant [15]. Indirect type of Health protection guidance is provided according to the VDV value. However, no guidance is provided for the running RMS method [15].

### *b) ISO 2631-5:2004*

ISO 2631-5:2004 addresses "human exposures to mechanical multiple shocks measured at the seat pad when a person is seated". The adverse health effect in contrast to long vibration exposure with multiple shocks is related to dose measures. This version of the ISO standard towards WBV was concerned to show the adverse health effect in the lumbar spine [15]. WBV limits for the eight-hour working condition according to health guidance caution zone (HGCZ) are shown in Table1 **(As per ISO 2631-1 1997, Annex B)**.

**Table1: (WBV limits for the eight-hour working condition according to health guidance caution zone (HGCZ) in (ISO 2631-1 1997, Annex B)**

| Parameter | Exposure action value (EAV) | Exposure limit value (ELV) | Units |
|---|---|---|---|
| RMS | 0.45 | 0.90 | $m/s^2$ |
| VDV | 8.5 | 17 | $m/s^{1.75}$ |

# II. ADVERSE IMPACT OF WBV ON HUMAN HEALTH

Mandal, 2006 [6] conducted detailed investigation on WBV exposure scenario of Indian mine workers and found that the vibration of frequencies between 0.5-80Hz is main reason for imposing detrimental effects on the human body parts and organs. The transmission of vibration through HEMMs to the body is dependent on body posture as well as other ergonomic factors. The effects of vibration are therefore complex. Exposure to WBV causes motions and influences on parts of the human body adversely, that may cause discomfort.

- Adversely affect performance.
- Aggravate pre-existing back injuries and
- Present a health and safety risk.
- Low-frequency vibration causes motion sickness

There are many adverse impacts related to WBV and some of the effects are shown in Figure 1.

*Figure 1 Problems in lumbar spine due to WBV exposure (Source: Safety news alert, 2014)*

# III. CONCEPTUAL STRUCTURAL EQUATION MODEL FOR INVESTIGATING VIBRATION IMPACT ON HUMAN BODY

## A. Theory and Hypothesis

### *a) Vehicle condition & maintenance*

In opencast mines, the vehicle conditions play a vital role with respect to vibration exposure of operators. Vehicle condition refers to the vehicle age, break down proneness and frequency of maintenance of machine etc. Vehicle condition and maintenance effect on vibration can be measured by considering different manifest variable viz. machine age, frequency of maintenance, break down proneness and working hour of the vehicle.

### *b) Haulage Road condition*

The haul road condition in Indian opencast mines is one of the main factors that affects human vibration exposure. If the road condition in mines is undulating and without proper dimension for transportation of ore/overburden to crusher plant or dump yard, then it leads high exposure of vibration. Blood et al. (2010) [16] concluded that "poor road conditions and maintenance of vehicles lead to an intermittent impact on operators in terms of spinal disorder and fatiguing of associated muscles". Impact of haulage road condition on vibration exposure can be measured by considering different manifest variables viz. frequency of road maintenance, feature of haul road, dimension of haul road and lead distance.

### *c) Operational culture*

Operational culture refers to the working procedure and character of miner. If the mine operators are aware of the vibration problem and is a skilled person then the vibration exposure will be less at that scenario. Mandal and Srivastava (2010) concluded that “poor environmental condition, habits of miners and posture relates to physical disorder in the form of back pain” [17]. Impact of Operational culture on vibration exposure can be measured by considering different manifest variable like training for operators, awareness of vibration, operators experience and overloading of machine.

### *d) Work time exposure*

Working time directly affects the vibration exposure. It can be varied by different manifest variables i.e., production load, availability of skilled operators, haul road condition and over time. Kim et al. (2018) proposed that “Operators of HEMM's having a long duration of operating time for excavation of mineral may enhance the biomechanical loading in the vertebra and its associated muscles” [18]. Researchers found that “regular exposure for a high time duration to WBV will have the risk of musculoskeletal injuries by fatiguing or damaging the soft parts related to the spine and related associated muscles” [19].

## *B.* In accordance with the above discussion on latent variables, we propose the following research hypothesis:

**H-1.** Machine condition and maintenance is inversely related to vibration exposure.

**H-2**. Haulage road condition (poor/good) is inversely related to vibration exposure.

**H-3**. Machine condition and maintenance is directly related to haul road condition.

**H-4**. Operational culture is inversely related to vibration exposure.

**H-5**. Work time exposure is directly related to vibration exposure.

**H-6**. Work time exposure is inversely related to haul road condition.

**H-7**. Machine condition and maintenance is directly related to operational culture.

## *C.* The conceptual structural equation model:

The conceptual structural equation model is developed to investigate the vibration exposure of mine operators at opencast mines. The conceptual structural model can be divided into two parts: the measurement model and the structural model. The measurement model denotes how latent constructs are depending on the manifest variables.

**A latent variable** or construct is a hypothesized and unobserved concept that can only be approximated by observable or measurable variables. **Manifest variable** is the observed or derived value for a specific item or questions, obtained either from the respondent’s responses to questions (as in questionnaires) or from observation by the researcher. Manifest variables are used as the indicators of latent constructs or variables.

The measurement model is established by 15 manifest variables such as machine age, frequency of maintenance, number of working hour per day, road maintenance, shape of road, distance of haul road, training, awareness, operators experience, overload condition, production load, availability of skilled operators, over time, haul road distance as indicator of five latent variables such as machine condition and maintenance, haul road distance, operational culture, work time exposure and vibration exposure. The five latent variables are correlated with each other.

The structural model equation represents the path relationship among the latent variables, explains the path effects, and allocates the explained variance. Path model is framed to scrutinize the strength and pattern of relationship amongst the machine condition and maintenance, haul road distance, operational culture, work time exposure and vibration exposure and their sequential relationship leading towards human body injury in mines.

In the path diagram, a straight line with a single arrowhead specifies that the manifest variable closest to the arrowhead is proposed to be caused by the latent variable from which the line emanates. The relationship between manifest variable (X) and latent variable (β) is denoted by lambda (λ). The conceptual Structural Equation Model (SEM) measurement (Figure 2) and structural model (Figure 3) are developed which are represented below schematically. The developed models will be tested for opencast mining industry in due course.

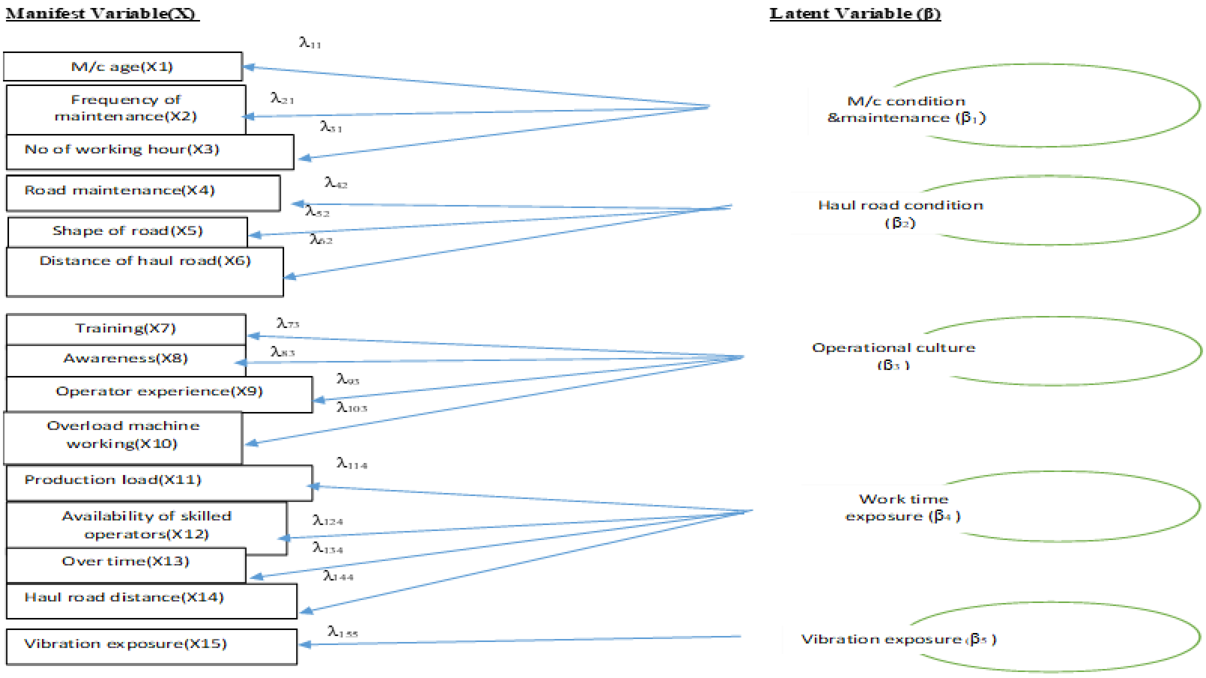


*Figure 2 Path diagram of measurement model*

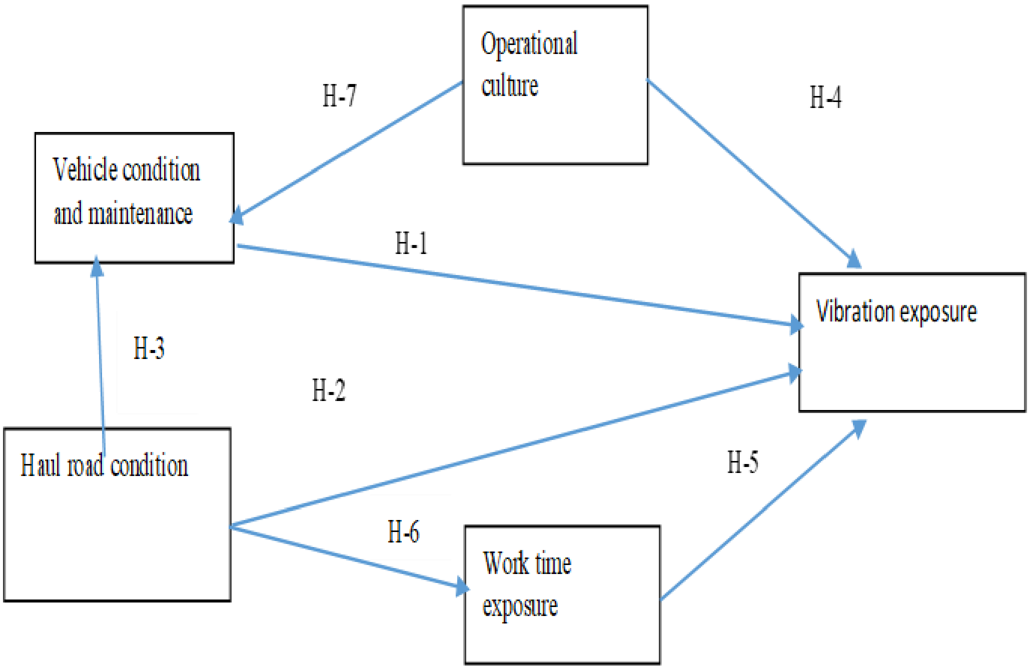


*Figure 3 Hypothesized path Diagram among the vibration exposure, m/c condition and maintenance, haul road, operational culture, and work time exposure*

## IV. CONCLUSION

Study on Whole-body vibration exposure on Indian opencast mine HEMM operators may be considered as a prime issue to improve occupational health and safety scenario of mining industry. It is observed that the detrimental ill-effects (fatigue, insomnia, headaches, and shakiness) are mainly caused by high frequency and magnitudes of vibration faced by the operators during HEMM operation. A conceptual structural equation model (SEM) is developed to show how the vibration exposure in an opencast mine is related to different factors. The relation can be measured by questionnaire survey and by measurement data analysis. Thus, validation of the conceptual model requires extensive field investigation. It is expected that model outcomes will help the mining fraternity to reduce the effect of WBV and enhance OH&S awareness. To sum up the current study highlights machine condition & maintenance, haul road condition, operational culture, and work time exposure as antecedents to vibration exposure of mine operators in open cast mines.

## V. ACKNOWLEDGMENTS

We extend our thanks to various authors given in the reference section for their quality research work to which we have referred and acknowledged thankfully.

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