PREDICTION MODEL OF HAND ARM VIBRATION EXPOSURE AMONG
HAND-HELD GRASS-CUTTERS IN MALAYSIA

NOR AZALI BIN AZMIR

A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy.

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

AUGUST 2016
For my beloved mother and father
ACKNOWLEDGEMENT

Alhamdullilah, I would like to thank several groups of people who have made this thesis possible.

First, I must thank Prof Mohd Imran bin Ghazali and Dr Musli Nizam bin Yahya for their helpful supervising throughout the duration of this research and accomplishment of the manuscript. Their technical, idea and literary advice were valuable.

I am grateful to my former colleagues for providing inspiration in the research, especially Mohamad Hanafi Ali, Mohamed Arshad Hj Bazik, and Md Zainorin Kasron, in addition to all of the members of the “Vibration & Noise Research Group”. Colleagues within the noise and vibration research cluster of the Department of Engineering Mechanics, Faculty of Mechanical and Manufacturing Engineering, make my research a pleasure to undertake. I also would like to acknowledge colleagues in National Institute of Occupational Safety & Health (NIOSH), Malaysia and Projek Penyelenggaraan Lebuhraya (PROPEL) Berhad for their support and contributions. This appreciation also goes to everyone involved directly or indirectly towards the compilation of this thesis.

It would not have been possible to complete this thesis without the unwavering support from Suzana, Mikael and Maisarah. I am fortunate to have such a wonderful family. Thank you Allah.
ABSTRACT

Prolonged exposures to hand-transmitted vibrations from grass-cutting machines have been associated with increasing occurrences of signs of occupational diseases related to the hand-arm vibration syndrome (HAVS). However, there are no specific processes available that cover the objective and subjective health cause-effects of the hand arm vibration risk factors during onsite operations. Most of the existing vibration control measures have not extensively integrated administration and engineering techniques to be utilized as health prediction screening models. Therefore, the main objectives of this study are to integrate the engineering and administration control approach for reducing HAVS among hand-held grass-cutting workers and to determine the significant correlation of the objective and subjective measurement variables of the Hand Arm Vibration Exposure Risk Assessment (HAVERA) on hand arm vibration symptoms and disorders. The study was conducted in two stages: evaluation of the HAVERA variables (Stage 1) and development of the health prediction cause-effect model of the HAVERA process using multiple linear regressions and feed forward neural network programming (Stage 2). For the onsite measurement, the daily vibration value depicted an exceeded exposure action value of 2.5 m/s\(^2\) for both hands; and experiences of any finger colour change were claimed by 80% of the 204 subjects. This shows that the HAVERA process provided a good indication of HAVS which are reported as vascular, neurological and musculoskeletal disorders. In the right and left hand prediction model development, the results of the neural network model demonstrated a higher reliability performance as compared to the linear model for hand grip strength and hand numerical scoring assessment. The prediction of the HAVERA model using the neural network method has been developed for monitoring health conditions due to hand-transmitted vibrations among hand-held grass-cutting workers in Malaysia.
ABSTRAK

Pendedahan yang berpanjangan kepada getaran dari mesin pemotong rumput telah dikaitkan dengan peningkatan kes penyakit pekerja yang berkaitan dengan sindrom getaran tangan-lengan. Walau bagaimanapun, tiada proses spesifik yang merangkumi kesihatan subjektif dan objektif yang terhasil daripada faktor dan risiko getaran semasa operasi. Sebahagian daripada langkah-langkah kawalan getaran yang sedia ada tidak diintegrasikan secara menyeluruh dalam teknik-teknik kejuruteraan dan pentadbiran untuk digunakan sebagai model ramalan saringan kesihatan. Oleh itu, objektif utama kajian ini adalah untuk mengintegrasikan pendekatan kawalan kejuruteraan dan pentadbiran bagi mengurangkan sindrom getaran tangan-lengan dalam kalangan pekerja pemotong rumput dan untuk menentukan signifikasi korelasi HAVERA antara subjektif dan objektif pembolehubah mengenai gejala dan penyakit getaran tangan-lengan. Kajian ini telah dilaksanakan dalam dua peringkat: penilaian terhadap pembolehubah HAVERA (peringkat 1) dan pembangunan model sebab-kesan kesihatan ramalan HAVERA memproses menggunakan regressi berganda dan suapan pengaturcaraan Rangkaian (peringkat 2). Untuk pengukuran tapak, nilai getaran harian adalah digambarkan sebagai melebihi nilai tindakan pendedahan, 2.5 m/s² dan 80% daripada 204 subjek menyatakan bahawa kedua-dua tangan dan jari-jari mereka pernah mengalami perubahan warna. Ini menunjukkan bahawa proses HAVERA menyediakan satu petunjuk yang baik untuk sindrom getaran lengan-tangan yang dilaporkan sebagai gangguan vaskular, saraf dan muskuloskeletal.

Dalam ramalan model pembangunan untuk tangan kiri dan kanan, keputusan model rangkaian neural menunjukkan prestasi kebolehpercayaan yang lebih tinggi berbanding model linear bagi kekuatan genggaman tangan dan penilaian pemarkahan berangka untuk tangan. Jangkaan untuk model HAVERA menggunakan kaedah rangkaian neural telah dibangunkan untuk memantau keadaan kesihatan yang disebabkan oleh getaran daripada mesin dalam kalangan pekerja pemotong rumput di Malaysia.
CONTENTS

TITLE i
DECLARATION ii
DEDICATION iii
ACKNOWLEDGEMENT iv
ABSTRACT v
ABSTRAK vi
CONTENTS vii
LIST OF TABLE xiv
LIST OF FIGURES xvii
LIST OF SYMBOLS ABBREVIATIONS xxi
LIST OF APPENDICES xxv

CHAPTER 1 INTRODUCTION 1
1.1 Overview of the Study 1
1.2 Background of the Problem 3
1.3 Problem Statements 4
1.4 Objectives of the Study 8
1.5 Research Questions 9
1.6 Scope of the Study 10
1.7 Significance of the Study 11

1.8 Hypothesis 12

1.9 Organization of the Thesis 12

CHAPTER 2 LITERATURE REVIEW 14

2.1 Introduction 14

2.2 Measuring Assessment in Hand-transmitted Vibration 15

2.2.1 Objective Measures 17

2.2.1.1 Risk Assessment 17

2.2.1.2 Hand-transmitted Vibration Exposure 18

2.2.1.3 Hand Arm Vibration Legislation 20

2.2.2 Subjective Measures 21

2.2.2.1 Questionnaires 21

2.2.2.2 Interview 23

2.2.2.3 Observation 23

2.3 Health Effects of Hand-transmitted Vibration 24

2.3.1 Vascular Disorders 26

2.3.2 Neurological Disorders 28

2.3.3 Musculoskeletal Disorders 29

2.4 Methods of Classifying Hand Arm Vibration Syndrome 31

2.4.1 Hand Numerical Scoring 32

2.4.2 Hand Grip Strength 33
2.4.3 Cause and Effect Relationships for Hand Arm Vibration Exposure  

2.5 Data Analysis Technique  

2.6 Hand-held Grass-cutter Research  

2.7 Reviews on Past Hand Arm Vibration Case Study in Malaysia  

2.8 Concluding Remarks  

CHAPTER 3 RESEARCH METHODOLOGY I: EVALUATION OF HAVERA PROCESS  

3.1 Introduction  

3.2 Subjects Workplace  

3.3 Hazard Identification, Risk Assessment & Risk Control (HIRARC)  

3.4 Objective Measure of Hand-transmitted Vibration Exposure  

3.5 Subjective Measure of HAVERA Questionnaire  

3.6 Objective and Subjective Measure of Health Effect  

3.7 Data Collection  

3.8 Evaluation of Variables  

3.8.1 Data Normalization  

3.8.2 Data Correlation Significance  

3.9 Concluding Remarks
CHAPTER 4 RESEARCH METHODOLOGY II: PREDICTION
CAUSE-EFFECT HEALTH MODEL OF
HAVERA PROCESS  

4.1 Introduction  

4.2 Significant Variables Correlate Health Effect  

4.2.1 Categorical HAVERA Variables  

4.2.1.1 Vascular Symptoms  

4.2.1.2 Neurological Symptoms  

4.2.1.3 Musculoskeletal Symptoms  

4.2.1.4 Awareness Symptoms  

4.2.2 Continuous HAVERA Variables  

4.2.2.1 Loss of Hand Grip Strength Disorder  

4.2.2.2 Finger Blanching Disorder  

4.3 Predicting Cause-effect Health Model  

4.3.1 Multiple Linear Regressions (Phase 1)  

4.3.2 Feed forward Neural Network (Phase 2)  

4.4 Performance Index  

4.5 Concluding Remarks  

CHAPTER 5 RESULTS & DISCUSSIONS I: EVALUATION OF
HAVERA PROCESS  

5.1 Introduction  

5.2 Risk Analysis  

5.2.1 Grass-cutting Hazard Identification  

5.2.2 Grass-cutting Risk Assessment
5.2.3 Grass-cutting Risk Control Recommendation 92

5.3 Results on Objective and Subjective Evaluation of HAVERA Process 93

5.3.1 Description of Hand-transmitted Vibration Monitoring 93

5.3.2 Description of HAVERA Questionnaires 96

5.3.3 Description of Hand Grip Strength Assessment 99

5.3.4 Description of Hand Numerical Scoring Assessment 100

5.4 Discussion on Evaluation of HAVERA Process 102

5.4.1 Objective Measures 103

5.4.2 Subjective Measures 105

5.5 Concluding Remarks 106

CHAPTER 6 RESULTS & DISCUSSIONS II: PREDICTION CAUSE-EFFECT HEALTH MODEL OF HAVERA PROCESS 108

6.1 Introduction 108

6.2 Results on HAVERA Significant Variables 109

6.2.1 Categorical Cause-Effect of Health Symptoms 109

6.2.2 Continuous Cause-Effect of Health Disorders 110

6.3 Discussion on Determination of HAVERA Variables 112
6.3.1 Categorical Symptoms 113

6.3.2 Continuous Disorders 114

6.4 Results on HAVERA Prediction Model for Continuous Data 116

6.4.1 Derivation of Linear Model (Phase 1) 117
   6.4.1.1 Linear Right Hand Grip Strength 117
   6.4.1.2 Linear Left Hand Grip Strength 118
   6.4.1.3 Linear Right Hand Numerical Scoring 119
   6.4.1.4 Linear Left Hand Numerical Scoring 121

6.4.2 Derivation of Neural Network Model (Phase 2) 122
   6.4.2.1 Neural Network Right Hand Grip Strength 122
   6.4.2.2 Neural Network Left Hand Grip Strength 123
   6.4.2.3 Neural Network Right Hand Numerical Scoring 125
   6.4.2.4 Neural Network Left Hand Numerical Scoring 126

6.5 Discussion on Derivation of HAVERA Prediction Model 128
   6.5.1 Phase 1 – Linear 128
   6.5.2 Phase 2 – Neural Network 130

6.6 Results on Performance Index of Phase 1 and
Phase 2

6.6.1 Regression (R) Value

6.6.2 Mean Square Error (MSE) Value

6.7 Discussion on Performance of HAVERA Prediction Model

6.7.1 Regression of HAVERA Model

6.7.2 Mean Square Error of HAVERA Model

6.8 Results on Reliability of HAVERA Prediction Model

6.8.1 Hand Grip Strength Test

6.8.2 Hand Numerical Scoring Test

6.9 Discussion on Reliability of HAVERA Prediction Model

6.9.1 Hand Grip Strength Model

6.9.2 Hand Numerical Scoring Model

6.10 Concluding Remarks

CHAPTER 7 CONCLUSIONS & RECOMMENDATIONS

7.1 Introduction

7.2 Conclusions

7.3 Recommendations

REFERENCES

APPENDIX
**LIST OF TABLES**

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Objective and subjective cause-effect assessment of hand-transmitted vibration</td>
<td>5</td>
</tr>
<tr>
<td>1.2</td>
<td>Hand-transmitted vibration exposure dose response relationship case studies</td>
<td>7</td>
</tr>
<tr>
<td>2.1</td>
<td>The summary of epidemiological study on HAVS in tropical climate</td>
<td>25</td>
</tr>
<tr>
<td>2.2</td>
<td>Scale for the classification of vascular stage of HAVS</td>
<td>27</td>
</tr>
<tr>
<td>2.3</td>
<td>Scale for the classification of sensorineural stage of HAVS</td>
<td>29</td>
</tr>
<tr>
<td>2.4</td>
<td>Grip strength norms for Malaysia population</td>
<td>34</td>
</tr>
<tr>
<td>2.5</td>
<td>Values of the daily vibration exposure $A(8)$ which may be expected to produce episodes of finger blanching in 10% of persons exposed for a given number of years, $D_y$</td>
<td>36</td>
</tr>
<tr>
<td>2.6</td>
<td>Reducing risk control measure on hand-held grass-cutting machine studies</td>
<td>40</td>
</tr>
<tr>
<td>2.7</td>
<td>Case study on hand arm vibration syndrome in Malaysia from 2011 to 2015</td>
<td>42</td>
</tr>
<tr>
<td>2.8</td>
<td>Inclusion criteria for predicting health effect model for HAVS among hand-held grass-cutting workers</td>
<td>43</td>
</tr>
<tr>
<td>3.1</td>
<td>Likelihood indicator using the following values</td>
<td>50</td>
</tr>
<tr>
<td>3.2</td>
<td>Severity indicator by using the following values</td>
<td>50</td>
</tr>
<tr>
<td>3.3</td>
<td>Risk assessment matrix</td>
<td>51</td>
</tr>
<tr>
<td>3.4</td>
<td>Determining priority based on the following range</td>
<td>51</td>
</tr>
<tr>
<td>3.5</td>
<td>Reliability statistics for HAVERA questionnaire</td>
<td>57</td>
</tr>
</tbody>
</table>
3.6 Vibration data normalization exploration using skewness approach 68
3.7 Positive correlation coefficient 69
3.8 Negative correlation coefficient 70
4.1 Experience and colour changes at fingers 75
4.2 Experience a numb and tingling sensation at fingers 76
4.3 Suffer from weakness at hand grip 76
4.4 Regular use of vibratory tools which are hazardous to health 77
4.5 Measurement of hand grip strength force 78
4.6 Hand numerical scoring due to finger blanching 79
5.1 Six hazard according to criticality of the risk in the grass-cutting activity 91
5.2 Hazard exposure risk percentage among hand-held grass-cutting worker 92
5.3 The technical specification of hand-held grass-cutting machines 93
5.4 Statistical data for daily vibration exposure, $A(8)$ for left and right hand by type of hand-held grass-cutting machine 94
5.5 Demographic of the workers in age-group in grass-cutting operation 99
5.6 Stockholm workshop scale of hand numerical score among hand-held grass-cutting workers 101
6.1 Categorical HAVERA significant cause-effect variables symptoms 110
6.2 Continuous HAVERA significant cause-effect variables disorders 111
6.3 Linear right hand grip strength for HAVERA health cause-effect model 117
6.4 Linear left hand grip strength for HAVERA health cause-effect model 119
6.5 Linear right hand numerical scoring for HAVERA
health cause-effect model

6.6 Linear left hand numerical scoring for HAVERA health cause-effect model

6.7 Neural network right hand grip strength for HAVERA cause-effect health model

6.8 Neural network left hand grip strength for HAVERA cause-effect health model

6.9 Neural network right hand numerical scoring for HAVERA cause-effect health model

6.10 Neural network left hand numerical scoring for HAVERA cause-effect health model

6.11 Linear and neural network regression (R) performance index of prediction model in percentage

6.12 Comparison between linear and neural network mean square error (MSE) performance index in percentage

6.13 Comparison of the linear and neural network hand grip strength result for actual and predicted data

6.14 Comparison of the linear and neural network hand numerical scoring result for actual and predicted data
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Occupational accidents by sector for the category of death, non-permanent disability and permanent disability until December 2013</td>
<td>3</td>
</tr>
<tr>
<td>2.1</td>
<td>The conceptual model of cause and effect relationship</td>
<td>16</td>
</tr>
<tr>
<td>2.2</td>
<td>The hierarchy of control in occupational safety and health</td>
<td>18</td>
</tr>
<tr>
<td>2.3</td>
<td>A modular system for hand arm vibration measurement analyser</td>
<td>19</td>
</tr>
<tr>
<td>2.4</td>
<td>Vibration exposure for predicted 10% prevalence of vibration induced white finger in a group of exposed person</td>
<td>36</td>
</tr>
<tr>
<td>2.5</td>
<td>Basic architecture model of feed forward neural network</td>
<td>38</td>
</tr>
<tr>
<td>3.1</td>
<td>Process of HAVERA method</td>
<td>46</td>
</tr>
<tr>
<td>3.2</td>
<td>Example of backpack grass-cutting machine</td>
<td>47</td>
</tr>
<tr>
<td>3.3</td>
<td>The worker position during grass-cutting operation</td>
<td>48</td>
</tr>
<tr>
<td>3.4</td>
<td>Hand-held grass-cutting workers’ detailed work process</td>
<td>49</td>
</tr>
<tr>
<td>3.5</td>
<td>Coordinate system for the “handgrip” position</td>
<td>52</td>
</tr>
<tr>
<td>3.6</td>
<td>The dynamometer used for hand grip strength measurement</td>
<td>56</td>
</tr>
<tr>
<td>3.7</td>
<td>Hand grip strength force assessment in HAVERA questionnaires</td>
<td>56</td>
</tr>
<tr>
<td>3.8</td>
<td>Hand numerical scoring of vascular and sensorineural symptoms of HAVS</td>
<td>57</td>
</tr>
</tbody>
</table>
3.9 Job hazard analysis (JHA) form 58
3.10 a) Weekly roll call activity; b) weight scale; c) height gauge; d) hand grip strength measurement 59
3.11 The tri-axial accelerometer calibrator 60
3.12 Vibration signal in time domain 62
3.13 The accelerometer attach position, a) right handle, and b) left handle 62
3.14 Schematics of HAVERA questionnaire and hand arm vibration exposure data collection process 64
3.15 Data distribution for worker height in Normal Q-Q plot 66
3.16 Distribution data for workers’ height in boxplot 66
4.1 HAVERA significant variables for categorical and continuous data 73
4.2 Significant sub symptoms element that induces to HAVS 74
4.3 Significant sub disorder element that induces to HAVS 78
4.4 Flowchart of predicting health cause-effect model derivation among hand-held grass-cutting workers 80
4.5 Screenshot of the standard analysis for HAVERA multiple linear regressions 82
4.6 Screenshot of the transformation of HAVERA significant variables into means value 83
4.7 FFNN architecture structure for developing neural network prediction model 86
4.8 Summary screen for the linear prediction model based on R and MSE value 87
4.9 Summary screen for the neural network prediction model based on R and MSE value 88
5.1 Bar graph showing mean of daily exposure values, $A(8)$ (for the right and left hand) for each type of hand-held grass-cutting machine 95
5.2 Mean total (lifetime) exposure duration in years which may be expected to produce episodes of finger blanching

5.3 Frequency in percentage (Blue colour – Yes; Red colour – No) HAVERA symptoms variables characteristics of hand-held grass-cutting workers

5.4 Type of permanent and non-permanent injury at arm or hand

5.5 Type of body illness due to grass-cutting operation

5.6 Mean of hand grip strength measurement before and after operating hand-held grass-cutting machine

5.7 Vibration exposure for predicted 10% prevalence of VIWF in a group of hand-held grass-cutting workers based on ISO 5439-1

6.1 The most significant correlation dependent - independent in 95% individual confident interval:
   a) Right hand grip strength – Height; b) Left hand grip strength – Weight; c) Right hand numerical score – Age; d) Left hand numerical score – Work experience

6.2 Regression fit line for linear HAVERA right hand grip strength force

6.3 Regression fit line for linear HAVERA left hand grip strength force

6.4 Regression fit line for linear HAVERA right hand numerical scoring

6.5 Regression fit line for linear HAVERA left hand numerical scoring

6.6 Regression fit line for neural network HAVERA right hand grip strength force

6.7 Regression fit line for neural network HAVERA left hand grip strength force
6.8 Regression fit line for neural network HAVERA right hand numerical scoring

6.9 Regression fit line for neural network HAVERA left hand numerical scoring
LIST OF SYMBOLS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>m/s²</td>
<td>meter per second squared (acceleration unit)</td>
</tr>
<tr>
<td>aₜ_{hw}</td>
<td>Root-mean-square (r.m.s) single axis acceleration value of the frequency weighted hand-transmitted vibration</td>
</tr>
<tr>
<td>aₜ_{hwx}</td>
<td>Values of aₜ_{hw}, in meters per second squared (m/s²), for the x axes</td>
</tr>
<tr>
<td>aₜ_{hwy}</td>
<td>Values of aₜ_{hw}, in meters per second squared (m/s²), for the y axes</td>
</tr>
<tr>
<td>aₜ_{hwx}</td>
<td>Values of aₜ_{hw}, in meters per second squared (m/s²), for the z axes</td>
</tr>
<tr>
<td>aₜ_{hv}</td>
<td>Vibration total value of frequency weighted r.m.s acceleration</td>
</tr>
<tr>
<td>A(8)</td>
<td>Daily vibration exposure</td>
</tr>
<tr>
<td>Dᵣ</td>
<td>Group mean total (lifetime) exposure duration, in years</td>
</tr>
<tr>
<td>T</td>
<td>Total daily duration of exposure to the vibration aₜ_{hv}</td>
</tr>
<tr>
<td>T₀</td>
<td>Reference duration of 8 hours (28 800 s)</td>
</tr>
<tr>
<td>Wₜ_h</td>
<td>Frequency weighting characteristics for hand-transmitted vibration</td>
</tr>
<tr>
<td>r.m.s</td>
<td>Root mean square</td>
</tr>
<tr>
<td>%</td>
<td>Percentage</td>
</tr>
<tr>
<td>s</td>
<td>Sigmoid</td>
</tr>
<tr>
<td>e</td>
<td>Exponent</td>
</tr>
<tr>
<td>o</td>
<td>Predicted Value</td>
</tr>
<tr>
<td>t</td>
<td>Target Value</td>
</tr>
<tr>
<td>σ/SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>p</td>
<td>Significant Level</td>
</tr>
<tr>
<td>R²</td>
<td>R-squared</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>s</td>
<td>Second</td>
</tr>
<tr>
<td>N</td>
<td>Sample size</td>
</tr>
<tr>
<td>Kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>mV/g</td>
<td>millivolt per gram</td>
</tr>
<tr>
<td>cc</td>
<td>Charge Capacity</td>
</tr>
</tbody>
</table>
$kW$ - Kilowatt
$rpm$ - Revolutions Per Minute
$Y$ - Dependent Variables
$X$ - Independent Variables
$\beta$ - Regression Coefficient
$\mu$ - Mean
$x$ - Random HAVERA Significant Data
$x'$ - Normalize Input Value Between 0 and 1
$\nu$ - Vascular Symptoms
$sn$ - Sensorineural Symptoms
$R$ - Regression
$MSE$ - Mean Square Error
$Hz$ - Hertz

$DOSH$ - Department of Occupational Safety and Health
$SOCSO$ - Social Security Organization
$ISO$ - International Organization for Standardization
$UTHM$ - Universiti Tun Hussein Onn Malaysia
$UM$ - Universiti Malaya
$UPM$ - Universiti Putra Malaysia
$UTeM$ - Universiti Teknikal Malaysia Melaka
$UKM$ - Universiti Kebangsaan Malaysia
$NIOSH$ - National Institute of Occupational Safety and Health
$PROPEL$ - Projek Penyelenggaraan Lebuhraya
$PLUS$ - Projek Lebuhraya Utara Selatan
$EU$ - European Union
$EAV$ - Exposure Action Value
$ELV$ - Exposure Limit Value
$TLV$ - Threshold Limit Value
$OSH$ - Occupational Safety & Health
$HAVS$ - Hand Arm Vibration Syndrome
$WF$ - White Finger
$FST$ - Finger Skin Temperature
$NPT$ - Nail Compression Test
$VPT$ - Vibrotactile Perception Threshold
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWI</td>
<td>Cold Water Immersion Test</td>
</tr>
<tr>
<td>RR</td>
<td>Relative Risk</td>
</tr>
<tr>
<td>CI</td>
<td>Confident Interval</td>
</tr>
<tr>
<td>LDV</td>
<td>Lifetime Vibration Dose</td>
</tr>
<tr>
<td>TOT</td>
<td>Total Operating Time</td>
</tr>
<tr>
<td>CEI</td>
<td>Cumulative Exposure Index</td>
</tr>
<tr>
<td>VIWF</td>
<td>Vibration Induced White Finger</td>
</tr>
<tr>
<td>CTS</td>
<td>Carpal Tunnel Syndrome</td>
</tr>
<tr>
<td>HTV</td>
<td>Hand-transmitted Vibration</td>
</tr>
<tr>
<td>HAVERA</td>
<td>Hand Arm Vibration Exposure Risk Assessment</td>
</tr>
<tr>
<td>MLR</td>
<td>Multiple Linear Regressions</td>
</tr>
<tr>
<td>FFNN</td>
<td>Feed Forward Neural Network</td>
</tr>
<tr>
<td>HVM</td>
<td>Human Vibration Meter</td>
</tr>
<tr>
<td>HIRARC</td>
<td>Hazard Identification, Risk Assessment &amp; Risk Control</td>
</tr>
<tr>
<td>JHA</td>
<td>Job Hazard Analysis</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>ICP</td>
<td>Integrated Circuit Piezoelectric</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for Social Science</td>
</tr>
<tr>
<td>RULA</td>
<td>Rapid Upper Limb Assessment</td>
</tr>
<tr>
<td>MLP</td>
<td>Multilayer Perceptron</td>
</tr>
<tr>
<td>SRO</td>
<td>Southern Region Office</td>
</tr>
<tr>
<td>CRO</td>
<td>Central Region Office</td>
</tr>
<tr>
<td>HNS</td>
<td>Hand Numerical Scoring</td>
</tr>
<tr>
<td>HGS</td>
<td>Hand Grip Strength</td>
</tr>
<tr>
<td>RH</td>
<td>Right Hand</td>
</tr>
<tr>
<td>LH</td>
<td>Left Hand</td>
</tr>
<tr>
<td>HGS_L</td>
<td>Linear Hand Grip Strength</td>
</tr>
<tr>
<td>HNS_L</td>
<td>Linear Hand Numerical Scoring</td>
</tr>
<tr>
<td>HGS_N</td>
<td>Neural Network Hand Grip Strength</td>
</tr>
<tr>
<td>HNS_N</td>
<td>Neural Network Hand Numerical Scoring</td>
</tr>
<tr>
<td>HGS_RHL</td>
<td>Right Hand Linear Hand Grip Strength</td>
</tr>
<tr>
<td>HGS_LHL</td>
<td>Left Hand Linear Hand Grip Strength</td>
</tr>
<tr>
<td>HGS_RHN</td>
<td>Right Hand Neural Network Hand Grip Strength</td>
</tr>
<tr>
<td>HGS_LHN</td>
<td>Left Hand Neural Network Hand Grip Strength</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>$HNS_{RH}$</td>
<td>Right Hand Linear Hand Numerical Scoring</td>
</tr>
<tr>
<td>$HNS_{LH}$</td>
<td>Left Hand Linear Hand Numerical Scoring</td>
</tr>
<tr>
<td>$HNS_{RHN}$</td>
<td>Right Hand Neural Network Hand Numerical Scoring</td>
</tr>
<tr>
<td>$HNS_{LHN}$</td>
<td>Left Hand Neural Network Hand Numerical Scoring</td>
</tr>
<tr>
<td>$HGS_{RH}$</td>
<td>Right Hand Grip Strength</td>
</tr>
<tr>
<td>$HGS_{LH}$</td>
<td>Left Hand Grip Strength</td>
</tr>
<tr>
<td>$HNS_{RH}$</td>
<td>Right Hand Numerical Scoring</td>
</tr>
<tr>
<td>$HNS_{LH}$</td>
<td>Left Hand Numerical Scoring</td>
</tr>
<tr>
<td>$OHSAS$</td>
<td>Occupational Health &amp; Safety Assessment Series</td>
</tr>
<tr>
<td>$MS$</td>
<td>Management System</td>
</tr>
</tbody>
</table>
# LIST OF APPENDICES

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>HAVERA Questionnaire</td>
<td>160</td>
</tr>
<tr>
<td>B</td>
<td>The operating procedure for hand-transmitted vibration exposure</td>
<td>164</td>
</tr>
<tr>
<td>C</td>
<td>Data Sheet: Monitoring Hand Arm Vibration Exposure</td>
<td>165</td>
</tr>
<tr>
<td>D</td>
<td>Data normalization exploration for HAVERA questionnaire variables</td>
<td>173</td>
</tr>
<tr>
<td>E</td>
<td>Data correlation significance exploration for categorical and continuous variables</td>
<td>175</td>
</tr>
<tr>
<td>F</td>
<td>Feed Forward Neural Network Program Code</td>
<td>180</td>
</tr>
<tr>
<td>G</td>
<td>HIRARC document for PROPEL subcontractor hand-held grass-cutting workers</td>
<td>192</td>
</tr>
<tr>
<td>H</td>
<td>HAVERA variables characteristics</td>
<td>197</td>
</tr>
<tr>
<td>I</td>
<td>Propose Guideline for Monitoring Hand Arm Vibration Exposure</td>
<td>199</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Overview of the Study

Hand-transmitted vibration (HTV) is a common physical hazard for occupational safety and health which is caused by harmful activities to workers who use vibrating equipment in their routine tasks (Bovenzi, 1998). The fundamental HTV evaluation is often an initial process for employers to evaluate hand-transmitted assessment due to the hand arm vibration hazard at workplace among their employees (Griffin, 1997; Edwards & Holt, 2005; Cederlund, Iwarsson & Lundborg, 2007). With this evaluation, it will assist the employers to measure whether the works or activities are exposed to risk factor that could induce hand arm vibration syndrome (HAVS). By measuring the HTV exposure towards health cause-effect factors; it also assists the employers to decrease the cost of occupational rehabilitations and work-related injuries (Friden, 2001; Mansfield, 2005; Edwards & Holt, 2006; Chan et al., 2011).

In European countries, there is a regulatory requirement to perform HTV exposure at workplace in which to improve employees’ health quality and this can be associated to the responsibility and accountability of employers (Edward & Holt, 2005; Cederlund et al., 2007).

It is an important requirement for the risk measurement, evaluation and assessment of hand arm vibration exposure among hand-held vibrating machine workers to be taken in the monitoring process of the safety and health management (Griffin, 1997, Bovenzi, 1998; Mansfield, 2005). The rationale of this study was established from occupational hand arm vibration knowledge for epidemiological methods used to identify and analyze the health cause-effects induce in a work...
related with vascular, neurological and musculoskeletal disorders at workplace. Hence, its principle method is to define a objective and subjective measures linked with the development of hand arm vibration syndrome (HAVS) which has a significant element for HTV in developing the health cause-effect of hand arm vibration exposure in Malaysia (Widia & Dawal, 2011; Su et al., 2011; Tamrin et al., 2012; Kamat et al., 2014; Su et al., 2014). The investigation of hand arm vibration exposure to the health cause-effect associated to the HAVS is becoming a major interest for both human factor and occupational health in conducting their research study (Tamrin et al., 2012; Kamat et al., 2014; Su et al., 2014).

Statistics of occupational accidents by sector, which caused death, permanent disability and non-permanent disability, have been widely investigated and represented a significant problem to the Malaysian industries. According to the Department of Occupational Safety and Health (DOSH) report on occupational accidents for the non-permanent disabilities category until December 2013 (Figure 1.1), about 1496 cases of non-permanent disability were reported by the manufacturing industries which show the highest figure. The agriculture, forestry, logging and fishing industry was the second highest of 488 cases of non-permanent disability reported, followed by utility industry (100 cases of casualties) and the transportation, storage and communication industry (84 cases of casualties) (DOSH, 2013). There were 161 compensation claims under musculoskeletal disorder (SOC50, 2010). The increasing number of occupational diseases showed about 110 workers applied to the Social Security Organization (SOC50) for compensation claims under the item diseases caused by vibration (disorders of muscles, tendons, bones, joints, peripheral blood vessels or peripheral nerves) (SOC50, 2012).
Hand arm vibration injuries begins with the workers exposing vibration transmitted energy to hand palm; hence experiencing discomfort or pain after operating hand-held vibrating equipment at a workplace (Virokannas, Anttonen & Niskanen, 1994; Su et al., 2011; Tamrin et al., 2012; Ab Aziz et al., 2012; Seri Rahayu, Nurulhuda & Rohana, 2013; Su et al., 2013). Due to the magnitude, frequency and duration of HTV exposure at workplaces, the discomfort will lead to an increase of severity of symptoms and will experience hand pains and injuries (Su et al., 2011; Tamrin et al., 2012; Su et al., 2013). The hand pains and injuries may eventually result in vascular, neurological and musculoskeletal disorders such as numbness, tingling, loss of finger sensation, or finger colour changes such as vibration induced white fingers (Lindsell & Griffin, 2002; Bovenzi, 2005; Su et al., 2013).

1.2 Background of the Problem

Hand arm vibration syndromes (HAVS) are a prevalence health difficulty and a main cause of permanent or temporary hand disabilities (Griffin & Bovenzi, 2001; Futatsuka et al., 2005; Yoo et al., 2005; Paakkonen et al., 2008; Sauni et al., 2009).
Combinations of physiology, psychology and physics vibration risk factors are connected to the development of HAVS. Hand arm vibration risk factors are based on magnitude, frequency, direction and duration of vibration exposure energy to the hand palm while performing the hand-held vibrating equipment (Griffin, 2004; European Agency for Safety and Health at Work, 2008; Ko, Ooi & Ripin, 2011; Rajbhandary, Leifer & Weems, 2011). Previous studies have shown that the hand-transmitted vibration effects of HAVS are significant consequences to the vascular disorders, neurological disorders and loss of hand grip strength (Farkkila, 1978; Gemne et al., 1987; Brammer, Taylor & Lundborg, 1987).

Vascular disorders begin with the workers experiencing finger or phalange colour changes due to temporary unstable of blood flow circulation through hand, while neurological disorders initiate with workers feeling numbness, tingling and loss of sense (Griffin, 1994; Bovenzi, 2005; Weir & Lander, 2005; Sutinen et al., 2006; Thompson et al., 2011). On the other hand, loss of hand grip strength embarks with the contraction and expansion of muscle due to oscillation force applied (Futatsuka et al., 2005; Widia & Dawal, 2011; Soo et al., 2012). Due to the repetitive vibration risk factors present while operating the machine, the disorder will induce to increase the occurrence of symptoms and will be experienced as pain and aches at hand arm (Lin et al., 2005; Yoo et al., 2005; Su et al., 2011). The hand arm pains and aches may result to vascular disorders such as vibration white fingers, neurological disorders such as peripheral nerve entrapment or musculoskeletal disorders such as Dupuytren’s contracture (Bovenzi, 2005; Heaver et al., 2011; Deros et al., 2014).

1.3 Problem Statements

Recent approaches to assess the exposure of hand-transmitted vibration (HTV) associated to hand arm vibration syndrome (HAVS) were using the observation, interview and measurement methods, mainly because it was reasonably practical for application in a broad variety of hand-held vibrating machine. In contrast to the other methods especially in determining the health cause-effect would be difficult because of the medical complication and cost increase (Griffin, 1997; Yoo et al., 2005; Su & Hoe, 2008; Su et al., 2011; Su et al., 2013).

Although there is established standard operating procedure to monitor the diagnosis of HTV exposure health cause-effect at workplace (Table 1.1) such as
vibration magnitude and duration (ISO 5349-1, 2001), observation (Griffin, 2004), questionnaires interview (Su & Hoe, 2008) and vibrotactile perception threshold (Tamrin et al., 2012), a need to improve the risk control measure either by engineering or administrative of HTV exposure and to investigate the interactions between variables especially in Malaysia industry is still required (Seri Rahayu et al., 2013). Most of the investigations related to HAVS diseases are merely different from each country due to different climatic environment condition and work activities (Su et al., 2012). Thus, the occupational health surveillance in which ‘early detection’ and ‘prevention’ for determining the health cause-effect due to HTV in the workplace acquire attention to improve occupational health among workers (Cederlund et al., 2007; Heaver et al., 2011; Palmer et al., 2014). Table 1.1 shown the techniques used by previous researchers for determine the health condition among workers whom exposed to HTV.

Table 1.1: Objective and subjective cause-effect assessment of hand-transmitted vibration.

<table>
<thead>
<tr>
<th>Assessment / Measure</th>
<th>Cause</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Measuring the hand arm vibration exposure level at each axis (x, y, z)</td>
<td></td>
<td>- Thermal threshold testing</td>
</tr>
<tr>
<td>- $a_v$ (vibration total value)</td>
<td></td>
<td>- Vibrotactile threshold testing</td>
</tr>
<tr>
<td>- $A(8)$ (eight hour energy equivalent total value)</td>
<td></td>
<td>- Rewarming time testing</td>
</tr>
<tr>
<td>- Lifetime vibration dose (LDV)</td>
<td></td>
<td>- Finger systolic blood pressure testing</td>
</tr>
<tr>
<td>- Total operating time (TOT)</td>
<td></td>
<td>- Hand grip strength</td>
</tr>
<tr>
<td>- Cumulative exposure index (CEI)</td>
<td></td>
<td>- Nail compression test</td>
</tr>
<tr>
<td>- Risk Assessment</td>
<td></td>
<td>- Cold water immersion test</td>
</tr>
<tr>
<td><strong>Subjective</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Observation</td>
<td></td>
<td>- Nerve conduction studies</td>
</tr>
<tr>
<td>- Interview</td>
<td></td>
<td>- Finger skin temperature</td>
</tr>
<tr>
<td>- Questionnaire</td>
<td></td>
<td>- Purdue pegboard</td>
</tr>
<tr>
<td>- Examination</td>
<td></td>
<td>- Phalen’s test</td>
</tr>
<tr>
<td>- Medical history</td>
<td></td>
<td>- Tinel’s test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Finger pinch strength</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Nail press test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Nailfold capillary microscopy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Thermography</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Laser Doppler Flowmetry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Thermal perception threshold</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Finger tapping test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Hand classification scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Finger tingling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Finger numbness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Finger blanching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Hand weakness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- White finger</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Pain of the fingers and hand</td>
</tr>
</tbody>
</table>
Furthermore, most of the established hand-transmitted assessment are not deeply revealing the health cause-effect due to complicated exposure dose response relationship (Table 1.2) during the data analysis process either by linear or neural network methods (Kuijt-Evers et al., 2007; Shirokov et al., 2011; Palmer et al., 2014; Edlund et al., 2014). The evaluations of the health cause-effect are the important components for predicting the HTV exposure prevalence to HAVS, particularly for Malaysian research that seeks to construct a cause-effect relationship model between HTV risk measures and HAVS health consequences (Widia & Dawal, 2011; Tamrin et al., 2012; Su et al., 2014). Su et al. (2014) stated that the presence of the symptoms associated to HAVS and the high level of daily vibration exposure in the tropical environment could contribute to the initial factor for controlling HTV hazard based on work activity. Hence, the analysis of cause-effect relationship between the HTV and the severity of HAVS assessment need to be reliably tested using prediction health cause-effect model (Bovenzi et al., 2011; Kamat et al., 2014).
Table 1.2: Hand-transmitted vibration exposure dose response relationship case studies.

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Sample</th>
<th>Health Variables</th>
<th>Data Analysis</th>
<th>Prediction Health Cause-Effect Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Objective</td>
<td>Subjective</td>
<td>Linear Method</td>
</tr>
<tr>
<td>Burdorf &amp; Monster, 1991</td>
<td>Aircraft industry</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Virokannas et al., 1994</td>
<td>Track maintenance workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>McGeoch et al., 1994</td>
<td>Heavy industry</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Kattel &amp; Fernandez, 1999</td>
<td>Rivet guns workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Ragni et al., 1999</td>
<td>Tractor operator</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Futatsuka et al., 2005</td>
<td>Quarry workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Yoo et al., 2005</td>
<td>Shipyard workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Sutinen et al., 2006</td>
<td>Chain saw workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Cederlund et al., 2007</td>
<td>Manufacturing workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Vergara et al., 2008</td>
<td>Hand-held power tools workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Paakkonen et al., 2008</td>
<td>Metal workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Su et al., 2011</td>
<td>Construction</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Seri Rahayu et al., 2013</td>
<td>Industrial Workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Ahn et al., 2013</td>
<td>Korean male workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Ahmad Nasaruuddin et al., 2014</td>
<td>Auto repair mechanics</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Mohamad et al., 2014</td>
<td>Motorcyclist</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Palmer et al., 2014</td>
<td>Random Workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Edlund et al., 2014</td>
<td>Office and manual workers</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>

Through research on HAVS among hand-held grass-cutting workers in Malaysia done by Universiti Tun Hussein Onn Malaysia (UTHM), the study found that there are symptoms that workers will experience disability in hand arm due to vibration exposure from grass cutter machine. The subject of this research focuses on the occupational health cause-effect when operating the high vibrating machine on
site. The study also revealed that hand-held grass-cutting workers induce to high risk of suffering HAVS as chronic health (Azmir, Ghazali & Yahya, 2014).

Safety and health cause-effect do important procedure for employers and employees to understand how to mitigate the HTV hazard which can benefit grass-cutting operators. Research has been recognized on human response to hand arm vibration measures, but has not penetrated at using a neural network methods by means of feed forward neural network to combine objective and subjective data in predicting health cause-effect among hand-held grass-cutting workers. Additionally, subjective surveys of HAVS have been proposed by scholars in Malaysia, yet no one has looked at classifying both hand numerical scoring and hand grip strength assessment at the same time, and combine results with objective measures to predict health cause-effect model.

This research will attempt to show that a feed forward neural network (FFNN) can be developed to predict health cause-effect using both objective and subjective measures for hand-held grass-cutting workers using vibrating machine. The solution will explain both hand numerical scoring and hand grip strength measurement, view at working and social history as well as the hand disability symptoms of the workers, report hand-transmitted vibration at both the right and left handles of grass cutter machine. To the author’s knowledge, there was no such study to design the process of hand arm vibration exposure risk assessment combining the health surveillance using objective and subjective measures on hand-held grass-cutting workers in Malaysia. This proposed process called hand arm vibration exposure risk assessment (HAVERA) will acquire intention to develop the health cause-effect prediction model of HTV which is integrated between engineering and administration control measure among hand-held grass-cutting workers in Malaysia. Therefore, this study intended to fill the gap by predicting health cause-effect of hand arm vibration exposure subjectively and objectively by FFNN program.

1.4 Objectives of the Study

The general objectives of this study are:-

i. To integrate the engineering and administration control approach for reducing hand arm vibration syndrome among hand-held grass-cutting workers.
ii. To determine the significant HAVERA correlation of objective and subjective measurement variables on hand arm vibration symptoms and disorders.

iii. To develop prediction model on health cause-effect of HAVERA process among hand-held grass-cutting workers using linear and neural network approaches.

The specific objectives of this study are:-

a. To measure the health objective and subjective risk during normal working condition among hand-held grass-cutting workers.

b. To determine on site the daily vibration value, $A(8)$ during hand-held grass-cutting operation.

c. To investigate the significant variables induced to vascular disorder, neurological disorder and musculoskeletal disorder using HAVERA questionnaire.

d. To analyse the significant variables to health cause-effect prediction model using multiple linear regression (linear) and feed forward neural network (neural network).

e. To compare the performance and reliability of prediction model based on the regression and mean square error techniques.

1.5 Research Questions

Some of the questions which the research sought to answer were the following:

i. How important are the objective and subjective measurement to the HAVS prediction?

ii. What is the most significant correlation variable that influences hand-held grass-cutting workers for the purpose of vascular and neurological symptoms?

iii. What is the suitable arrangement of feed forward neural network model used to predict the HAVS of hand-held grass-cutting workers?

iv. What are the main factors that affect the prediction performance and reliability using linear and neural network model?
v. Can a new process be developed to predict the HAVS among hand-held grass-cutting workers? 

The author hopes that this project clarifies some of the above listed questions and accurately describes the process to predict health cause-effect model of hand arm vibration exposure among hand-held grass-cutting workers using objective and subjective measures that were developed.

### 1.6 Scope of the Study

The boundary of this study solely focuses on the following:

i. The prediction model of hand-transmitted vibration (HTV) were used multiple linear regression (MLR) and feed forward neural network (FFNN) techniques that covers the vibration risk factors related to hand arm vibration syndrome (HAVS) specifically for vascular, neurological and hand grip strength disorders among hand-held grass-cutting workers.

ii. The HAVERA questionnaires were consisted of personal identification, social history, workers’ health, occupational history, machine safety inspection and symptoms as the inclusion variables. Only two health effects which are hand grip strength force and numerical scoring of vascular and neurological symptoms of HAVS are determined by using dynamometer and professional judgement observation, respectively.

iii. The data collection was carried out among 204 out of 400 hand-held grass-cutting workers (Male) performing grass-cutting operation on site (located at Projek Lebuhraya Utara Selatan (PLUS) Expressway and open facilities area under PROPEL management).

iv. The normality kurtosis value of ±2, significant value of less than 0.05 and positive correlation value was choose as the individual objective and subjective significant correlation variables which induced to vascular, neurological and hand grip strength occupational diseases.

v. Only positive significant correlation of continuous data were selected in prediction model development for both hands grip strength and numerical scoring.

vi. Both of the models’ performances were assessed by means of regression (R) and mean square error (MSE) values.
vii. Both of the models’ were compared through reliability test between linear prediction model and neural network prediction model using 8 actual data collected onsite.

1.7 Significance of the Study

The proposed prediction health cause-effect model for this study will contribute to the extend body of occupational vibration knowledge in tropical environment research field, especially for monitoring hand arm vibration exposure. This is because the liability of prediction model in producing vibration white finger diseases (ISO 5349-1, 2001) were poor correlated with warm tropical countries like Malaysia (Futatsuka et al., 2005; Su et al., 2012). To date, no study regarding hand-held grass-cutting workers prediction health model has been developed to cover the HTV related to HAVS in which carried out with the comparison between linear and neural network development methods. This is the first HAVERA process to address the objective and subjective measures that meet the research needs for practical monitoring methods in order to evaluate and define the cause-effect relationship to a work associated with HAVS using vibrating machine.

The results of this study are useful for employers of grass maintenance and also occupational health practitioners who monitor the HTV exposure among their employees. This combination of objective and subjective measures will be perfect monitoring process since they do not involve expensive sensory testing equipment and a trained operator. Hence, critical information might be introduced to identify the health surveillance condition especially on employee hand arm system which involves vibrating machine in their daily operation.

In addition, assessing exposure to each work activity induces to HAVS is an essential step in the management and prevention of HAVS, whereby it may contribute from part of physical risk assessment program at workplace (Edwards & Holt, 2005; Edwards & Holt 2006; Griffin, 2008). At best, the cost effective and reliable assessment techniques in assessing the hand arm vibration exposure risk factors associated to reduce the HAVS have been an essential principle for both occupational health and mechanical engineering in conducting research studies especially in Malaysia (Su & Hoe, 2008; Widia & Dawal, 2011; Ab Aziz et al., 2012; Md Salleh et al., 2013).
1.8 Hypothesis

The main hypothesis is a feed forward neural network prediction model will be able to accurately predict health cause-effect of right and left hand numerical scoring and hand grip strength levels by considering objective and subjective measures. A linear model will not predict health cause-effect levels as accurately compared to neural network model. The sub-hypotheses of this study are:

i. Daily vibration exposure value will be higher than exposure limit value (ELV).

ii. Neural network prediction model will have better accuracy than linear prediction model in HAVERA process.

iii. Chronic hand disability will occur based on working experience and injury will become worst.

iv. There will be no significant relationship between hand numerical scoring and hand grip strength value.

1.9 Organization of the Thesis

This thesis consists of seven chapters. The chapters are arranged according to the sequence of the objective and rationale of the research. The seven chapters consist of Chapter 1 (Introduction), Chapter 2 (Literature Review), Chapter 3 (Research Methodology I: Evaluation of HAVERA process), Chapter 4 (Research Methodology II: Prediction Cause-effect Health Model of HAVERA Process), Chapter 5 (Results and Discussion I: Evaluation of HAVERA process), Chapter 6 (Results and Discussion II: Prediction Cause-effect Health Model of HAVERA Process) and Chapter 7 (Conclusions and Recommendations).

Chapter 1 describes the background of the research, the objectives to be achieved, the research scopes, the research significance, and the organization of the thesis. Chapter 2 gives an overview of literature primarily focusing on the discussion of the human response to hand-transmitted vibration and health measurement methods used in assessing the HAVS. The chapter is also divided into five main categories which are measuring assessment in hand-transmitted vibration, health effects on hand-transmitted vibration, methods of classifying HAVS and hand-held grass-cutting studies and data analysis technique. At the end of the chapter, reviews
of the past HAVS’s case studies in Malaysia were concluded. Chapter 3 explains the first research methodology that primarily focuses on the sampling on the hand-held grass-cutting workers, HAVERA process design, data collection, analysis and evaluation of variables and HAVERA prediction health cause-effect model of HAVS.

Chapter 4 describe a detail on the second research methodology on development of HAVERA prediction model of HAVS among hand-held grass-cutting workers which is divided into two phases including prediction cause-effect of HAVS using statistics linear regression model (Phase 1) and prediction cause-effect of HAVS using feed forward neural network model (Phase 2). Chapter 5 shows the first stage of results and discussion of the hazard identification, risk assessment and risk control as well as objective and subjective evaluation of HAVERA process. It is divided into four descriptions namely, hand-transmitted vibration monitoring, HAVERA questionnaires, hand grip strength assessment and hand numerical scoring assessment. Chapter 6 describe the second stage of results and discussion that includes the HAVERA significant correlation of health cause-effect, HAVERA prediction cause-effect health model for continuous data, performance index between MLR and FFNN prediction model and reliability of prediction model for linear (Phase 1) and neural network (Phase 2).

Finally, Chapter 7 concludes the summary and recommendation on this occupational hand arm vibration exposure research.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The review of the literature primarily focuses on the hand-transmitted vibration (HTV) exposure cause-effect by means of safety and health monitoring process implemented in assessing the Hand Arm Vibration Syndrome (HAVS). It is divided into eight sections namely, introduction, measuring assessment in hand-transmitted vibration, health effect of hand-transmitted vibration, methods of classifying hand arm vibration syndrome, data analysis technique, hand-held grass-cutting studies, review of past HAVS case study in Malaysia and concluding remarks. Section 2.2 discusses details of the common causes of hand-transmitted vibration exposure objective and subjective variables that have been used for HAVS surveillance. Meanwhile, Section 2.3 and 2.4 presents health cause-effect due to hand-transmitted vibration exposure at workplace consisting of vascular disorders, neurological disorders and musculoskeletal disorders as well as the approach to determine the severity of disorders, respectively. Section 2.5 discusses briefly of the two data analysis techniques which are multiple linear regression and feed forward neural network. On the other hand, Section 2.6 merely reviews details of the hand-held grass-cutting machine research from 1996 to 2015 associated with the hand-transmitted vibration risk control measures. To identify the gaps of knowledge in this research, Section 2.7 presents details of the evaluation techniques that have been used by researchers in Malaysia for evaluating the HAVS. This section also discusses the type of case study based on several criteria. The inclusion criteria of deciding the cause-effect assessment in Malaysia were as followed: (1) the latest 5 years back in
scientific articles from 2010 to 2015; (2) objectives of the assessment; (3) objective and subjective variables investigated by assessment; and (4) the data analysis process in terms of using linear or neural network methods for relationship between cause and effect studies. Based on these master plans, it would be functional for the author to predict a health cause-effect model based on the gaps of knowledge in Section 2.7. Consequently, the designing methodology for the development of prediction model on the proposed assessment process is in Chapters 3 and 4.

2.2 Measuring Assessment in Hand-transmitted Vibration

In the measuring classification and diagnosis of hand arm vibration syndrome (HAVS), many researchers have looked at both objective and subjective measurement variables (Burstrom et al., 1998; Kuijt-Evers et al., 2007; Shirokov et al., 2011). According to Mansfield (2005), the subjective methods rely on the honesty of the patient but easy to complete. However, the objective measurement was claimed to be more reliable but usually required trained professional operator and expensive sensory equipment. A study by Sauni et al., (2009) found that human illness actually showed that there was a relationship between hand-transmitted vibration and clinical examination. The combination between the objective and subjective measures is important in predicting health cause-effect of hand-transmitted vibration exposure (Poole & Mason, 2007). Subjective measures attempt to gauge the user’s degree of HAVS prevalence through questionnaires (Su & Hoe, 2008; Paakkonen et al., 2008). These measures are influenced by the worker’s experience, quality of life, current state of health, comfort ability and perceptions (Kuijt-Evers et al., 2007; Cederlund et al., 2007). Objective measure provides numbers and evidence that are repeatable and not influenced by human perception (Griffin, 1997).

Complicated approach for investigating hand-transmitted vibration exposure using quality and quantity methods in HAVS studies can usually be combined into three categories which are physiology, physics of vibration and biomechanics response (Mansfield, 2005). Hence, these combinations will provide important information for the measurement, evaluation and risk assessment which may be used in specific work activity. Figure 2.1 illustrates a conceptual model of factors
influencing cause-effect relationships for hand-transmitted vibration exposure, and may be used as a guide for developing prediction on health cause-effect model.

Figure 2.1: The conceptual model of cause and effect relationship. (Dong, Wu & Welcome, 2005)

In general, objective measures with assistance of instrumentation give the most specific and accurate information estimation, but involves significant cost. This technique would be necessary for monitoring individual vibration exposure in specific work activity at workplace to determine the vibration magnitude, frequency, direction as well as daily vibration exposure. Hence, this will provide the reliable risk assessment information based on the current hand arm vibration legislation. Subjective measure using interview, observation and questionnaire methods can be used to a large population but the data obtained have low validity and has potential bias. This will require significant management resources and expertise. However, this subjective information will be beneficial to researchers regarding the personal identification, working history and health symptoms. The following sections discuss details on the objective and subjective measures which is risk assessment, hand-transmitted vibration exposure and hand arm vibration legislation; interview, observation and questionnaires, respectively.
2.2.1 Objective Measures

Griffin (1994) stated that the data collection on exposure of hand-transmitted vibration (HTV) in the workplace using objective measures can be procured from risk assessment, vibration measurement and establish standard or legislation. The most important information in data collection using objective measures are the magnitude of vibration, frequency of the vibration and the duration of vibration exposure (Griffin, 1997). Other information can also be collected, such as lifetime vibration dose, total operating time and cumulative exposure index.

The degree of accuracy of the objective measures may vary depending on factors such as works and tools’ condition, work activities and biodynamic response (Dong et al., 2005). However, the risk assessment would be the best document management reference in evaluating the consequence and severity of work activities (Yakubu & Bakri, 2013). Hence, it is compulsory to have a standard legislation reference to assess the level of hand-transmitted vibration exposure risk of the occupational group (Griffin, 2008). The levels acquired from vibration measurement for 8 hours are used as the basic for monitoring hand-transmitted vibration exposure at workplace (ISO 5349-1, 2001).

2.2.1.1 Risk Assessment

The dynamics of occupational disease and injuries at workplace can be understood from parts of the basic concept which is relationship between work and health, by means when the workers were exposed to situation with the potential to harm. Factors that influence the worker while in operation are called hazard which include physical, chemical, biological, ergonomics and physiological in nature (Sarak & Susil, 2012). So, there is a need to identify the hazard at each specific work activity such as while operating and setting up the equipment. The risk assessment can also be used as performance factor in investigating the work safety (Mihaela & George, 2015).

The benefit of risk assessment is that it is used in occupational safety and health management system, which can be applied to any working situations, and are suitable for evaluating a complex system as well as reviewing document process. To ensure that the risk analysis represents the risk level, the consequence or likelihood
of an event multiplied by severity of occurrence was used (DOSH, 2008). The relative risk value can be used to prioritize necessary actions to effectively manage workplace hazard. Hazard assessed as “High Risk” must have immediate actions to reduce risk to worker health. Hence, the control measure (Figure 2.2) will be introduced to control the risk from any injuries or accident. The most effective control measure was elimination of the hazard while the least effective control measure was using personal protective equipment.

![Hierarchy of Control](image)

Figure 2.2: The hierarchy of control in occupational safety and health.

2.2.1.2 Hand-transmitted Vibration Exposure

Attaching an accelerometer sensor directly to the vibrating equipment is one of the measures developed to measure the exposure quantity at the workplace. Simple hand-held portable device and electronic analyser can be used to obtain vibration measurements and determine the magnitude of the hand-transmitted vibration while operating the machine. To measure the vibration at \( x \), \( y \) and \( z \) axis, a tri-axial accelerometer is commonly used to measure the amplitude and frequency of energy transmitted to hand palm worker together with equivalent systems for computerized data analysis (Fereydooni et al., 2012). A practical system of measuring hand-transmitted vibration exposure is illustrated in Figure 2.3. Initially, an accelerometer was attached to the vibrating surface which covers the mechanical oscillation into the electrical property. At last, the basic measurement of vibration such as total value of frequency weighted \( r.m.s \) acceleration, \( r.m.s \) single-axis acceleration value of the
frequency weighted hand-transmitted vibration and daily vibration exposure in meter per-second squared (m/s²) was produced.

Figure 2.3: A modular system for hand arm vibration measurement analyser.
(Mansfield, 2005)

The vibration emitted by tools is important to characterize vibration emissions in order to provide recognition of the exposure sign on the dose-response relationship (McDowell et al., 2008). Vibration characterization is also important for development of active vibration control (Ko et al., 2011) and for improved tool design (Mallick, 2008). The four primary characteristics of vibration exposure evaluation are vibration frequency, vibration magnitude, exposure duration and cumulative exposure (ISO 5349-1, 2001). This vibration measurement is a compulsory requirement in assessing vibration exposure stated in either European Directive or guidelines stipulated in monitoring vibration exposure (Griffin, 2008; Brereton, 2011).
2.2.1.3 Hand Arm Vibration Legislation

The Department of Occupational Safety and Health, (DOSH) Malaysia establishes the guidelines of minimum health and safety requirements regarding the occupational vibration of workers involved in vibrating tool. The guidelines state that the vibration transmitted to the hand arm system is to be measured in accordance to the international standard (ISO 5349-1, 2001). Furthermore, American Conference of Governmental Industrial Hygienist (ACGIH) specifies the threshold limit value and duration of exposure to be complied for the purpose of mitigating HAVS (Janicak, 2004). Besides that, European Directive established the regulation to protect workers from vibration hazard (Directive, 2002). Although, there are several detail safety descriptions related to human response to vibration, it indicated that hand arm vibration disease reduces after implementing the Directive 2002/44/EC in Great Britain (Brereton, 2011). Even though the guidelines in occupational vibration have been introduced by DOSH, there is still lack of awareness to mitigate the vibration hazard in Malaysia. It's caused by the less compliance to the guidelines compared to regulation or industrial code of practice.

For hand arm vibration assessment, articles 3 of directive 2002/44/EC establish the following safety limits for $A(8)$:

- Exposure limit value (ELV) = 5.0 m/s$^2$
- Exposure action value (EAV) = 2.5 m/s$^2$

The ELV is the maximum amount of HTV exposed by a worker in any single day. It indicates a potential high risk above which worker should not be exposed. The EAV is the daily amount of HTV exposure which employer is required as far as reasonably practicable to take acceptable and suitable control measure. Hence, providing periodical health surveillances for the workers involved. In Malaysia, guidelines on occupational vibration (DOSH, 2003) were used as reference for workers involved in hand arm vibration operation. In this particular guidelines, established threshold limit value (TLV) and exposure duration for vibration transmitted to hand arm in $A(8)$:

- 4 hours and less than 8 hours = 4 m/s$^2$
- 2 hours and less than 4 hours = 6 m/s$^2$
- 1 hours and less than 2 hours = 8 m/s$^2$
- Less than 1 hour = 12 m/s$^2$
The TLV is the vibration acceleration component levels and the duration of exposure for hand arm vibration. The values shall be used as a basis for the control measure of HTV exposure.

When comparing both stated two limit values which are threshold limit and exposure limit, there will more complicated measurement to determine the actual total vibration value for each work process. It is due to random vibration signal acquired and the duration of operation time. However, the exposure limit value quantifies the daily vibration exposure by clearly stating that the vibration should not exceed the limit value even though workers require a short operation time. Hence, it will be easier to follow the exposure limit value rather than threshold limit value.

2.2.2 Subjective Measures

There is a normal practice to include subjective measure in occupational safety and health study, which is relevant to evaluate the workers’ perception at workplace (Yovi, Gandaseca & Adiputra, 2012), assessing vibration risk exposure duration (McCallig et al., 2010) and conducting research on comfort or uncomforted condition (Openshaw, 2011). Although this is an easy method of measure, the bias of the data collected on vibration hazard is always introduced. Therefore, by using subjects who reflect the demographics and experience level of population, researchers would obtain results that are more representative of their subject area. Researchers have primarily used subjective measures such as questionnaires, interview and observation approaches. A simple combination of subjective measure can be used to recognize and evaluate the awareness level of hand-transmitted vibration hazards in the workplace. Further subsection discusses the details of the subjective measures for HAVS.

2.2.2.1 Questionnaires

Griffin and Bovenzi (2001) had prepared the self-reported questionnaire for detection and prevention of injuries due to occupational vibration exposure. The report consists of screening method to determine the vascular disorders, neurological disorder and musculoskeletal disorder due to hand-transmitted vibration exposure. The report was also selected as benchmark in proposing the hand arm vibration syndrome study in
Malaysia (Su et al., 2008) and Finland (Paakkonen et al., 2008). In spite of that, an international Southampton workshop 2000 was convened with invited experts, medical doctor, scientists and engineers familiar with hand-transmitted vibration and symptoms. Hence, standard draft Hand Arm Vibration Syndrome (HAVS) questionnaire had been drafted for European Vibration Injury Network.

The advantage of the HAVS questionnaires is that it is easy to use which can be applied to a wide range of workplace that operates the vibrating equipment. Sekaran, (2006) stated that data collection method through questionnaire survey form is an efficient method as one of the mechanisms used to collect data. Furthermore, Paakkonen et al. (2008) stated that the questionnaire is the best suited technique for collecting data in the observation approach of study. The main element in HAVS questionnaires are the demographic, work and health history and symptoms of pain. From the work and health history, the data regarding the working experience using vibrating equipment which induced to pain can be determined (Shirokov et al., 2011). For example, claims of having experienced hand and arm pain were found to increase the probability of workers claiming higher frequency and durations of hand-transmitted vibration exposure compared to workers who were in control occupational group (Su et al., 2011; Tamrin et al., 2012).

The answers of HAVS questionnaires normally consist of several scales which are either in nominal or ordinal scale. The nominal type differentiates between items based only on their names or categories while ordinal scale type allows for rank order (Su et al., 2008). Thus, these two types of scales were used to determine the level of consequences and severity of health effect. However, the ordinal scale was chosen to two answers provided either “yes” or “no” due to foreign contract workers who were unable to understand the complicated question and answer sheets. On the other hand, the types of questions consisted of mixed open and close ended such as “Do your fingers go numb” and “How many years involved with vibrating equipment”, respectively (Su et al., 2008). The exposure to hand-transmitted vibration and symptoms can be recommended to screen at workplaces by a simple questionnaire yet effective (Paakkonen et al., 2008).
2.2.2.2 Interview

There are three types of interviews conducted for investigation studies which are management interview, safety and health committee interview and workers’ interview (Yakubu & Bakri, 2013). From the management and safety and health committee interview, the interviewer was able to find information about the existing control measure on how to mitigate the vibration hazard as well as the accident report during operation. However, an interview with groups of workers revealed the absolute reason and realisation regarding safety and health issues at workplace (Yovi et al., 2012; Mihaela & George, 2015). Besides that, the best approach to answer the HAVS questionnaire was administered by face to face interview with the workers (Aini & Huda, 2015).

Workers should be interviewed by the safety and health practitioner which can determine or screen the health condition of workers (McCallig et al., 2010). An interviewer conducted interviews and collected information on exposure and outcomes due to vibration hazard (Su et al., 2011). By interview too, information was collected for workers’ whole lifetime about the number of years in hand-transmitted vibration exposure and duration of exposure per day (Burstrom et al., 1998). The information required from interview was used as the basis for hazard identification as well as prevention of HAVS at the workplace (Janicak, 2004).

2.2.2.3 Observation

Observation and physical examination were conducted by the researcher to see the external changes at hand arm especially at hand fingers due to experiencing vibrating equipment at workplace (McCallig et al., 2010; Su et al., 2011). There are many techniques used by medical practitioners to diagnose the health effect of hand-held vibrating machine such as Phalen’s test, Tinel’s test and finger tapping test. The quantitative measurement of the severity can be determined by professional judgement or trained workers. The simplest and low cost assessments are positive characteristics in the process of screening hand-transmitted vibration hazard at the workplace. Section 2.4 discusses the details of observation approach for classifying vascular, neurological and musculoskeletal disorders.
2.3 Health Effects of Hand-transmitted Vibration

Most of the interest with hand-transmitted vibration is due to the disorders that are often observed in populations who use vibrating tools. Disorders can be broadly divided into vascular and nonvascular categories (Griffin, 1990). Nonvascular disorders can be further subdivided into neurological and musculoskeletal disorders. Collectively, both types of symptoms are referred to as HAVS. The HAVS is a disease that implies circulatory disorders (i.e. vibration white fingers), motor and sensory disorders and musculoskeletal disorders, which may occur in workers who use vibrating hand-held tools such as jackhammers, electric drills and saws, grinders and pneumatic drills (Weir & Lander, 2005).

The relevance of studying hand arm vibration in power tools for industry is emphasized by a statistical revelation that the prevalence of HAVS ranges from 2.5% to more than 82.8% globally depending on the duration and magnitude of vibration as well as climatic factors (Lin et al., 2005). However, this percentage will increase as the working environment temperature decreases, thus the vibration induced white fingers renowned by low ambient temperature countries compared to warm environment countries. Its prevalence in warm environment such as Malaysia is not well established compared to European Union (EU) countries since there is no regulation concern about occupational hand arm vibration hazard (Su et al., 2011).

In line with the occupational vibration epidemiological study at temperature climate countries, structure review done by Su et al., (2011) revealed that the applicability of ISO 5349-1 dose response for a 10% prevalence of vibration induce white fingers prediction model in tropical countries as the disease of HAVS could be overestimated. The hand-transmitted vibration exposures were different between industry or work specification. Hence, the prevalence of neurological symptoms (finger tingling and numbness) were higher which range from 13.0% to 67.6% than vascular symptoms (Table 2.1) and was investigated in countries such as Indonesia, Vietnam, South Africa and Malaysia.
**REFERENCES**


