DEVELOPMENT OF LOWER BACK PAIN PREVENTION INDEX DUE TO WHOLE BODY VIBRATION: SYSTEM DYNAMICS

BY

VITHARANAGE HASHINI PARAMITHA VITHARANA

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (ENGINEERING AND TECHNOLOGY)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY

ACADEMIC YEAR 2018

DEVELOPMENT OF LOWER BACK PAIN PREVENTION INDEX DUE TO WHOLE BODY VIBRTION: SYSTEM DYNAMICS

BY

VITHARANAGE HASHINI PARAMITHA VITHARANA

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (ENGINEERING AND TECHNOLOGY)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

THAMMASAT UNIVERSITY

ACADEMIC YEAR 2018

DEVELOPMENT OF LOWER BACK PAIN PREVENTION INDEX DUE TO WHOLE BODY VIBRATION: SYSTEM DYNAMICS

A Dissertation Presented

By

VITHARANAGE HASHINI PARAMITHA VITHARANA

Submitted to
Sirindhorn International Institute of Technology
Thammasat University
In partial fulfilment of the requirements for the degree of
DOCTOR OF PHILOSOPHY (ENGINEERING AND TECHNOLOGY)

Approved as to style and content by

Advisor and Chairperson of Thesis Committee ______________________

(Assoc. Prof. Dr. Thanwadee Chinda)

Co-Advisor ______________________

(Assoc. Prof. Dr. Veeris Ammarapala)

Committee Member and
Chairperson of Examination Committee ______________________

(Asst. Prof. Dr. Suthathip Suanmali)

Committee Member C. Soralump

(Asst. Prof. Dr. Cheema Soralump)

Committee Member Thunyaseth S.

(Dr. Thunyaseth Sethaput)

External Examiner: Prof. Dr. P.V.De Silva (MD)

AUGUST 2018

Acknowledgements

The past few years have been a time of challenge and growth of my knowledge. Much has changed since I first entered Thailand, another country which has turned out to be my second home today. My journey to PhD is succeeded with the supportive hands of all the loving people around me.

First and foremost, I would like to thank my supervisor Associate Professor Dr. Thanwadee Chinda, for the given opportunity, valuable guidance and consistent encouragement throughout my research life as a PhD student.This would not have been possible without her remarkable inspiration and valuable support.

I am glad to express my sincere gratitude to Associate Professor Dr. Veeris Ammarapala, Assistant Professor Dr. Suthathip Sunmali, Assistant Professor Dr. Cheema Soralump, and Dr. Thunyaseth Sethaput for providing effective guidance and support throughout my study.

I am much obliged to School of Management Technology, Sirindhorn International Institute of Technology, Thammasat University for provision of EFS Scholarship throughout my PhD study. I would also like to thank SIIT staffs, students and seniors who with their great guidance make my study life pleasant.

I received an immense support from managers and workers of Sri Lankan construction companies during data collection process. I am much delighted and proud as a Sri Lankan to successfully complete my research data collection in my own country to support the worldwide research platform.

I am perpetually obligated and thankful to Dr. Subashi De Silva, Dr. Sudhira De Silva, and Dr. J.A.P. Bodhika for making me an innovative researcher as I am today.

I appreciate all the love showered on me during my stay at SIIT Bangkadi International Residence Hall. I felt home even with the presence of different nationalities and multi-language-based conversations. It was also an opportunity for me to understand myself and improve my personality.

Finally, I sincerely thank my parents and siblings for being there throughout my life, giving support in all the possible means. I owe you my life and more.

Lastly, I convey my thanks to ones who have shaped my life in some means, and helped me to become Dr. V.H.P. Vitharana, Thank you.

Abstract

DEVELOPMENT OF LOWER BACK PAIN PREVENTION INDEX DUE TO WHOLE BODY VIBRATION: SYSTEM DYNAMICS

by

VITHARANAGE HASHINI PARAMITHA VITHARANA

Bachelor of Science (Physics Special), University of Ruhuna, Sri Lanka, 2011
Master of Philosophy, University of Ruhuna, Sri Lanka, 2015
Doctor of Philosophy (Engineering and Technology) Sirindhorn International Institute of Technology, Thammasat University, 2018

Prolonged exposure to whole body vibration (WBV) is a major health hazard for construction workers, leading to various chronic health problems. Heavy equipment operators (HEOs) are exposed to WBV most of the time. This causes both short and long-term health effects, such as headache, motion sickness, spinal disc disease, and lower back pain (LBP). LBP due to WBV exposure causes high compensation cost, and a long–term LBP prevention program is needed to reduce the compensation cost. To develop an effective program to reduce LBP due to WBV exposure in the long-term, however, there are a number of influential factors to consider, for example, working hour, age of the worker, age of the machine, job satisfaction, and working experience. These factors also have influence on each other, making it hard to plan for long-term implementation. This study, thus, develops a dynamic model of LBP prevention index to reduce LBP due to WBV exposure in the construction industry in the long-term.

Five key factors affecting due to WBV exposure are hypothesized, together with 17 associated items, based on a number of construction and health related literatures. A questionnaire survey is then developed; based on the 17 items, for data collection in Sri Lankan construction industry.The collected data are screened and

performed with the exploratory factor analysis to confirm five key factors affecting LBP due to WBV exposure with their associated items. The organizational and equipment factors are extracted with four associated items each, while the personal, job related, and social context factors are associated with three items each.

Five key factors are performed with the structural equation modelling to examine causal relationships among those factors. The results reveal that the organizational factor plays a primary role in improving LBP prevention program, as it influences the other four factors directly and indirectly, while equipment factor is affected by the other four factors. It is then suggested that providing new machines are not effective in reducing LBP symptoms without proper training and good working conditions .

The dynamic model of the LBP prevention index is then developed based on the five key factors, and their inter relationships utilizing a system dynamics modelling technique. The LBP prevention index developed, in the model is used to assess a current level of LBP prevention maturity. The developed dynamic model is simulated, and the results show that with proper LBP prevention program, the construction company achieves a higher LBP prevention index through time.

The results show that the construction company is currently in level 2 of maturity. With supports from management, the company reaches level 3 in year 4 and level 4 in eight years. To achieve level 5, however, it takes both effort and support, mainly on budget, to proceed with program implementation. With continuous improvement, the company can reach level 5 of maturity at the end of year 39. The results also show the importance of workers over equipment provision to achieve higher maturity levels. The company, therefore, should focus on providing adequate budget to support the LBP-related activities, such as LBP–related training, job rotation, and exercise scheme to reduce chances of having LBP.

The construction company can perform alternative strategies to effectively plan for LBP prevention maturity. Strategies, such as hiring workers, training workers, purchasing new equipment, and mixed strategies are tested to achieve higher LBP prevention index in the long-term.

The dynamic model of LBP prevention index brings insights into five key factors, affecting LBP due to WBV exposure, as well as their inter relationships. A construction company can use the developed dynamic model to effectively plan for

LBP prevention program to achieve higher maturity level in the long-term. This proves the contribution of the study to the world-wide construction industry.

Keywords: Construction industry, Exploratory factor analysis, Lower back pain index, Structural equation modelling, System dynamics modelling, Whole body vibration

Table of Contents

Chapter	Title	Page
	Signature page	i
	Acknowledgements	ii
	Abstract	iv
	Table of Contents	vii
	List of Tables	xii
	List of Figures	xiv
	List of Abbreviations	xvi
1	Introduction	1
	1.1 General overview	1
	1.2 Construction industry	1
	1.3 Whole body vibration (WBV) exposure	2
	1.3.1 Heavy equipment operators and WBV exposure	3
	1.3.2 Chronic LBP problems among HEOs	6
	1.4 Problem statement	6
	1.5 Research aim and research objectives	7
	1.6 Thesis organization	8
2	Research Methodology	9
	2.1 General overview	9
	2.2 Research framework, research activities, and expected outcomes	9
	2.3 Introduction to exploratory factor analysis	11
	2.4 Introduction to structural equation modelling	13
	2.5 Introduction to system dynamics modelling	14
	2.6 LBP prevention maturity level	16
3	Literature Review	20
	3.1 General overview	20
	3.2 Sri Lankan construction industry	20

3.3 Items affecting LBP due to WBV exposure among HEOs in the construction industry 21
3.3.1 Age of the machine (AOM) 25
3.3.2 Age of the worker (AOW) 25
3.3.3 Exercise (EXR) 25
3.3.4 Education (EDU) 26
3.3.5 Job rotation (JOR) 26
3.3.6 Job satisfaction (JOS) 27
3.3.7 Night shift (NSF) 27
3.3.8 Safety and health budget (SBT) 27
3.3.9 Seat type (STP) 28
3.3.10 Smoking (SMK) 28
3.3.11 Soil type (SOT) 28
3.3.12 Training program (TPM) 28
3.3.13 WBV exposure (VEX) 28
3.3.14 WBV standard (VST) 29
3.3.15 Weight of the worker (WGT) 32
3.3.16 Working experience (WEP) 32
3.3.17 Working hour (WHO) 33
3.4 Factors affecting LBP among HEO in the construction industry 33

4 Data Collection and Preliminary Analysis 41

4.1 General overview 41
4.2 Data collection method 41
4.3 Questionnaire survey and data collection 42
4.4 Sample characteristics of the respondents 42
4.4.1 Age distribution 43
4.4.2 Education background 44
4.4.3 Common working hour 45
4.4.4 Safety training record 46
4.5 Data screening 47
4.5.1 Test of normality 47
4.5.2 Outlier test 49

5 Exploratory Factor Analysis 53

5.1 General overview 53
5.2 Steps to perform an EFA 53
5.2.1 Assessment of the suitability of data 53
5.2.2 Factor extraction 54
5.2.3 Factor rotation and interpretation 54
5.2.4 Factor loading 55
5.3 The EFA results 55
5.4 Reliability test 58

6 Structural Equation Modelling of LBP Prevention among HEOs 60

6.1 General overview 60
6.2 Structural equation modelling 60
6.3 Measurement model of LBP prevention 64
6.4 Structural model of LBP prevention 66
6.4.1 Direct and indirect relationships of the ORF factor 68
6.4.2 Direct and indirect relationships of the PNF factor 68
6.4.3 Direct and indirect relationships of the JRF factor 69
6.4.4 Direct and indirect relationships of the SCF factor 69

7 Dynamic Model of LBP Prevention Index 71

7.1 General overview 71
7.2 Causal loop diagram of LBP prevention index 71
7.3 A dynamic model of LBP prevention index 74
7.3.1 Personal factor sub-model 79
7.3.1.1 Age of the worker 81
7.3.1.2 Weight of the worker 82
7.3.1.3 Working hour 83
7.3.2 Organizational factor sub-model 88
7.3.2.1 Safety and health budget 90
7.3.2.2 Training program 90
7.3.2.3 WBV standard 93
7.3.2.4 Working experience 94

7.3.3 Equipment factor sub-model 95
7.3.3.1 Seat type 96
7.3.3.2 Age of the machine 97
7.3.3.3 WBV exposure 97
7.3.3.4 Soil type 98
7.3.4 Job-related factor sub-model 98
7.3.4.1 Night shift 99
7.3.4.2 Job rotation 100
7.3.4.3 Exercise 100
7.3.5 Social context factor sub-model 101
7.3.5.1 Job satisfaction 102
7.3.5.2 Smoking 103
7.3.5.3 Education 103
7.3.6 LBP prevention index sub-model 105
7.4 Simulation results 108
7.5 Model verification and validation 112
7.5.1 Structure test 113
7.5.1.1 Structure verification test 113
7.5.1.2 Parameter verification test 113
7.5.1.3 Dimensional consistency test 114
7.5.2 Behaviour validity test 114
7.5.2.1 Behaviour prediction test 114
7.5.2.2 Behaviour sensitivity test 115
7.6 Scenario analysis 115
7.6.1 Single strategy 115
7.6.1.1 Hiring rate strategy 115
7.6.1.2 Safety and health budget strategy 118
7.6.1.3 Exercise strategy 120
7.6.1.4 Equipment acquisition strategy 122
7.6.1.5 Training strategy 125
7.6.2 Mix strategy 127
7.6.2.1 Safety and health budget and hiring rate 127
7.6.2.2 Safety and health budget and exercise 129
7.6.2.3 Hiring rate, training, and equipment acquisition 132

8 Conclusion and Recommendation 135

8.1 General overview 135
8.2 Major findings 135
8.3 Contribution 137
8.4 Limitations and recommendations for future studies 137
8.5 Closure 138

References 139

Appendices 162

Appendix A 163
Appendix B 164
Appendix C 166
Appendix D 168
Appendix E 169
Appendix F 175
Appendix G 181
Appendix H 183
Appendix I 185
Appendix J 187

List of Tables

Tables	Page
1.1 Health effects among construction workers exposing to WBV	4
2.1 SEM applications in different areas	13
2.2 Different maturity levels used in ergonomic, safety and health-related areas	17
3.1 Items affecting LBP due to WBV exposure among HEOs	22
3.2 Chances of having LBP due to WBV exposure with exercise (Rainville et al., 2004)	26
3.3 Chances of having LBP due to WBV exposure with education background (Udom et al., 2016)	26
3.4 Chances of having LBP due to WBV exposure with job satisfaction (Hoogendoorn et al., 2002)	27
3.5 Different international standards related to WBV exposure	30
3.6 Chances of having LBP with weight (Alghadir and Anwer, 2015)	32
3.7 Factors and associated items affecting LBP due to WBV exposure based on literature	35
3.8 Hypothesized factors and items with their associated factors affecting LBP due to WBV exposure	39
4.1 Skewness and kurtosis values of the 17 items affecting LBP due to WBV exposure	48
4.2 Mean, 5% trimmed mean, and difference between mean values of 17 items	49
4.3 Frequency of potential outlier of data sets	51
4.4 Frequency of potential outlier of items	51
5.1 Bartlett's test of sphericity and the KMO index	54
5.2 Four factors extracted from the 17 items	55
5.3 Five factors affecting LBP due to WBV exposure extracted from the EFA	57
5.4 Cronbach's Alpha value of five factors	58
6.1 Definition and acceptable range of fit indices	62
6.2 Fit indices of measurement and structural model	64
6.3 Direct and indirect path coefficients of five key factors	70
7.1 Input data of the dynamic model development	75
7.2 Simulation results of LBP prevention index	110
7.3 Simulation results of LBP prevention index of five key factors	111

7.4 Model verification and validation tests 112
7.5 Behaviour prediction test results 114
7.6 LBP prevention index with different hiring rates 116
7.7 LBP prevention index with different safety and health budget increasing rates 119
7.8 LBP prevention index with different exercise schemes 121
7.9 LBP prevention index with different equipment acquisition percentage 123
7.10 LBP prevention index with different training rates 125
7.11 LBP prevention index with different safety and health budget increasing rates, and hiring rates 128
7.12 LBP prevention index with different safety and health budget increasing rates and exercise rates 130
7.13 LBP prevention index with different hiring rates, training rates, and equipment acquisition 133

List of Figures

Figures	Page
2.1 Research framework, activities and expected outputs	10
2.2 Interface of the SPSS software	12
2.3 AMOS software interface	14
2.4 iThink software components	16
2.5 LBP prevention maturity levels	18
3.1 Age of the worker and chances of having LBP due to WBV exposure (John Lant and Partners, 2015)	25
3.2 Vibration level and health risk of construction workers (McPhee et al., 2001)	29
4.1 Respondents in management and operational levels	43
4.2 Age distribution among the managerial position	43
4.3 Age distribution among HEOs	44
4.4 Education background of managerial position	44
4.5 Education background of HEOs	45
4.6 Working hour among managerial position	45
4.7 Working hour among HEOs	46
4.8 Safety training in managerial position	46
4.9 Safety training among HEOs	47
4.10 An example of box plot	50
5.1 The conceptual model of LBP due to WBV exposure achieved from the EFA	59
6.1 Best fit measurement model	65
6.2 Final model of LBP due to WBV exposure	67
7.1 Causal loop diagram of LBP prevention index	72
7.2 Example of a positive causal loop	73
7.3 Example of a negative causal loop	73
7.4 Personal factor sub-model	80
7.5 Organizational factor sub-model	89
7.6 Equipment factor sub-model	95
7.7 Job-related factor sub-model	99
7.8 Social context factor sub-model	102
7.9 LBP prevention index sub-model	106

7.10 Graphical results of the dynamic model of LBP prevention index 111
7.11 LBP prevention index with different hiring rates 116
7.12 Graphical results of LBP prevention index with different safety and health budget increasing rates 118
7.13 Graphical results of LBP prevention index with different exercise schemes 121
7.14 Graphical results of LBP prevention index with different equipment acquisition percentage 123
7.15 Graphical results of LBP prevention index with different training rates 125
7.16 Graphical results of LBP prevention index with different safety and health budge increasing ratest, and hiring rates 127
7.17 Graphical results of LBP prevention index with different safety and health budget increasing rates and exercise rates 130
7.18 Graphical results of LBP prevention index with different hiring rates, training rates, and equipment acquisition 132

List of Abbreviations

AAHOs	Total hired additional A workers
ABHOs	Total hired additional B workers
ACHOs	Total hired additional C workers
AOM	Age of the machine
AOW	Age of the worker
APop	A population
APopR	Ratio of group A population to total population
ATCPP	Training cost per worker in group A
BHAOs	Expenditure to hire group A workers
BHBOs	Budget expenditure for hire B operators
BHCOs	Expenditure to hire group C workers
BPop	B population
BPopR	Ratio of group B population to total population
BTCPP	Training cost per worker in group B
CAEDU	Chance of having LBP based on the EDU item in group A
CAOM	Chance of having LBP based on the AOM item
CAOW	Chance of having LBP based on the AOW item
CBEDU	Chance of having LBP based on the EDU item in group B
CCEDU	Chance of having LBP based on the EDU item in group C
CEDU	Chance of having LBP based on the EDU item
CEQF	Chance of having LBP based on the EQF factor
CEXR	Chance of having LBP based on the EXR item
Check JOR NSF &WHO	Fully implementation of the JOR, NSF, and WHO items
Check_machine	Fully implementation of the AOM items
Check_seat	Fully implementation of the STP items
Check_Train	Fully implementation of the TPM items
CJOR	Chance of having LBP based on the JOR item
CJOS	Chance of having LBP based on the JOS item
CJRF	Chances of having LBP due to JRF factor

CLWHO	Chance of having LBP among HEOs work less than 8 hours
CMWHO	Chance of having LBP among HEOs work more than 8 hours
CNSF	Chance of having LBP based on the NSF item
CORF	Chance of having LBP based on the ORF factor
CPNF	Chance of having LBP based on the personal factor
CPop	C population
CPopR	Ratio of group C population to total population
CSCF	Chance of having LBP based on the SCF factor
CSMK	Chance of having LBP based on the SMK item
CSOT	Chances of having LBP based on the SOT item
CSR	Cushion seat ratio to total seats
CSTP	Chances of having LBP based on the STP item
CTCPP	Training cost per group C worker
CTPM	Chance of having LBP based on the TPM item
CVST	Chance of having LBP based on the VST item
CWEP	Chance of having LBP based on the WEP item
CWGT	Chance of having LBP based on the WGT item
CWHO	Chance of having LBP based on the WHO item
delta_CJRF	A change of chances of having LBP due to WBV exposure of the JRF factor
delta_CORF	A change of chances of having LBP due to WBV exposure of the ORF factor
delta_CPNF	A change of chances of having LBP due to WBV exposure of the PNF factor
delta_CSCF	A change of chance of having LBP due to WBV exposure of the SCF factor
EBY	Equipment buying year
EDU	Education
ESB	Budget for processing equipments and seats
EXR	Exercise

Final EQF	Final chances of having LBP due to WBV exposure based on the EQF factor
Final JRF	Final chances of having LBP due to WBV exposure based on the JRF factor
Final PNF	Final chances of having LBP due to WBV exposure based on the PNF factor
Final SCF	Final chances of having LBP due to WBV exposure based on the SCF factor
HAEDU	Percentage of group A workers with >12th grade education background
HBEDU	Percentage of group B workers with >12th grade education
HCEDU	Percentage of group C workers with >12th grade education
HEOs	Heavy Equipment Operators
HRO	Hiring rate of workers
IntSBT	Initial safety and health budget
IRSBT	Increasing rate of safety and health budget
JOR	Job rotation
JOS	Job satisfaction
LAEDU	Percentage of group A workers with ≤ 5th grade education background
LBEDU	Percentage of group B workers with ≤ 5th grade education background
LBP	Lower Back Pain
LCEDU	Percentage of group C workers with ≤ 5th grade education background
LHAOs	Leftover budget after hiring group A workers
LHBOs	Leftover budget after hiring group B workers
LHCOs	Leftover budget after hiring group C workers
LWEP	Workers who have less than 10-year experience
LWHOs	Workers deduct 12 hour to 8 hours
MWEP	Workers who have more than 10-year experience

NCSs	Number of cushion seats to be replaced
NMAEDU	Percentage of group A workers with 6^{th} –12^{th} grade education background
NMBEDU	Percentage of group B workers with 6^{th} –12^{th} grade education background
NMCEDU	Percentage of group C workers with 6^{th} –12^{th} grade education background
NPEXR	Ratio of workers who never exercise
NSF	Night shift
NSOs	Non-standard workers
NSRR	New equipment ratio to total equipments
PBWGT	Obese population
PBWGTR	Ratio of obese population to total population
PILBP	LBP prevention index
PNWGT	Normal weight population
PNWGTR	Ratio of normal weight population to total population
POWGT	Overweight population
POWGTR	Ratio of overweight population to total population
PSR	Price of a soil roller
PSS	Unit price of a suspension seat
PUWGT	Underweight population
PUWGTR	Ratio of underweight population to total population
RAAOs	Required additional A workers
RABOs	Required additional B workers
RACOs	Required additional C workers
RAOs	Required additional workers
RAPSMK	Ratio of smokers in A group to total population
RBPSMK	Ratio of smokers in B group to total population
RBSS	Required budget for process suspension seats
RCPSMK	Ratio of smokers in C group to total population
RGJOSP	Ratio of HEOs with good job satisfaction
RLWEP	Ratio of workers who have less than 10-year experience

RMHAOs	Required budget to hire group A workers
RMHBOs	Required budget to hire group B workers
RMHCOs	Required budget to hire group C workers
RMJOSP	Ratio of HEOs with moderate job satisfaction
RMWEP	Ratio of workers who have more than 10-year experience
RNOs	Ratio of non standard operators
RPEXR	Ratio of workers who exercise regularly
RRJOSP	Ratio of HEOs with regular job satisfaction to total population
SBT	Safety and health budget
SBY	Seat buying year
SD	System Dynamics
SMK	Smoking
SOT	Soil type
SPEXR	Ratio of workers who sometimes exercise
SRBR	Soil roller buying rate
STA	Number of group A workers entitled to be trained
STB	Number of group B workers entitled to be trained
STC	Number of group C workers entitled to be trained
STP	Seat type
TCIT	Increasing rate of training cost
TCLBP	Final chances of having LBP
TPA	Expected number of group A workers to be trained
TPB	Expected number of group B workers to be trained
TPC	Expected number of group C workers to be trained
TPCY	Training percentage
TPM	Training program
TPop	Total population
TR	Ratio of operators received a training program
TSBT	Budget for training
TY	Train year
VEX	WBV exposure

VST	WBV standard
WBV	Whole Body Vibration
WEP	Working experience
WEPerYear	Number of working hours per week
WGT	Weight of the worker
WHO	Working hour
WHRA	Weekly hiring rate of A group
WHRB	Weekly hiring rate of B group
WHRC	Weekly hiring rate of C group

Chapter 1
Introduction

1.1 General overview

This chapter illustrates background of this research study. Characteristics of the construction industry, nature of heavy equipment operators (HEOs) and their health problems, and whole body vibration (WBV) exposure among HEOs are explained in this chapter. The research problem, aim, and objectives of the study are outlined at the end of the chapter.

1.2 Construction industry

The construction industry is an important industry in both developed and developing countries (Kazaz et al., 2008). The employment share of the construction sector is an indicator of the development of a country (Kazaz et al., 2008). The major employment positions in construction industry include management, skilled worker, semiskilled worker, and unskilled worker (Vitharana et al., 2015). Average educational level of the construction workers is, however, low. Only 3% of them have completed high school (Solís–Carcaño and Franco–Poot, 2014).

The construction industry consists of several phases of activities, such as design, decommission, demolition, clearness, execution, planning, and viability (Hassan, 2012). These make the industry a complex and dynamic industry. Moreover, the industry is considered as a heavy-duty industry with high death rate (Hassan, 2012). Falling from heights, lifting activities, electrical shocks, and vibration from tools are major health hazards, which lead to a large number of deaths in the industry as they cause damages in lower back, lung, kidney, shoulder, knee, hip, wrist, and finger with negligence (Vitharana et al., 2015; Hassan, 2012).

The above mentioned health hazards can be divided into two major types: health hazard with acute health effects and health hazard with chronic health effects

(Vitharana et al., 2015; Ringen et al., 1995). Effects of acute health hazards can be seen within a short period of time, while the effects of chronic health hazards are visible after a prolonged period of time. Ladder, roof work, harmful chemical, plant and machinery, and fire are considered health hazards that cause acute health problems. Noise, whole body vibration (WBV) exposure, and skin irritant are, on the other hand, considered as health hazards that lead to chronic health problems (Vitharana et al., 2015). Among the chronic health hazards, WBV exposure is becoming more crucial, and is considered as one of the major health problems in the construction industry (Smith and Leggat, 2005).

1.3 Whole body vibration (WBV) exposure

Vibration is oscillation motion of solid bodies. Vibration exposure of human body can be categorized as whole body vibration (WBV) and segmental vibration (McPhee et al., 2001). Generally, WBV is considered as the vibration that is conveyed to the complete human body via a contact with vibration emission source (Smith and Leggat, 2005). It is transmitted to the whole body via seat or floor. Segmental vibration, in contrast, is the vibration transmitted to specific segments of the body, such as hand, arm, foot, and leg.

Vibration energy can be transmitted to human body from vehicles, rough roads, vibration tools, and vibration machines. WBV has the vibration ranges from 0.5 to 80 Hz. Different frequencies of WBV level cause different types of health problems. Frequencies below 1 Hz cause motion sickness, while around 5 Hz frequency causes alerting effect, chest and abdomen pain, and degrade of manual actions. Frequencies of 8–10 Hz cause back problems. Frequencies around 20 Hz cause intestine and bladder pain, and degrade vision controls and manual actions (Shivakumara and Sridhar, 2010).

In the construction industry, around 40% of workforce is exposed to WBV (Donati, 2008). In USA, 6.8 million of workers are exposed to WBV, and majority of them, work with heavy equipment (Paschold and Mayton, 2011; Smith and Leggat, 2005; McPhee et al., 2001).

1.3.1 Heavy equipment operators and WBV exposure

Soil roller, excavator, motor grader, skid steer loader, and pile machine operators are exposed to high level of WBV in the construction industry (Vitharana et al., 2014). According to the ISO 2631-1 Guidelines, the exposure level of operators must not exceed the value of 2.00 ms-2. Nevertheless, the WBV exposure level of those heavy equipment operators (HEOs) exceeds the limited value, specifically among the soil roller operators (Vitharana et al., 2014; International Organization for Standardization, 1997).

Exposure to high level of WBV causes both acute and chronic health problems. Increase in heart rate, hyperventilation, headache, loss of balance, motion sickness, muscle fatigue, discomfort, and effect of vision are acute effects, while degenerative disorder, spinal disc disease, lower back pain (LBP), and disorders of the gastrointestinal system are considered as chronic effects (Smith and Leggat, 2005) (see Table 1.1). Among those, LBP is reported as the most common health problem caused by WBV exposure (Bovenzi et al., 2017). Bovenzi et al. (2017), for example, mentioned that a major cause of LBP prevalence is WBV exposure. Azlis-sani et al. (2015) conducted a cross sectional study among the light rail transit drivers in Malaysia, and found that 82% of them suffer from LBP due to WBV exposure. Funakoshi et al. (2004) likewise mentioned that around half of taxi drivers in Japan suffer from LBP due to WBV exposure. Issever et al., (2003) conducted a study among HEOs in Turkey construction industry, and concluded that permanent WBV exposure causes negative physical impacts, especially LBP. Boshuizen et al. (1990) confirmed that highest prevalence health problem among tractor drivers in the agricultural industry in Netherland is LBP due to WBV exposure. They added that LBP occurrence increases with the WBV exposure time.

Table 1.1 Health effects among construction workers exposing to WBV

Health problem	Reference	Purpose of the study
Lower back pain (LBP)	Bovenzi et al., 2017; Azlis-sani et al., 2015; Mayton et al., 2014; Paschold and Mayton, 2011; Hutchinson et al., 2010; Salmoni et al., 2008; Tiemessen et al., 2007; Smith and Leggat, 2005; Funakoshi et al., 2004; Kittusamy and Buchholz, 2004; Issever et al., 2003; McPhee et al., 2001; Magnusson et al., 1998; Boshuizen et al., 1990	• Investigate relationships between LBP and WBV exposure • Assess WBV exposure level and related health problems • Identify and manage risks associated with WBV exposure • Illustrate issues and challenges of WBV exposure
Problems in digestive system	Paschold and Mayton, 2011; Smith and Leggat, 2005; McPhee et al., 2001	• Assess WBV exposure level and related health problems • Identify and manage risks associated with WBV exposure
Reproductive damages in female	Paschold and Mayton, 2011; Kittusamy and Buchholz, 2004; McPhee et al., 2001	• Identify and manage risks associated with WBV exposure
Gastrointestinal tract problem	Salmoni et al., 2008; Kittusamy and Buchholz, 2004	• Identify work related injuries and illnesses

Impairment of vision or balance	Salmoni et al., 2008; McPhee et al., 2001	• Illustrate issues and challenges of WBV exposure
Irritation to the lung, bladder, and abdomen	Paschold and Mayton, 2011	• Assess WBV exposure level and related health problems
Loss of hearing	Salmoni et al., 2008	• Illustrate issues and challenges of WBV exposure
Nausea	Salmoni et al., 2008	• Illustrate issues and challenges of WBV exposure
Spinal degeneration	Salmoni et al., 2008	• Illustrate issues and challenges of WBV exposure
Discomfort	McPhee et al., 2001	• Identify and manage risks associated with WBV exposure
Cardiovascular, respiratory, endocrine and metabolic changes	McPhee et al., 2001	• Identify and manage risks associated with WBV exposure

1.3.2 Chronic LBP problems among HEOs

Chronic LBP is defined as an occurrence of LBP longer than three months (Karunanayake et al., 2013). It is the most commonly reported health problem from all sources of WBV exposures (McPhee et al., 2001). Joubert and London, (2007), for example, stated that 92% of forklift drivers in South Africa reported LBP due to WBV exposure. Okunribido et al. (2006) mentioned half of delivery drivers in Scotland suffer from LBP due to WBV exposure. Bovenzi et al. (2006) investigated LBP due to WBV exposure among the Italian professional drivers and found that 71.4% of them suffer from chronic LBP due to WBV exposure, and 23% of them become disabled.

In the construction industry, the LBP among HEOs is strongly related to WBV exposure (Paschold and Mayton, 2011). It is the major cause of workers' compensation claim, sick leave, and early retirement (Hutchinson et al., 2010; Freburger et al., 2009; McPhee et al., 2001). Countries, such as Belgium, Germany, Netherland, and France categorize LBP as a compensation-qualifying occupational disease (Paschold and Mayton, 2011).

1.4 Problem statement

LBP due to WBV exposure has been a crucial issue in the construction industry over the last three decades. Life time prevalence of LBP due to WBV exposure has been estimated at 59% - 90% of HEOs in the construction industry (De Beeck and Hermans, 2000). It causes loss of working days with consequent rate of welfare payment by government (Magnusson et al., 1998). Total direct cost for LBP in Netherlands, for example, is 367.6 million US$ per year. Moreover, expenditure due to absenteeism is 3.1 billion US$ and that due to disablement is 1.5 billion US$. These represent 1.7% of gross national product in the country (Vlaeyen et al., 2001; De Beeck and Hermans, 2000).

Appropriate application of ergonomic intervention can save a considerable amount of money for the construction industry (Lahiri et al., 2005). Long-term LBP prevention program is, therefore, needed especially for among HEOs. A construction company should also be able to assess its current LBP prevention maturity, through the LBP prevention index, and effectively plan for index enhancement in the long-term.

1.5 Research aim and research objectives

This study aims to develop a dynamic model of LBP prevention index for HEOs in Sri Lankan construction industry utilizing the exploratory factor analysis (EFA), structural equation modelling (SEM), and system dynamics (SD) modelling approaches. To achieve the aim, the following research objectives are defined:

- To extract items affecting LBP due to WBV exposure from literature reviews.
- To develop a questionnaire survey for data collection in Sri Lanka.
- To confirm key factors and items affecting LBP due to WBV exposure with an EFA method.
- To examine the relationships between key factors utilizing an SEM approach.
- To develop a dynamic model of LBP prevention index for HEOs in the construction industries using an SD modelling approach.
- To assess LBP prevention index and LBP prevention maturity level from the developed dynamic model.
- To perform several scenario analyses to assist the construction company to plan for LBP prevention index improvement, and achieve higher maturity levels in the long-term.

1.6 Thesis organization

Eight chapters are included in this thesis. The main content of each chapter is described below.

- Chapter 1 introduces background of the study, nature of the construction industry, WBV exposure among HEOs, and chronic LBP problems among HEOs. The chapter further presents the problem statement, research aim, and objectives.
- Chapter 2 outlines the utilized research methodology and the expected outcomes.
- Chapter 3 reviews literature related to Sri Lankan construction industry, WBV exposure, and LBP due to WBV exposure among HEOs. The introductions of the LBP prevention, EFA, SEM, maturity level, and SD modelling are also presented.
- Chapter 4 details the questionnaire survey development and data collection. Preliminary analyses are also performed to increase confidence in the data collected.
- Chapter 5 presents an EFA method to extract key factors affecting LBP due to WBV exposure.
- Chapter 6 performs an SEM analyses to examine causal relationships among key factors extracted from the EFA method.
- Chapter 7 develops a dynamic model of LBP prevention index for HEOs using an SD approach. Model validation and verification are performed to increase confidence in the developed model. Various scenarios to enhance the LBP prevention index in the long-term are also examined in this chapter.
- Chapter 8 summarizes main findings, contributions to the existing knowledge, limitations, and recommendations for the future research.

Chapter 2
Research Methodology

2.1 General overview

This chapter presents the research frame work, research activities, and expected outcomes. The introductions to EFA, SEM, and SD modelling approaches presented. The LBP prevention maturity level is also reviewed at the end of the chapter.

2.2 Research framework, research activities, and expected outcomes

Research framework, activities, and outcomes are as shown in Figure 2.1. Literature related to WBV exposure, LBP due to WBV exposure, health problems among HEOs, and characteristics of the Sri Lankan construction industry is reviewed to identify research gaps (see Chapters 1 and 3). Shivakumara and Sridhar (2010), for example, studied WBV exposure and health-related problems, while Vitharana et al. (2014), Cann et al. (2003), and Burdorf and Sorock (1997) focused on WBV exposure of HEOs in the construction industry.

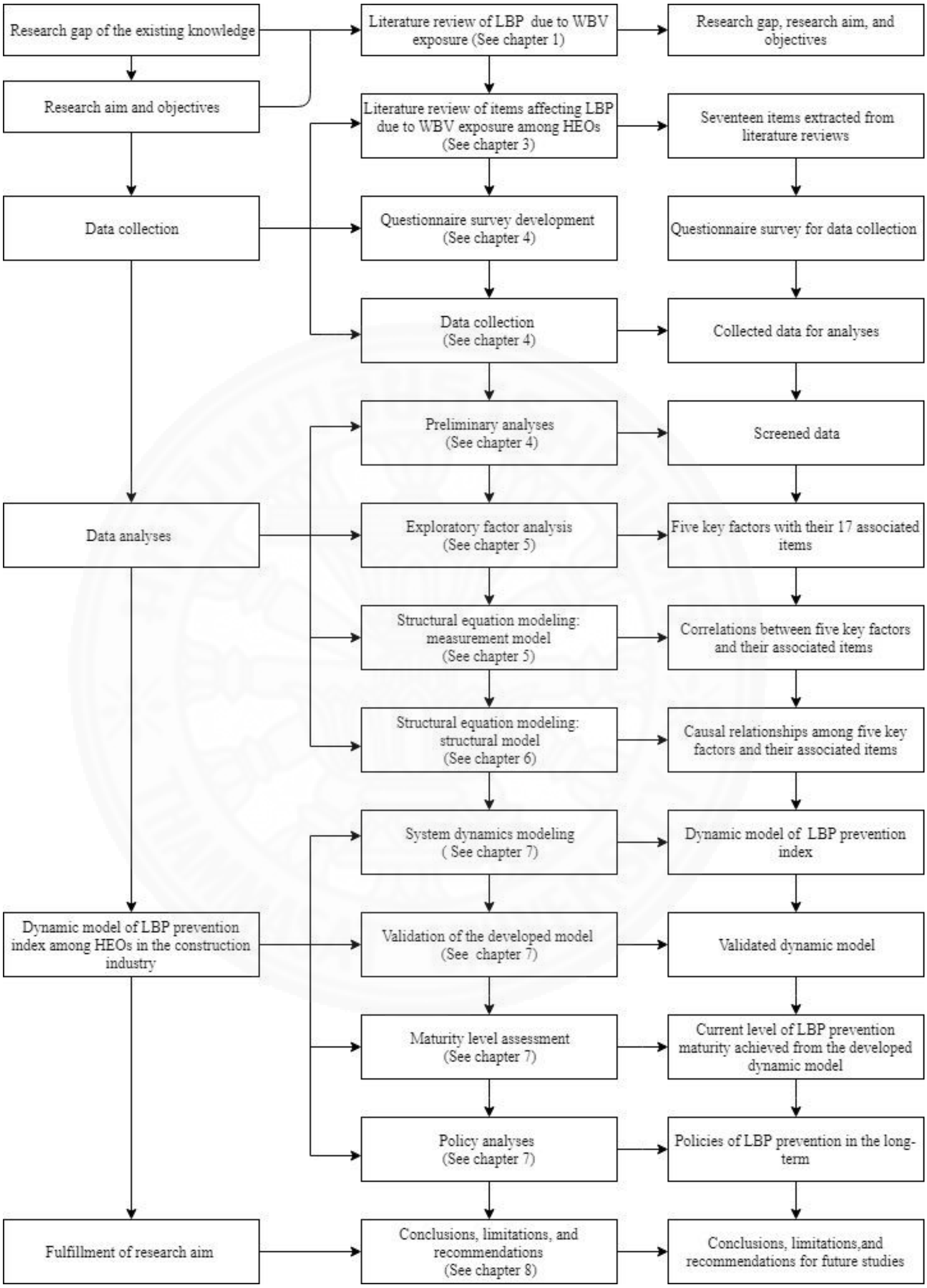

Figure 2.1 Research framework, activities and expected outputs

Research aim and objectives are then set to fulfil the research gaps (see Chapter 1). To achieve the research aim and objectives, the EFA, SEM, and SD modelling analyses are performed. It is expected that the EFA results extract key factors affecting LBP due to WBV exposure in the construction industry. The relationships among those key factors are achieved through the SEM analysis. The LBP prevention index, used for the maturity level assessment, is expected to achieve through the SD modelling.

To perform the above analyses, a questionnaire survey is developed in Chapter 4 for data collection. Interviews are also conducted with managers in the construction industry to gather insight information for a dynamic model development. Collected data are performed with the preliminary analyses, including normality and outlier tests to screen data. The EFA is then conduced with the screened data to group items affecting LBP due to WBV exposure into key factors (see Chapter 5). The relationships among key factors are examined through the SEM analysis in Chapter 6.

The dynamic model of LBP prevention index is then developed based on key factors and their interrelationships achieved from the EFA and SEM results (see Chapter 7). The developed dynamic model is validated using a number of validation tests. Different policies to improve the LBP prevention program are examined with the developed model to recommend suitable policies for the construction company. Major findings of the study, contributions to the existing knowledge, limitations, and recommendations for future studies are finally presented in the last chapter, Chapter 8.

2.3 Introduction to exploratory factor analysis

Exploratory factor analysis (EFA) is a statistical method that explains the relationships among variables in terms of fundamental entity called factors (Gaskin and Happell, 2014; Cudeck, 2000). It is used in various areas, such as construction, chronic health, education, energy, environmental, and mining. Kim et al. (2017), for example, utilized an EFA to identify factors affecting water quality variation of the monitoring network of Nakdong River, Korea. Bovwe et al. (2016) assessed factors affecting energy generation from solid waste in Nigeria. Jamil et al. (2015) utilized an EFA to extract factors influencing performance of learning styles in Malaysia.

Kakurina et al. (2015) performed an EFA analyses to examine the correlations between clinical activities of rheumatoid arthritis and human parvovirus infection.

In the construction industry, the EFA method is utilized in a number of studies. Chinda (2016), for example, examined key factors affecting selection of safety equipment in Thai construction industry. Mustapha et al. (2016) used an EFA method to determine indicators affecting employees' actions towards health and safety compliance in construction sites. Fang et al. (2006) extracted key factors affecting safety climate in Hong Kong construction industry utilizing an EFA method. Sawacha et al. (1999) determined factors affecting safety in construction industry.

Various software programs can be used to conduct an EFA analysis, such as statistical package for the social sciences (SPSS), statistical analysis system (SAS), and bio-medical data package (BMDP) (Lorenzo-Seva and Ferrando, 2006). SPSS Version 20, however, is chosen in this study, as it is a user friendly software package (Landau and Everitt, 2004) (see Figure 2.2). Each column represents a variable while a row represents a participant.

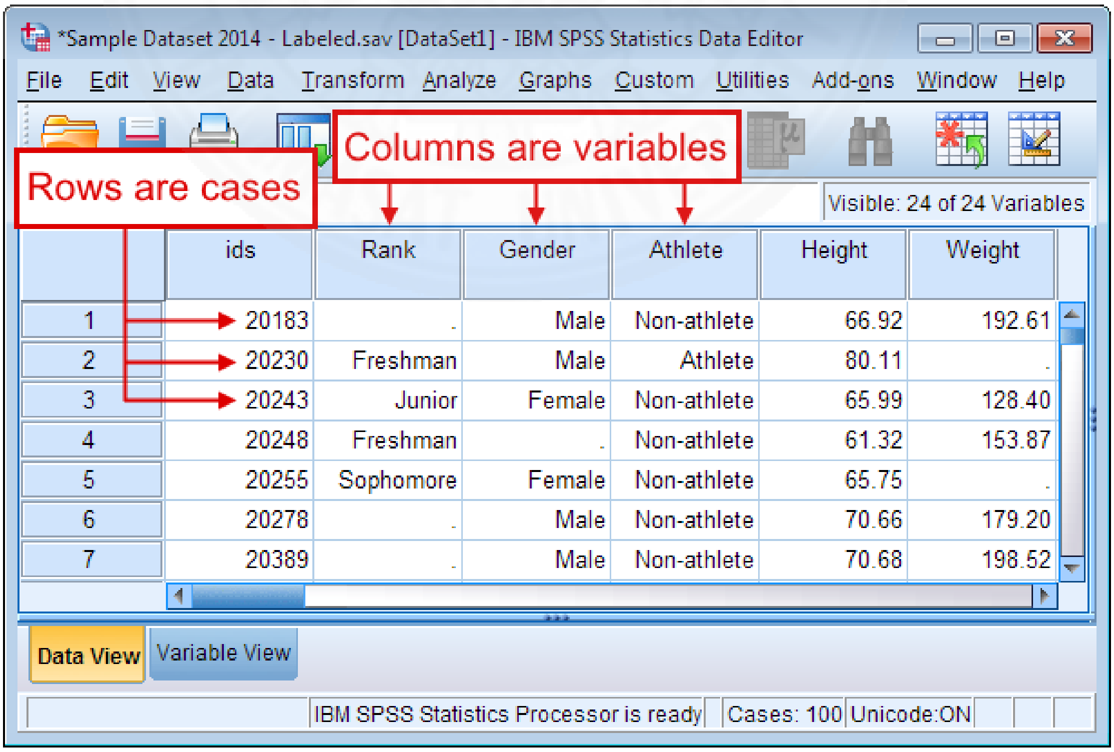

Figure 2.2 Interface of the SPSS software

2.4 Introduction to structural equation modelling

A number of methods can be used to examine interrelationships between factors, such as structural equation modelling (SEM), partial least squares (PLS), Tetrad analysis, and latent class analysis (Rigdon, 2014). The SEM however, is used in this study, as it has the capability to handle complex interrelationships between factors and items. It has been proposed in number of health-related studies (see Table 2.1). For example, Rahman et al. (2017) identified forearm, shoulder, and LBP as factors in musculoskeletal disorders, and examined relationships among those factors with work-related fatigue. Murri et al. (2017) examined relationships between diabetes, depression, and other factors using an SEM approach. Kwon and Shin (2016) developed an SEM model to identify effects of physical exercise on daytime sleepiness.

Table 2.1 SEM applications in different areas

Application	Reference
Identification of psychological paths to suicide among people lives with HIV.	Wang et al., 2018
Examination of factors affecting musculoskeletal disorders among nurses.	Rahman et al., 2017
Modelling of cross–national invariance and predications by gender and age.	Lewis et al., 2017
Examination of relationships between diabetes, depression, and other factors.	Murri et al., 2017
Identification of effects of physical exercise on daytime sleepiness.	Kwon and Shin, 2016
Assessment of risk factors on sexual risk behaviour.	Van Horn et al., 2016

Various software packages can be used to perform an SEM analysis, such as analysis of moment structures (AMOS), statistical analysis system (SAS), programmed random occurrence (Proc), structural equation modelling software (EQS), and Mplus (Narayanan, 2012). Narayanan (2012), however, commented that the AMOS software package, which has an excellent graphical interface and well organized and quickly accessible formal outputs, outperforms the other packages. It is, thus, utilized in this study. The interface of AMOS software is as shown in Figure 2.3.

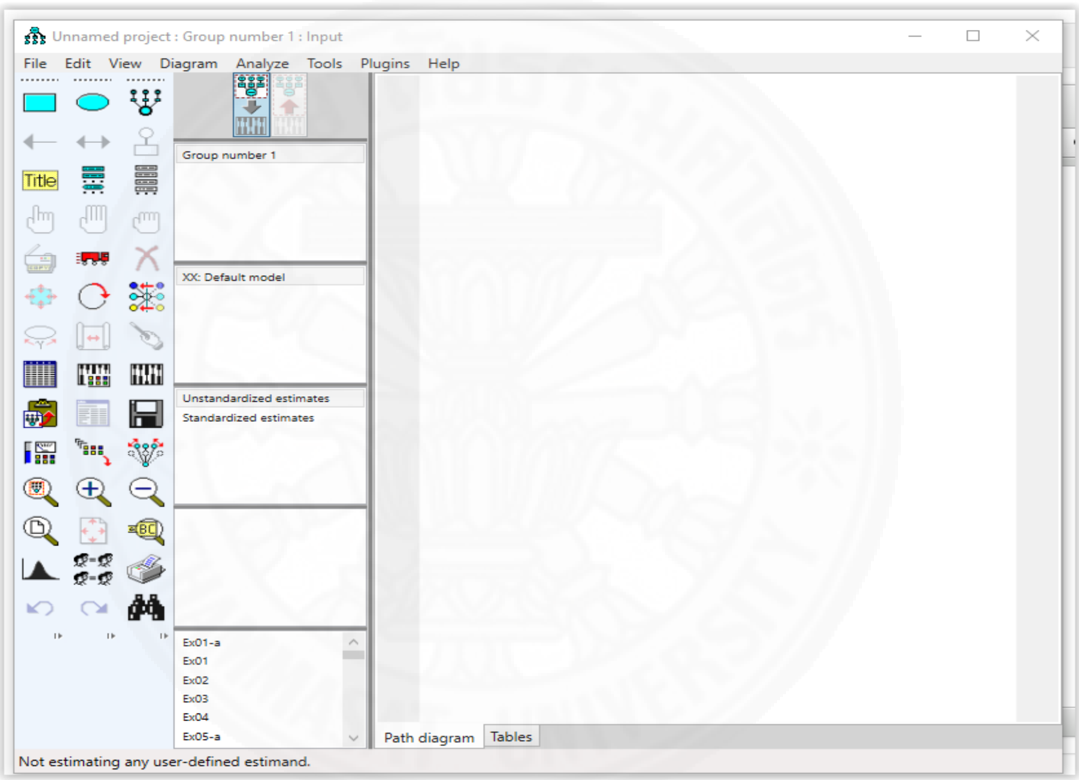

Figure 2.3 AMOS software interface

2.5 Introduction to system dynamics modelling

Several methods, such as regression analysis, artificial neural network, SD modelling, and genetic algorithm can be used to assess the health-related problems. Campbell et al. (2013), for example, determined short and long-term outcomes of primary LBP care service using a Cox regression analysis. Glombiewski et al. (2010) utilized a regression analysis to predict the depression among the back pain patients in

Germany. Hallner and Hasenbring (2004) applied an artificial neural network to examine risk of LBP development in Germany.

In this study, a, SD modelling is used to develop a dynamic model of LBP prevention index. It is a simulation method to examine the structure of complex systems and their behaviours over time (Marshall et al., 2015; Yu et al., 2015). It can be used to guide policy and system design in numerous fields (Groff, 2013). Doan and Chinda (2016) mentioned that an SD modelling can be used to deal with dynamic changes, in which a change can cause other changes through time.

SD method is used in various researches, such as business, construction, education, economy, policy, environment, medicine, urban planning, and health (Yu et al., 2015; Groff, 2013). Jetha et al. (2016), for example, developed a dynamic model to examine relationships among individual, psychosocial, and organizational factors affecting work disability and return to work. Shin et al. (2014) utilized an SD model to examine the effectiveness of safety improvement in Korean construction industry. Feng et al. (2013) developed an SD model to examine demand of future energy and carbon emission in Beijing. Groff (2013) utilized an SD model to design the future education system in US. Mohamed and Chinda (2011) developed a construction safety culture index to be used in Thai construction industry. Ritchie-Dunham and Galvan (1999) utilized an SD model to better understand the impacts of alternative strategies for addressing national epidemics.

This study utilizes the iThink software Version 6.1.30 to develop the dynamic model of LBP prevention index. It contains visualized symbols, such as converter, flow, connector, and stock, as presented in Figure 2.4. Converter stores the information about the state of the system. Flow, on the other hand, changes the state that affects a stock at any point of time. Connector interprets a relationship between two variables. Stock accumulates the influences it receives over time (Bauer and Bodendorf, 2005).

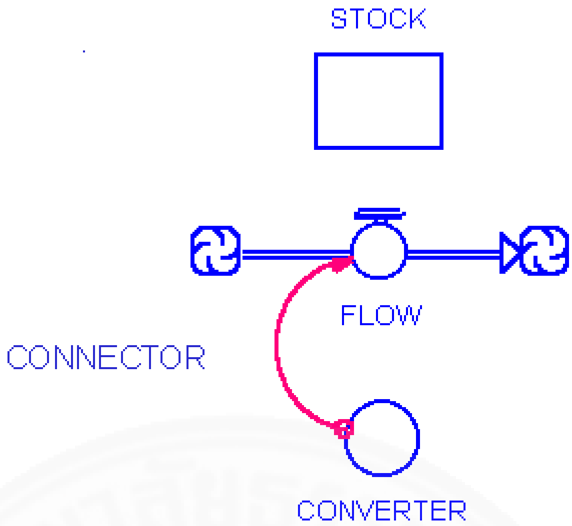

Figure 2.4 iThink software components

2.6 LBP prevention maturity level

A number of studies have been conducted to define ergonomic, safety, and health-related maturity levels (see Table 2.2). Hopkinson et al. (2015), for example, developed a health risk management maturity index for the construction industry with a total of five levels, in which each level contains 10 points. Vidal et al. (2012) divided an ergonomic maturity into five levels, namely informal, organized, structured, managed, and optimized levels. Mohamed and Chinda (2011) developed a construction safety culture maturity index to assess a current level of construction safety culture. They divided 1,000 points into five levels, with equal score range of 200 points in each level.

Table 2.2 Different maturity levels used in ergonomic, safety and health-related areas

Maturity index	Level	Score range	Area	Reference
Health risk management maturity index	Unknown	0–10	Construction industry	Hopkinson et al., 2015
	Reactive	10–20		
	Compliant	20–30		
	Proactive	30–40		
	Enlightened	40–50		
Ergonomic maturity level	Informal	0–1	Ergonomic practitioners	Vidal et al., 2012
	Organized	1–2		
	Structured	2–3		
	Managed	3–4		
	Optimized	4–5		
Construction safety culture maturity index	Level 1	0–200	Construction industry	Mohamed and Chinda, 2011
	Level 2	201–400		
	Level 3	401–600		
	Level 4	601–800		
	Level 5	801–1,000		

In this study, the LBP prevention index, to be developed through the dynamic model of LBP prevention index, is used to assess a level of LBP prevention maturity. A total of 1,000 points of LBP prevention index are divided into five levels with equal score of 200 points in each level (see Figure 2.5). Details of each level are as follows.

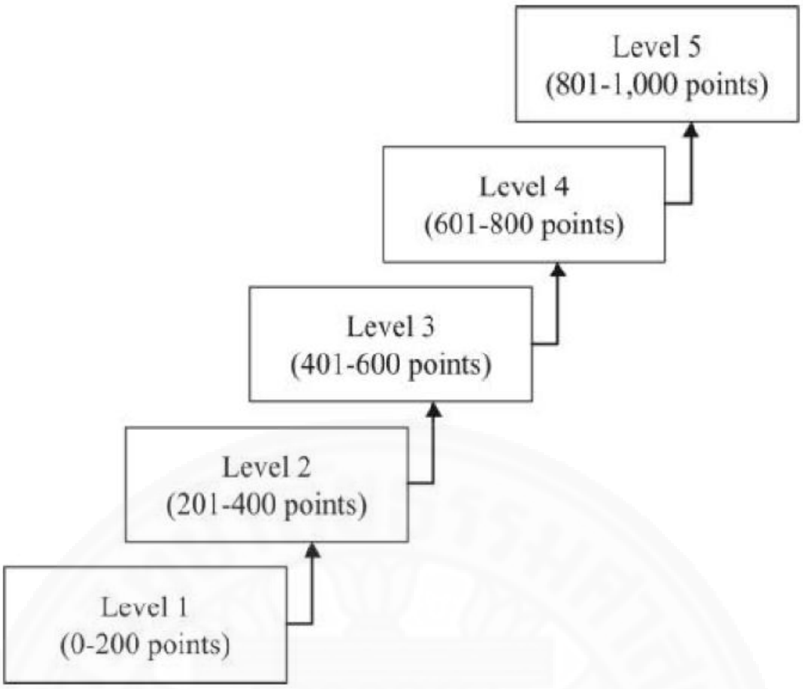

Figure 2.5 LBP prevention maturity levels

- Level 1: This level has a score range of 0–200 points. In this level, the company does not consider LBP due to WBV exposure among HEOs as a key business risk. The company considers chances of having LBP due to WBV exposure as part of the job. There is no proper LBP-related training for HEOs. There is a high potential for illegal safety practices, and superficial incident investigation is occurred in this level (Foster and Hoult, 2013).
- Level 2: This level has a score range of 201–400 points. In this level, the company sees LBP prevalence among HEOs as a business risk, and puts efforts to reduce chance of repeated occurrence. Prevention of LBP due to WBV exposure among HEOs is defined in terms of rules, procedures, and engineering controls. There is, however, minimum or inconsistent training in this level. Disciplinary actions are taken for misconduct of safety activities, and personal protective equipment is accepted to eliminate exposure of hazards (Foster and Hoult, 2013).
- Level 3: This level has a score range of 401–600 points. In this level, the company is convinced that involvement of HEOs in LBP prevention is a must. Majority of HEOs accept personal responsibility to reduce chances of

having LBP due to WBV exposure. Appropriate training and awareness programs are implemented, and workers are strictly enforced to use personal protective equipment (Foster and Hoult, 2013).

- Level 4: This level has a score range of 601–800 points. In this level, LBP prevention among HEOs is important in both moral and economic point of view. The company develops the LBP- and WBV- related guidelines to reduce chances of having LBP (Foster and Hoult, 2013).
- Level 5: This level has a score range of 801–1,000 points. In this level, company has a sustained period without reporting LBP due to WBV exposure incidents. HEOs believe that LBP prevention is a critical aspect of their job. The company invests a considerable effort to reduce LBP among HEOs. Managers and HEOs are engaged to continuing reducing LBP prevalence (Foster and Hoult, 2013).

The five maturity levels are used, together with the LBP prevention index, to assess a current level of LBP prevention maturity of a construction company, and plan for an index improvement in the long-term.

Chapter 3
Literature Review

3.1 General overview

This chapter presents characteristics of Sri Lankan construction industry. Literature related to LBP due to WBV exposure among HEOs in the construction industry is reviewed. Items affecting LBP due to WBV exposure are extracted and used for questionnaire survey development for data collection.

3.2 Sri Lankan construction industry

Sri Lankan construction industry contributes 8% of country's gross domestic products (Barnabas and Sriram, 2011). It is the third largest industry in the country (Amarasekara, 2014). There are three main entities of contractors enrolled with construction activities: 1) registered contractors of the Institute of Construction Training and Development (ICTAD), 2) international contactors, and 3) unregistered informal contractors (Barnabas and Sriram, 2011). The ICTAD is the institute responsible for registration and grading of contractors in Sri Lanka (Amarasekara, 2014). More than 2,000 contractors have been registered under the existing scheme (i.e. C1–C10) (Amarasekara, 2014; Barnabas and Sriram, 2011). This registration and grading system is based on financial limited value. The construction companies with C1 grade have the highest limited value of more than 4.2 million US dollars (Amarasekara, 2014). Currently, 50 companies are registered under the C1 category. Those companies contribute mainly to buildings and road construction projects all around Sri Lanka, and are used as a target group of this research study.

Construction workers in the construction industry are divided into four groups including, 1) professional (consultant and engineer), 2) technical (supervisor and foreman), 3) craft (mason and carpenter), and 4) machine operator (construction machinery operator) (Amarasekara, 2014). It is found that HEOs in Sri Lankan construction industry are exposed to high WBV level (2.19 to 4.69 ms^{-2}). This is higher than the acceptable value of 2.00 ms^{-2} based on the ISO 2631 Guide lines, which is an international standard for mechanical vibration and shock-evaluation of human exposed to WBV (Vitharana et al., 2014).

3.3 Items affecting LBP due to WBV exposure among HEOs in the construction industry

A number of studies mentioned various items affecting LBP due to WBV exposure among HEOs in the construction industry. Chaudhary et al. (2015), for example, stated that age of the machine, seat type, and soil type are items associated with LBP due to WBV exposure among HEOs. Ramond-Roquin et al. (2015) concluded that age and weight of the worker and job satisfaction are leading items causing LBP due to WBV exposure. Hutchinson et al. (2010) commented that training program initiation, suspension seat, and WBV standard enforcement help reduce chances of having LBP due to WBV exposure.

Griffin et al. (2006) stated that high level of WBV exposure and long working hour cause LBP due to WBV exposure. McPhee et al. (2001) explained that age of the machine, seat type, soil type, job rotation, and vibration exposure affect LBP prevalence among HEOs. Based on the literature, 17 items associated with LBP due to WBV exposure among HEOs in the construction industry are summarized in Table 3.1.

Table 3.1 Items affecting LBP due to WBV exposure among HEOs

No.	Item	Reference
1.	Age of the machine (AOM)	Chaudhary et al., 2015; Govindu and Babski-Reeves, 2014; Mayton et al., 2014; Paschold and Mayton, 2011; Subhash and Ario, 2011; Kordestani, 2010; Miller and Gariephy, 2008; Salmoni et al., 2008; Tiemessen et al., 2007; Gillin et al., 2006; Gervais, 2003; McPhee et al., 2001; Magnusson et al., 1998; Krause et al., 1997; Zimmermann et al., 1997
2.	Age of the worker (AOW)	Yang et al., 2016; Chaudhary et al., 2015; Ramond-Roquin et al., 2015; Karunanayake et al., 2013; Ferguson et al., 2012; Murtezani et al., 2011; Hutchinson et al., 2010; Malchaire et al., 2001; De Beeck and Hermans, 2000; Bovenzi and Hulshof, 1998; Burdorf and Sorock, 1997; Krause et al., 1997; Zimmermann et al., 1997
3.	Exercise (EXR)	Lunde et al., 2014; Karunanayake et al., 2013; Murtezani et al., 2011; Miller and Gariephy, 2008; Rainville et al., 2004; Malchaire et al., 2001; Magnusson et al., 1998; Burdorf and Sorock, 1997
4.	Education (EDU)	Udom et al., 2016; Karunanayake et al., 2013; Murtezani et al., 2011; Hutchinson et al., 2010; Miller and Gariephy, 2008; Bovenzi and Hulshof, 1998; De Beeck and Hermans, 2000; Magnusson et al., 1998; Burdorf and Sorock, 1997
5.	Job rotation (JOR)	Paschold and Mayton, 2011; Frazer et al., 2003; Malchaire et al., 2001; Zimmermann et al., 1997
6.	Job satisfaction (JOS)	Ramond–Roquin et al., 2015; Govindu and Babski-Reeves, 2014; Manek and MAcGregor, 2005; Malchaire et al., 2001; De Beeck and Hermans, 2000; Bovenzi and Hulshof, 1998; Burdorf and Sorock, 1997

7.	Night shift (NSF)	Yang et al., 2016; Takahashi et al., 2015; Lunde et al., 2014; Manek and MAcGregor, 2005; Krause et al., 1997; Zimmermann et al., 1997
8.	Safety and health budget (SBT)	Pellicer et al., 2014; Fan and Jin, 2011; Hutchinson et al., 2010;Gervais, 2003; Bovenzi and Hulshof, 1998
9.	Seat type (STP)	Mayton et al., 2014; Paschold and Mayton, 2011; Subhash and Ario, 2011; Miller and Gariephy, 2008; Tiemessen et al., 2007; Makhsous et al., 2005; McPhee et al., 2001; Zimmermann et al., 1997
10.	Smoking (SMK)	Govindu and Babski-Reeves, 2014; Karunanayake et al., 2013; Murtezani et al., 2011; Malchaire et al., 2001; De Beeck and Hermans, 2000; Bovenzi and Hulshof, 1998 ; Magnusson et al., 1998; Burdorf and Sorock, 1997
11.	Soil type (SOT)	Chaudhary et al., 2015; Subhash and Ario, 2011; Tiemessen et al., 2007; Griffin et al., 2006
12.	Training program (TPM)	Langer et al., 2015; Paschold and Mayton, 2011; Miller and Gariephy, 2008; Tiemessen et al., 2007; Lahiri et al., 2005; Gervais, 2003; De Beeck and Hermans, 2000; Zimmermann et al., 1997
13.	WBV exposure (VEX)	Raffler et al., 2016; Langer et al., 2015; Ramond-Roquin et al., 2015; Mayton et al., 2014; Cvetanović, 2013; Murtezani et al., 2011; Paschold and Mayton, 2011; Subhash and Ario, 2011; Donati, 2008; Miller and Gariephy, 2008; Salmoni et al., 2008; Tiemessen et al., 2007; Griffin et al., 2006; Makhsous et al., 2005; Manek and MAcGregor, 2005; Kittusamy and Buchholz, 2004; Malchaire et al., 2001; McPhee et al., 2001;

		De Beeck and Hermans, 2000; Magnusson et al., 1998; Bovenzi and Hulshof, 1998; Burdorf and Sorock, 1997; Zimmermann et al., 1997
14.	WBV standard (VST)	Chaudhary et al., 2015; Paschold and Mayton, 2011; Donati, 2008; Miller and Gariephy, 2008; Salmoni et al., 2008; Magnusson et al., 1998
15.	Weight of the worker (WGT)	Alghadir and Anwer, 2015; Chaudhary et al., 2015; Govindu and Babski-Reeves, 2014; Karunanayake et al., 2013; Ferguson et al., 2012; Murtezani et al., 2011; Malchaire et al.,2001; Burdorf and Sorock, 1997; Krause et al., 1997; Zimmermann et al., 1997
16.	Working experience (WEP)	Chaudhary et al., 2015; Murtezani et al., 2011; Miller and Gariephy, 2008; Bovenzi and Hulshof, 1998; Zimmermann et al., 1997
17.	Working hour (WHO)	Takahashi et al., 2015; Griffin et al., 2006; Miller and Gariephy, 2008; Malchaire et al., 2001; Krause et al., 1997; Zimmermann et al., 1997

3.3.1 Age of the machine (AOM)

Outdated machine increases the probability of vibration emission, which increases chances of having LBP due to WBV exposure. When the age of the machine is increasing, the efficiency of the machine decreases, resulting in an increased WBV exposure (Mansfield, 2004). Chaudhary et al. (2015) commented that machines used in the construction industry last for 15–20 years.

3.3.2 Age of the worker (AOW)

There is a positive relationship between the LBP prevalence and worker's age (De Beeck and Hermans, 2000). Figure 3.1 shows that senior workers experience higher chances of having LBP due to WBV exposure than young workers (John Lant and Partners, 2015).

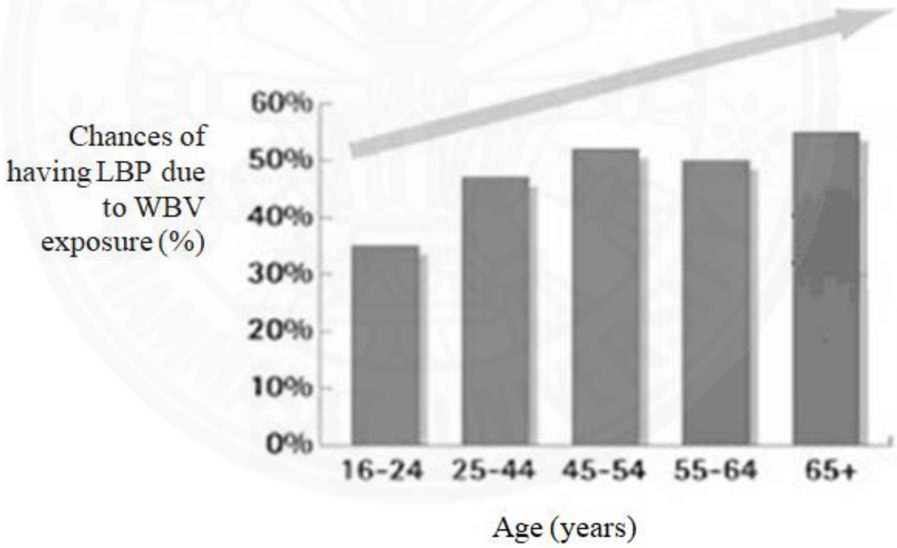

Figure 3.1 Age of the worker and chances of having LBP due to WBV exposure (John Lant and Partners, 2015)

3.3.3 Exercise (EXR)

Karunanayake et al. (2013) showed that exercise has a significant role in reducing LBP occurrence. Rainville et al. (2004) added that exercise is widely used as a LBP treatment. Workers who exercise regularly (i.e. three to four times a week) experience only half chance of having LBP due to WBV exposure (see Table 3.2).

Table 3.2 Chances of having LBP due to WBV exposure with exercise (Rainville et al., 2004)

Exercise pattern	Chance of having LBP due to WBV exposure
No exercise	82%
Randomly exercise	70%
Regular exercise	50%

3.3.4 Education (EDU)

According to De Beeck and Hermans (2000), LBP prevelance is higher with workers who have low education level. In this study, workers are divided into three different education background; workers who never attend school or achieve up to 5th grade, workers who attend 6th to 12th grade, and workers who achieved higher than 12th grade (Udom et al., 2016; Karunanayake et al., 2013) (see Table 3.3).

Table 3.3 Chances of having LBP due to WBV exposure with education background (Udom et al., 2016)

Education background	Chance of having LBP due to WBV exposure
≤ 5th grade	64.60%
6th –12th grade	45.80%
>12th grade	41.50%

3.3.5 Job rotation (JOR)

Job rotation should be introduced in work, so that exposure time of individuals can be reduced (Paschold and Mayton, 2011). Frazer et al. (2003) mentioned that

LBP prevalence could be reduced by half when the second job is introduced to the workers.

3.3.6 Job satisfaction (JOS)

De Beeck and Hermans (2000) showed that low job satisfaction has a positive relationship with the LBP occurrence. When workers are highly satisfied, with their job, chances of having LBP reduce to 19.48% (Hoogendoorn et al., 2002) (see Table 3.4).

Table 3.4 Chances of having LBP due to WBV exposure with job satisfaction (Hoogendoorn et al., 2002)

Job satisfaction level	Chance of having LBP due to WBV exposure
Low	34.78%
Medium	25.30%
High	19.48%

3.3.7 Night shift (NSF)

Working night shift causes a number of LBP-related problems. Workers who work night shift experience 42% chance of having LBP, while those who do not work night shift have only 18% chance of having LBP (Takahashi et al., 2015).

3.3.8 Safety and health budget (SBT)

To reduce LBP prevalence, safety and health budget must be adequately provided so that a number of LBP prevention activities can be implemented. These include hiring more workers to reduce night shifts and working hours, purchasing new equipment, and training workers with LBP-related programs. According to Pellicer et al. (2014), safety and health budget of a construction company should be at least 5% of the total budget.

3.3.9 Seat type (STP)

Makhsous et al. (2005) concluded that proper seat design helps relieve reduce musculoskeletal pain. Subash and Ario (2011) and Tiemessen et al. (2007) agreed that by replacing cushion seat with suspension seat, WBV exposure can be reduced.

3.3.10 Smoking (SMK)

Smokers have higher chances of having LBP. Nicotine decreases the blood flow, and diminishes mineral content of bones, thus causing bone fractures (De Beeck and Hermans, 2000). According to Alghadir and Anwer (2015), smokers experience 15% higher chance of having LBP than non-smokers.

3.3.11 Soil type (SOT)

WBV exposure is dependent on soil type on site (Subhash and Ario, 2011). Construction work in Sri Lanka, deals with different soil types, including heavy clay, silty clay, mixture of gravel, and sand and clay. The compaction level of each soil type is different, resulting in different vibration exposure levels exposed to HEOs working with heavy equipment (Government of Ministry of Railways, India, 2005).

3.3.12 Training program (TPM)

LBP-related training programs should be provided to HEOs to avoid LBP prevalence (Paschold and Mayton, 2011). Lahiri et al. (2005) mentioned that the vibration-related training helps reduce chances of having LBP by 15%.

3.3.13 WBV exposure (VEX)

McPhee et al. (2001) showed relationships between health risk of construction workers and WBV exposure level with time, as shown in Figure 3.2. It is found that workers who expose to WBV for long duration have higher health risk at the same exposure level.

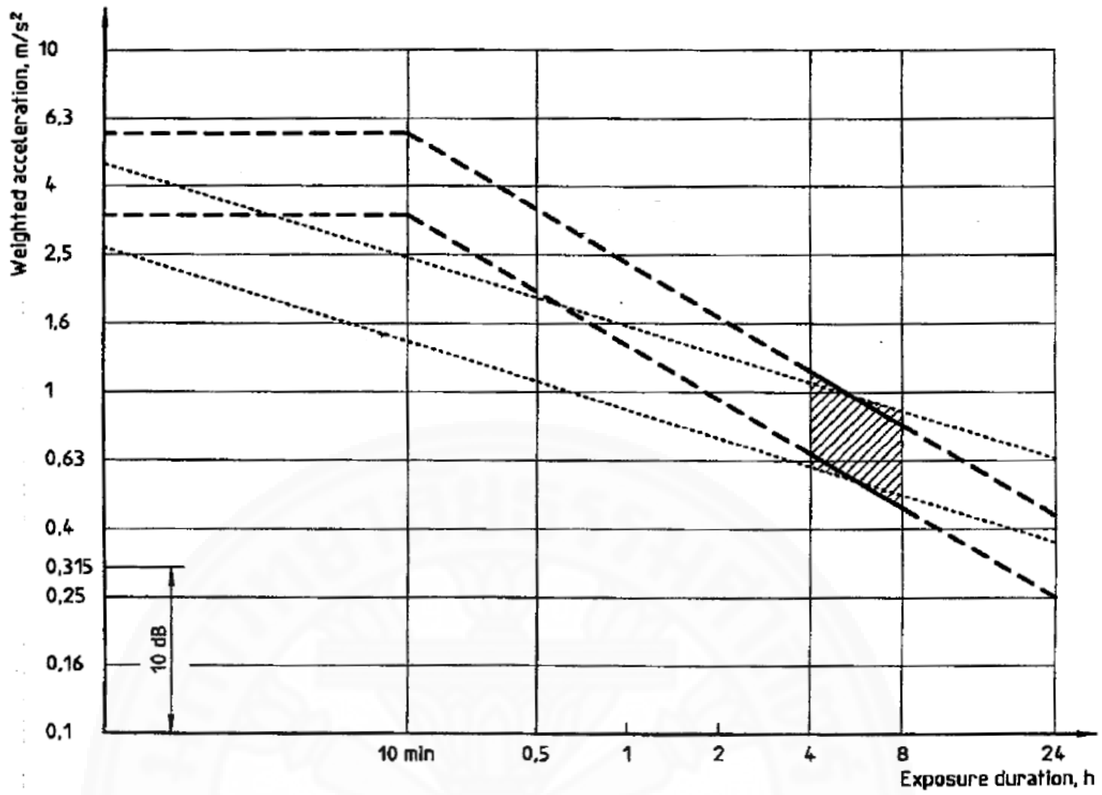

Figure 3.2 Vibration level and health risk of construction workers (McPhee et al., 2001)

3.3.14 WBV standard (VST)

There are a number of international standards explaining about WBV exposure in the construction; air craft, agriculture, fisheries, forestry, health care, and mining industries (see Table 3.5).

Table 3.5 Different international standards related to WBV exposure

Standard	Industry	Reference	Established country (Year)
ISO 2631-1 (1997)	Construction, aircraft, accident prevention, agriculture, fisheries, forestry, health care, mining	Chaudhary et al., 2015; Cvetanović, 2013; Paschold and Mayton, 2011; Subhash and Ario, 2011; Miller and Gariephy, 2008; Salmoni et al., 2008; Gillin et al., 2006; Griffin et al., 2006; Lundström et al., 1998	Switzerland, 1987
ISO 2631-5	Construction, aircraft, accident prevention, agriculture, fisheries, forestry, health care, mining	Zhao and Schindler, 2014; Cvetanović, 2013	Switzerland, 2004
ISO 2631	Construction, aircraft, accident prevention, agriculture, fisheries, forestry, health care, mining	Cvetanović, 2013	Switzerland, 1974
ISO 10326-1:1992	Laboratory methods	Cvetanović, 2013	Switzerland , 1992
ISO 10326-2:2001	Laboratory methods and railway vehicles	Cvetanović, 2013	Switzerland, 2001
ISO 7096:2000	Laboratory evaluation of operator seat vibration	Cvetanović, 2013	Switzerland, 2000

ISO 5007:2003	Laboratory measurement for transmitted vibration	Cvetanović, 2013	Switzerland, 2003
Directive 2002/44/EC	Construction, aircraft, accident prevention, agriculture, fisheries, forestry, health care, mining	Cvetanović, 2013; Paschold and Mayton, 2011; Subhash and Ario, 2011; Salmoni et al., 2008; Tiemessen et al., 2007	European Union, 2002
Machinery Directive (Directive 98/37/EEC)	Manufactures, importers, and suppliers	Cvetanović, 2013	European commission, 1998
BS 6841	Construction, aircraft, accident prevention, agriculture, fisheries, forestry, health care, mining	Paschold and Mayton, 2011; Salmoni et al., 2008	United Kingdom, 1987
BS EN 13490:2001	Industrial trucks	Cvetanović, 2013	United Kingdom, 2004
BS EN13490:2003	Construction, aircraft, accident prevention, agriculture, fisheries, forestry, health care, mining	Cvetanović, 2013	United Kingdom, 2004
AS 2670-2001	Construction, aircraft, accident prevention, agriculture, fisheries, forestry, health care, mining	Cvetanović, 2013	Australia, 2001

Based on Table 3.5, the most identified standard is the ISO Standards 2631-1 (1997). This standard was published in 1987. It uses three orthogonal directions (i.e. X = fore and aft direction, Y = lateral, and Z = vertical) to explain and evaluate the WBV exposure (Griffin et al., 2006; Lundström et al., 1998). The improved version, the ISO 2631-5 developed in 2004, provided a guideline to predict health effects from WBV containing multiple shocks (Zhao and Schindler, 2014). This international standard is mainly considered in this study.

3.3.15 Weight of the worker (WGT)

Weight of the worker affects chance of getting LBP. Table 3.6 emphasizes the 100% chances of having LBP of underweight workers.

Table 3.6 Chances of having LBP with weight (Alghadir and Anwer, 2015)

Weight	Chance of having LBP due to WBV exposure
Underweight	100%
Normal	40.63%
Overweight	50.00%
Obese	58.62%

3.3.16 Working experience (WEP)

Years of working experience affect chances of having LBP. Janwantanakul et al. (2011) showed that chance of having LBP among workers who have less than 10–year experience is 55.6%. Workers with more than 10–year experience, on the other hand, experience around 10% less chance of having LBP.

3.3.17 Working hour (WHO)

In South Asian countries, including Sri Lanka, common working hour is 12 hours per day (Vaid, 1999). Trejo (1993) however, argued that each worker should only work for eight hours per day. Alghadir and Anwer (2015) added that working more than eight hours per day causes more than half the chance of having LBP, while, working less than eight hours per day incur less than half the chance of having LBP.

3.4 Factors affecting LBP among HEO in the construction industry

Many research studies attempt to group the 17 items affecting LBP due to WBV exposure into key factors (see Table 3.7). Chaudhary et al. (2015), for example, conducted field measurement in the mine industry in India to identify three key factors affecting LBP due to WBV exposure, including 1) machine-related, 2) individual, and 3) rock-related factors. Age of the machine, seat type, and WBV exposure items are categorized under the machine-related factor, while age and weight of the worker are in the individual factor. Ramond-Roquin et al. (2015) utilized a multistep logistic regression model to conclude four risk factors affecting LBP among French male employees, including biomechanical, organizational, psychosocial, and individual factors with a total of 21 associated items. Govindu and Babski-Reeves (2014) identified three key factors affecting LBP due to WBV exposure including job-related, personal, and psychosocial. Age, smoking, and weight are categorized under personal factor, while VEX item is in job-related factor, and JOS item as psychosocial factor (Govindu and Babski-Reeves, 2014).

Manek and MAcGregor (2005) conducted an in-depth review of literature to identify risk factors and their associated items affecting LBP prevalence. They concluded that smoking, weight of the worker, and education background items are grouped into the individual risk factor, while the WBV exposure and night shift items are grouped in the occupational risk factor, and the job satisfaction item in the psychosocial risk factor. De Beeck and Hermans (2000) developed a conceptual frame work of musculoskeletal disorders due to WBV exposure with five key factors, namely 1) personal, 2) job-related, 3) organizational, 4) equipment, and 5) social context factors. They categorized vibration exposure, seat type, and age of the machine as the equipment factor, job rotation and training program as the organizational factor, and education and smoking as the social context factor.

Table 3.7 Factors and associated items affecting LBP due to WBV exposure based on literature

Reference	Equipment / Machine related	Job-related/ Occupational	Organizational	Personal/ Individual	Social-context	Psychological	Biomechanical	Rock-related
Yang et al., 2016	-	-	JOR NSF VST WHO	-	-	JOS	-	-
Chaudhary et al., 2015	AOM STP VEX	-	-	AOW WGT	-	-	-	SOT
Ramond-Roquin et al., 2015	-	-	WOH	AOW WGT	-	JOS	VEX	-
Govindu and Babski-Reeves, 2014	-	VEX	-	AOW SMK WGT	-	JOS	-	-

Yilmaz and Dedeli, 2014	-	JOS NSF VEX	-	AOW SMK WGT	-	-	-	-
Murtezani et al., 2011	-	VEX	-	JOS SMK WGT	-	-	-	-
Wong et al., 2010	-	EDU JOS TPM VEX WEP	-	AOW EXR SMK	-	-	-	-
Miller and Gariephy, 2008	AOM STP	VEX WOH	-	AOM AOW	-	-	-	-
Manek and MAcGrego, 2005	-	NSF VEX	-	AOW EDU SMK WGT	-	JOS	-	-

Muzammil et al., 2004	SOT VEX	JOS	-	-	-	-	-	-
Bovenzi et al., 2002	-	VEX	WEP	AOW SMK	-	-	-	-
Fransen et al., 2002	-	WHO VEX	-	AOW EDU SMK WGT	-	JOS	-	-
Malchaire et al., 2001	-	JOR VEX WEP WHO	-	AOW EDU SMK WGT	EDU	JOS	-	-
De Beeck and Hermans, 2000	AOM STP VEX	JOS	JOR SBT TPM	AOW WGT	EDU SMK	-	-	-
Magnusson et al., 1998	-	AOM STP VEX WEP	-	-	EDU EXR JOS SMK	-	-	-

		WHO						
Bernard and Putz-Anderson, 1997	-	EXR JOS VEX	-	AOW WGT WHO	EDU	-	-	-
Burdorf and Sorock, 1997	VEX	-	-	ADU AOW EXR SMK WGT	-	JOS	-	-
Krause et al., 1997	AOM	JOS	WHO NSF	AOW WGT	-	-	-	-
Zimmermann et al., 1997	-	TPM VEX WHO	-	-	-	-	-	-

Based on the Table 3.7, this study hypothesizes five key factors affecting LBP due to WBV exposure with a total of 17 associated items as shown in Table 3.8. The five key factors and their associated items are later confirmed with an EFA analysis (see Chapters 4 and 5) to represent key factors affecting LBP due to WBV exposure in Sri Lankan construction industry.

Table 3.8 Hypothesized factors and items with their associated factors affecting LBP due to WBV exposure

Factor	Item	Reference
Equipment	Age of the machine	Chaudhary et al., 2015; De Beeck and Hermans, 2000
	Seat type	Chaudhary et al., 2015; De Beeck and Hermans, 2000
	Soil type	Muzammil et al., 2004
	Vibration exposure	Chaudhary et al., 2015; De Beeck and Hermans, 2000
Job-related	Exercise	Bernard and Putz-Anderson, 1997
	Job rotation	Malchaire et al., 2001
	Night shift	Yilmaz and Dedeli, 2014 Manek and MAcGregor, 2005
Organizational	Safety and health budget	De Beeck and Hermans, 2000
	Training program	De Beeck and Hermans, 2000
	Vibration standard	Yang et al., 2016
	Working experience	Bovenzi et al., 2002
Personal	Age of the worker	Chaudhary et al., 2015; Ramond-Roquin et al., 2015; Govindu and Babski-Reeves , 2014; Manek and MAcGregor, 2005; De Beeck and Hermans, 2000

	Weight	Ramond-Roquin et al., 2015, Chaudhary et al., 2015; Manek and MAcGregor, 2005; De Beeck and Hermans, 2000
	Working hour	Bernard and Putz-Anderson, 1997
Social context	Education	De Beeck and Hermans, 2000
	Job satisfaction	Magnusson et al., 1998
	Smoking	De Beeck and Hermans, 2000; Magnusson et al., 1998

Chapter 4

Data Collection and Preliminary Analysis

4.1 General overview

This chapter presents data collection based on the questionnaire survey. Descriptive and preliminary analyses, including the normality, skewness and kurtosis, and outlier tests are performed in this chapter.

4.2 Data collection method

Different data collection methods are used by various studies, such as experiment, survey, structured questionnaire, and qualitative research (Hox and Boeije, 2005). Generally, data are separated as primary and secondary data. Primary data is data collected for specific research goal. Secondary data are, on the other hand, collected by different studies, and can be reused for other research questions (Hox and Boeije, 2005).

In this study, secondary data are collected through a number of construction-, ergonomics-, and health-related studies. The questionnaire survey method is, on the other hand used to collect primary data, as it is a common tool for data collection (Mathers, 2007). Apart from questionnaire survey, interviews and observations on sites are conducted to collect necessary data for the dynamic model development. A total of 45 managers and engineers are interviewed with specific questions, such as training history and safety and budget available for safety- and health-related activities. Observations on site are conducted to collect such data as soil type, working condition, and site condition. These data are later used to develop equations for a dynamic model of LBP prevention index.

4.3 Questionnaire survey and data collection

The target group of this study is the construction industry in Sri Lanka. Target respondents are those in managerial positions and HOEs to gain perception on both strategies and operation level. Questionnaire survey is developed for each group of respondents. For management level, part 1 consists of 10 questions about personal information, such as age, weight and working experience. Part 2 consists of statements representing items affecting LBP due to WBV exposure. Respondents are requested to rate their opinions on the items affecting LBP due to WBV exposure using a 5-point Likert scale (1 = strongly disagree, 3 = neither agree nor disagree, 5 = strongly agree). For HEOs, part 1 requires demographic information, such as age, education background, and LBP history. Similar to management level part 2 asks opinion on each statement representing item affecting LBP due to WBV exposure using a 5-point Likert scale. Sample statements are as follows:

- Age of the worker has an effect on LBP prevalence.
  - In this statement, respondents are asked to consider if different ages have significant effect on LBP prevalence.
- Age of the machine has an effect on LBP prevalence.
- Education background of the worker has an effect on LBP prevalence.
- Exercise has an effect on LBP prevalence.
- Training program has an effect on LBP prevalence.

Full details on the questionnaire surveys are provided in Appendices B, C, and D.

4.4 Sample characteristics of the respondents

One hundred and forty–nine questionnaire surveys were distributed to both management and operation positions, with a response rate of 100% (see raw data in Appendix E). All of the surveys are returned, as surveys are given directly to the respondents, and returned immediately after completion. Ratio between management level and HEOs is 3:7 (see Figure 4.1).

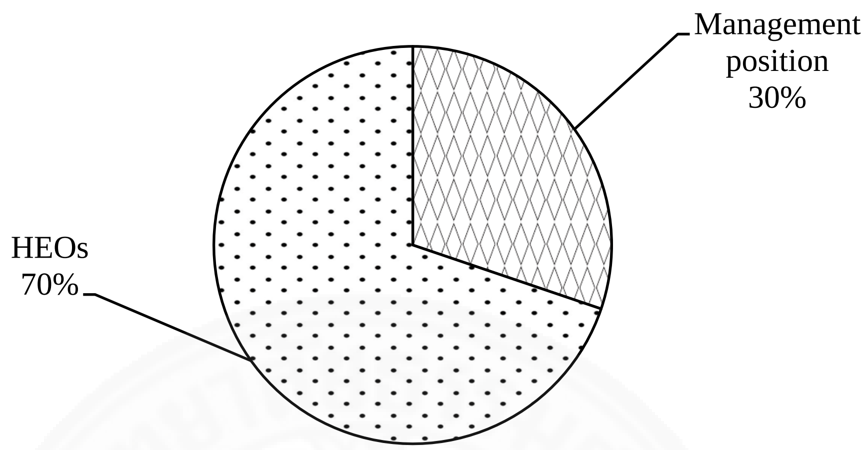

Figure 4.1 Respondents in management and operational levels

4.4.1 Age distribution

Almost all of the respondents, both in management and operation positions, age between 25–45 years (see Figure 4.2 and Figure 4.3).

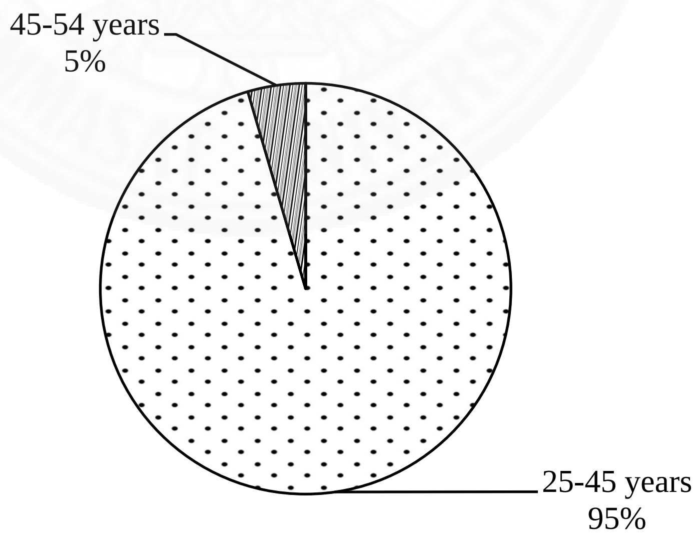

Figure 4.2 Age distribution among the managerial position

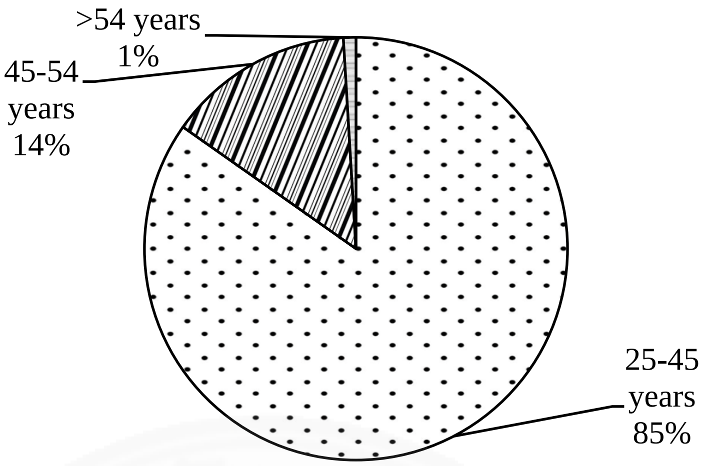

Figure 4.3 Age distribution among HEOs

4.4.2 Education background

Majority of the respondents in management position hold bachelor degrees, while almost all of HEOs hold moderate education (i.e. education background between 6th –12th grade) (see Figure 4.4 and Figure 4.5).

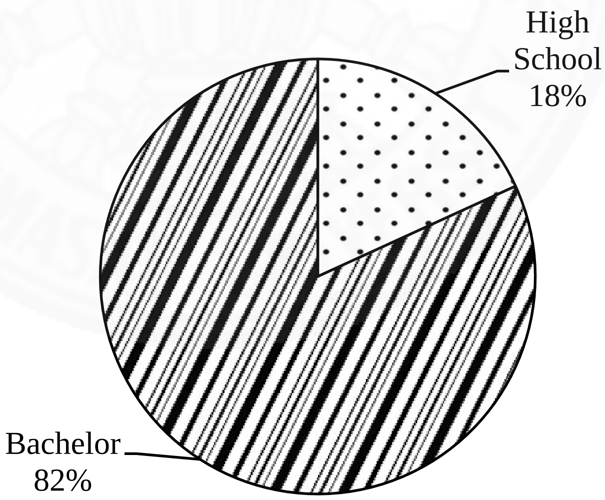

Figure 4.4 Education background of managerial position

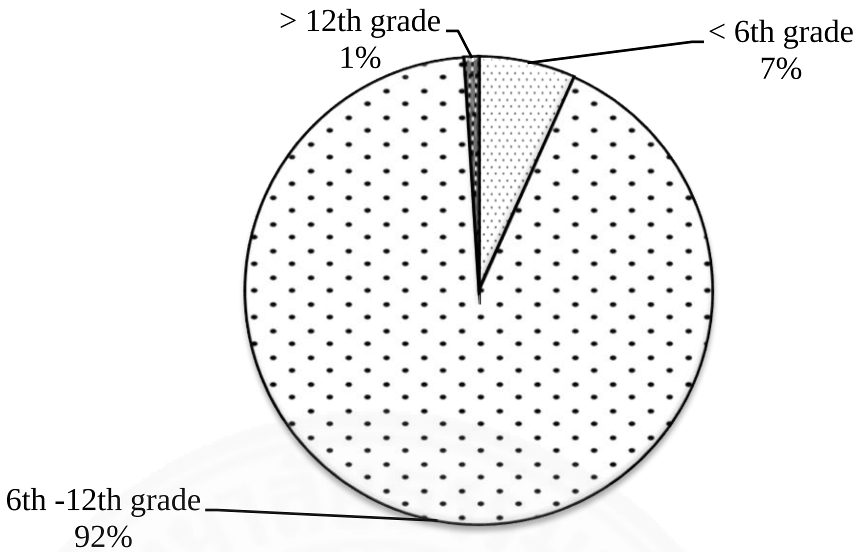

Figure 4.5 Education background of HEOs

4.4.3 Common working hour

Seventy five percent of respondents in management position work more than eight hours per day, while around half of HEOs work longer than eight hours per day (see Figure 4.6 and Figure 4.7).

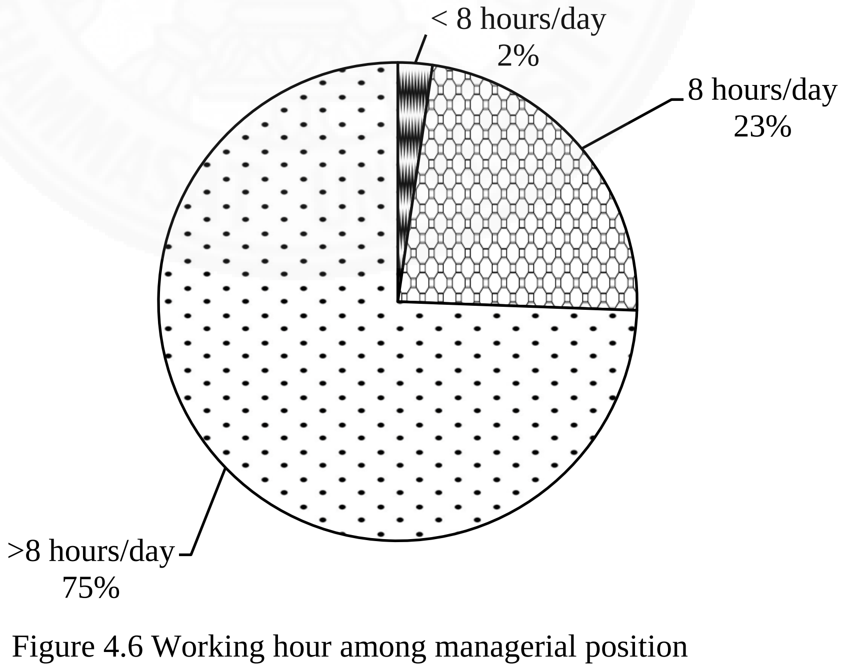

Figure 4.6 Working hour among managerial position

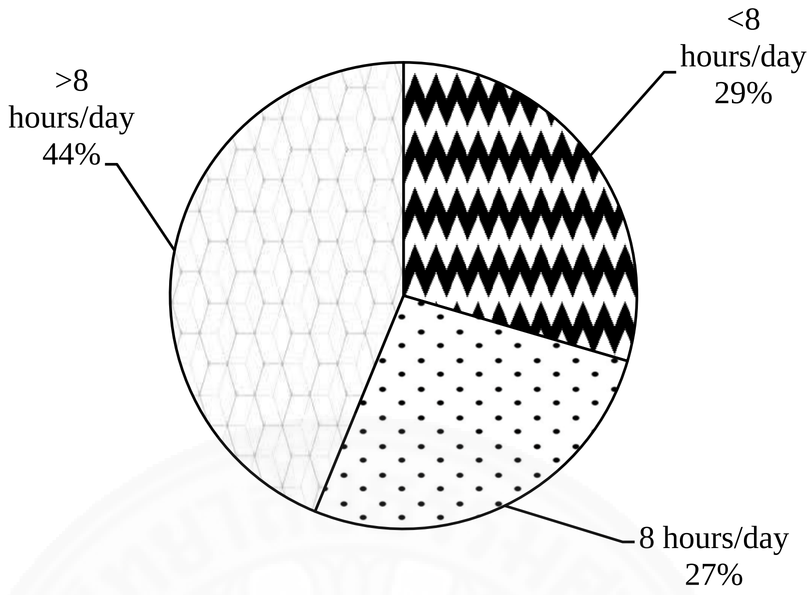

Figure 4.7 Working hour among HEOs

4.4.4 Safety training record

Half of the respondents in management position receive safety- and health-related training (see Figure 4.8). On the other hand, 37% of HEOs receive specific training, such as site safety and personal protective equipment training (see Figure 4.9).

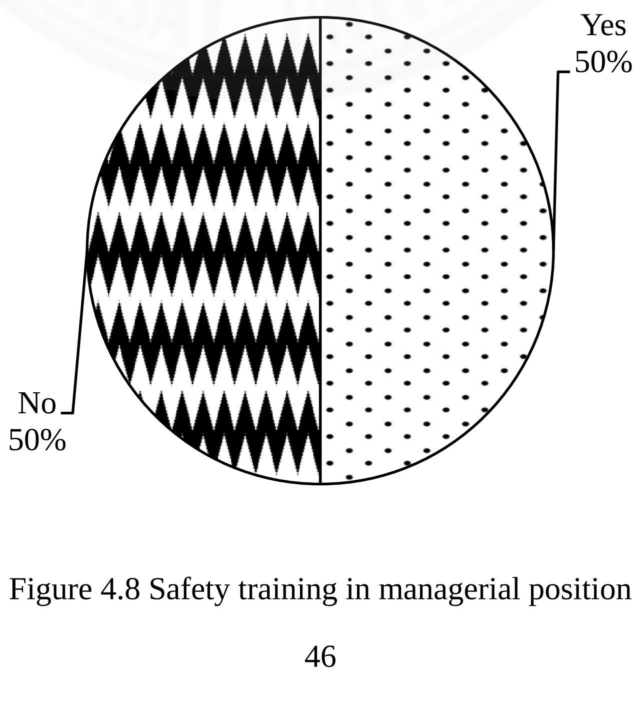

Figure 4.8 Safety training in managerial position

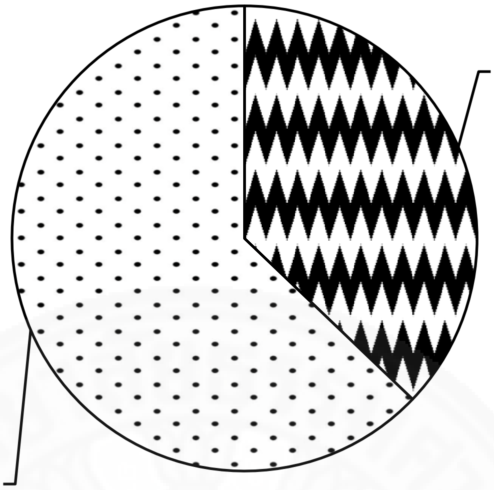

Figure 4.9 Safety training among HEOs

4.5 Data screening

To increase confidence in data to be used with the EFA, a number of data screening processes are performed. According to Hair and Lukas (2014), various methods can be performed to screen data; however common methods used in health-related studies are normality and outlier tests (Rose et al., 2017; Shaw et al., 2016; Kim, 2013).

4.5.1 Test of normality

According to Das and Imon, (2016), data used for statistical analysis must have a normal distribution. In this study, skewness and kurtosis are two measures used to test normality of the data (Park, 2015). Skewness determines the relative position of the median and mean (Von Hippel, 2005). If the data skew is positive, then the median and mean lay right aside of the data. Kurtosis, on the other hand, is used to measure the symmetric distribution (Groeneveld and Meeden, 1984).

Various studies consider different acceptable values for skewness and kurtosis. Common ranges for skewness and kurtosis are, however, are, ±2.00 and

±7.00 respectively (Kim, 2013; Abdulwahab et al., 2011; Ryu, 2011). These values are considered as the acceptable ranges of skewness and kurtosis in this research study. A total of 149 data sets from both management and operational levels, are tested with normality using an SPSS version 20. The analysis results show that all data sets have skewness and kurtosis values in acceptable ranges, confirming normal distribution of the data (see Table 4.1).

Table 4.1 Skewness and kurtosis values of the 17 items affecting LBP due to WBV exposure

Item	Skewness (Statistic values)	Kurtosis (Statistic values)
AOM	-1.00	0.52
AOW	-0.11	-1.36
EXR	-0.85	-0.41
EDU	0.14	-1.20
JOR	-0.84	-0.38
JOS	-0.40	-1.25
NSF	0.15	-1.43
SBT	-1.16	0.83
STP	-1.18	2.07
SMK	0.55	-0.83
SOT	-1.07	0.65
TPM	-1.29	2.86
WGT	0.49	-1.24
VEX	-0.97	0.24
VST	-1.46	3.96
WEP	-1.13	1.56
WHO	-1.04	0.54

Note: See full names of abbreviations in the list of abbreviations

4.5.2 Outlier test

An outlier is a data that is too large or small compared with other data sets (Seo, 2006). It can negatively affect data analyses. Detection of outlier is thus an important part of data analysis. According to Dan and Ijeoma (2013), the box plot, 5% trimmed mean, and *Z* score tests are commonly used to detect outliers. Box plot (see Figure 4.10) graphically represents the dispersion of the data within first quartile, second quartile, third quartile, and largest observation (Dan and Ijeoma, 2013). The distance between the various parts of the box indicates the degree of dispersion, and helps identify outliers.

The difference between mean and 5% trimmed mean of greater than 0.2 causes problems in the analysis (Pallant, 2005). The results in Table 4.2 show that all 17 items have the difference between mean and 5% trimmed mean of less than 0.2, confirming no other outlier of 145 data sets. The Z-score test is also performed with the 145 data sets. The value exceeds ±3.29 is considered as a potential outlier (Tabachnick and Fidell, 2007). The highest Z-score in this study is 3.17 proving the absence of outliers of the 145 data sets (see Appendix F).

The 145 screened data sets are used to perform with the EFA method to group the 17 items affecting LBP due to WBV exposure into key factors. Details are in the next chapter.

Table 4.2 Mean, 5% trimmed mean, and difference between mean values of 17 items

Item	Mean	5%Trimmed mean	∆ mean
AOM	3.72	3.76	0.04
AOW	3.22	3.21	0.01
EXR	3.41	3.45	0.04
EDU	3.05	3.02	0.03
JOR	3.58	3.59	0.01
JOS	3.30	3.29	0.01

NSF	3.11	3.09	0.02
SBT	3.62	3.66	0.01
STP	4.07	4.14	0.07
SMK	2.74	2.71	0.03
SOT	3.77	3.79	0.02
TPM	3.93	3.97	0.04
WGT	2.80	2.76	0.04
VEX	3.77	3.79	0.02
VST	3.91	3.96	0.05
WEP	3.83	3.86	0.03
WHO	3.86	3.91	0.05

Note: See full names of abbreviations in the list of abbreviations

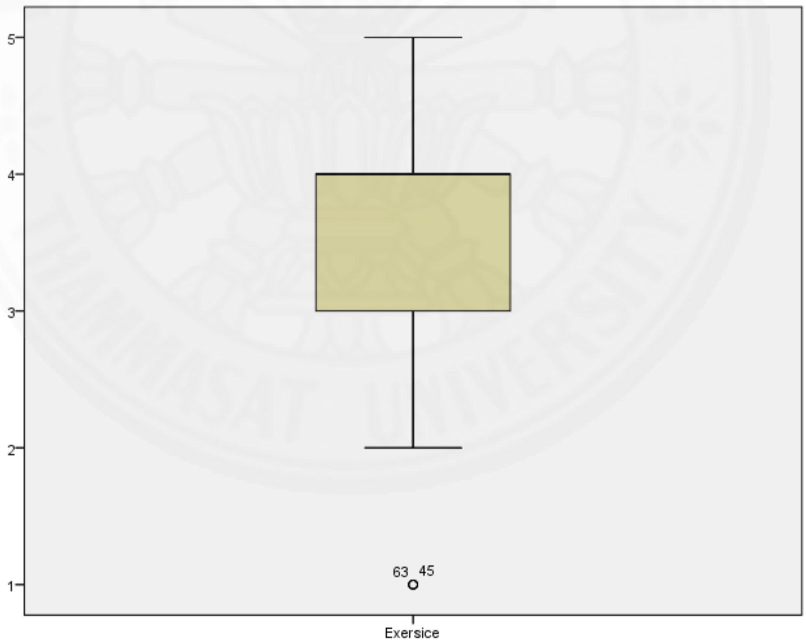

Figure 4.10 An example of box plot

Table 4.3 and Table 4.4 show data sets and items with higher frequencies of potential outliers. It appears those data sets 61, 63, 67, and 81 contains items with high frequencies of potential outliers, such as the SOT, TPM, and VEX items. These four data sets are then removed from the data file resulting in the remaining 145 data sets for further screening processes.

Table 4.3 Frequency of potential outlier of data sets

Data set	Item with potential outlier	Total frequency of potential outlier
63	EXR, SOT, TPM, VEX	4
67	AOM , SOT, TPM, VST	4
61	TPM, VST , WHO	3
81	SOT, VEX, WHO	3
28	STP , WHO	2
48	SBT , WEP	2
60	SBT , WEP	2
62	SOT, TPM	2
64	AOM, SBT	2
75	SOT, TPM	2
80	AOM, VEX	2
89	STP, WHO	2
91	SOT, WHO	2
92	TPM, WHO	2

Table 4.4 Frequency of potential outlier of items

Item	Data set with potential outlier	Frequency of potential outlier
SOT	62, 63, 67, 75, 77, 81, 91, 126, 127, 135, 140, 148	12
TPM	59, 61, 62, 63, 67, 75, 92, 113, 117, 118, 129, 147	12
VEX	57, 63, 78, 80, 81, 119, 132, 141, 142, 147, 148, 149	12
WEP	48, 51, 56, 60, 85, 110, 112, 117, 119, 122, 123, 126	12
WHO	18, 20, 28, 61, 81, 89, 91, 92, 134, 137, 140	12

STP	19, 28, 33, 89, 113, 120, 130, 132, 135, 142, 144	11
AOM	46, 64, 66, 67, 80, 96, 100, 105, 130, 143	10
VST	40, 41, 49, 50, 55, 60, 61, 65, 67, 73	10
EXR	45, 63	2
SBT	64, 48	2

Chapter 5

Exploratory Factor Analysis

5.1 General overview

In this chapter, the 17 items are performed with the EFA method to extract key factors affecting LBP due to WBV exposure.

5.2 Steps to perform an EFA

An EFA consists of three main steps: 1) assessment of the suitability of data, 2) factor extraction, and 3) factor rotation. The details of these research steps are described below (Yong and Pearce, 2013).

5.2.1 Assessment of the suitability of data

There are two main issues when a suitability of a data set is assessed: sample size and sampling adequacy (Williams et al., 2010). Comrey and Lee (2013) stated that sample size of 100, 200, 300, 500, and more than 500 are poor, fair, good, very good, and excellent, respectively. Nevertheless, Hair et al. (1995) suggested that sample size of 100 sets or greater is suitable for factor analysis. A total of 145 cases are thus considered acceptable for the analysis in this study. Measure of sampling adequacy evaluates how strongly an item is correlated with other items in EFA correlation matrix (Williams et al., 2010). Bartlett's test of sphericity and Kaoser-Mayer-Olkin (KMO) index test are normally applied to check the suitability of data for factor analysis (Williams et al., 2010). Bartlett's test of sphericity should be significant ($p<0.05$), and KMO index should be at least 0.6 to confirm sampling adequacy for factor analysis (Taherdoost et al., 2014). The values of the Bartlett's test of sphericity and KMO index are as shown in the Table 5.1. They indicate that the 145 data sets are suitable for the EFA.

Table 5.1 Bartlett's test of sphericity and the KMO index

Test	Recommended value	Calculated value
Bartlett's test of sphericity	< 0.05	0.000
KMO index	> 0.60	0.614

5.2.2 Factor extraction

Factor extraction is a process to determine the smallest number of factors that best represent the interrelationships among set of items (Henson and Roberts, 2006). There are several methods used for factor extraction, including principle component analysis (PCA), principle axis factoring (PAF), maximum likelihood, unweighted least squares, generalized least square, alpha factoring, and image factoring (Costello and Osbone, 2005). According to Henson and Roberts (2006), PCA and PAF methods tend to be the most common method in factor extraction. Nevertheless, Costello and Osbone (2005) suggested that the PCA method is preferable in factor analysis. Therefore, the PCA method is used for the analysis in this research study.

5.2.3 Factor rotation and interpretation

Rotation method must be decided for the factor extraction. The goal of rotation is to simplify and clarify data structure (Costello and Osbone, 2005). There are different rotation methods, in which each method uses slightly different algorithms to achieve broad goal-simplification of the factor structure (Osborne, 2015). Osborne (2015) proposed two broad categories: orthogonal and oblique rotation methods. Most of the studies, however, use the orthogonal rotation method, since uncorrelated factors are easily interpreted.

Common orthogonal rotation methods are varimax, quartimax, and equamax (Costello and Osbone, 2005). Varimax rotation is by far the most utilized orthogonal rotation as it helps to maximize the variance of factor loadings by making a clear difference between high and low loadings of each factor (Osborne, 2015; Costello and Osbone, 2005).This study, therefore, considers a varimax rotation method for the EFA.

5.2.4 Factor loading

It is important to identify which items load on each retained factor (Cappelleri et al., 2000). This is known as factor loadings, which is the correlation coefficient between the items and factors. For example, factor loading of 0.40 represents that there is 40% of an approximate relationship with the item to the factor.

According to Taherdoost et al., (2014), factor loading of 0.30 is minimal, 0.40 is important, 0.50 is practical. If the factor loading is less than 0.30, then it is considered as no relationship between an item and its related factor (Taherdoost et al., 2014). In this study, therefore, a minimum factor loading of 0.3 is used as cut-off loading for the EFA.

5.3 The EFA results

In summary the principal component analysis is used, together with varimax rotation method and factor loading of 0.30, to extract the 17 items affecting LBP due to WBV exposure into groups. The first run extracts four factors, as shown in Table 5.2.

Table 5.2 Four factors extracted from the 17 items

Item	Factor loading			
	Factor 1	Factor 2	Factor 3	Factor 4
STP	0.68	-	-	-
VEX	0.60	-	-	-
AOM	0.59	-	-	-
SOT	0.34	-	-	-
JOR	-	0.67	-	-
WGT	-	0.57	-	-
WHO	-	0.56	-	-
NSF	-	0.54	-	-

EXR	-	0.36	-	-
AOW	-	0.34	-	-
TPM	-	-	0.63	-
VST	-	-	0.63	-
SBT	-	-	0.58	-
WEP	-	-	0.45	-
JOS	-	-	-	0.57
SMK	-	-	-	0.55
EDU	-	-	-	0.54

Factor 1 is accounted by four items explaining mainly about equipment and machines, and is called equipment (EQF) factor. This is consistent with the EQF factor previously hypothesized in Table 3.8 in Chapter 3. Chaudhary et al. (2015) also recommended the STP, AOM, and VEX items grouped into an equipment-related factor. Factor 2 is accounted by six items relating to personal and job characteristics. Factor 3 is associated with four items, including TPM, VST, SBT, and WEP. These items are in an organizational context, therefore is called as the organizational (ORF) factor. Factor 4 is associated with three items explaining mainly about social context (SCF) factor (seeTable 3.8) in chapter 3. This is consistent with Magnusson et al. (1998) that the JOS, SMK, and EDU explain the social-context. Close examination of Factor 2 reveals potential in further extracting six items into groups that are previously hypothesized in Chapter 3 (see Table3.8). The principal component analysis method is again used with varimax rotation and factor loading of 0.30 to extract from Factor 2 into groups. The results divide six items into two new factors. The first factor is called personal (PNF) factor, and is associated with three items: the AOW, WGT, and WHO. The second factor is called job related (JRF) factor, and consists of the EXR, JOR, and NSF items. This is consistent with factors and their associated items hypothesized in Table 3.8 in Chapter 3.

In summary, a total of five key factors affecting LBP due to WBV exposure are as shown in Table 5.3.

Table 5.3 Five factors affecting LBP due to WBV exposure extracted from the EFA

Item	Factor loading				
	EQF	PNF	ORF	SCF	JRF
STP	068	-	-	-	-
VEX	0.60	-	-	-	-
AOM	0.59	-	-	-	-
SOT	0.34	-	-	-	-
AOW	-	0.73	-	-	-
WGT	-	0.71	-	-	-
WOH	-	0.67	-	-	-
TPM	-	-	0.63	-	-
VST	-	-	0.63	-	-
SBT	-	-	0.58	-	-
WEP	-	-	0.45	-	-
JOS	-	-	-	0.57	-
SMK	-	-	-	0.55	-
EDU	-	-	-	0.54	-
EXR	-	-	-	-	0.76
JOR	-	-	-	-	0.74
NSF	-	-	-	-	0.39

5.4 Reliability test

To further confirm the five key factors extracted from the EFA, the reliability test is performed. It confirms the accuracy and precision of the factors and their associated items (Suhr, 2003). It concerns with internal consistency, stability, and dependence of the scores. According to Vehkalahti et al. (2009) there are two methods used in reliability test, namely Tarkkonen's rho and Cronbach's alpha. However, the widely used reliability test is Cronbach's alpha (Yu and Richardson, 2015; Suhr, 2003). In this study, therefore, the Cronbach's alpha is used. Cronbach's alpha value ranges from 0 to 1. Cronbach's alpha value of 0.4 is used, with a minimum value of 0.4 is considered reliable (Ghazanfarpour, 2014). The results, as shown in Table 5.4 show Cronbach's alpha values of the five factors of at least 0.4 to, thus, confirming the five key factors to explain LBP due to WBV exposure.

Table 5.4 Cronbach's Alpha value of five factors

Factor	Cronbach' s Alpha value
PNF	0.56
EQF	0.51
ORF	0.41
SCF	0.40
JRF	0.40

The conceptual model of LBP due to WBV exposure is then developed based on the five key factors and their 17 associated items (see Figure 5.1). They are used to perform the SEM analysis in the next chapter.

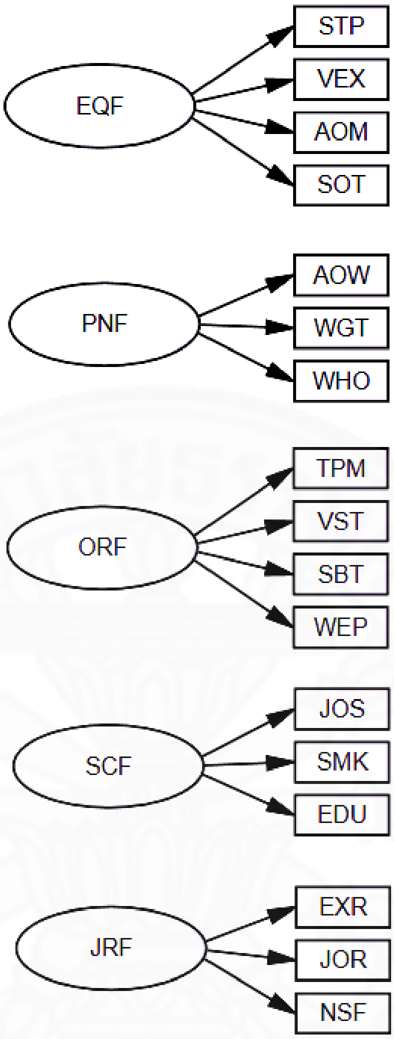

Figure 5.1 The conceptual model of LBP due to WBV exposure achieved from the EFA

Chapter 6

Structural Equation Modelling of LBP Prevention among HEOs

6.1 General overview

In this chapter, structural equation modelling (SEM) is performed to examine direct and indirect relationships between key factors extracted from the EFA method.

6.2 Structural equation modelling

SEM is the technique that provides a good theoretical basic analysis (Kohn et al., 2011). It is used to examine the independent factors and combined mediated relationships (Bardenheier et al., 2013). Chinda and Mohamed (2008) mentioned that the SEM method can be used to investigate the causal relationships among factors.

SEM consists of two models: measurement and structural models (Chinda and Mohamed, 2008). Measurement model depicts the pattern of observed variables (known as “items” in this study) and latent variables (known as “factors” in this study) in the hypothesized model (Schreiber et al., 2006). It also identifies the interrelationships and covariance among latent variables. The structural model on the other hand, confirms direction of relationships between latent variables (Schreiber et al., 2006).

To assess the model fit and accept the best fit model, a number of indices are used. Different researchers recommend different indices in assessing model fit, such as chi square per degree of freedom (χ^2/DF) or CMIN/DF, root mean squared error of approximation (RMSEA), comparative fit index (CFI), goodness of fit index (GFI), Bentler-Bonett normed fit index (NFI), incremental fit index (IFI), and Turcker-Lewis index (TLI) (Jonathan et al., 2001). Details of each index are as shown in Table 6.1. In this study χ^2/DF, RMSEA, and CFI are used to assess model fit of measurement and structural models, as they are commonly used in construction-, and health-related studies (Li et al., 2017; Khosravi et al., 2013; Chinda and Mohamed, 2008).

Table 6.1 Definition and acceptable range of fit indices

Fit index	Description	Acceptable value	Reference
χ^2/DF	It tests the closeness of the fit between the sample covariance matrix and the fitted covariance matrix.	< 2.00	Li et al., 2017; Gao et al., 2016; Ghazanfarpour et al., 2014; Khosravi et al., 2013; Chinda and Mohamed, 2008
RMSEA	It measures the lack of fit per degree of freedom.	< 0.08	Li et al., 2017; Gao et al., 2016; Ghazanfarpour et al., 2014; Khosravi et al., 2013; Chinda and Mohamed, 2008
CFI	It compares the existing model fit with a null model.	> 0.90	Li et al., 2017; Gao et al., 2016; Khosravi et al., 2013; Chinda and Mohamed, 2008; Shadfar and Malekmohammadi, 2003
GFI	It calculates the proportion of variance accounted for by the estimated population covariance.	> 0.90	Gao et al., 2016; Hooper et al., 2008
IFI	It compares the chi-square for the hypothesized model to one from a null model.	> 0.90	Gao et al., 2016; Miles and Shevlin, 2007
NFI	It assesses the difference between chi-square of the hypothesized model and null model.	> 0.90	Gao et al., 2016; Hooper et al., 2008

TLI	It adjusts the model complexity.	> 0.90	Gao et al., 2016; Kim et al., 2016

6.3 Measurement model of LBP prevention

In this study, the five confirmed factors affecting LBP due to WBV exposure and their 17 associated items (see Figure 5.1) are used to develop a measurement model of LBP prevention to examine correlations among them. At the beginning, it is assumed that all the factors are correlated. Then the model is run, and the fit indices results are achieved. To improve the model and achieve a better fit the modification index (MI) and path correlations are used (Hox and Bechger, 2007). MI, achieved from the model output, suggests whether a path between two items should be added or removed. To add a path in the model, however, it is important to ensure that linked path can be explained in real practice. Paths with low correlations are, on the other hand, removed .The measurement model of LBP prevention is run, and the results are as shown in Table 6.2. The results show good fits in the χ^2/DF and RMSEA with the values of 1.24 and 0.04, respectively. The CFI results, however, requires adjustment to achieve a better fit. The paths between the ORF and JRF factors and ORF and SCF factors are deleted, due to low correlations .Moreover, correlations with high MI values are added as followings.

- A correlation between the AOM and STP items: This is confirmed by Donati (2008), that new machine facilitates less vibration exposure.
- A correlation between the VST and JOR items: This correlation is confirmed by Paschold (2008) that, improving standards related to WBV exposure lead to more job rotation.

Table 6.2 Fit indices of measurement and structural model

Fit indices	Base measurement model	Best fit measurement model	Best fit structural equation model
CMIN/DF	1.24	1.14	1.07
RMSEA	0.04	0.03	0.02
CFI	0.86	0.92	0.96

After the modifications, the model is run, and the fit indices results are as shown in Table 6.2 and Appendix H. The results show that all indices fall into acceptable range, leading to the best fit measurement model, as shown in Figure 6.1.

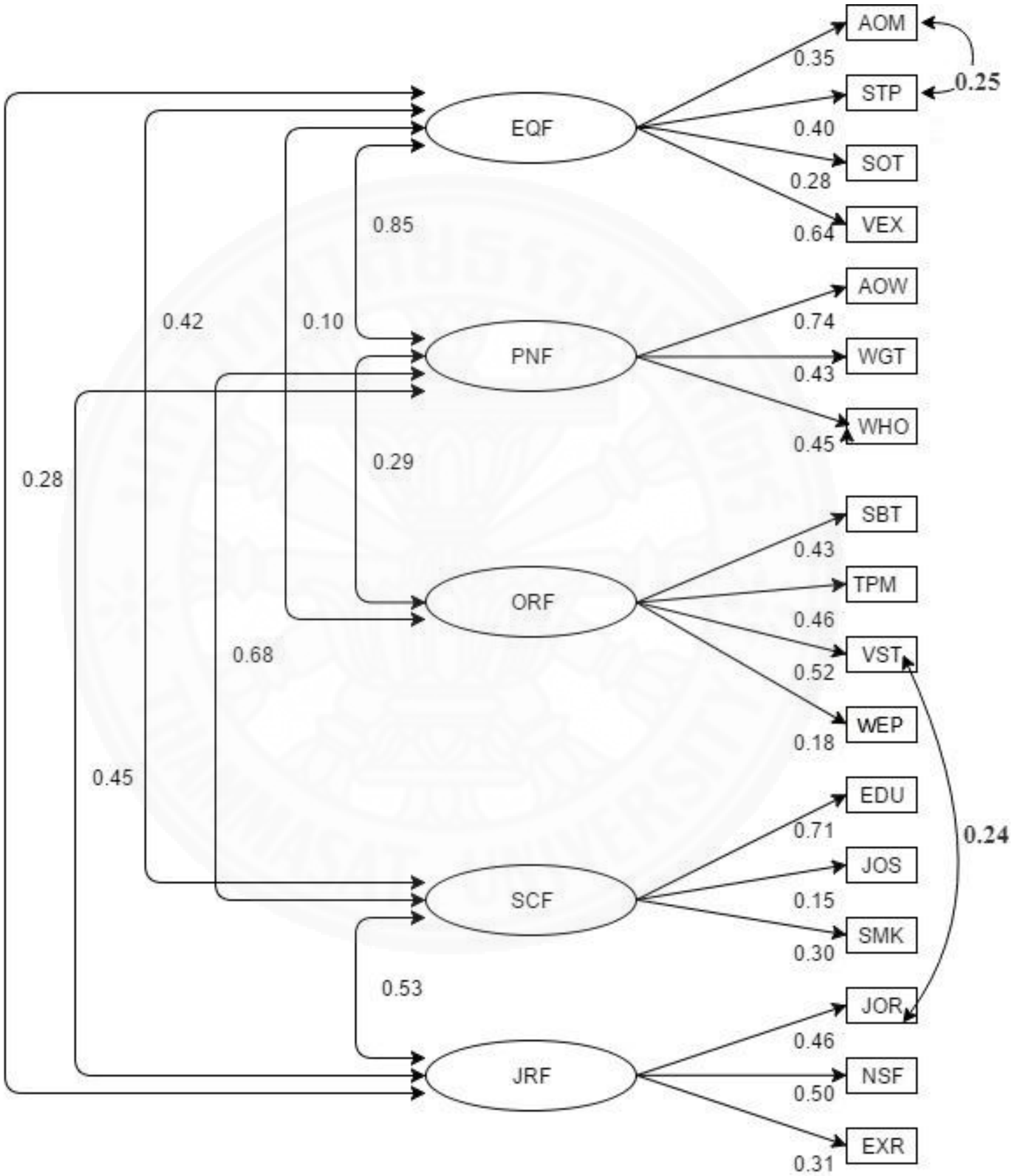

Figure 6.1 Best fit measurement model

Five key factors and their 17 associated items affecting LBP due to WBV exposure are confirmed with the best fit measurement model. It is concluded that the AOW, EDU, VEX, VST, and NSF items have high effects on LBP due to WBV exposure, as they have high loading on their respective factors (0.74, 0.71, 0.64, 0.52, and 0.50, respectively). The correlations of the five key factors affecting LBP due to WBV exposure are also confirmed. The EQF and PNF factors have the highest path correlation of 0.85. This is consistent with, for example, Donati (2008) that seat adjustment (an item in the EQF factor) for different body weights (an item in the PNF factor) is important to reduce WBV exposure. The SCF and PNF factors have the second highest path correlation with the value of 0.68. According to Beeck and Hermans (2000), time pressure causes low job satisfaction leading to a positive association of LBP disorders due to WBV exposure. The EQF and ORF factors, on the other hand, have the lowest path coefficient with the value of 0.10, indicating less influence the two factors have on each other.

6.4 Structural model of LBP prevention

The best fit measurement model is then performed with the structural model to examine directions of relationships between the five key factors. A correlation between two factors (a double headed arrow) is substituted with a path (a single headed arrow), to perform the structural model (Schreiber et al., 2006). In this study, eight correlations are replaced with eight paths with the hypothesized directions derive from a number of construction-related literature as the following.

- The ORF factor influences the PNF factor (ORF→PNF): Maintaining WBV standards requires appropriate working hours (Griffin, 1998).
- The ORF factor influences the EQF factor (ORF→EQF): Experienced workers manage to operate outdated vehicles with less chances of having LBP (Jailer et al., 2015).
- The PNF factor forces the EQF factor (PNF→EQF): Less working hour results in less WBV exposure (Donati, 2008).
- The PNF factor forces the JRF factor (PNF→JRF): Underweight and overweight workers should regularly exercise to reduce LBP prevalence (Nilsen et al., 2011).

- The PNF factor affects the SCF factor (PNF→SCF): Workers working long hours tend to smoke; this leads to high chance of having LBP (Ueno et al., 1999).
- The SCF factor affects the EQF factor (SCF→EQF): Good education leads the operators to operate machines safely (Jailer et al., 2015).
- The JRF factor influences the EQF factor (JRF→EQF): Having job rotation reduces chances of WBV exposure (Frazer et al., 2003).
- The JRF factor forces the SCF factor (JRF→SCF): Having job rotation increases job satisfaction (Kaymaz, 2010).

The above eight hypothesized relationships are tested with structural model. The MI values, achieved in the model output, suggest correlations between the the WEP and VEX items, the VST and AOM items, and the VST and WGT items. After the modification, the best fit structural model (i.e. the final model of LBP due to WBV exposure) is achieved (see Table 6.2 and Figure 6.2). The final model has the lowest χ^2/DF and RMSEA values of 1.07 and 0.02, respectively, and the highest CFI value of 0.96.

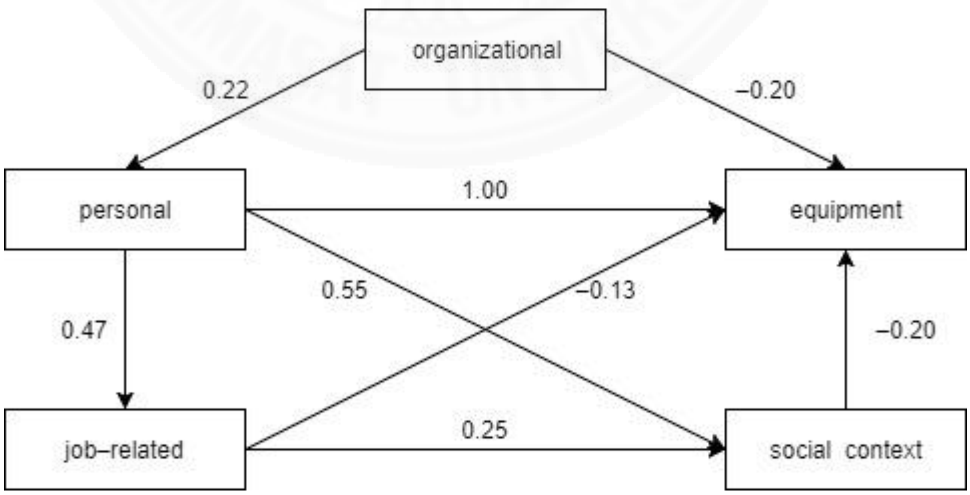

Figure 6.2 Final model of LBP due to WBV exposure

6.4.1 Direct and indirect relationships of the ORF factor

The ORF factor directly influences the PNF and EQF factors with path coefficients of 0.22 and -0.20, respectively (see Figure 6.2). To explain, the PNF factor increases by 0.22 of standard deviation when the ORF factor increases by one standard deviation. This is confirmed by Griffin (1998) that maintaining a good WBV standard (an item in the ORF factor) results in an appropriate working hour (an item in the PNF factor) and less chance of having LBP. The EQF factor, in contrast, decreases by 0.20 of standard deviation when the ORF factor increases by one standard deviation. This is confirmed by Langer et al. (2012) that specific WBV-related training (an item in the ORF factor) leads operators to effectively use of outdated equipment and machines (an item in the EQF factor).

The ORF factor also indirectly affects the EQF, SCF, and JRF factors through the implementation of the PNF factor. For example, the use of safety and health budget (an item in the ORF factor) in hiring more workers reduce overall working hour (an item in the PNF factor) and night shifts (an item in the JRF factor), and increase job rotation (an item in the JRF factor), leading to lower chances of having LBP (De Beeck and Hermans, 2000). Less working hour also reduces WBV exposure (an item in the EQF factor), and brings higher job satisfaction (an item in the SCF factor) (De Beeck and Hermans, 2000; Griffin, 1998).

6.4.2 Direct and indirect relationships of the PNF factor

The PNF factor has the strongest relationship with the EQF factor with a path coefficient of 1.00 (see Figure 6.2). It also positively affects the SCF and JRF factors with path coefficients of 0.55 and 0.47, respectively. Donati (2002) concluded the relationships between the body-weight (an item in the PNF factor) and seat adjustment (an item in the EQF factor) in reducing LBP among HEOs. Nilsen et al. (2011) also mentioned that overweight workers should regularly exercise to reduce the risk of LBP prevalence.

The PNF factor, on the other hand, indirectly influences the SCF factor through the implementation of the JRF factor. Kaymaz (2010), for example, stated that appropriate working hour (an item in the PNF factor) provides workers with job rotation (an item in the JRF factor), thus, enhancing job satisfaction (an item of the SCF factor). The PNF factor also indirectly affects the EQF factor through the JRF and SCF factors. New generation workers (young workers, an item in the PNF factor) tend to have higher education background (an item in the SCF factor), and that they can use heavy equipment effectively (Hoeckel, 2008).

6.4.3 Direct and indirect relationships of the JRF factor

The JRF factor directly affects the SCF and EQF factors with path coefficients of 0.25 and -0.13 respectively (see Figure 6.2). Having a job rotation (an item in the JRF factor) assists the HEOs in applying new knowledge (an item in the SCF factor) to work with different site conditions (an item in the EQF factor) (Hoeckel, 2008).

6.4.4 Direct and indirect relationships of the SCF factor

The SCF factor has a negative relationship with the EQF factor (see Figure 6.2). This is consistent with Beeck and Hermans (2000) that workers who exercise regularly (an item in the JRF factor) are better fit, and are able to work with the outdated machine (an item in the EQF factor) with less risk of injuries.

Direct and indirect relationships among the five key factors are summarized in Table 6.3. Path coefficients less than 0.10 are not included, as they show insignificant effects (Suhr, 2008). It is observed that some factors are strongly correlated with the other factors, while some factors affect the other factors indirectly through the intermediaries. For example, the ORF factor directly influences the EQF factor by 20%, but indirectly affects the EQF factor through the implementation of the PNF factor by 22% (see Table 6.3). It is also noticed that the EQF factor does not have any influences on the other four factors.

Table 6.3 Direct and indirect path coefficients of five key factors

Factor	Correlation coefficient
Organizational	-
Personal	0.22 × ORF
Job related	(0.47 × PNF) + (0.22 × 0.47 × PNF × ORF)
Equipment	(1.00 × PNF) + (-0.20 × ORF) + (-0.20 × SCF) + (-0.13 × JRF) + (0.22 × 1.00 × PNF × ORF)
Social context	(0.55 × PNF) + (0.25 × JRF) + (0.22 × 0.55 × PNF × ORF) + (0.47 × 0.25 × JRF × PNF)

Note: The ORF factor is not influenced by the other four factors.

The ORF factor plays an important role in reducing LBP due to WBV exposure among HEOs, as it directly and indirectly influences all other four factors. The company, therefore, needs to focus on the implementation of items in the ORF factor. Such actions as adequately provision of safety and health budget and initiation of specific training program could be implemented to reduce LBP prevalence.

To further examine the LBP prevention program, and plan for long-term improvement, a system dynamics modelling is performed in the next chapter.

Chapter 7
Dynamic Model of LBP Prevention Index

7.1 General overview

This chapter presents causal relationships of key factors and items affecting LBP due to WBV exposure. A dynamic model of LBP prevention index is then developed utilizing an SD modelling approach. Model validation and verification are performed to increase confidence in the developed model. A number of scenarios are finally conducted to test different strategies to prevent LBP among HEOs in the construction industry in the long-term.

7.2 Causal loop diagram of LBP prevention index

One of the major steps of SD model development is to develop a causal relationship diagram (Bouloiz et al., 2013). The diagram shows whether a relationship between each pair of variables is positive or negative, that is if the influence of one variable on another is amplifying (positive influence) or stabilizing (negative influence) (Bouloiz et al., 2013). Typically, there are two components of a casual loop diagram: causal link and closed loop.

Causal link consists of an element and an arrow. Element A to element B is considered as a positive causal link if a change in A produces a change in B in the same direction. If a change in A affects B in the opposite direction, then it is a negative causal link (Kirkwood, 1998).

A causal loop, on the other hand, is a closed sequence of causes and effects (Kirkwood, 1998). A positive causal feedback loop starts and ends with the same direction. It contains even numbers of negative link. On the other hand, if the loop starts and ends in different direction, and then it is known as a negative causal loop. It contains odd numbers of negative causal links (Kirkwood, 1998).

Seventeen items, under five key factors, create a number of causal links and causal loops, as shown in Figure 7.1. For instance, with adequate safety and health budget (SBT), the company can afford to purchase good quality machines (AOM) (Vitharana and Chinda, 2016). This makes a positive causal link between the SBT and AOM items. Good machine (AOM) incurs less WBV exposure level (VEX), representing a negative causal link between the AOM and VEX items (Vitharana et al., 2014). Less VEX indicates good WBV standard (VST) (a negative causal link), encouraging a company to support more budget (SBT) to improve the program implementation (a positive causal link) (Blood et al., 2010). This, thus, closes a positive causal loop between the SBT, AOM, VEX, and VST items (see Figure 7.2).

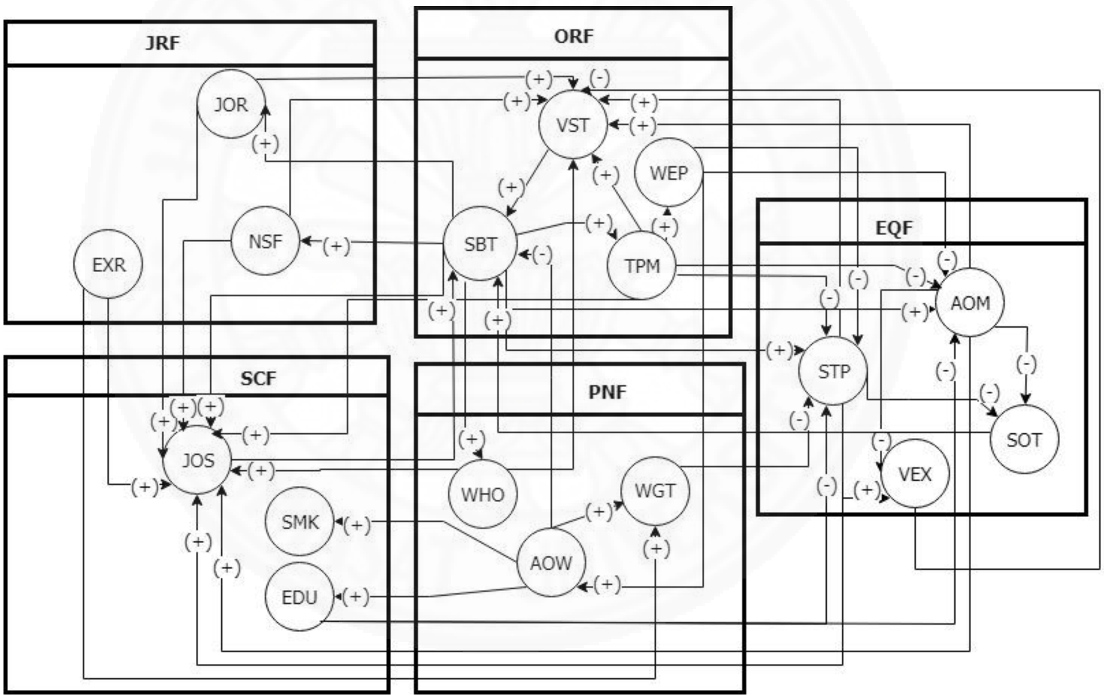

Figure 7.1 Causal loop diagram of LBP prevention index

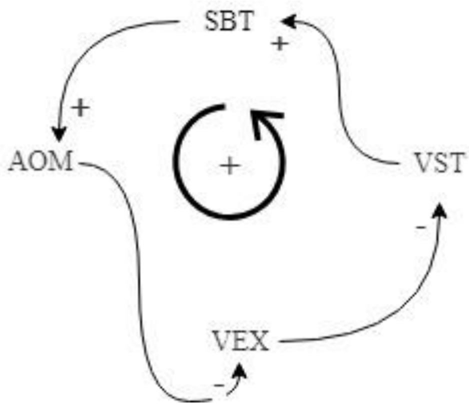

Figure 7.2 Example of a positive causal loop

The safety and health budget (SBT) can also be used to train (TPM) HEOs with LBP-related programs (Lahiri et al., 2005). This represents a positive causal link between the SBT and TPM items. Trained workers work more effectively and gain more experience (WEP) through time (Lee and Tserng, 2006). Experienced workers tend to work longer in the industry. This represents a positive causal link between the WEP and AOW items. However, senior workers (AOW), as they are older than young workers, are less fit (Sawacha et al., 1999). With senior workers, less budget (SBT) might be provided for the training (Lahiri et al., 2005). This, then, makes a negative causal link between the AOW and SBT items, and closes a negative causal loop between the SBT, TPM, WEP, and AOW items (see Figure 7.3).

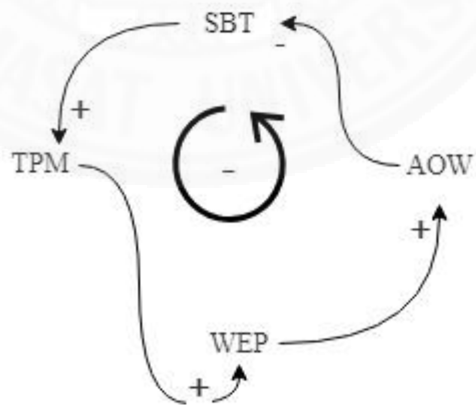

Figure 7.3 Example of a negative causal loop

The positive and negative causal links are used to develop the equations in a dynamic model of LBP prevention index.

7.3 A dynamic model of LBP prevention index

A dynamic model of LBP prevention index is developed using an SD modelling approach. The model consists of six sub-models, namely 1) personal factor sub-model, 2) organizational factor sub-model, 3) equipment factor sub-model, 4) job-related factor sub-model, 5) social context factor sub-model, and 6) LBP prevention index sub-model. Primary data collected from questionnaire survey and interviews, and secondary data collected through in-depth literature are used to develop equations for the dynamic model of LBP prevention (see Table 7.1).

Table 7.1 Input data of the dynamic model development

Factor and item	Description	Chance of having LBP	Reference
Personal factor			
AOW	Young age (group A), middle age (group B), and senior (group C) experience different chances of having LBP. • Group A ranges between 25-44 years. • Group B ranges between 45-54 years. • Group C ages more than 54 years old.	• Group A: 48% • Group B: 54% • Group C: 50%	Vitharana and Chinda, 2016; Paschold, 2008
WGT	There are four different weight types in this study; underweight, normal weight, overweight, and obese.	• Underweight: 100% • Normal weight: 40.63% • Overweight: 50% • Obese: 58.62%	Alghadir and Anwer, 2015
WHO	Standard working hour is eight hours per day. Many countries in South Asia, including Sri Lanka, however use, 12 working hours per day.	• Work less than eight hours per day: 48.8% • Work more than eight hours per day: 51.2%	Alghadir and Anwer, 2015

Organizational factor			
SBT	Safety and health budget of a construction company is approximately 5% of the total budget.	-	Pellicer et al., 2014
TPM	Different training programs are required for different age groups. • Training cost for group A is 100 US$ per person. • Training cost for group B is 127 US$ per person. • Training cost for group C is 100 US$ per person. • HEOs should receive training every three years.	• Group A: 33% • Group B: 39% • Group C: 35%	Lahiri et al., 2005
VST	The ISO 2631 Guidelines and EU Directives are used as guidelines for WBV exposure in this study.	-	Paschold, 2008
WEP	Working experience is separated into: less than ten years experience and more than ten years experience.	• Less than ten years: 55.6% • More than ten years: 44.3%	Janwantanakul et al., 2011
Equipment factor			
STP	Common seats used with heavy equipment are cushion and suspension seats.	• Cushion seat: 63% • Suspension seat: 30.4%	Subhash and Ario, 2011
AOM	Vibration level of the machine becomes higher after ten years. • Machine should be replaced every ten years.	• Old machine: 63% • New machine: 30.4%	Vitharana and Chinda, 2016; Paschold, 2008

	• Price of a machine is average at 100,000 US$.		
VEX	WBV exposure is reflected by the AOM, JOR, NSF, STP, TPM, and WHO items.	-	Vitharana and Chinda, 2016
SOT	Different soil types incur different compaction levels. Four soil types are defined, including heavy clay, silty clay, mixture of gravel, and sand and clay.	• Maximum chance: 63%	Rainville et al., 2004
	Job-related factor		
NSF	Working night shift causes higher chance of having LBP.	• With night shift: 42% • Without night shift: 21.5%	Takahashi et al., 2015
JOR	Having job rotation reduces half the chance of having LBP.	• With job rotation: 40% • Without job rotation: 80%	Frazer et al., 2003
EXR	Exercise helps reduce chance of having LBP. Exercise is separated into three groups, including regular, sometimes, and never exercise.	• Regular: 50% • Sometimes: 70% • Never: 82%	Rainville et al., 2004
	Social context factor		
JOS	Job satisfaction is separated into moderate, reasonable, and good satisfaction.	• Moderate: 34.30% • Reasonable: 25.30%	Hoogendoorn et al., 2002

		• Good: 19.48%	
SMK	LBP prevalence is higher among smokers.	• Smoker: 57.14% • Non-smoker: 43.13%	Alghadir and Anwer, 2015
EDU	Education background is separated into bachelor degree, high school, and primary school	• Bachelor degree: 41.5% • High school: 45.8% • Primary school: 64.6%	Udom et al., 2016

7.3.1 Personal factor sub-model

The PNF factor sub-model consists of three associated items, including 1) age of the worker (AOW), 2) weight of the worker (WGT), and 3) working hour (WHO) (see Figure 7.4). Each item has a maximum chance of LBP prevalence of 1,000 points.

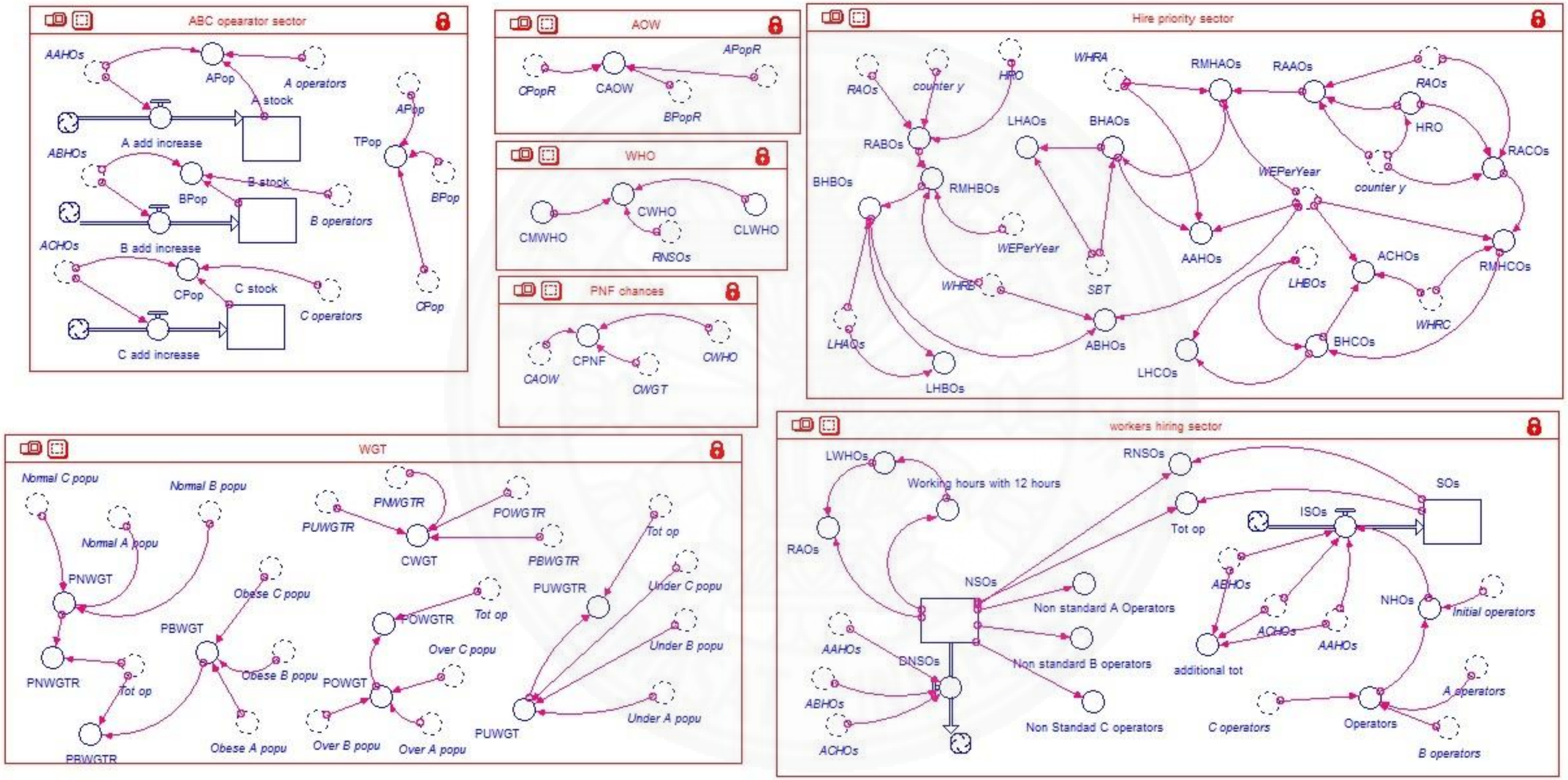

Figure 7.4 Personal factor sub-model

7.3.1.1 Age of the worker

Chance of having LBP varies with age. According to John Lant and Partners (2015), HEOs are separated into three age groups: group A (young HEOs who age between 25–44 years), group B (middle aged HEOs who age between 45–54 years), and group C (senior HEOs more with than 54 years old). Groups A, B, and C experience 48%, 54%, and 50% chances of having LBP, respectively (John Lant and Partners, 2015). Total chance of LBP prevalence based on this item is the sum of chances of each age group (see equations 7.1–7.4).

$$ApopR = APop/ TPop \qquad (7.1)$$

$$BpopR = BPop/ TPop \qquad (7.2)$$

$$CpopR = CPop/ TPop \qquad (7.3)$$

$$CAOW = ((48 \times APopR) + (54 \times BPopR) + (50 \times CPopR)) \times 1000 \qquad (7.4)$$

When,

APop	= A population
APopR	= Ratio of group A population to total population
BPop	= B population
BPopR	= Ratio of group B population to total population
CAOW	= Chance of having LBP based on the AOW item
CPop	= C population
CPopR	= Ratio of group C population to total population
TPop	= Total population

7.3.1.2 Weight of the worker

According to Alghadir and Anwer (2015), HEOs are separated into four weight ranges with the different chances of having LBP. Underweight (PUWGT) workers experience 100% chance of having LBP, while normal (PNWGT), overweight (POWGT), and obese (PBWGT) workers experience 40.63%, 50%, and 58.62% chances of having LBP, respectively (see equations 7.5–7.9).

$$PUWGTR = PUWGT/ TPop \tag{7.5}$$

$$PNWGTR = PNWGT/ TPop \tag{7.6}$$

$$POWGTR = POWGT/ TPop \tag{7.7}$$

$$PBWGTR = PBWGT/ TPop \tag{7.8}$$

$$CWGT = (((40.63 \times PNWGT) + (58.62 \times PBWGT) + (50 \times POWGT) + (100 \times PUWGT))) \times 1000 \tag{7.9}$$

When,

CWGT	= Chance of having LBP based on the WGT item
PBWGT	= Obese population
PBWGTR	= Ratio of obese population to total population
PNWGT	= Normal weight population
PNWGTR	= Ratio of normal weight population to total population
POWGT	= Overweight population
POWGTR	= Ratio of overweight population to total population
PUWGT	= Underweight population
PUWGTR	= Ratio of underweight population to total population

7.3.1.3 Working hour

In South Asian countries, including Sri Lanka, common working hour is 12 hours per day (Vaid, 1999). However, Trejo (1993) argued that workers should work only eight hours per day. Alghadir and Anwer (2015) mentioned that workers who work eight hours per day have less chance of having LBP than those who work longer hours. In this study, safety and health budget is spent to hire additional workers to reduce working hour of each HEOs, from 12 to eight hours per day.

Workers are hired based on the physical conditions of each age group. First priority is given to group A workers. Hiring rate of workers (HRO) increases from 4%–100% when company has more budget to support this strategy (Dixon, 2009) (see equation 7.10).

$$HRO = IF\ (0.04+ ((counter\_y - 1) \times 0.5/100)) < 1\ THEN\ (0.04+ ((counter\_y - 1) \times 0.5/ 100))\ ELSE\ 1 \quad (7.10)$$

When,

HRO = Hiring rate of workers

New HEOs are considered as standard workers with eight working hours per day. HEOs who work 12 hours per day are considered as non-standard workers (NSOs). Based on LWHOs and NSOs, the required additional workers (RAOs) are calculated (see equation 7.11).

$$RAOs = IF\ ((LWHOs - NSOs) > 0)\ THEN\ (LWHOs - NSOs)\ ELSE\ 0 \quad (7.11)$$

When,

LWHOs = Workers deduct 12 hour to 8 hours

NSOs = Non-standard workers

RAOs = Required additional workers

Based on the required additional workers (RAOs), required additional A workers (RAAOs), required additional B workers (RABOs), and required additional C workers (RACOs) are then calculated (see equations 7.12 –7.14).

RAAOs = IF (RAOs = 0) THEN 0 ELSE IF (counter_y = 1) THEN 0 ELSE ROUND (((RAOs × 0.85 × HRO) + 0.5)) (7.12)

RABOs = IF (RAOs = 0) THEN 0 ELSE IF (counter_y = 1) THEN 0 ELSE ROUND (((RAOs × 0.14 × HRO)) - 0.5) (7.13)

RACOs = IF (RAOs = 0) THEN 0 ELSE IF (counter_y = 1) THEN 0 ELSE ROUND (((RAOs × 0.01 × HRO)) - 0.5) (7.14)

When,

RAAOs = Required additional A workers

RABOs = Required additional B workers

RACOs = Required additional C workers

RAOs = Required additional workers

Based on equation 7.12–7.14, required budget to hire group A workers (RMHAOs), group B workers (RMHBOs), and group C workers (RMHCOs), are calculated, as shown in equation 7.15 – 7.17.

RMHAOs = WHRA × WEPerYear × RAAOs (7.15)

RMHBOs = WHRB × WEPerYear × RABOs (7.16)

RMHCOs = WHRC × WEPerYear × RACOs (7.17)

When,

WEPerYear	= Number of working hours per week
WHRA	= Weekly hiring rate of A group
WHRB	= Weekly hiring rate of B group
WHRC	= Weekly hiring rate of C group

By considering the physical fitness of the workers, expenditure to hire group A workers (BHAOs) is first calculated from the available budget (see equation 7.18). Total additional A workers (AAHOs) are then calculated (see equation 7.19).

$$\text{BHAOs} = \text{IF (SBT} > \text{RMHAOs) THEN RMHAOs ELSE SBT} \quad (7.18)$$

$$\text{AAHOs} = \text{ROUND ((BHAOs/ (WHRA} \times \text{WEPerYear)))} \quad (7.19)$$

When,

AAHOs	= Total hired additional A workers
BHAOs	= Expenditure to hire group A workers
RMHAOs	= Required budget to hire group A workers
SBT	= Safety and health budget
WEPerYear	= Number of working hours per week
WHRA	= Weekly hiring rate of A group

Leftover budget after hiring group A workers (LHAOs) is then calculated, and used to hire additional group B workers (see equation 7.20–7.22).

$$\text{LHAOs} = \text{IF (SBT} > \text{BHAOs) THEN (SBT - BHAOs) ELSE 0} \quad (7.20)$$

$$\text{BHBOs} = \text{IF (LHAOs} > \text{RMHBOs) THEN RMHBOs ELSE LHAOs} \quad (7.21)$$

$$\text{ABHOs} = \text{ROUND ((BHBOs/ (WHRB} \times \text{WEPerYear)))} \quad (7.22)$$

When,

ABHOs	= Total hired additional B workers
BHAOs	= Expenditure to hire group A workers
BHBOs	= Budget expenditure for hire B operators
LHAOs	= Leftover budget after hiring group A workers
RMHBOs	= Required budget to hire group B workers
SBT	= Safety and health budget
WEPerYear	= Number of working hours per week
WHRB	= Weekly hiring rate of B group

Leftover budget after hiring group B workers (LHBOs) is then calculated, and used to hire additional group C workers (see equation 7.23–7.25).

LHBOs = IF (LHAOs > BHBOs) THEN (LHAOs - BHBOs) ELSE 0 (7.23)

BHCOs = IF (LHBOs > RMHCOs) THEN RMHCOs ELSE LHBOs (7.24)

ACHOs = ROUND ((BHCOs/ (WHRC × WEPerYear))) (7.25)

When,

ACHOs	= Total hired additional C workers
BHBOs	= Expenditure to hire group B workers
BHCOs	= Expenditure to hire group Cworkers
LHAOs	= Leftover budget after hiring group A workers
LHBOs	= Leftover budget after hiring group B workers
RMHCOs	= Required budget to hire group C workers
WEPerYear	= Number of working hours per week
WHRC	= Weekly hiring rate of B group

Leftover budget after hiring group C workers (LHCOs) is then calculated (see equation 7.26). This Leftover budget is then use for training (TSBT).

LHCOs = IF (LHBOs > BHCOs) THEN (LHBOs - BHCOs) ELSE 0 (7.26)

When,

BHCOs	= Expenditure to hire group Cworkers
LHBOs	= Leftover budget after hiring group B workers
LHCOs	= Leftover budget after hiring group C workers

Addidtional workers reduce working hour of each HEO, leading to less chance of having LBP. Chance of having LBP based on the WHO item (CWHO) is then calculated (see equation 7.27).

$$CWHO = (CMWHO \times RNSOs) + (CLWHO \times (1- RNSOs)) \times 1000 \quad (7.27)$$

When,

CLWHO	= Chance of having LBP among HEOs work less than 8 hours
CMWHO	= Chance of having LBP among HEOs work more than 8 hours
CWHO	= Chance of having LBP based on the WHO item
RNOs	= Ratio of non standard operators

Total chance of having LBP due to WBV exposure based on the PNF factor (CPNF) is then the average of the chances of its three associated items (the AOW, WGT, and WHO items) with a maximum score of 1,000 points (see equation 7.28).

The implementation of the PNF factor influences the implementation of the other three factors, including the EQF, JRF, and SCR factors. The CPNF score then affects the EQF, JRF, and SCF factors' scores by 100%, 47%, and 55%, respectively (see Figure 6.2 in Chapter 6).

$$CPNF = (CAOW + CWGT + CWHO)/ 3 \quad (7.28)$$

When,

CPNF = Chance of having LBP based on the personal factor
CAOW = Chance of having LBP based on the AOW item
CWGT = Chance of having LBP based on the WGT item
CWHO = Chance of having LBP based on the WHO item

7.3.2 Organizational factor sub-model

The ORF factor sub-model consists of four items, namely safety and health budget (SBT), training program (TPM), WBV standard (VST), and working experience (WEP) (see Figure 7.5). Each item has a maximum chance of LBP prevalence of 1,000 points.

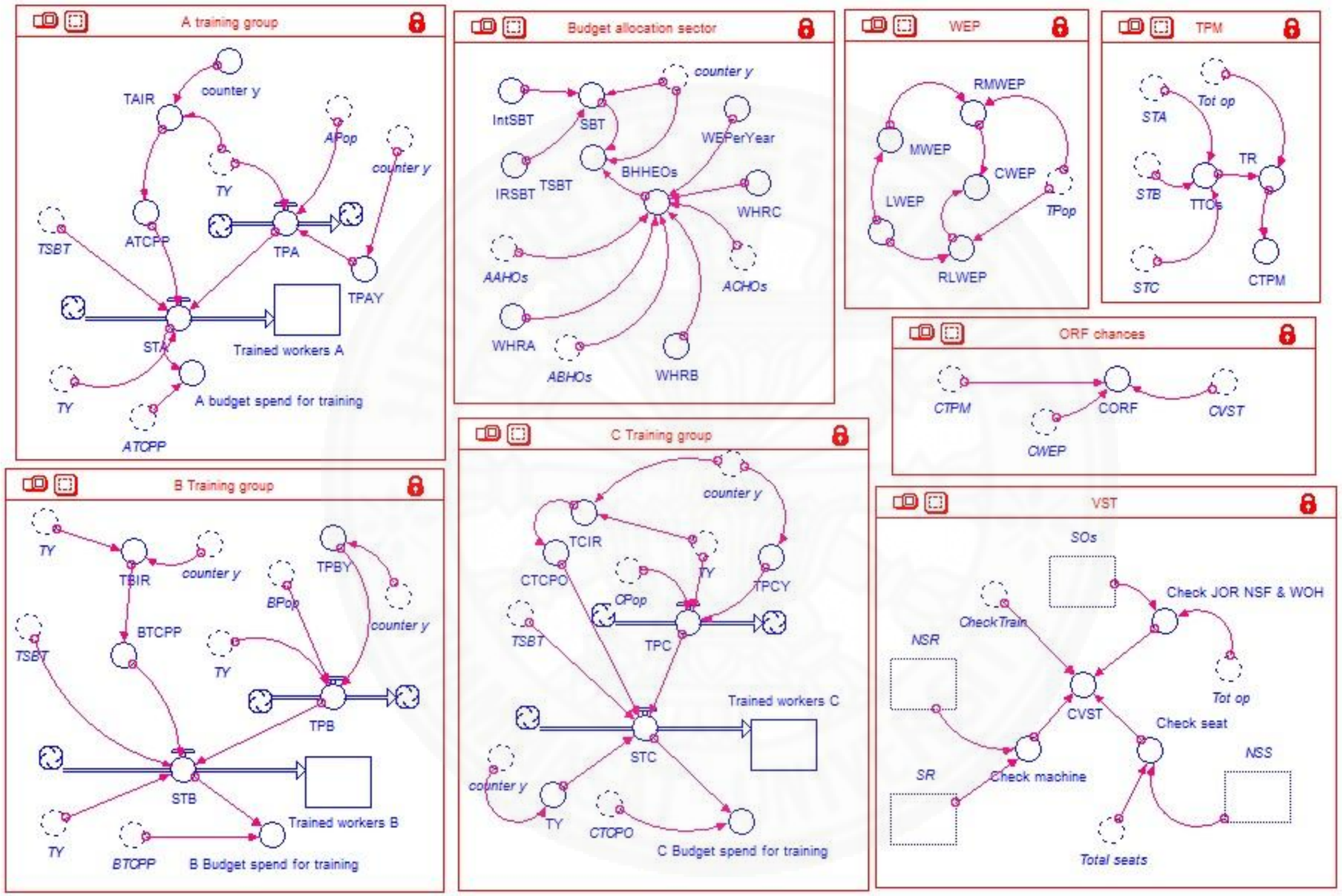

Figure 7.5 Organizational factor sub-model

7.3.2.1 Safety and health budget

To effectively implement the LBP prevention program, it is necessary for the company to provide adequate safety and health budget. Pellicer et al. (2014) stated that safety and health budget of a construction company should be approximately 5% of the total budget, with an increasing rate of 2% per year (Barnabas and Sriram, 2011) (see equation 7.29). Huang (2006) added that safety and health budget is commonly used in five areas, including 1) environment and heredity, 2) personal failing, 3) unsafe behaviour or physical hazard, 4) accident, and 5) injury. LBP due to WBV exposure is, however, categorized under the physical hazard, and that the budget is used in this category to 1) reduce night shift and working hour of HEOs, 2) train HEOs with LBP–related program, and 3) purchase suspension seat and heavy equipment, respectively. The priority of budget spending is based on the importance of each item, as shown in factor loadings in Figure 6.1 in Chapter 6. To explain, the NSF item has a highest factor loading of 0.50, while AOM item has the lowest loading of 0.35 among the NSF, TPM, and AOM items.

$$SBT = (IntSBT \times IRSBT) \wedge (counter\_y) \qquad (7.29)$$

When,

IntSBT	= Initial safety and health budget
IRSBT	= Increasing rate of safety and health budget
SBT	= Safety and health budget

7.3.2.2 Training program

According to Lahiri et al. (2005), a proper training assists in reducing chance of having LBP. To explain, groups A, B, and C experience 48%, 54%, and 50% chances of having LBP due to WBV exposure without training. The chances of having LBP due to WBV exposure reduce to 33%, 39%, and 35%, for groups A, B, and C respectively, after the training program is introduced.

In this study, the budget is used to train HEOs based on the necessity of each age group. To explain, group C workers are less fit than those in groups A and B. They should have the first priority to be trained first to prevent LBP due to WBV exposure. Training cost per group C worker (CTCPP) is calculated (see equation 7.30). The cost increases by 6% per year (Barriuso et al., 2018).

$$CTCPP = 100 \times TCIR \quad (7.30)$$

When,

CTCPP	= Training cost per group C worker
TCIT	= Increasing rate of training cost

According to Tam et al., (2004) minimum and maximum number of workers to be trained should be 54% and 80% of total workers, respectively. Training percentage (TPCY) is then caluculated, as shown in equation 7.31. Expected number of group C workers to be trained (TPC) is also calculated (see equation 7.32).

TPCY = IF (counter_y = 1) THEN 0.54 ELSE (IF (counter_y = 4) THEN 0.6433 ELSE (IF (counter_y = 7) THEN 0.7711 ELSE (0.80))) (7.31)

TPC = IF (TY = 1) THEN ROUND ((CPop × TPCY) - 0.5) ELSE 0 (7.32)

When,

Cpop	= C population
TPC	= Expected number of group C workers to be trained
TPCY	= Training percentage
TY	= Train year

Number of groups A, B, and C workers entitled to be trained can be calculated, as shown in equation 7.33–7.35.

STC = IF (TY = 1) THEN (IF (ROUND (TPC) > ROUND ((TSBT/ CTCPP)) - 0.5)
THEN (ROUND (TSBT/ CTCPP) - 0.5) ELSE (ROUND (TPC))) ELSE (0)
(7.33)

STB= IF (TY=2) THEN (IF (ROUND (TPB)>ROUND ((TSBT /BTCPP) - 0.5))
THEN (ROUND ((TSBT /BTCPP)-0.5)) ELSE (ROUND (TPB))) ELSE (0)
(7.34)

STA = IF (TY=0) THEN (IF (ROUND (TPA)>ROUND ((TSBT /ATCPP)) - 0.5)
THEN (ROUND ((TSBT /ATCPP)-0.5)) ELSE (ROUND (TPA))) ELSE (0)
(7.35)

When,

ATCPP	= Training cost per worker in group A
BTCPP	= Training cost per worker in group B
CTCPP	= Training cost per worker in group C
STA	= Number of group A workers entitled to be trained
STB	= Number of group B workers entitled to be trained
STC	= Number of group C workers entitled to be trained
TPA	= Expected number of group A workers to be trained
TPB	= Expected number of group B workers to be trained
TPC	= Expected number of group C workers to be trained
TSBT	= Budget for training

Total chance of having LBP due to WBV exposure based on the TPM item (CTPM) is as shown in equation 7.36.

$$CTPM = ((1 - TR) \times 63) + (TR \times 48)) \times 1000 \quad (7.36)$$

When,

CTPM = Chance of having LBP based on the TPM item

TR = Ratio of operators received a training program

7.3.2.3 WBV standard

The ISO 2631 Guidelines and the EU Directives are two international standards relating to WBV exposure (Paschold, 2008). They focus mainly on organizational, human, and equipment perspectives by suggesting decreasing night shift (NSF), increasing job rotation (JOR), reducing working hour (WHO), providing a number of ergonomic-related trainings (TPM), and supporting with safety- and health-related equipment to reduce WBV exposure level (see equation 7.37).

$$CVST = ((\text{Check JOR NSF \&WHO} + \text{Check\_Train} + \text{Check\_seat} + \text{Check\_machine}) \times 1000)/ 6 \quad (7.37)$$

When,

Check JOR NSF &WHO = Fully implementation of the JOR, NSF, and WHO items

Check_machine = Fully implementation of the AOM items

Check_seat = Fully implementation of the STP items

Check_Train = Fully implementation of the TPM items

CVST = Chance of having LBP based on the VST item

7.3.2.4 Working experience

Janwantanakul et al. (2011) stated that chance of having LBP among workers who have less than 10-year experience (LWEP) is 55.6%. Workers with more than 10-year experience (MWEP), on the other hand, experience around 10% less chance of having LBP. Chance of having LBP based on this item (CWEP) is, then, the summation of the two worker groups (see equation 7.38–7.40).

$$RLWEP = LWEP/ TPop \quad (7.38)$$

$$RMWEP = MWEP/ TPop \quad (7.39)$$

$$CWEP = ((55.60 \times RLWEP) + (44.3\times RMWEP)) \times 1000 \quad (7.40)$$

When,

CWEP = Chance of having LBP based on the WEP item

LWEP = Workers who have less than 10-year experience

MWEP = Workers who have more than 10-year experience

RLWEP = Ratio of workers who have less than 10-year experience

RMWEP = Ratio of workers who have more than 10-year experience

TPop = Total population

Total chance of having LBP due to WBV exposure based on the ORF factor (CORF) is then the average of chances of its associated items with a maximum score of 1,000 points (see equation 7.41). The implementation of the ORF factor not only affects LBP prevention index, but also influences the implementation of the other two factors, which are the PNF and EQF factors (see Figure 6.2 in Chapter 6).

$$CORF = (CWEP + CTPM + CVST)/ 3 \quad (7.41)$$

When,

CORF	= Chance of having LBP based on the ORF factor
CTPM	= Chance of having LBP based on the TPM item
CVST	= Chance of having LBP based on the VST item
CWEP	= Chance of having LBP based on the WEP item

7.3.3 Equipment factor sub-model

The EQF factor sub-model consists of four items, namely seat type (STP), age of the machine (AOM), WBV exposure (VEX), and soil type (SOT) (see Figure 7.6). Each item has a maximum chance of LBP prevalence of 1,000 points.

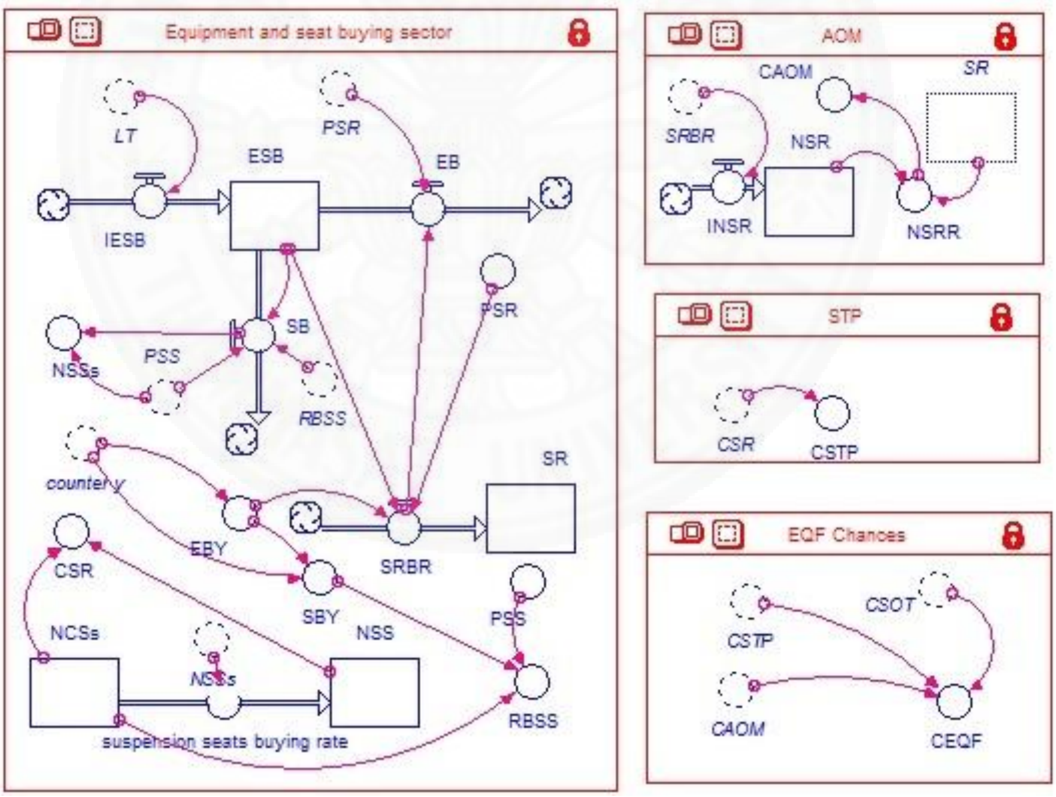

Figure 7.6 Equipment factor sub-model

7.3.3.1 Seat type

Common seat used with heavy equipment is the cushion seat. However, the cushion seat creates 63% chance of having LBP due to WBV exposure, while suspension seat incurs 30.4% chance of having LBP (Subhash and Ario, 2011). In this study, the leftover budget after hiring and training workers (LT) is used for suspension seat purchasing. The budget is used for replace old seats every 5 years (SBY).

Required budget for suspension seat acquisition (RBSS) is calculated based on a unit price (PSS), and number of cushion seats to be replaced (NCSs) (see equation 7.42).

$$RBSS = NCS \times PSS \times SBY \qquad (7.42)$$

When,

RBSS	= Required budget for process suspension seats
NCSs	= Number of cushion seats to be replaced
PSS	= Unit price of a suspension seat
SBY	= Seat buying year

Chance of having LBP based on the STP item (CSTP) is as shown in equation 7.43.

$$CSTP = ((30.4 \times (1 - CSR)) + (63 \times CSR)) \times 1000 \qquad (7.43)$$

When,

CSR	= Cushion seat ratio to total seats
CSTP	= Chance of having LBP based on the STP item

7.3.3.2 Age of the machine

WBV emission level is high in an old machine .Based on Vitharana and Chinda (2016), heavy equipment should be replaced every ten years (EBY). Therefore, leftover budget after hiring workers, training workers, and purchasing suspension seats is used to replace heavy equipment (see equation 7.44).

$$SRBR = IF\ (EBY = 0)\ THEN\ (ROUND\ ((ESB/ PSR) - 0.5))\ ELSE\ (0) \quad (7.44)$$

When,

EBY = Equipment buying year

ESB = Budget for processing equipments and seats

PSR = Price of a soil roller

SRBR = Soil roller buying rate

Chances of having LBP based on the AOM item (CAOM) is calculated based on old and new machines (see equation 7.45).

$$CAOM = (((1 - NSRR) \times 63) + (NSRR \times 30.40)) \times 1000 \quad (7.45)$$

When,

CAOM = Chance of having LBP based on the AOM item

NSRR = New equipment ratio to total eqiupments

7.3.3.3 WBV exposure

In this study, the WBV exposure (VEX) item indirectly affects chance of having LBP through the AOM, JOR, NSF, STP, TPM, and WHO items (Vitharana and Chinda, 2017). Use of old machine, for example, causes high chance of having LBP (Chaudhary et al., 2015).

7.3.3.4 Soil type

The construction work in Sri Lanka, deals with different soil types, including heavy clay, silty clay, mixture of gravel, and sand and clay (Barnabas and Sriram, 2011). In this study, chance of having LBP based on the SOT item (CSOT) is set at 63% to represent the highest vibration level that might occur (Kittusamy and Buchholz, 2004).

Total chance of having LBP due to WBV exposure based on the EQF factor (CEQF) is then the average of its four associated items with a maximum score of 1,000 points (see equation 7.46).

$$CEQF = (CAOM + CSOT + CSTP)/3 \qquad (7.46)$$

When,

CAOM	=	Chances of having LBP based on the AOM item
CEQF	=	Chance of having LBP based on the EQF factor
CSOT	=	Chances of having LBP based on the SOT item
CSTP	=	Chances of having LBP based on the STP item

The EQF factor has no influence on the other factors. Instead, the implementation of this factor is based on the implementation of its four associated items, together with the influences from the other four factors.

7.3.4 Job-related factor sub-model

The JRF factor sub-model consists of three associated items, namely night shift (NSF), job rotation (JOR), and exercise (EXR) (see Figure 7.7). Each item has a maximum chance of LBP prevalence of 1,000 points.

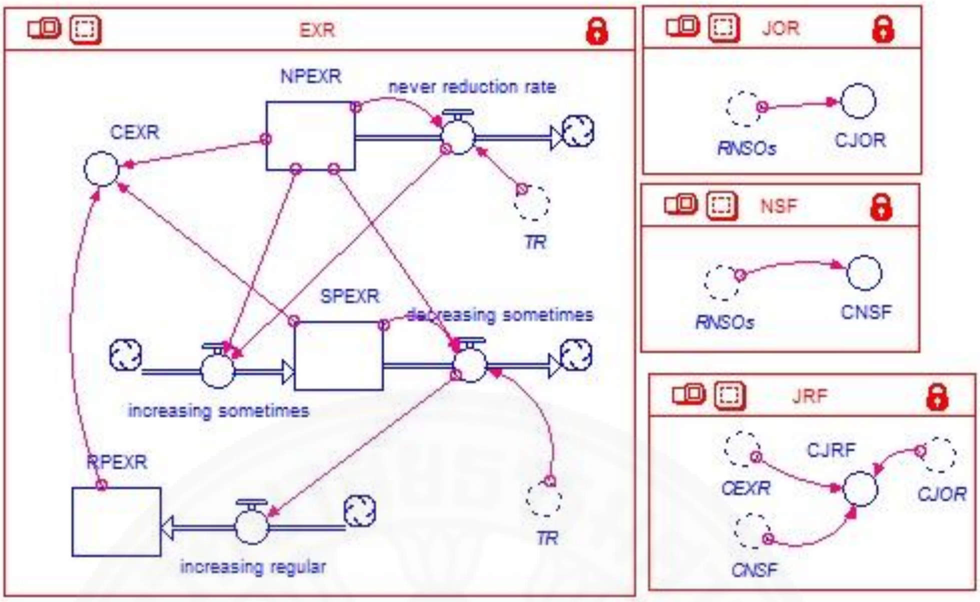

Figure 7.7 Job-related factor sub-model

7.3.4.1 Night shift

According to Takahashi et al. (2015), workers who work night shifts experience 42% chance of having LBP, while those who do not engage in night shifts experience around half the chance of those who work night shifts. Chance of having LBP based on this item (CNSF) is then calculated (equation 7.47).

$$CNSF = ((42 \times RNSOs) + (1 - RNSOs \times 21.5)) \times 1000 \quad (7.47)$$

When,

CNSF = Chance of having LBP based on the NSF item

RNOs = Ratio of non standard operators

7.3.4.2 Job rotation

Frazer et al. (2003) stated that chance of having LBP can be reduced by half by rotating jobs. Chance of having LBP based on the JOR item (CJOR) is calculated based on workers with and without job rotations (see equation 7.48).

$$CJOR = ((80 \times RNSOs) + ((1 - RNSOs) \times 40)) \times 1000 \quad (7.48)$$

When,

CJOR = Chance of having LBP based on the JOR item

RNOs = Ratio of non standard operators

7.3.4.3 Exercise

According to Rainville et al. (2004), workers who regularly exercise experience 50% chance of having LBP, while those who do not exercise has 82% of LBP prevalence. In this study, workers are separated into three groups: those who regularly exercise (RPEXR), those who sometimes exercise (SPEXR), and those who never exercise (NPEXR) (see equation 7.49).

$$CEXR = ((50 \times RPEXR) + (70 \times SPEXR) + (82 \times NPEXR)) \times 1000 \quad (7.49)$$

When,

CEXR = Chance of having LBP based on the EXR item

NPEXR = Ratio of workers who never exercise

RPEXR = Ratio of workers who exercise regulary

SPEXR = Ratio of workers who sometimes exercise

Total chance of having LBP due to WBV exposure based on the JRF factor (CJRF) is then the average of chances of its three associated items with a maximum score of 1,000 points (see equation 7.50).

$$CJRF = (CJOR + CEXR + CNSF)/ 3 \quad (7.50)$$

When,

CEXR	= Chance of having LBP based on the EXR item
CJOR	= Chance of having LBP based on the JOR item
CJRF	= Chances of having LBP due to JRF factor
CNSF	= Chance of having LBP based on the NSF item

The JRF factor also influences the EQF and SCF factors by 13% and 25%, respectively. To explain, when the chance of having LBP in the JRF factor increases by 100%, the chances of having LBP in the EQF and SCF factors increase by 13% and 25%, respectively (see Figure 6.2 in Chapter 6).

7.3.5 Social context factor sub-model

The SCF factor sub-model consists of three associated items: job satisfaction (JOS), smoking (SMK), and education (EDU) (see Figure 7.8). Each item has a maximum chance of having LBP of 1,000 points.

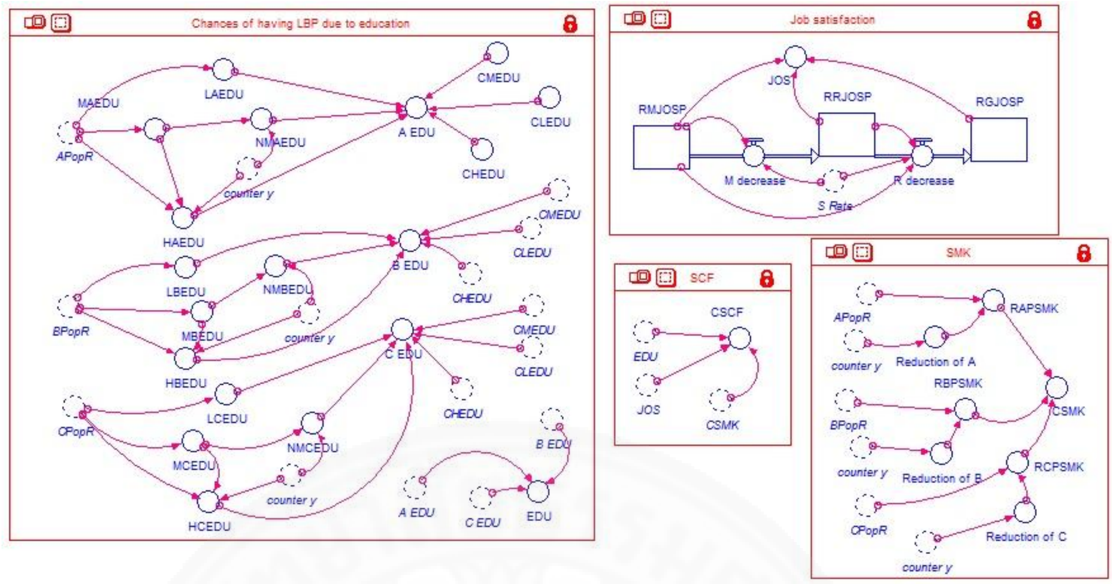

Figure 7.8 Social context factor sub-model

7.3.5.1 Job satisfaction

Hoogendoorn et al. (2002) classified job satisfaction into three levels with three chances of having LBP: moderate with 34.30% chance, reasonable with 25.30% chance, and good with 19.48% chance. In this study, job satisfaction can be enhanced by hiring more HEOs to reduce working hour, training HEOs with LBP-related programs, and supply HEOs with new equipment to reduce LBP prevalence (Abiyev et al., 2016). Chance of having LBP based on the JOS item (CJOS) is then calculated (see equation 7.51).

$$CJOS = ((19.48 \times RGJOSP) + (25.30 \times RRJOSP) + (34.78 \times RMJOSP)) \times 1000 \quad (7.51)$$

When,

CJOS = Chance of having LBP based on the JOS item

RGJOSP = Ratio of HEOs with good job satisfaction

RMJOSP = Ratio of HEOs with moderate job satisfaction

RRJOSP = Ratio of HEOs with regular job satisfaction to total population

7.3.5.2 Smoking

Chance of having LBP based on the SMK item (CSMK) is based on ratio of smokers and non smokers in each group (see equation 7.52).

$$CSMK = (((((1 - RAPSMK) \times 0.4313) + (RAPSMK \times 0.5714) + ((1 - RBPSMK) \times 0.4313) + (RBPSMK \times 0.5714) + ((1 - RCPSMK) \times 0.4313) + (RCPSMK \times 0.5714)) \times 1000)) \quad (7.52)$$

When,

CSMK = Chance of having LBP based on the SMK item
RAPSMK = Ratio of smokers in A group to total population
RBPSMK = Ratio of smokers in B group to total population
RCPSMK = Ratio of smokers in C group to total population

7.3.5.3 Education

This study considers three education levels in each age group. Chances of having LBP based on the education in groups A,B, and C are as shown in equations 7.53–7.55.

$$CAEDU= (HAEDU \times 41.50) + (LAEDU \times 64.60) + (NMAEDU \times 45.80) \quad (7.53)$$

$$CBEDU= (HBEDU \times 41.50) + (LBEDU \times 64.60) + (NMBEDU \times 45.80) \quad (7.54)$$

$$CCEDU= (HCEDU \times 41.50) + (LCEDU \times 64.60) + (NMCEDU \times 45.80) \quad (7.55)$$

When,

CAEDU = Chance of having LBP based on the EDU item in group A

CBEDU = Chance of having LBP based on the EDU item in group B

CCEDU = Chance of having LBP based on the EDU item in group C

HAEDU = Percentage of group A workers with >12^{th} grade education background

HBEDU = Percentage of group B workers with >12^{th} grade education

HCEDU = Percentage of group C workers with >12^{th} grade education

LAEDU = Percentage of group A workers with ≤ 5^{th} grade education background

LBEDU = Percentage of group B workers with ≤ 5^{th} grade education background

LCEDU = Percentage of group C workers with ≤ 5^{th} grade education background

NMAEDU = Percentage of group A workers with 6^{th} –12^{th} grade education background

NMBEDU = Percentage of group B workers with 6^{th} –12^{th} grade education background

NMCEDU = Percentage of group C workers with 6^{th} –12^{th} grade education background

Based on the three age groups, chances of having LBP based on the EDU (CEDU) item is then calculated (see equation 7.56).

$$CEDU= ((CAEDU + CBEDU + CCEDU) \times 1000) \qquad (7.56)$$

When,

CAEDU = Chance of having LBP based on the EDU item in group A

CBEDU = Chance of having LBP based on the EDU item in group B

CCEDU = Chance of having LBP based on the EDU item in group C

CEDU = Chance of having LBP based on the EDU item

Total chance of having LBP due to WBV exposure based on the SCF factor (CSCF) is then the average of chances of its three associated items with a maximum score of 1,000 points (see equation 7.57).

$$CSCF = (CJOS + CSMK + CEDU) / 3 \quad (7.57)$$

When,

CEDU = Chance of having LBP based on the EDU item
CJOS = Chance of having LBP based on the JOS item
CSCF = Chance of having LBP based on the SCF factor
CSMK = Chance of having LBP based on the SMK item

7.3.6 LBP prevention index sub-model

The LBP prevention index sub-model is shown in Figure 7.9. Chance of having LBP due to WBV exposure not only comes from the implementation of each factor, but is also achieved by the influences each factor has on each other. For instance, total chance of having LBP due to WBV exposure of the EQF factor comes from the implementation of its four items (i.e. the STP, AOM, VEX, and SOT items) and the influences this factor achieves from the PNF, ORF, JRF, and SCF factors (see equation 7.58).

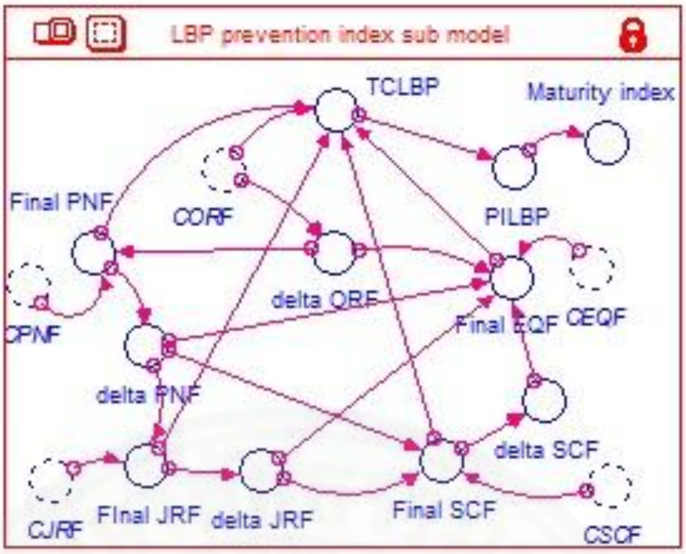

Figure 7.9 LBP prevention index sub-model

Final EQF = CEQF + ((delta_CPNF × 1) - (delta_CSCF × 0.2) - (delta_CJRF × 0.13)) - (delta_CORF × 0.20) (7.58)

When,

CEQF = Chance of having LBP based on the EQF factor

delta_CJRF = A change of chances of having LBP due to WBV exposure of the JRF factor

delta_CORF = A change of chances of having LBP due to WBV exposure of the ORF factor

delta_CPNF = A change of chances of having LBP due to WBV exposure of the PNF factor

delta_CSCF = A change of chance of having LBP due to WBV exposure of the SCF factor

Final EQF = Final chances of having LBP due to WBV exposure based on the EQF factor

Final chance of having LBP (TCLBP) is then the average chance of the five key factors (see equation 7.59).

TCLBP = (CORF + Final PNF + Final SCF + Final JRF + Final EQF)/ 5 (7.59)

When,

CORF = Chance of having LBP based on the ORF factor

Final EQF = Final chances of having LBP due to WBV exposure based on the EQF factor

Final JRF = Final chances of having LBP due to WBV exposure based on the JRF factor

Final PNF = Final chances of having LBP due to WBV exposure based on the PNF factor

Final SCF = Final chances of having LBP due to WBV exposure based on the SCF factor

TCLBP = Final chances of having LBP

Based on the TCLBP, the LBP prevention index (PILBP) and maturity level are calculated (see equations 7.60 and 7.61).

PILBP = 1000 - TCLBP (7.60)

Maturity index = IF (PILBP<200) THEN 1 ELSE (IF (PILBP = 200 OR (PILBP>
200 AND PILBP <400))THEN 2 ELSE(IF (PILBP = 400 OR (PILBP>
400 AND PILBP <600))THEN 3 ELSE IF (PILBP = 600 OR (PILBP> 600
AND PILBP <800))THEN 4 ELSE IF (PILBP = 800 OR (PILBP> 600
AND (PILBP <1000 OR PILBP = 1000)))THEN 5 ELSE 0)) (7.61)

When,

TCLBP = Final chances of having LBP

PILBP = LBP prevention index

7.4 Simulation results

The dynamic model of LBP prevention index is simulated, and the base run results are as shown in Figure 7.10, Table 7.2, and Table 7.3. At the beginning a construction company achieves level 2 of maturity with the LBP prevention index of 269.29 points. This could be explained with, for example, some young age HEOs with different working experiences and education background.

It takes three years for the company to progress from level 2 to level 3 of maturity, when safety and health budget is provided to improve the LBP prevention index. When the LBP prevention program is implemented, the company starts to follow the ISO 2631 Guidelines and EU Directives by focusing on reducing working hour, cutting-off night shift, and improving job rotation. Specific training program is also initiated.

The company spends four more years to progress from level 3 to level 4 of maturity (i.e. year 8). In this level, HEOs have full awareness of LBP symptoms, and attempt to avoid them. The company provides more budget to train workers with LBP-related programs, and purchases better equipment to reduce LBP prevalence.

After level 4 is achieved, it takes 30 years for the company to achieve level 5 of maturity. To achieve the final maturity level, the company focuses on continuous improvement with adequate safety and health budget to, for example, eliminate long working hour and night shift, and support workers with LBP preventive activities.

The base run results show that the company achieves level 5 of maturity at the end of year 39 with the LBP prevention index of 802.96 points.

Table 7.3 shows that the JRF factor is the first factor that achieves its maximum score (i.e. 1,000 points) at the end of year 24. This is due to the provision of safety and health budget to cut-off night shift, reduce working hour, and improve job rotation. The EQF factor, on the other hand, achieves the lowest score among the five key factors. This might be because not enough budget is provided to replace old machines, as each machine costs over 100,000 US$.

Table 7.2 Simulation results of LBP prevention index

Year	PILBP (points)	Maturity Level	Year	PILBP (points)	Maturity Level
1	269.29	2	21	763.48	4
2	309.00	2	22	764.44	4
3	390.46	2	23	765.83	4
4	456.46	3	24	768.45	4
5	492.53	3	25	767.71	4
6	544.85	3	26	767.66	4
7	568.40	3	27	769.69	4
8	602.47	4	28	768.88	4
9	624.50	4	29	768.70	4
10	639.01	4	30	765.56	4
11	651.16	4	31	764.75	4
12	662.55	4	32	764.66	4
13	669.54	4	33	771.27	4
14	676.33	4	34	770.19	4
15	684.05	4	35	769.84	4
16	743.75	4	36	771.69	4
17	747.82	4	37	770.59	4
18	753.75	4	38	770.27	4
19	756.46	4	39	802.96	5
20	759.17	4	40	801.90	5

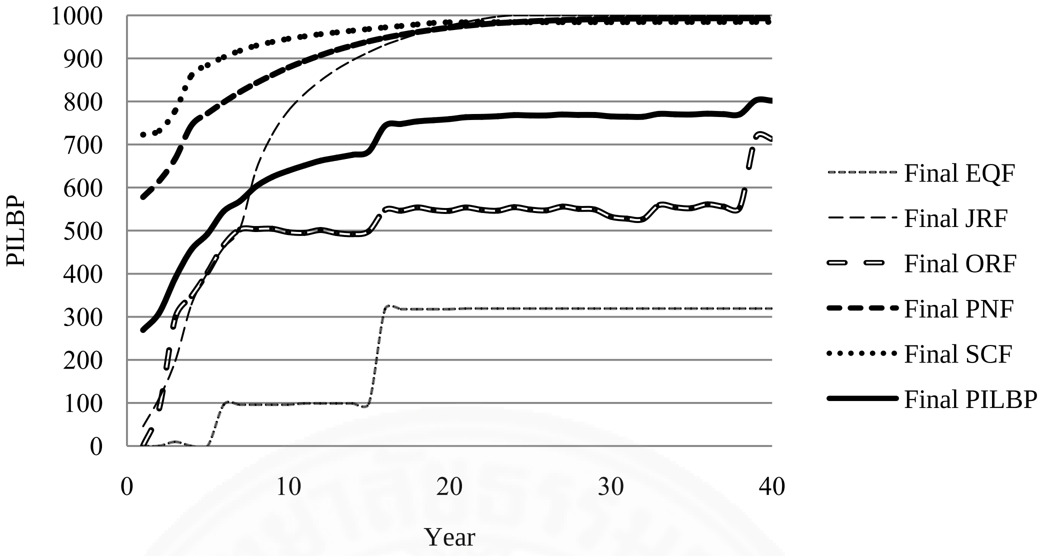

Figure 7.10 Graphical results of the dynamic model of LBP prevention index

Table 7.3 Simulation results of LBP prevention index of five key factors

Year	LBP prevention index (points)				
	Final EQF	Final JRF	Final ORF	Final PNF	Final SCF
1	0	45.66	0	578.06	722.75
2	0	110.85	86.99	615.22	731.92
3	9.45	197.37	298.62	667.74	779.11
4	0	328.49	348.18	744.63	860.97
5	0	402.55	403.18	772.57	884.34
6	95.92	460.79	466.61	798.17	902.75
7	95.92	503.56	502.67	821.87	917.97
8	95.92	639.90	503.79	842.88	929.84
9	95.92	722.43	504.42	861.44	938.32
10	95.92	778.11	496.56	878.85	945.61
11	98.67	817.16	494.90	893.65	951.42
12	98.67	848.59	501.51	907.46	956.52
13	98.67	874.35	494.45	919.67	960.55
14	98.67	896.01	492.03	930.12	964.79
15	98.67	914.59	499.08	939.62	968.29

16	317.58	931.52	548.23	948.08	972.14
17	317.58	944.67	546.45	955.02	975.38
18	317.58	956.87	553.93	961.36	979.02
19	317.58	967.51	547.82	966.81	982.60
20	317.58	976.69	546.02	971.77	983.79
21	319.20	984.62	553.86	975.77	983.97
22	319.20	991.41	548.25	979.23	984.10
23	319.20	997.14	546.40	982.19	984.21
24	319.20	1,000	554.61	984.12	984.32
25	319.20	1,000	549.18	986.10	984.09

7.5 Model verification and validation

Verification and validation of a model is an important process of model development (Martis, 2006). Validation is a process of establishing the confidence of the model (Senge and Forrester, 1980). Building up good confidence helps enhancing the understanding of the model, and leads to better policies. In this study, three structures and two behaviour tests are used to verify and validate the developed dynamic model (Barlas, 1996) (see Table 7.4).

Table 7.4 Model verification and validation tests

Type	Test	Explanation
Structure	Structure verification	This test reviews model assumptions with real-world system.
	Parameter verification	This test compares the model parameters with knowledge of the real-world system, both conceptually and numerically.
	Dimensional consistency	Equations used in the model should be checked for consistency.

Behaviour	Behaviour prediction	This test confirms the consistency of the model results and the real world system.
	Behaviour sensitivity	This test determines the sensitivity of model behaviour to changes in parameter values.

7.5.1 Structure test

Structure test assesses structures and parameters of the model, and not examining relationships between structures and behaviours (Senge and Forrester, 1980). This test includes the structure verification, parameter verification, and dimensional consistency tests.

7.5.1.1 Structure verification test

Structure verification test compares model assumptions to description of organizational relationships found in relevant literature (Senge and Forrester, 1980). The dynamic model of LBP prevention index is developed based on a number of reliable sources, such as textbooks, annual reports, proceedings, and international journal papers in construction and health related areas. Examples are Chaudhary et al. (2015), Ramond-Roquin et al. (2015), Yilmaz and Dedeli (2014), Miller and Gariephy (2008), Manek and MAcGregor (2005), Malchaire et al. (2001), De Beeck and Hermans (2000), and Bernard and Putz-Anderson (1997). Those references are used in, for example, item extraction, methodology verification, and data acquisition for equations development.

7.5.1.2 Parameter verification test

Parameter verification test compares model parameters to knowledge of the real-world system (Senge and Forrester, 1980). The parameters used in the LBP prevention index dynamic model are based on well-known journal papers, such as Udom et al. (2016), Alghadir and Anwer (2015), and Hoogendoorn et al. (2002).

7.5.1.3 Dimensional consistency test

The equations developed in the dynamic model of LBP prevention index are checked to ensure dimensional consistency. It is confirmed that the units in both left and right–hand sides are consistent, such as US dollar for safety and health budget, years of working experience in the construction industry, and weights of HEOs in kilograms.

7.5.2 Behaviour validity test

Behaviour validity test evaluates the adequacy of model structure through analysis of behaviour generated by the structure. This test consists of the behaviour prediction and behaviour sensitivity tests (Barlas, 1996; Forrester and Senge, 1980).

7.5.2.1 Behaviour prediction test

The consistency between the simulation results and other research studies are needed (Barlas, 1996). In this study, it is found that the simulation results are consistent with studies in USA and UK (see Table 7.5) (Thiese et al., 2014; Watson, 2007). This, thus, confirms the utilization of the developed model in real practices.

Table 7.5 Behaviour prediction test results

Country	Industry	Profit margin		Source
		Max	Min	
Sri Lanka	The construction industry	26.91%	80.20%	The results of the study
USA	Drivers	36.60%	79.20%	Thiese et al., 2014
UK	Drivers	25.00%	82.50%	Watson, 2007

7.5.2.2 Behaviour sensitivity test

The behaviour sensitivity test, or the scenario analysis, concentrates on sensitivity of model behaviour to changes in parameter values. The dynamic model of LBP prevention index is tested with a number of parameters, as described in the next section.

7.6 Scenario analysis

To examine alternative strategies construction companies can implement to prevent LBP occurrence, a scenario analysis is performed. The scenario analysis consists of single and mix strategies. In this study, single strategies are performed to examine the LBP prevention program in the construction industry under changes of five key parameters, including 1) hiring rate, 2) safety and health budget, 3) exercise, 4) equipment acquisition, and 5) training. Mix strategies are also performed to evaluate the LBP prevention index when at least two parameters are changed. In this study, three mix strategies scenarios are performed, including, 1) safety and health budget and hiring rate, 2) safety and health budget and exercise, and 3) hiring rate, training, and equipment acquisition.

7.6.1 Single strategy

7.6.1.1 Hiring rate strategy

According to Dixon (2009), hiring rate could range from 4%–100% of current HEOs. The simulation results show that 100% hiring rate assists in achieving higher index score, as more workers help reduce, night shift and working hour (see Figure 7.11 and Table 7.6). At the beginning, the LBP prevention index is the same, regardless of hiring rate due to the limited safety and health budget. The results also show that at least 50% of hiring rate assists company to achieve level 5 of LBP prevention maturity.

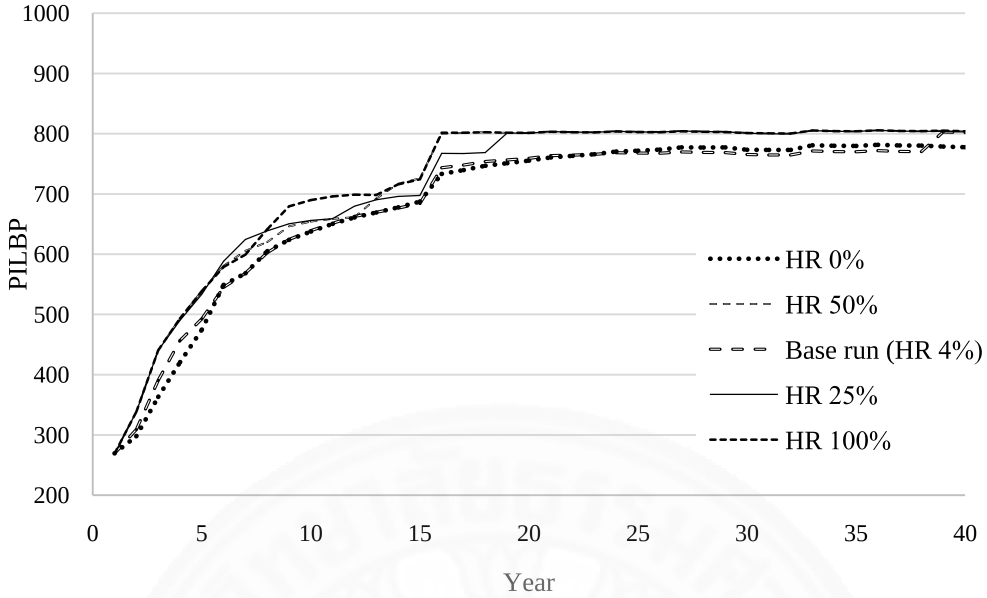

Figure 7.11 LBP prevention index with different hiring rates

Table 7.6 LBP prevention index with different hiring rates

Year	LBP prevention index (Points)				
	HR 0%	Base run HR 4%	HR 25%	HR 50%	HR 100%
1	269.29	269.29	269.29	269.29	269.29
2	297.91	309.00	338.50	338.50	338.50
3	363.16	390.46	440.39	440.39	440.39
4	420.51	456.46	489.99	493.20	493.20
5	474.50	492.53	533.44	538.76	538.76
6	548.69	544.85	588.37	580.46	578.69
7	568.18	568.40	624.45	605.58	599.28
8	604.84	602.47	638.82	620.18	641.43
9	623.85	624.50	650.46	646.15	679.24
10	637.46	639.01	656.08	654.02	689.79
11	650.35	651.16	658.83	658.59	695.86
12	661.01	662.55	679.71	661.20	698.64
13	669.24	669.54	690.14	692.02	698.31

14	677.59	676.33	695.76	716.94	715.87
15	687.24	684.05	697.34	725.75	724.32
16	733.27	743.51	767.22	800.04	801.46
17	739.51	747.82	767.15	801.24	801.43
18	746.83	753.75	768.72	800.96	802.46
19	750.84	756.46	801.11	803.74	801.47
20	755.16	75917	800.80	802.72	801.18
21	760.61	763.48	803.52	802.42	803.26
22	763.06	764.44	802.55	804.16	802.27
23	765.87	765.83	802.26	803.12	801.97
24	770.36	768.45	804.00	802.80	803.67
25	771.65	767.71	803.00	804.55	802.66
26	773.59	767.66	802.62	803.59	802.28
27	777.19	769.69	804.38	803.20	804.06
28	777.11	768.88	803.42	801.28	803.07
29	777.22	768.70	803.03	800.29	802.70
30	773.17	765.56	800.70	800.02	800.92
31	772.91	764.75	799.72	805.23	800.56
32	772.96	764.66	799.48	800.02	800.27
33	780.74	771.27	805.11	801.28	805.36
34	779.82	770.19	804.00	800.02	804.25
35	779.58	769.84	803.65	804.55	803.89
36	781.51	771.69	805.42	803.59	805.66
37	780.51	770.59	804.29	803.20	804.53
38	780.21	770.27	803.89	801.28	804.12
39	778.62	802.96	803.88	800.29	804.96
40	777.64	801.90	802.79	800.02	803.84

7.6.1.2 Safety and health budget strategy

Jaselskis et al. (1996) recommended that safety and health budget provided should be increased by 2%–10% of total budget each year. Figure 7.12 and Table 7.7 prove that the LBP prevention index is improved when more safety and health budget is provided. The results show that with 10% increasing rate, the index reaches level 5 of maturity in 30 years, almost 10 years earlier than the base run results. The results show that the more SBT increasing rate, the higher the LBP prevention index.

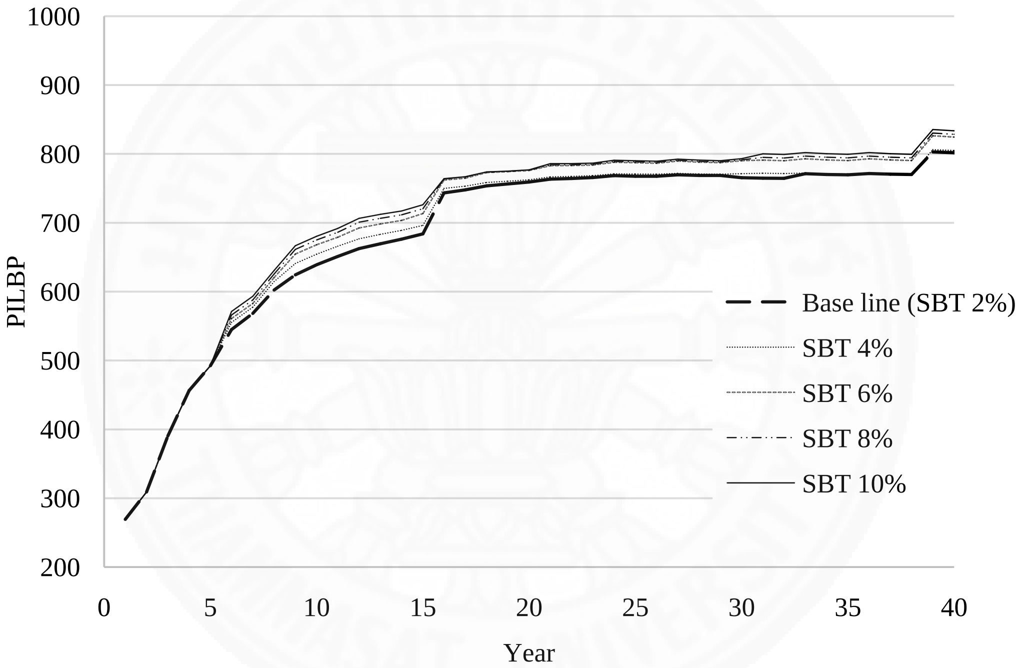

Figure 7.12 Graphical results of LBP prevention index with different safety and health budget increasing rates

Table 7.7 LBP prevention index with different safety and health budget increasing rates

Year	LBP prevention index (Points)				
	Base run (SBT 2%)	SBT 4%	SBT 6%	SBT 8%	SBT 10%
1	269.29	269.29	269.29	269.29	269.29
2	309.00	309.00	309.00	309.00	309.00
3	390.46	390.46	390.46	390.46	390.46
4	456.46	456.46	456.46	456.46	456.46
5	492.53	492.53	492.53	492.53	492.53
6	544.85	555.40	561.00	566.00	571.34
7	568.40	577.49	582.86	587.86	593.19
8	602.47	614.64	620.51	625.51	630.84
9	624.50	640.96	654.73	661.50	666.83
10	639.01	654.36	668.26	675.10	680.43
11	651.16	666.02	679.14	686.25	691.94
12	662.55	676.85	692.57	700.90	706.59
13	669.54	683.27	698.37	706.55	712.25
14	676.33	689.04	703.47	711.53	717.23
15	684.05	696.29	713.57	720.50	726.19
16	743.51	749.86	761.98	763.75	764.07
17	747.82	753.29	764.93	766.65	766.97
18	753.75	758.54	773.08	773.62	773.94
19	756.46	760.34	774.31	774.85	775.17
20	75917	762.62	776.08	776.60	776.92
21	763.48	766.62	782.98	784.19	785.91
22	764.44	767.39	783.19	784.39	786.11
23	765.83	768.61	783.88	785.09	786.80
24	768.45	771.20	787.97	789.17	790.89
25	767.71	770.93	787.29	788.50	790.21
26	767.66	770.73	787.56	787.77	789.49

27	769.69	771.84	789.62	790.83	792.55
28	768.88	770.93	788.15	789.35	791.07
29	768.70	770.66	787.32	788.53	790.25
30	765.56	771.44	790.23	791.43	793.15
31	764.75	771.95	791.16	795.15	800.20
32	764.66	771.59	790.22	794.21	799.27
33	771.27	772.23	792.99	796.97	802.03
34	770.19	771.16	791.29	795.27	800.33
35	769.84	770.81	790.33	794.32	799.37
36	771.69	772.61	793.03	797.02	802.08
37	770.59	771.52	791.31	795.30	800.35
38	770.27	771.17	790.35	794.34	799.40
39	802.96	806.31	826.38	830.36	835.42
40	801.90	801.15	824.59	828.58	833.63

7.6.1.3 Exercise strategy

Exercise helps reduce LBP occurrence. Figure 7.13 and Table 7.8 show the LBP prevention indices when workers are encouraged with different levels of exercising. It is found that, with no exercise, the company struggles to reach level 5 of maturity in the long-term.

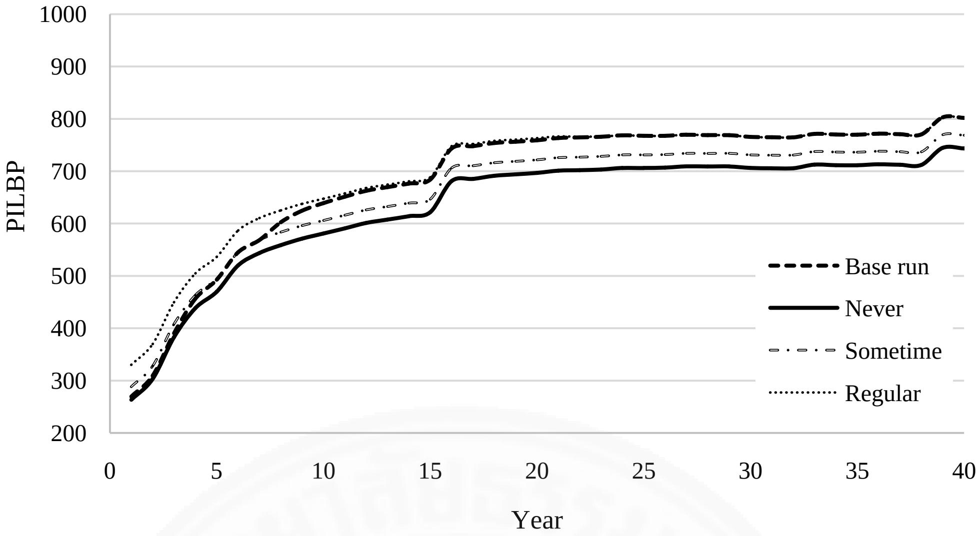

Figure 7.13 Graphical results of LBP prevention index with different exercise schemes

Table 7.8 LBP prevention index with different exercise schemes

Year	LBP prevention index (Points)			
	Base line	Never	Sometimes	Regular
1	269.29	263.26	288.26	329.93
2	309.00	302.97	327.97	369.63
3	390.46	382.87	407.87	449.54
4	456.46	438.21	463.21	504.88
5	492.53	469.67	494.67	536.34
6	544.85	519.99	544.99	586.66
7	568.40	543.76	568.76	610.43
8	602.47	558.55	583.55	625.22
9	624.50	571.05	596.05	637.71
10	639.01	580.87	605.87	647.54
11	651.16	590.85	615.85	657.51
12	662.55	601.14	626.14	667.80
13	669.54	607.54	632.54	674.2
14	676.33	614.04	639.04	680.71
15	684.05	621.63	646.63	688.29

16	743.51	681.01	706.01	747.67
17	747.82	685.28	710.28	751.95
18	753.75	691.19	716.19	757.86
19	756.46	693.89	718.89	760.56
20	759.17	696.59	721.59	763.26
21	763.48	700.91	725.91	766.45
22	764.44	701.86	726.86	766.05
23	765.83	703.25	728.25	766.29
24	768.45	706.14	731.14	768.34
25	767.71	706.09	731.09	767.61
26	767.66	706.67	731.67	767.55
27	769.69	709.20	734.20	769.58
28	768.88	708.85	733.85	768.77
29	768.70	709.02	734.02	768.59
30	765.56	706.21	731.21	765.46
31	764.75	705.60	730.60	764.64
32	764.66	705.71	730.71	764.55
33	771.27	712.50	737.50	771.16
34	770.19	711.53	736.53	770.08
35	769.84	711.26	736.26	769.73
36	771.69	713.20	738.20	771.58
37	770.59	712.17	737.17	770.48
38	770.27	711.92	736.92	770.16
39	802.96	744.61	769.61	802.85
40	801.90	743.55	768.55	801.79

7.6.1.4 Equipment acquisition strategy

The equipment acquisition scenario examines when all safety and health budget are allocated and not allocated to acquire suspension seats and new heavy equipment. The results shown in Figure 7.14 and Table 7.9 reveal that investing all safety and health budget in equipment, without considering human resources improvement, is not recommended, as the LBP prevention index might never reach level 5 of maturity. Not investing on equipment, on the other hand, results in longer times in achieving level 5 of maturity, compared with the base run results.

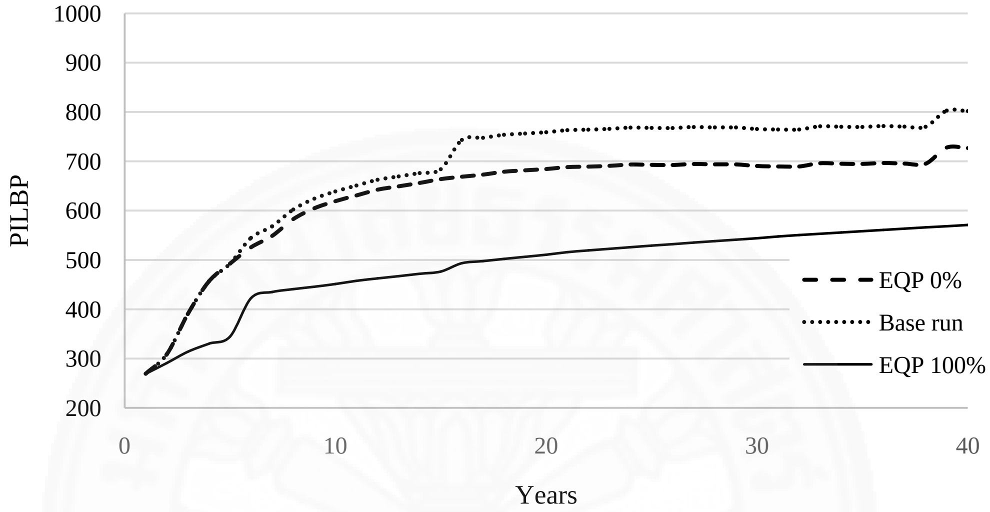

Figure 7.14 Graphical results of LBP prevention index with different equipment acquisition percentage

Table 7.9 LBP prevention index with different equipment acquisition percentage

Year	LBP prevention index (Points)		
	Base line	EQP 100%	EQP 0%
1	269.29	269.29	269.29
2	309.00	290.88	309.00
3	390.46	313.86	390.46
4	456.46	330.20	456.46
5	492.53	344.45	492.53
6	544.85	422.58	525.66
7	568.40	435.15	548.86
8	602.47	440.73	582.79
9	624.50	445.77	604.81
10	639.01	451.18	619.36

11	651.16	457.76	630.95
12	662.55	462.58	642.43
13	669.54	467.16	649.50
14	676.33	471.93	656.35
15	684.05	476.51	664.13
16	743.51	493.49	668.74
17	747.82	497.80	673.09
18	753.75	502.20	679.05
19	756.46	506.55	681.78
20	759.17	510.66	684.50
21	763.48	515.82	688.50
22	764.44	519.26	689.46
23	765.83	522.62	690.86
24	768.45	525.85	693.49
25	767.71	528.99	692.75
26	767.66	532.19	692.70
27	769.69	535.28	694.73
28	768.88	538.29	693.92
29	768.70	541.29	693.74
30	765.56	544.16	690.61
31	764.75	547.66	689.80
32	764.66	550.49	689.71
33	771.27	553.25	696.32
34	770.19	555.87	695.25
35	769.84	558.50	694.89
36	771.69	561.09	696.75
37	770.59	563.61	695.64
38	770.27	566.10	695.32
39	802.96	568.49	728.01
40	801.90	570.89	726.95

7.6.1.5 Training strategy

This scenario examines the LBP prevention index when no and all workers are trained with LBP-related trainings. The LBP prevention index as shown in Figure 7.15 and Table 7.10, is higher when all HEOs receive the training. With no training provided, it is hard for the construction company to achieve level 5 of maturity.

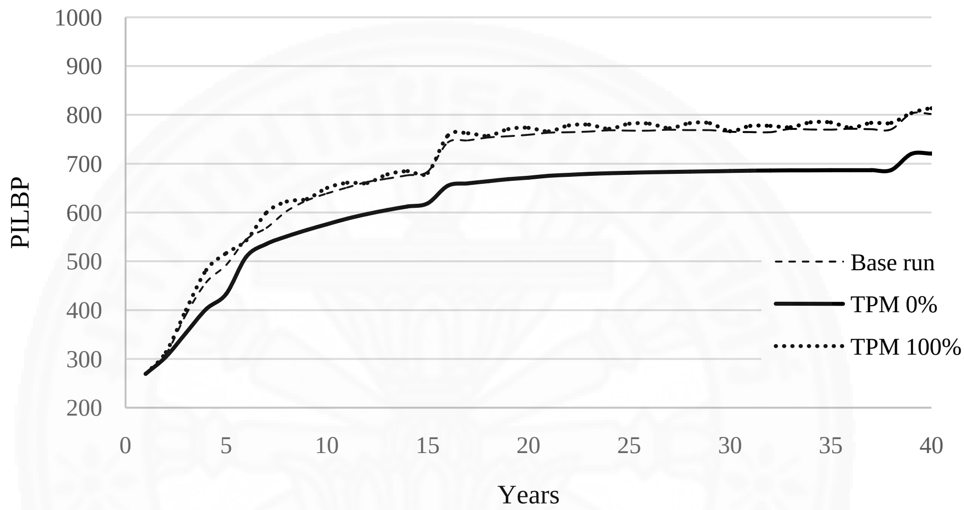

Figure 7.15 Graphical results of LBP prevention index with different training rates

Table 7.10 LBP prevention index with different training rates

Year	LBP prevention index (Points)		
	Base line	TPM 0%	TPM 100%
1	269.29	269.29	269.29
2	309.00	304.05	313.32
3	390.46	353.24	400.34
4	456.46	401.93	481.9
5	492.53	433.17	516.49
6	544.85	509.47	542.83
7	568.40	535.64	599.82
8	602.47	550.94	622.52
9	624.50	564.02	627.64

10	639.01	576.06	650.22
11	651.16	587.38	660.94
12	662.55	596.79	660.39
13	669.54	604.98	678.01
14	676.33	612.27	684.73
15	684.05	618.69	681.16
16	743.51	654.91	757.89
17	747.82	659.69	762.33
18	753.75	664.23	757.06
19	756.46	668.25	770.84
20	759.17	671.38	773.64
21	763.48	675.14	766.45
22	764.44	677.25	778.44
23	765.83	679.05	779.98
24	768.45	680.32	771.64
25	767.71	681.37	781.98
26	767.66	682.35	782.05
27	769.69	683.16	772.90
28	768.88	683.86	783.14
29	768.70	684.39	783.07
30	765.56	684.88	766.63
31	764.75	685.76	777.29
32	764.66	686.05	777.38
33	771.27	686.32	774.80
34	770.19	686.42	784.79
35	769.84	686.53	784.58
36	771.69	686.67	773.73
37	770.59	686.74	783.73
38	770.27	686.85	783.57
39	802.96	720.14	803.59
40	801.90	720.79	813.69

7.6.2 Mix strategy

7.6.2.1 Safety and health budget and hiring rate

Figure 7.16 and Table 7.12 show the LBP prevention index with different safety and health budget increasing rates and hiring rates to reduce night shift, working hour, and job rotation. With the minimum budget increasing rate of 2% and no hiring the company cannot reach level 5 of maturity. On the other hand, with maximum budget provided to hire as many workers as possible the company reaches level 5 of maturity in less than 20 years.

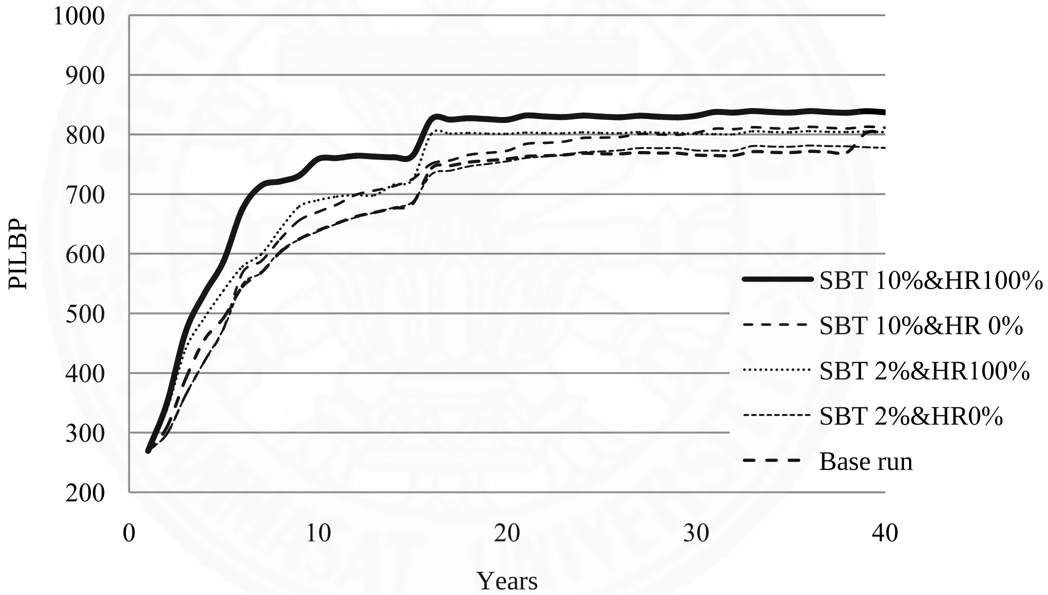

Figure 7.16 Graphical results of LBP prevention index with different safety and health budge increasing rates, and hiring rates

Table 7.11 LBP prevention index with different safety and health budget increasing rates, and hiring rates

Year	LBP prevention index (Points)				
	SBT 10% and HR100%	SBT 10% and HR 0%	SBT 2% and HR100%	SBT 2% and HR0%	Base run
1	269.29	269.29	269.29	269.29	269.29
2	349.34	297.91	338.50	297.91	309.00
3	469.65	363.16	440.39	363.16	390.46
4	534.11	420.51	493.20	420.51	456.46
5	587.30	474.50	538.76	474.50	492.53
6	674.85	568.35	578.69	548.69	544.85
7	714.35	587.85	599.28	568.18	568.40
8	721.36	624.51	641.43	604.84	602.47
9	731.02	656.01	679.24	623.85	624.50
10	758.81	670.11	689.79	637.46	639.01
11	760.40	682.62	695.86	650.35	651.16
12	764.32	698.81	698.64	661.01	662.55
13	762.88	706.05	698.31	669.24	669.54
14	761.94	713.55	715.87	677.59	676.33
15	764.28	725.44	724.32	687.24	684.05
16	825.78	751.09	801.46	733.27	743.51
17	824.91	756.58	801.43	739.51	747.82
18	827.28	765.93	802.46	746.83	753.75
19	825.64	769.15	801.47	750.84	756.46
20	824.71	772.74	801.18	755.16	759.17
21	831.90	784.21	803.26	760.61	763.48
22	830.25	785.91	802.27	763.06	764.44
23	829.30	788.03	801.97	765.87	765.83
24	831.68	794.12	803.67	770.36	768.45
25	830.02	794.72	802.66	771.65	767.71

26	828.99	795.96	802.28	773.59	767.66
27	831.49	800.99	804.06	777.19	769.69
28	829.85	800.23	803.07	777.11	768.88
29	828.84	799.68	802.70	777.22	768.70
30	831.34	803.00	800.92	773.17	765.56
31	837.85	809.87	800.56	772.91	764.75
32	836.81	809.08	800.27	772.96	764.66
33	839.39	812.20	805.36	780.74	771.27
34	837.63	810.63	804.25	779.82	770.19
35	836.66	809.78	803.89	779.58	769.84
36	839.25	812.69	805.66	781.51	771.69
37	837.46	811.05	804.53	780.51	770.59
38	836.44	810.14	804.12	780.21	770.27
39	839.10	813.01	804.96	778.62	802.96
40	837.31	811.28	803.84	777.64	801.90

7.6.2.2 Safety and health budget and exercise

The results (see Figure 7.17 and Table 7.12) show that with no financial support to improve LBP prevention index, the index score can be improved with various exercise schemes. With both financial support and full exercise encouragement, on the other hand, the company achieves level 5 of maturity in around 30 years. This proves the importance of exercising in enhancing the LBP prevention index.

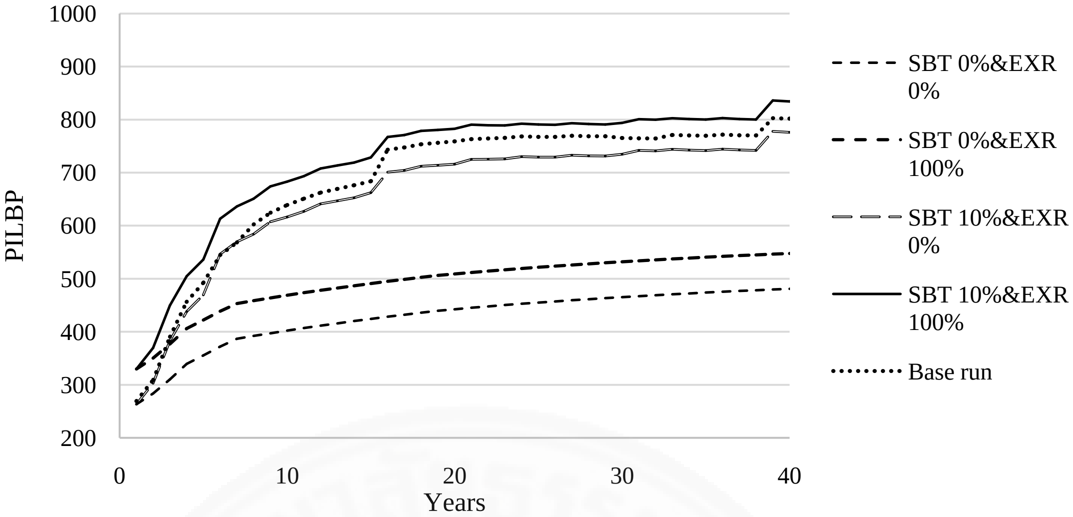

Figure 7.17 Graphical results of LBP prevention index with different safety and health budget increasing rates and exercise rates

Table 7.12 LBP prevention index with different safety and health budget increasing rates and exercise rates

Year	LBP prevention index (Points)				
	SBT 0% and EXR 0%	SBT 0% and EXR 100%	SBT 10% and EXR 0%	SBT10% and EXR 100%	Base run
1	263.26	329.93	263.26	329.93	269.29
2	283.71	350.38	302.97	369.63	309.00
3	310.13	376.80	382.87	449.54	390.46
4	339.37	406.04	438.21	504.88	456.46
5	355.41	422.08	469.67	536.34	492.53
6	372.10	438.76	546.48	613.15	544.85
7	386.70	453.36	569.89	636.56	568.40
8	392.15	458.81	584.35	651.02	602.47
9	397.17	463.84	607.47	674.14	624.50
10	402.36	469.02	616.48	683.14	639.01
11	406.98	473.65	626.96	693.62	651.16
12	411.62	478.28	641.34	708.00	662.55

13	415.91	482.58	646.90	713.57	669.54
14	420.21	486.87	652.62	719.29	676.33
15	424.39	491.06	662.28	728.94	684.05
16	428.41	495.08	700.92	767.59	743.51
17	432.13	498.80	704.47	771.14	747.82
18	435.97	502.63	712.17	778.84	753.75
19	439.62	506.29	714.12	780.78	756.46
20	442.48	509.15	716.11	782.78	759.17
21	445.25	511.92	725.13	790.67	763.48
22	447.88	514.55	725.36	789.55	764.44
23	450.40	517.06	726.08	789.12	765.83
24	452.81	519.48	730.18	792.38	768.45
25	455.06	521.72	729.46	790.98	767.71
26	457.29	523.96	729.38	790.26	767.66
27	459.44	526.11	732.96	793.34	769.69
28	461.53	528.20	731.96	791.87	768.88
29	463.52	530.19	731.49	791.06	768.70
30	465.41	532.07	734.72	793.97	765.56
31	467.25	533.92	741.99	801.02	764.75
32	469.08	535.74	741.30	800.14	764.66
33	470.78	537.45	744.25	802.90	771.27
34	472.39	539.06	742.64	801.20	770.19
35	473.98	540.65	741.76	800.23	769.84
36	475.54	542.20	744.59	802.97	771.69
37	476.98	543.65	742.93	801.24	770.59
38	478.42	545.09	742.08	800.31	770.27
39	479.75	546.42	778.09	836.32	802.96
40	481.10	547.77	776.32	834.56	801.90

7.6.2.3 Hiring rate, training, and equipment acquisition

Closer examination of budget spending to improve LBP prevention index reveals two areas of improvement: human resources and equipment scopes. Human resources aim to improve human performance by reducing night shift, reducing working hour, and providing workers with LBP related training. Equipment scope, on the other hand, focuses on replacing cushion with suspension seats, and purchasing new heavy equipment. The results, shown in Figure 7.18 and Table 7.13, prove the importance of human resources over the equipment acquisition in improving LBP prevention index in the long-term.

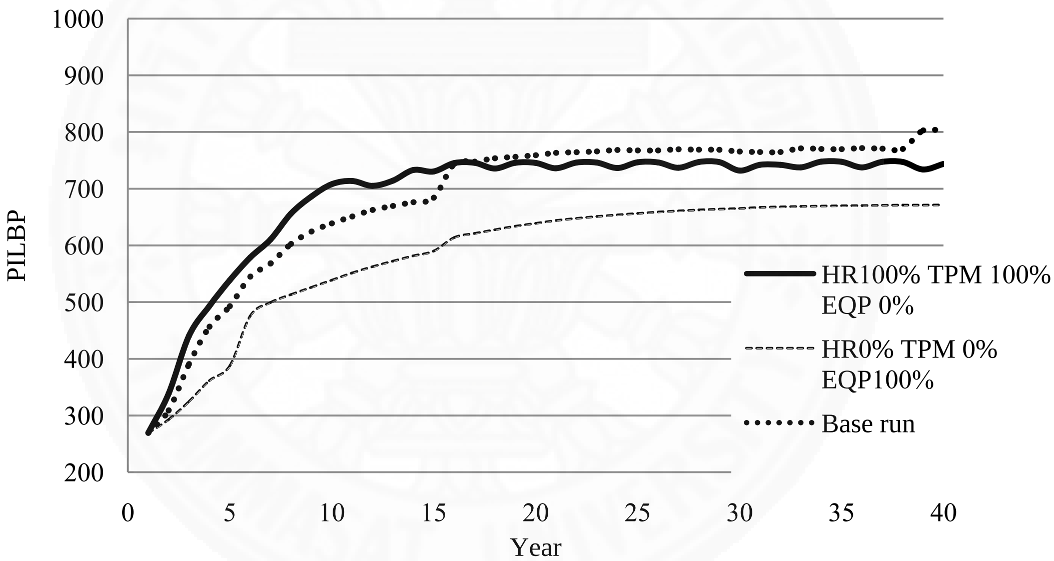

Figure 7.18 Graphical results of LBP prevention index with different hiring rates, training rates, and equipment acquisition

Table 7.13 LBP prevention index with different hiring rates, training rates, and equipment acquisition

Year	LBP prevention index (Points)		
	HR100%, TPM 100%, and EQP 0%	HR0%, TPM 0% , and EQP100%	Base run
1	269.29	269.29	269.29
2	338.50	292.95	309.00
3	440.39	324.91	390.46
4	493.20	361.48	456.46
5	538.76	387.89	492.53
6	578.69	475.66	544.85
7	610.53	499.44	568.40
8	656.00	513.45	602.47
9	686.41	526.19	624.50
10	708.18	538.82	639.01
11	713.78	551.63	651.16
12	705.16	562.60	662.55
13	714.38	572.51	669.54
14	733.08	581.70	676.33
15	730.53	590.09	684.05
16	745.37	613.96	743.51
17	745.81	621.11	747.82
18	735.68	627.79	753.75
19	745.79	634.03	756.46
20	745.62	639.05	759.17
21	736.21	644.02	763.48
22	746.28	647.82	764.44
23	746.11	651.15	765.83
24	736.64	654.08	768.45
25	746.72	656.57	767.71
26	746.47	658.94	767.66

27	737.08	660.95	769.69
28	747.15	662.69	768.88
29	746.89	664.17	768.70
30	732.02	665.30	765.56
31	742.17	667.20	764.75
32	742.08	668.05	764.66
33	737.81	668.83	771.27
34	747.77	669.43	770.19
35	747.54	669.97	769.84
36	737.67	670.43	771.69
37	747.60	670.80	770.59
38	747.35	671.07	770.27
39	733.92	671.30	802.96
40	743.99	671.52	801.90

Chapter 8
Conclusion and Recommendation

8.1 General overview

This chapter concludes major findings of the study. Contributions to the existing body of knowledge, limitations, and recommendations for future studies are also presented.

8.2 Major findings

The main aim of this study is to develop a LBP prevention index to examine a current LBP prevention maturity level, and plan to improve the LBP prevention index in the long-term. To achieve the aim, a number of objectives are defined as follows:

- Identify items and factors affecting LBP due to WBV exposure based on a number of literature review.
- Develop a questionnaire survey for data collection.
- Perform an EFA to confirm key factors affecting LBP due to WBV exposure and their associated items.
- Perform an SEM analysis to examine relationships among key factors affecting LBP due to WBV exposure.
- Develop a dynamic model of LBP prevention index to asses a current LBP prevention maturity level.
- Perform various scenario analyses to improve the LBP prevention index, and achieve higher maturity level in the long-term.

To achieve the above objectives, a number of construction-, health-, ergonomic-, and WBV exposure-related literatures are reviewed, and five key factors and their 17 associated items are hypothesized. A questionnaire survey is then developed based on the extracted items to gather data for the analysis. Data collection is performed with managers and HEOs in Sri Lankan construction companies. Collected data are tested with two major data screening processes, including normality and outlier tests to increase the confidence in data. The screened data are then performed with an EFA to confirm five key factors affecting LBP due to WBV exposure, namely 1) organizational, 2) equipment, 3) personal, 4) job-related, and 5) social-context factors.

To further examine causal relationships among five key factors affecting LBP due to WBV exposure, an SEM model is developed, including measurement and structural models. The best fit measurement model confirms correlations among five key factors except those between the organizational and job-related factors, and the organizational and social context factors. The model also confirms a strong relationship between the equipment and personal factors. In contrast, equipment and organizational factors are found having a weak relationship.

The directions of relationships among five key factors are confirmed with the structural model. The best fit structural model reveals that the organizational factor is the most important factor, as it influences the other four factors, both directly and indirectly .The organizational factor has a positive impact on the personal factor, but a negative effect on the equipment factor .It also indirectly influences the job-related and social context factors through the implementation of the personal factor .

To plan for the LBP prevention program in the long term, a dynamic model of LBP prevention index is developed based on the confirmed five factors and their relationships. A construction company can reach level 5 of maturity with the LBP prevention index higher than 800 points in the long-term. Simulation results reveal that at the beginning years, a construction company achieves level 2 of maturity, with support from the company, both physically and financially, the company can progress to higher levels of maturity.

A number of scenarios are performed to examine different strategies a construction company can develop to improve the LBP prevention index. The company should also initiate a number of activities, such as training and exercising, to improve the maturity level; and achieve higher LBP index in the long-term. The results confirm the importance of financial support in hiring additional workers to improve the LBP prevention index.

8.3 Contribution

The dynamic model of LBP prevention index is developed based on the data collected in Sri Lankan construction industry. The study results contribute to the body of knowledge in the following areas.

- Most of the studies examine items and factors affecting health among HEOs. However, none of them look at causal relationships among factors affecting LBP due to WBV exposure in specific. This study, therefore, enlarges the understandings of LBP due to WBV exposure.
- The developed dynamic model consolidates key factors and their associated items to reduce chances of having LBP among HEOs in the construction industry. By analyzing the different scenarios to reduce LBP prevalence, managers can select the best policy that matches their situation.
- The developed model also assists a construction company effectively utilizing the limited budget to improve the LBP prevention index in the long-term.
- Even though the study is based on the construction industry, the results can be immensely beneficial for academic purposes. The developed dynamic model can be applied in similar areas of studies.

8.4 Limitations and recommendations for future studies

There are limitations in this study. Data used in this study are based on the construction industry in Sri Lanka, which is a developing country. Therefore, applying the study results in other developing or developed countries may need some adjustments. Items such as gender, posture, and weather are not included in this study. Moreover, the maturity levels used in this study are based on literature review. In-depth interview can be conducted to adjust the score ranges of the maturity level in compliance with the company.

8.5 Closure

The dynamic model of LBP prevention index provides a deep perception into interactions among key factors and items affecting LBP due to WBV exposure in the construction industry. It assists a construction company in planning for the long-term reduction of LBP prevalence, thus, enhancing safety and health standard in the construction industry.

References

Books and Book Articles

Comrey, A. L., & Lee, H. B. (2013). A first course in factor analysis. Bloomberg: Psychology Press.

Hair Jr, J. F., & Lukas, B. (2014). Marketing research (Vol. 2). Australia: McGraw-Hill Education.

Hair, J. F., Anderson, R. E., Tatham, R. L., & William, C., Black (1995), Multivariate Data Analysis. New York: Macmillan.

Landau, S., & Everitt, B.S. (2004). A handbook of statistical analyses using SPSS. New York: CRC.

Mansfield, N. J. (2004). Human response to vibration. Florida: CRC press.

McPhee, B., Foster, G., & Long, A. (2001). Bad Vibrations: A Handbook on Whole body Vibration Exposure in Mining. Australia: Long Joint Coal Board Health and Safety Trust.

Pallant, J.(2). (2005). SPSS survival manual: a step by step guide to data analysis using SPSS for window (version 12). Crows Nest, NSW, Australia: Allen and Unwin.

Rigdon, E. E. (2014). Structural equation modeling: Non-traditional alternatives. Wiley StatsRef: Statistics Reference Online, 1-12.

Tabachnick, B. G., Fidell, L. S. (2007). Using multivariate statistics. 5th ed. USA: Pearson/ Allyn &Bacon.

Vaid, K.N. (1999). Contract labour in the construction industry in India, in D.P.A. Naidu (ed.): Contract labour in South Asia, Geneva: ILO, Bureau for Workers' Activities.

Vehkalahti, K., Puntanen, S., & Tarkkonen, L. (2009). Implications of dimensionality on measurement reliability. In Statistical inference, econometric analysis and matrix algebra . Heidelberg, Physica-Verlag HD. DOI: https://doi.org/10.1007/978-3-7908-2121-5_10.

Articles

Abdulwahab, L., Zulkhairi, M. D., & Galadima, M. B. (2011). Data screening and preliminary analysis of the determinants of user acceptance of telecentre. *International Journal of Information Systems the New Paradigm*, 1(1); 11-23.

Alghadir, A., & Anwer, S. (2015). Prevalence of musculoskeletal pain in construction workers in Saudi Arabia. *The Scientific World Journal*, 2015,1-5 .

Amarasekara, S. K. S. (2014). *Construction industry resource requirements*. Proceedings of the 20th Asia construct conference, Hong Kong.

Azlis-Sani, J., bin Zaid, M. F., Yahya, M. N., Ismail, S. M., Tajedi, A., Aqilah, N., ... & Zein, R. M. (2015). Evaluation of Whole Body Vibration and Back Pain Problem Among Light Rapid Transit (LRT) Drivers. *In Applied Mechanics and Materials*, 773, 845-849.

Bardenheier, B. H., Bullard, K. M., Caspersen, C. J., Cheng, Y. J., Gregg, E. W., & Geiss, L. S. (2013). A novel use of structural equation models to examine factors associated with prediabetes among adults aged 50 years and older. *Diabetes Care*, 36(9), 2655-2662.

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System dynamics review*, 12(3), 183-210.

Bauer, C., & Bodendorf, F. (2005). Component-Based Composition of System Dynamics Models. In Proceedings of the 19th European Conference on Modelling and Simulation, Latvia.

Blood, R. P., Ploger, J. D., Yost, M. G., Ching, R. P., & Johnson, P. W. (2010). Whole body vibration exposures in metropolitan bus drivers: A comparison of three seats. Journal of Sound and Vibration, 329(1), 109-120.

Boshuizen, H. C., Bongers, P. M., & Hulshof, C. T. (1990). Self-reported back pain in tractor drivers exposed to whole-body vibration. *International archives of occupational and environmental health*, 62(2), 109-115.

Bouloiz, H., Garbolino, E., Tkiouat, M., & Guarnieri, F. (2013). A system dynamics model for behavioral analysis of safety conditions in a chemical storage unit. *Safety science*, 58, 32-40.

Bovenzi, M., & Hulshof, C. T. J. (1998). An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain. *Journal of Sound and vibration*, 215(4),595-611.

Bovenzi, M., Rui, F., Negro, C., D'Agostin, F., Angotzi, G., Bianchi, S., ... & Rondina, L. (2006). An epidemiological study of low back pain in professional drivers. *Journal of sound and vibration*, 298(3), 514-539.

Bovenzi, M., Schust, M., & Mauro, M. (2017). An overview of low back pain and occupational exposures to whole-body vibration and mechanical shocks. *La Medicina del lavoro*, 108(6), 419-433.

Bovwe, O., Nwaogazie, I. L., & Agunwamba, J. C. (2016). Exploratory Factor Analysis & Assessment of Energy Potential of Generated Solid Waste in Nigeria. *International Journal of Civil Engineering and Technology*, 7 (1), 274-289.

Burdorf, A., & Sorock, G. (1997). Positive and negative evidence of risk factors for back disorders. Scandinavian journal of work, *Environment & health*, 23(4), 243-256.

Campbell, P., Foster, N. E., Thomas, E., & Dunn, K. M. (2013). Prognostic indicators of low back pain in primary care: five-year prospective study. *The journal of pain*, 14(8), 873-883.

Cann, A. P., Salmoni, A. W., Vi, P., & Eger, T. R. (2003). An exploratory study of whole-body vibration exposure and dose while operating heavy equipment in the construction industry. *Applied occupational and environmental hygiene*, 18(12), 999-1005.

Cappelleri, J. C., Gerber, R. A., Kourides, I. A., & Gelfand, R. A. (2000). Development and factor analysis of a questionnaire to measure patient satisfaction with injected and inhaled insulin for type 1 diabetes. *Diabetes care*, 23(12), 1799-1803.

Chaudhary, D. K., Bhattacherjee, A., Patra, A. K., & Chau, N. (2015). Whole-body vibration exposure of drill operators in iron ore mines and role of machine-related, individual, and rock-related factors. *Safety and health at work*, 6(4), 268-278.

Chinda, T. (2016). Factors Influencing Construction Safety Equipment Selection. *International Journal of Structural and Civil Engineering Research*, 5(4), 333-336.

Chinda, T., & Mohamed, S. (2008). Structural equation model of construction safety culture. Engineering, *Construction and Architectural Management*, 15(2), 114-131.

Costello, A. B., & Osborne, J. W. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical assessment, research & evaluation*, 10(7), 1-9.

Cvetanović, B. (2013). *Legislation and standardization related to whole body vibration*. In Proceedings of the 11th International conference on accomplishments in electrical and mechanical engineering and information technology, Banja Luka.

Dan, E., & Ijeoma, O. (2013). STATISTICAL ANALYSIS/METHODS OF DETECTING OUT LIERS IN A UNIVARIATE DATA IN A REGRESSION ANALYSIS MODEL. *International journal of education and research*, 1(5), 1-24.

Das, K. R., & Imon, A. H. M. R. (2016). A brief review of tests for normality. *American Journal of Theoretical and Applied Statistics*, 5(1), 5-12.

Doan, D. T., & Chinda, T. (2016). Modeling construction and demolition waste recycling program in Bangkok: Benefit and cost analysis. *Journal of Construction Engineering and Management*, 142(12).DOI: 10.1061/ (ASCE) CO.1943-7862.0001188.

Fan, H., & Jin, Z. (2011). *A study on the factors affecting the economic life of heavy construction equipment*. Proceedings of the 28th ISARC, Korea.

Fang, D., Chen, Y., & Wong, L. (2006). Safety climate in construction industry: A case study in Hong Kong. *Journal of construction engineering and management*, 132(6), 573-584.

Ferguson, S. A., Allread, W. G., Burr, D. L., Heaney, C., & Marras, W. S. (2012). Biomechanical, psychosocial and individual risk factors predicting low back functional impairment among furniture distribution employees. *Clinical Biomechanics*, 27(2), 117-123.

Foster, P., & Hoult, S. (2013). The safety journey: Using a safety maturity model for safety planning and assurance in the UK coal mining industry. *Minerals*, 3(1), 59-72.

Fransen, M., Woodward, M., Norton, R., Coggan, C., Dawe, M., & Sheridan, N. (2002). Risk factors associated with the transition from acute to chronic occupational back pain. *Spine*, 27(1), 92-98.

Frazer, M., Norman, R., Wells, R., & Neumann, P. (2003). The effects of job rotation on the risk of reporting low back pain. *Ergonomics*, 46(9), 904-919.

Freburger, J. K., Holmes, G. M., Agans, R. P., Jackman, A. M., Darter, J. D., Wallace, A. S., ... & Carey, T. S. (2009). The rising prevalence of chronic low back pain. *Archives of internal medicine*, 169(3), 251-258.

Gao, R., Chan, A. P., Utama, W. P., & Zahoor, H. (2016). Multilevel safety climate and safety performance in the construction industry: Development and validation of a top-down mechanism. *International journal of environmental research and public health*, 13(11), 1-14.

Gaskin, C. J., & Happell, B. (2014). On exploratory factor analysis: A review of recent evidence, an assessment of current practice, and recommendations for future use. *International journal of nursing studies*, 51(3), 511-521.

Gervais, M. (2003). Good management practice as a means of preventing back disorders in the construction sector. *Safety science*, 41(1), 77-88.

Ghazanfarpour, M., Kaviani, M., Rezaiee, M., Ghaderi, E., & Zandvakili, F. (2014). Cross cultural adaptation of the menopause specific questionnaire into the

Persian language. *Annals of medical and health sciences research*, 4(3), 325-329.

Gillin, E. K., Cann, A., Vi, P., Eger, T., Hunt, M., & Salmoni, A. (2006). *Evaluation of scraper operator exposure to whole-body vibration in the construction industry: a task analysis*. In Proceedings of the First American Conference on Human Vibration, Morgantown, West Virginia, USA.

Glombiewski, J. A., Hartwich-Tersek, J., & Rief, W. (2010). Depression in chronic back pain patients: prediction of pain intensity and pain disability in cognitive-behavioral treatment. *Psychosomatics*, 51(2), 130-136.

Govindu, N. K., & Babski-Reeves, K. (2014). Effects of personal, psychosocial and occupational factors on low back pain severity in workers. *International Journal of Industrial Ergonomics*, 44(2), 335-341.

Griffin, M. J. (1998). A comparison of standardized methods for predicting the hazards of whole-body vibration and repeated shocks. *Journal of sound and vibration*, 215(4), 883-914.

Groeneveld, R. A., & Meeden, G. (1984). Measuring skewness and kurtosis. *The Statistician*, 33(4), 391-399.

Groff, J. (2013). Dynamic systems modeling in educational system design & policy. *Journal of New Approaches in Educational Research (NAER Journal)*, 2(2), 72-81.

Hallner, D., & Hasenbring, M. (2004). Classification of psychosocial risk factors (yellow flags) for the development of chronic low back and leg pain using artificial neural network. *Neuroscience letters*, 361(1-3), 151-154.

Henson, R. K., & Roberts, J. K. (2006). Use of exploratory factor analysis in published research: Common errors and some comment on improved practice. *Educational and Psychological measurement*, 66(3), 393-416.

Hoogendoorn, W. E., Bongers, P. M., De Vet, H. C. W., Ariens, G. A. M., Van Mechelen, W., & Bouter, L. M. (2002). High physical work load and low job satisfaction increase the risk of sickness absence due to low back pain: results of a prospective cohort study. *Occupational and environmental medicine*, 59(5); 323-328.

Hooper, D., Coughlan, J., & Mullen, M. (2008). Structural equation modelling: Guidelines for determining model fit. *Electronic Journal of Business Research Methods*, 6(1), 53-60.

Hox, J. J., & Bechger, T. M. (2007). An introduction to structural equation modeling. *Journal of family science review*, 11, 354-373.

Hox, J. J., & Boeije, H. R. (2005). Data collection, primary versus secondary. *Encyclopedia of social measurement*,1, 593-599.

Huang, X., & Hinze, J. (2006). Owner's role in construction safety. *Journal of construction engineering and management*, 132(2), 164-173.

Issever, H., Aksoy, C., Sabuncu, H., & Karan, A. (2003). Vibration and its effects on the body. *Medical Principles and Practice*, 12(1), 34-38.

Jamil, N. I., Baharuddin, F. N., & Maknu, T. S. R. (2015). Factors Mining in Engaging Students Learning Styles Using Exploratory Factor Analysis. *Procedia Economics and Finance*, 31, 722-729.

Janwantanakul, P., Pensri, P., Moolkay, P., & Jiamjarasrangsi, W. (2011). Development of a risk score for low back pain in office workers-a cross-sectional study. *BMC musculoskeletal disorders*, 12(1), 23.

Jaselskis, E. J., Anderson, S. D., and Russell, J. S. (1996). “Strategies for achieving excellence in construction safety performance.” Journal of Construcion Engineering and Management, *122*(1), 61–70.

Jetha, A., Pransky, G., Fish, J., & Hettinger, L. J. (2016). Return-to-Work within a complex and Dynamic organizational work disability system. *Journal of occupational rehabilitation*, 26(3), 276-285.

Joubert, D. M., & London, L. (2007). A cross-sectional study of back belt use and low back pain amongst forklift drivers. *International journal of industrial ergonomics*, 37(6), 505-513.

Kakurina, N., Kadisa, A., Lejnieks, A., Mikazane, H., Kozireva, S., & Murovska, M. (2015). Use of exploratory factor analysis to ascertain the correlation between the activities of rheumatoid arthritis and infection by human parvovirus B19. *Medicina*, 51(1), 18-24.

Karunanayake, A. L., Pathmeswaran, A., Kasturiratne, A., & Wijeyaratne, L. S. (2013). Risk factors for chronic low back pain in a sample of suburban Sri Lankan adult males. *International journal of rheumatic diseases*, 16(2); 203-210.

Kaymaz, K. (2010). The Effects of Job Rotation Practices on Motivation: A Research on Managers in the Automotive Organizations/Is Rotasyonu Uygulamalarinin Motivasyon Üzerine Etkileri: Otomotiv Isletmelerinde Görev Yapan Yöneticiler Üzerinde Bir Arastirma. *Business and Economics Research Journal*, 1(3), 69-85.

Kazaz, A., Manisali, E., & Ulubeyli, S. (2008). Effect of basic motivational factors on construction workforce productivity in Turkey. *Journal of civil engineering and management*, 14(2), 95-106.

Khosravi, Y., Asilian-Mahabadi, H., Hajizadeh, E., Hassanzadeh-Rangi, N., Bastani, H., Khavanin, A., & Mortazavi, S. B. (2013). Modeling the factors affecting unsafe behavior in the construction industry from safety supervisors' perspective. *Journal of research in health sciences*, 14(1), 29-35.

Kim, H. Y. (2013). Statistical notes for clinical researchers: assessing normal distribution (2) using skewness and kurtosis. *Restorative dentistry & endodontics*, 38(1), 52-54.

Kim, H., Ku, B., Kim, J. Y., Park, Y. J., & Park, Y. B. (2016). Confirmatory and exploratory factor analysis for validating the Phlegm Pattern Questionnaire for healthy subjects. *Evidence-Based Complementary and Alternative Medicine*, 2016, 1-8.

Kim, S. E., Seo, I. W., & Choi, S. Y. (2017). Assessment of water quality variation of a monitoring network using exploratory factor analysis and empirical orthogonal function. *Environmental Modelling & Software*, 94, 21-35.

Kittusamy, N. K., & Buchholz, B. (2004). Whole-body vibration and postural stress among operators of construction equipment: A literature review. *Journal of safety research*, 35(3), 255-261.

Kohn, J. W., McGinnis, M. A., & Kara, A. (2011). A structural equation model assessment of logistics strategy. *The International Journal of Logistics Management*, 22(3), 284-305.

Krause, N., Ragland, D. R., Greiner, B. A., Syme, L., & Fisher, J. M. (1997). Psychosocial job factors associated with back and neck pain in public transit operators. *Scandinavian journal of work, environment & health*, (23), 179-186.

Kwon, A. M., & Shin, C. (2016). Structural equation modelling for the effect of physical exercise on excessive daytime sleepiness. *Public health*, 141, 95-99.

Lahiri, S., Gold, J., & Levenstein, C. (2005). Estimation of net-costs for prevention of occupational low back pain: Three case studies from the US. *American journal of industrial medicine*, 48(6), 530-541.

Langer, T. H., Iversen, T. K., Andersen, N. K., Mouritsen, O. Ø., & Hansen, M. R. (2012). Reducing whole-body vibration exposure in backhoe loaders by education of operators. *International Journal of Industrial Ergonomics*, 42(3), 304-311.

Lee, M. H., & Tserng, H. P. (2006). Applying knowledge map for junior construction engineer. ISARC2006, Japan.

Lewis, A. J., Rowland, B., Tran, A., Solomon, R. F., Patton, G. C., Catalano, R. F., & Toumbourou, J. W. (2017). Adolescent depressive symptoms in India, Australia and USA: Exploratory Structural Equation Modelling of cross-national invariance and predictions by gender and age. *Journal of affective disorders*, 212, 150-159.

Li, C. P., & Lan, H. C. (2017). Psychometric properties of the indicators of professional competence for exercise instructors for elderly people. *Neuropsychiatry (London)*, 7(3), 197-203.

Lorenzo-Seva, U., & Ferrando, P. J. (2006). FACTOR: A computer program to fit the exploratory factor analysis model. *Behavior research methods*, 38(1), 88-91.

Lunde, L. K., Koch, M., Knardahl, S., Wærsted, M., Mathiassen, S. E., Forsman, M., ... & Veiersted, K. B. (2014). Musculoskeletal health and work ability in physically demanding occupations: study protocol for a prospective field study on construction and health care workers. *BMC public health*, 14(1), 1-11.

Lundström, R., & Holmlund, P. (1998). Absorption of energy during whole-body vibration exposure. *Journal of Sound and Vibration*, 215(4), 789-799.

Magnusson, M. L., Pope, M. H., Hulshof, C. T. J., & Bovenzi, M. (1998). Development of a Protocol for Epidemiologal Studies of Whole-Body Vibration and Musculoskeletal Disorders of the Lower Back. *Journal of sound and vibration*, 215(4); 643-651.

Makhsous, M., Hendrix, R., Crowther, Z., Nam, E., & Lin, F. (2005). Reducing whole-body vibration and musculoskeletal injury with a new car seat design. *Ergonomics*, 48(9), 1183-1199.

Malchaire, J., Cock, N., & Vergracht, S. (2001). Review of the factors associated with musculoskeletal problems in epidemiological studies. *International archives of occupational and environmental health*, 74(2), 79-90.

Manek, N. J., & MacGregor, A. J. (2005). Epidemiology of back disorders: prevalence, risk factors, and prognosis. *Current opinion in rheumatology*, 17(2), 134-140.

Marshall, D. A., Burgos-Liz, L., IJzerman, M. J., Osgood, N. D., Padula, W. V., Higashi, M. K., ... & Crown, W. (2015). Applying dynamic simulation modeling methods in health care delivery research—the SIMULATE checklist: report of the ISPOR Simulation Modeling Emerging Good Practices Task Force. *Value in health*, 18(1), 5-16.

Martis, M. S. (2006). Validation of simulation based models: a theoretical outlook. *The electronic journal of business research methods*, 4(1), 39-46.

Mayton, A. G., Jobes, C. C., & Gallagher, S. (2014). Assessment of whole-body vibration exposures and influencing factors for quarry haul truck drivers and loader operators. *International journal of heavy vehicle systems*, 21(3); 241-261.

Miles, J., & Shevlin, M. (2007). A time and a place for incremental fit indices. *Personality and Individual Differences*, 42(5), 869-874.

Mohamed, S., & Chinda, T. (2011). System dynamics modelling of construction safety culture. *Engineering, Construction and Architectural Management*, 18(3), 266-281.

Murri, M. B., Mamberto, S., Briatore, L., Mazzucchelli, C., Amore, M., & Cordera, R. (2017). The interplay between diabetes, depression and affective temperaments: a structural equation model. *Journal of affective disorders*, 219, 64-71

Murtezani, A., Ibraimi, Z., Sllamniku, S., Osmani, T., & Sherifi, S. (2011). Prevalence and risk factors for low back pain in industrial workers. *Folia medica*, 53(3), 68-74.

Mustapha, Z., Aigbavboa, C. O., & Thwala, W. D. (2016). Exploratory factor analysis of employee's actions towards health and safety compliance in construction. *Proceedings of the creative construction conference 2016, Hungray*, 25-28 June 2016 Hungary.

Muzammil, M., Siddiqui, S. S., & Hasan, F. (2004). Physiological effect of vibrations on tractor drivers under variable ploughing conditions. *Journal of occupational health*, 46(5), 403-409.

Narayanan, A. (2012). A review of eight software packages for structural equation modeling. *The American Statistician*, 66(2), 129-138.

Nilsen, T. I. L., Holtermann, A., & Mork, P. J. (2011). Physical exercise, body mass index, and risk of chronic pain in the low back and neck/shoulders: longitudinal data from the Nord-Trøndelag Health Study. *American journal of epidemiology*, 174(3), 267-273.

Okunribido, O. O., Magnusson, M., & Pope, M. (2006). Delivery drivers and low-back pain: A study of the exposures to posture demands, manual materials handling and whole-body vibration. *International Journal of Industrial Ergonomics*, 36(3), 265-273.

Osborne, J. W. (2015). What is rotating in exploratory factor analysis. Practical Assessment, *Research & Evaluation*, 20(2), 1-7.

Paschold, H. W. (2008). Whole-Body Vibration An Emerging Topic For the SH&E Profession. *Professional Safety*, 53(06), 52-57.

Paschold, H. W., & Mayton, A. G. (2011). Whole-body vibration: building awareness in SH&E. *professional Safety*, 56(4), 30-35.

Pellicer, E., Carvajal, G. I., Rubio, M. C., & Catalá, J. (2014). A method to estimate occupational health and safety costs in construction projects. *KSCE journal of civil engineering*, 18(7), 1955-1965.

Raffler, N., Ellegast, R., Kraus, T., & Ochsmann, E. (2016). Factors affecting the perception of whole-body vibration of occupational drivers: an analysis of posture and manual materials handling and musculoskeletal disorders. *Ergonomics*, 59(1), 48-60.

Rahman, H. A., Abdul-Mumin, K., & Naing, L. (2017). Psychosocial factors, musculoskeletal disorders and work-related fatigue amongst nurses in Brunei: structural equation model approach. *International emergency nursing*, 34, 17-22.

Rainville, J., Hartigan, C., Martinez, E., Limke, J., Jouve, C., & Finno, M. (2004). Exercise as a treatment for chronic low back pain. *The Spine Journal*, 4(1), 106-115.

Ramond-Roquin, A., Bodin, J., Serazin, C., Parot-Schinkel, E., Ha, C., Richard, I., ... & Roquelaure, Y. (2015). Biomechanical constraints remain major risk factors for low back pain. Results from a prospective cohort study in French male employees. *The Spine Journal*, 15(4); 559-569.

Ringen, K., Seegal, J., & England, A. (1995). Safety and health in the construction industry. *Annual review of public health*, 16(1), 165-188.

Ritchie- Dunham, J. L., & Méndez Galván, J. F. (1999). Evaluating epidemic intervention policies with systems thinking: a case study of dengue fever in Mexico. *System Dynamics Review: The Journal of the System Dynamics Society*, 15(2), 119-138.

Rose, J. P., Aspiras, O., Vogel, E., Haught, H., & Roberts, L. (2017). Comparative Optimism and Event Skewness. *Journal of Behavioral Decision Making*, 30(2), 236-255.

Ryu, E. (2011). Effects of skewness and kurtosis on normal-theory based maximum likelihood test statistic in multilevel structural equation modeling. *Behavior research methods*, 43(4), 1066-1074.

Salmoni, A. W., Cann, A. P., Gillin, E. K., & Eger, T. R. (2008). Case studies in whole-body vibration assessment in the transportation industry–Challenges in the field. *International Journal of Industrial Ergonomics*, 38(10), 783-791.

Sawacha, E., Naoum, S., & Fong, D. (1999). Factors affecting safety performance on construction sites. *International journal of project management*, 17(5), 309-315.

Schreiber, J. B., Nora, A., Stage, F. K., Barlow, E. A., & King, J. (2006). Reporting structural equation modeling and confirmatory factor analysis results: A review. *The Journal of educational research*, 99 (6), 323-338.

Senge, P. M., & Forrester, J. W. (1980). Tests for building confidence in system dynamics models. System dynamics, *TIMS studies in management sciences*, 14, 209-228.

Shadfar, S., & Malekmohammadi, I. (2013). Application of Structural Equation Modeling (SEM) in restructuring state intervention strategies toward paddy production development. *International Journal of Academic Research in Business and Social Sciences*, 3(12), 576-618.

Shaw, D., Hoops, D., Butler, K. M., & Nahar, A. (2016). *Statistical outlier screening as a test solution health monitor*. In Test Conference (ITC), 2016 IEEE International, Texas.

Shin, M., Lee, H. S., Park, M., Moon, M., & Han, S. (2014). A system dynamics approach for modeling construction workers' safety attitudes and behaviors. *Accident Analysis & Prevention*, 68, 95-105.

Shivakumara, B. S., & Sridhar, V. (2010). Study of vibration and its effect on health of the motorcycle rider. *Online Journal of Health and Allied Sciences*, 9(2), 1-4.

Smith, D. R., & Leggat, P. A. (2005). Whole-Body Vibration. *Professional safety*, 50(7), 35-40.

Solís-Carcaño, R. G., & Franco-Poot, R. J. (2014). Construction workers' perceptions of safety practices: A case study in Mexico. *Journal of Building Construction and Planning Research*, 2(01), 1-11.

Suhr, D. (2003). Reliability, exploratory & confirmatory factor analysis for the scale of athletic priorities. *Diambil pada tanggal*, 2, 274-278.

Suhr, D. (2008). *Step your way through path analysis*. In Western users of SAS software conference proceedings, California.

Taherdoost, H. A. M. E. D., Sahibuddin, S. H. A. M. S. U. L., & Jalaliyoon, N. E. D. A. (2014). Exploratory factor analysis: Concepts and theory. *Advances in Applied and Pure Mathematics*, 375-382.

Takahashi, M., Matsudaira, K., & Shimazu, A. (2015). Disabling low back pain associated with night shift duration: sleep problems as a potentiator. *American journal of industrial medicine*, 58(12), 1300-1310.

Tam, C. M., Zeng, S. X., & Deng, Z. M. (2004). Identifying elements of poor construction safety management in China. *Safety Science*, 42(7), 569-586.

Thiese, M. S., Hegmann, K. T., Wood, E. M., Garg, A., Moore, J. S., Kapellusch, J. M., ... & Biggs, J. (2014). Low-back pain ratings for lifetime, 1-month period, and point prevalence in a large occupational population. *Human factors*, 56(1), 86-97.

Tiemessen, I. J., Hulshof, C. T., & Frings-Dresen, M. H. (2007). The development of an intervention programme to reduce whole-body vibration exposure at work induced by a change in behavior: a study protocol. *BMC Public Health*, 7(1), 329-339.

Trejo, S.J. (1993). Overtime pay, overtime hours, and labor unions. *Journal of Labor Economics*. 11(2), 253-78.

Udom, C., Janwantanakul, P., & Kanlayanaphotporn, R. (2016). The prevalence of low back pain and its associated factors in Thai rubber farmers. *Journal of occupational health*, 58(6), 534-542.

Ueno, S., Hisanaga, N., Jonai, H., SHIBATA, E., & KAMIJIMA, M. (1999). Association between musculoskeletal pain in Japanese construction workers and job, age, alcohol consumption, and smoking. *Industrial health*, 37(4), 449-456.

Van Horn, J. E., Reinders, M., Eisenberg, M. J., de Lima-Heijns, A., & Posthumus, J. (2016). Using structural equation modeling to assess the impact of factors on sexual risk and delinquent behavior in Dutch female offenders. *Children and youth services review*, 71, 233-240.

Vidal, M. C., Guizze, C. L. C., Bonfatti, R. J., & Silva e Santos, M. (2012). Ergonomic sustainability based on the ergonomic maturity level measurement. *Work*, 41(Supplement 1), 2721-2729.

Vitharana, V. H. P., & Chinda, T. (2017). Structural equation modelling of lower back pain due to whole-body vibration exposure in the construction industry. *International Journal of Occupational Safety and Ergonomics*, 1-11.

Vitharana, V. H. P., De Silva, G. H. M. J., & De Silva, S. (2015). Health hazards, risk and safety practices in construction sites–a review study. *Engineer*, 48(3), 35-44.

Vitharana, V. H. P., De Silva, G. S., & De Silva, G. (2014). *Whole Body Vibration Exposures of Workers in Construction Sites in Sri Lanka*. Proceedings of the 4th Annual Sessions of the Society of Structural Engineers, Colombo, Sri Lanka, 24th September 2014 (pp. 17-24): Society of structural engineers.

Vithrana, V. H. P., & Chinda, T. (2016) Factors Affecting Health Problems among Construction Workers due to Whole Body Vibration (WBV): Literature Review. TIMES-iCON2016, 71-78.

Vlaeyen, J. W., de Jong, J., Geilen, M., Heuts, P. H., & van Breukelen, G. (2001). Graded exposure in vivo in the treatment of pain-related fear: a replicated single-case experimental design in four patients with chronic low back pain. *Behaviour research and therapy*, 39(2), 151-166.

Von Hippel, P. T. (2005). Mean, median, and skew: Correcting a textbook rule. *Journal of Statistics Education*, 13(2), 1-13.

Wang, W., Wang, Y., Xiao, C., Yao, X., Yang, Y., Yan, H., & Li, S. (2018). Psychological pathway to suicidal ideation among People Living with HIV/AIDS in China: A Structural Equation Model. *Psychiatry research*, 260, 255-261.

Williams, B., Onsman, A., & Brown, T. (2010). Exploratory factor analysis: A five-step guide for novices. *Australasian Journal of Paramedicine*, 8(3), 1-13.

Wong, T. S., Teo, N., & Kyaw, M. (2010). Prevalence and Risk Factors Associated with Low Back Among Health Care Providers in a District Hospital. *Malaysian Orthopaedic Journal*, 4(2), 23-28.

Yang, H., Hitchcock, E., Haldeman, S., Swanson, N., Lu, M. L., Choi, B., ... & Baker, D. (2016). Workplace psychosocial and organizational factors for neck pain in workers in the United States. *American journal of industrial medicine*, 59(7), 549-560.

Yong, A. G., & Pearce, S. (2013). A beginner's guide to factor analysis: Focusing on exploratory factor analysis. *Tutorials in quantitative methods for psychology*, 9(2), 79-94.

Yu, T., & Richardson, J. C. (2015). An Exploratory Factor Analysis and Reliability Analysis of the Student Online Learning Readiness (SOLR) Instrument. *Online Learning*, 19(5), 120-141.

Zhao, X., & Schindler, C. (2014). Evaluation of whole-body vibration exposure experienced by operators of a compact wheel loader according to ISO 2631-1: 1997 and ISO 2631-5: 2004. *International Journal of Industrial Ergonomics*, 44(6), 840-850.

Zimmermann, C. L., Cook, T. M., & Rosecrance, J. C. (1997). Operating engineers: work-related musculoskeletal disorders and the trade. *Applied occupational and environmental hygiene*, 12(10), 670-680.

Other materials

Barnabas, W. D., & Sriram, V. (2011). *Industry report on Sri Lanka*. Sri Lanka:A report published by ICRA and IMaCS.

Bernard, B. P., & Putz-Anderson, V. (1997). *Musculoskeletal disorders and workplace factors; a critical review of epidemiologic evidence for work-*

related musculoskeletal disorders of the neck, upper extremity, and low back. USA: National institute for occupational safety and health centers for disease control and prevention.

Cudeck, R. (2000). *Exploratory factor analysis. In Handbook of applied multivariate statistics and mathematical modeling*. Minnesota: Department of Psychology, University of Minnesta (pp. 265-296).

De Beeck, R. O., & Hermans, V. (2000). *Work-related low back disorders*. Luxembourg: Office for official publications of the European communities.

Dixon, S. (2009). *A profile of temporary workers and their employment outcomes. Department of Labour research paper*. Retrieved from www. dol. govt. nz/publications/research/temporaryworkers/temporarywork ers_04. asp.

Donati, P. (2008). *Workplace exposure to vibration in Europe: an expert review* (No. 7). Belgium: Office for Official Publications of European Communities.

Government of India. (2005). *Study report on compaction equipment and construction machinery*. Manak Nagar, Lucknow: Research design & standards organization

Griffin, M. J., Howarth, H. V. C., Pitts, P. M., Fischer, S., Kaulbars, U., Donati, P. M., & Bereton, P. F. (2006). *Guide To Good Practice on Whole-Body Vibration. Non-binding guide to good practice with a view to implementation of Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibrations).* Retrived from http://resource.isvr.soton.ac.uk/HRV/VIBGUIDE/2008_11_08%20WBV_Good_practice_Guide%20v6.7h%20English.pdf

Hassan, S. A. (2012). *Health, Safety & Environmental Practices in the Construction Sector of Pakistan* (MS dissertation), Retrieved from Uppsala University.

Hoeckel, K. (2008). *Costs and benefits in vocational education and training*. Paris: Organization for Economic Cooperation and Development.

Hopkinson, J., Fox, D., Lunt, J.(2015). *Development of a health risk management maturity index(HeRMMIn) as a performance leading indicator within the construction industry*. London: Health and safety Laboratory.

Hutchinson, G. (2010). *National Hazard Exposure Work Surveillance: Vibration exposure and the provision of vibration control measures in Australian workplaces. Safe Work Australia.* Australia: Australian Safety and Compensation Council.

International Organization for Standardization (ISO). (1997). *Mechanical vibration and shock evaluation of human exposure to whole-body vibration*. Geneva: ISO; 1997. Standard No. ISO 2631-1:1997.

Jailer, T., Lara-Meloy, M., & Robbins, M. (2015). *Workers' Guide to Health and Safety*. Berkeley (CA): Hesperian Health Guides.

John Lant and Partners. (2015). Back pain and Ageing, Retrieved 17-11-2015 from http://www.johnlant.co.uk/back%20facts%20(1).htm,Last access 17-11-2015

Kirkwood, C. W. (1998). *System dynamics methods*. USA: College of Business Arizona State University.

Kordestani, A. (2010). *Ride vibration and compaction dynamics of vibratory soil compactors* (Doctoral dissertation, Concordia University), Retrieved from Concordia University.

Mathers, N., Fox, N., & Hunn, A. (2007). *Surveys and questionnaires*. Sheffield: RDSU.

Miller, L., & Gariepy, C. (2008). *Heavy Mobile Equipment-Ergonomics and the Prevention of Musculoskeletal Injuries*. In BC Mines Conference, California.

Park, H. M. (2015). *Univariate analysis and normality test using SAS, Stata, and SPSS*. Retrieved from http://cef-cfr.ca/uploads/Reference/sasNORMALITY.pdf.

Seo, S. (2006). *A review and comparison of methods for detecting outliers in univariate data sets* (Doctoral dissertation), Retrieved from University of Pittsburgh.

Subhash, R., & Ario, K. (2011). *Evaluation of Whole-Body Vibration Exposure of Operator of Soil Compactors. Noise and Vibration, Studies and Research Project Report*. Quebec: IRSST Communication Division.

Watson, E. D. (2007). *Morphological variables as possible risk factors for the drivers of rubber tyred gantry cranes at the port of Felixstowe, UK*(Doctoral dissertation), Retrieved from Stellenbosch, Stellenbosch University.

Yilmaz, E., & Dedeli, O. (2014). *Effect of physical and psychosocial factors on occupational low back pain.* Retrieved from http://www.hsj.gr/medicine/effect-of-physical-and-psychosocial-factors-on-occupational-low-back-pain.pdf

Appendices

Appendix A
Publication

1. Vitharana, V.H.P. and Chinda, T. (2018). Development of a lower back pain prevention index for heavy equipment operators in the construction industry: System dynamics modeling, Journal of occupational safety and ergonomics, (Under review).
2. Vitharana, V.H.P. and Chinda, T. (2017). Structural equation modeling of lower back pain due to whole body vibration exposure in the construction industry, Journal of occupational safety and ergonomics, DOI 10.1080/10803548.2017.1366119.
3. Vitharana, V.H.P., Chinda T. (2017). Policy analysis of the budget used in training program for reducing lower back pain among heavy equipment operators in the construction industry: System dynamics approach, IconCEES2017, Langkavi, Malaysia.
4. Vitharana V.H.P., Chinda T. (2016). Factors Affecting Health Problems among Construction Workers due to Whole Body Vibration (WBV): Literature Review, TIMES-iCON2016, Bangkok, Thailand (Best paper award).

Appendix B

Questionnaire Survey for Management Level

Survey of identifying factors affecting health effects among soil roller compactors M

School of Management Technology,
Sirindhorn International Institute of Technology,
ThammasatUniversity,
Rangsit,Thailand

PhD Research
Under EFS Scholarship

Date: __/__/____ Time:__:__ Form Number: Project Budget:____SLR

1.0 Personal Information

01. Position ☐ Project manager ☐ Project engineer ☐ Site engineer
☐ Others (please specify) __________

02. Age ☐ 25-45 ☐ 45-54 ☐ >54

03. Education background ☐ High school ☐ Bachelor ☐ Masters ☐ Doctoral

04. Working experience
☐ In current company ________ years
☐ In construction industry ________ years

05. Working hours per day ☐ < 8 ☐ 8 ☐ > 8

06. Have you ever received a safety training program? ☐ Yes ☐ No
☐ If yes, please specify _________________

07. What standards do your company maintain?(can answer more than one) ☐ EC directives ☐ BS code ☐ ISO 2631 ☐ Other _________

08. What is the life time of a soil roller compactor? _______ years

09. Price of a soil roller compactor ________ SLR

10. On average, what is the budget the company provides for safety and health activities? ☐ 1-5 % ☐ 5-10%
☐ Other (Please specify) ________________ (out of total budget)

Survey of identifying factors affecting health effects among soil roller compactors

2.0 Factors

Please rate the degree of your agreement in each statement relating to factors affecting health problems among soil roller compactor operators using the scale 1 to 5.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Statement	Scale				
1. Age of the machine has an effect to LBP.	1	2	3	4	5
2. Age of the worker has an effect to LBP.	1	2	3	4	5
3. Exercise has an effect to LBP.	1	2	3	4	5
4. Education background has an effect to LBP.	1	2	3	4	5
5. Job rotation has an effect to LBP.	1	2	3	4	5
6. Job satisfaction has an effect to LBP.	1	2	3	4	5
7. Night shift has an effect to LBP	1	2	3	4	5
8. Safety and health budget has an effect to LBP	1	2	3	4	5
9. Seat type of the soil roller compactor has an effect to LBP.	1	2	3	4	5
10. Smoking has an effect to LBP.	1	2	3	4	5
11. Soil type at the site has an effect to LBP.	1	2	3	4	5
12. Training program has an effect to LBP.	1	2	3	4	5
13. Weight of the worker has an effect of LBP	1	2	3	4	5
14. Whole body vibration has an effect to LBP.	1	2	3	4	5
15. Whole body vibration standard has an effect to LBP.	1	2	3	4	5
16. Working experience has an effect to LBP.	1	2	3	4	5
17. Working hours has an effect to LBP.	1	2	3	4	5
18. My wage is good.	1	2	3	4	5
19. All my talent and skills are used at work.	1	2	3	4	5
20. On the whole, I believe work is good for my physical health.	1	2	3	4	5

- **Note: LBP= Low back pain**

Thank you for your co-operation

Appendix C

Questionaire Surevey for HEO Operators

Survey of identifying, factors affecting health effects among soil roller compactors W

School of Management Technology,
Sirindhorn International Institute of Technology,
ThammasatUniversity,
Rangsit,Thailand.

PhD Research
Under EFS Scholarship

Date: __/__/____ Time:__:__ Form Number:_______

☐ Smooth wheel/ Vibratory roller ☐ Sheep's foot/ tamping roller ☐ Pneumatic tired roller ☐ Grid roller

1.0 Personal Information

01. Age	☐ 25-45	☐ 45-54	☐ >54
02. Weight	__________________	kg.	
03. Height	__________________	m.	
04. Education background	☐ Not attended or attended less than 5th standard GCE A/L	☐ Attended 6th standard to 12th standard	☐ Higher education
05. Working experience	In current company	_______________	years
	As a soil roller operator	_______________	years
	In construction industry	_______________	years
06. Working hours per day	☐ <8	☐ 8	☐ >8
07. Exercise	☐ Never	☐ Sometimes	☐ Regularly
08. Are you smoking?	☐ Never	☐ Occasionally	☐ Regularly
09. Have you ever received a safety training program?		☐ Yes If yes, please specify	☐ No ______________
10. Have you taken any medication to deal with the Low Back Pain (LBP)?		☐ Never ☐ Regularly	☐ Sometimes
11. Have you suffered from LBP in the last 6 months?		☐ Yes ☐ If yes, please describe the severity of the pain experienced:	☐ No

No pain Extreme pain

0 1 2 3 4 5 6 7 8 9 10

12. What is the life time of a soil roller compactor? _______________ years

Survey of identifying factors affecting health effects among soil roller compactors

2.0 Factors

Please rate the degree of your agreement in each statement relating to factors affecting health problems among soil roller compactor operators using the scale 1 to 5.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Statement	Scale				
1. Age of the machine has an effect to LBP.	1	2	3	4	5
2. Age of the worker has an effect to LBP.	1	2	3	4	5
3. Exercise has an effect to LBP.	1	2	3	4	5
4. Education background has an effect to LBP.	1	2	3	4	5
5. Job rotation has an effect to LBP.	1	2	3	4	5
6. Job satisfaction has an effect to LBP.	1	2	3	4	5
7. Night shift has an effect to LBP	1	2	3	4	5
8. Safety and health budget has an effect to LBP	1	2	3	4	5
9. Seat type of the soil roller compactor has an effect to LBP.	1	2	3	4	5
10. Smoking has an effect to LBP.	1	2	3	4	5
11. Soil type at the site has an effect to LBP.	1	2	3	4	5
12. Training program has an effect to LBP.	1	2	3	4	5
13. Weight of the worker has an effect of LBP	1	2	3	4	5
14. Whole body vibration has an effect to LBP.	1	2	3	4	5
15. Whole body vibration standard has an effect to LBP.	1	2	3	4	5
16. Working experience has an effect to LBP.	1	2	3	4	5
17. Working hours has an effect to LBP.	1	2	3	4	5
18. My wage is good.	1	2	3	4	5
19. All my talent and skills are used at work.	1	2	3	4	5
20. On the whole, I believe work is good for my physical health.	1	2	3	4	5

- **Note: LBP= Low back pain**

Thank you for your co-operation

Appendix D
Cover Letter for the Questionaire Surevey

School of Management Technology ,
Sirindhorn International Institute of Technology,
131 Moo 5, Tivanond Road,
Bangkadi Industrial Park, Bangkadi,
Muang, Pathumthani 12000, Thailand

20th March 2016

Dear Sir/Madam,

I am V.H.P.Vitharana who is a doctoral degree student under the supervision of Asst.Prof.Dr.Thanwadee Chinda in Thammasat University, Thailand. Now my adviser and I are planning to develop a system dynamic model for examining the chronic health effect of the soil roller operators due to whole body vibration.

For that, a questionnaire survey among soil roller operators and management level of construction companies will be conducted in Sri Lanka from March 20- April, 2016 It will be highly appreciated if you can set aside 20 minutes to fill in the questionnaire survey. The information will be kept confidentially, and will be used for academic purpose only.

The questionnaire survey consists of two parts.

- ☐ Part I collects personal information
- ☐ Part II asks the respondent to rate his agreement on statements relating to factors affecting Low Back Pain using the 1-5 scale.

Please return the completed survey by putting it in the envelop provided. If you have any question, please feel free to contact me via +94712767575 or vhashi@yahoo.com.

Thank you very much for your corporation.

Best Regards,

Yours sincerely	Endorsement
------------------	------------------
V.H.P.Vitharana	Asst.Prof.Dr.Thanwadee Chinda
PhD Candidate	Principal Supervisor

Appendix E

Raw Data

Case	AOM	AOW	EXC	EDU	JRN	JSN	NSF	SBT	STP	SMK	SOT	TPM	WGT	WBV	WBS	WEP	WKH
1	5	4	4	3	4	4	4	1	5	3	4	4	4	5	4	4	4
2	4	4	2	2	4	4	3	4	5	4	4	3	2	5	4	4	5
3	4	4	4	4	4	5	4	4	5	4	4	4	2	4	5	3	5
4	2	2	3	2	4	2	4	2	4	2	5	5	2	4	2	5	4
5	4	4	3	4	2	4	4	4	4	4	4	4	4	4	4	4	4
6	4	3	4	4	4	2	2	2	4	4	3	4	3	4	4	5	4
7	4	4	4	4	5	3	5	4	5	2	4	4	4	5	4	4	5
8	4	4	3	4	5	3	4	3	4	2	4	4	4	4	5	3	5
9	5	5	3	2	4	4	5	3	5	3	5	4	5	5	5	5	5
10	4	4	3	1	4	4	2	2	5	4	4	5	4	5	5	3	4
11	4	5	4	4	3	1	2	5	4	1	4	4	5	5	5	4	5
12	4	4	2	4	2	4	4	3	5	4	2	4	4	3	4	3	5
13	4	4	5	4	5	5	4	5	4	5	5	5	4	4	4	5	5
14	3	4	4	4	4	2	2	4	5	2	5	4	4	4	4	4	5
15	5	4	3	5	5	4	5	3	4	3	4	4	5	5	5	4	5
16	4	4	4	4	2	4	2	4	4	3	4	4	2	4	3	4	4
17	5	5	3	3	4	5	5	5	5	4	5	4	3	4	3	3	5
18	5	5	3	4	4	4	5	3	5	3	5	4	3	5	4	5	3
19	4	4	3	4	4	4	3	4	3	4	4	4	2	4	4	4	4
20	4	3	4	4	3	4	2	4	4	3	4	4	3	4	4	4	3
21	5	5	5	5	5	3	3	4	5	5	5	5	3	4	4	5	5
22	5	5	2	5	5	2	2	2	5	3	4	4	4	4	5	4	5

Case	AOM	AOW	EXC	EDU	JRN	JSN	NSF	SBT	STP	SMK	SOT	TPM	WGT	WBV	WBS	WEP	WKH
23	5	5	4	3	3	4	2	4	5	3	4	4	2	5	4	4	4
24	5	4	4	4	4	3	2	4	5	3	3	4	4	4	4	4	4
25	5	5	2	4	2	2	2	4	5	4	4	4	2	5	2	4	4
26	3	3	2	2	2	4	4	4	2	4	4	2	4	4	4	4	4
27	2	4	4	4	2	4	4	3	4	3	4	5	4	4	4	4	5
28	3	4	4	4	3	4	2	5	3	2	5	5	2	4	4	5	3
29	5	4	4	3	4	5	5	5	4	1	4	5	2	4	5	4	4
30	4	4	2	3	3	2	2	5	5	1	4	5	4	4	5	5	2
31	4	4	2	2	3	3	4	4	4	2	4	4	4	4	4	3	4
32	4	4	2	4	4	2	4	4	4	2	4	4	4	4	4	4	4
33	4	4	4	5	4	4	3	3	3	4	4	5	2	4	4	5	3
34	3	4	4	3	4	2	4	3	4	3	3	3	3	4	4	3	4
35	2	4	4	4	3	4	5	4	4	4	4	4	2	4	4	4	4
36	4	4	3	4	4	4	5	5	4	3	4	5	3	5	4	5	5
37	3	4	4	2	4	4	4	4	4	2	4	4	4	4	4	4	4
38	3	4	2	4	4	3	4	3	4	4	2	4	3	4	4	3	4
39	4	4	4	4	4	4	4	4	5	2	4	4	2	4	4	4	4
40	4	5	5	4	5	3	5	5	4	3	4	5	3	5	5	5	5
41	4	4	3	4	3	5	3	4	4	4	3	4	5	4	5	4	4
42	4	4	4	3	4	4	2	4	4	2	4	4	4	4	4	4	4
43	4	4	2	4	3	2	2	4	4	4	4	2	4	4	4	4	4
44	3	4	3	4	4	3	4	4	4	3	4	4	3	4	4	4	4
45	3	3	1	4	2	2	2	4	5	3	4	3	2	3	4	2	2
46	1	5	4	5	3	4	5	4	5	4	4	4	5	5	2	4	4
47	3	2	4	2	4	4	2	2	2	4	4	4	2	4	4	4	2
48	5	5	4	3	2	2	3	1	5	1	2	2	2	5	2	5	4
49	4	2	4	5	4	2	4	2	3	2	2	2	4	4	2	4	5
50	4	3	4	4	4	2	4	2	5	5	5	2	4	4	2	2	4
51	4	2	4	4	4	3	3	4	5	3	4	3	2	4	4	5	2

Case	AOM	AOW	EXC	EDU	JRN	JSN	NSF	SBT	STP	SMK	SOT	TPM	WGT	WBV	WBS	WEP	WKH
52	2	2	4	2	4	4	2	4	2	4	5	4	2	4	4	4	4
53	4	2	4	2	4	4	2	2	5	2	4	4	4	5	4	4	5
54	4	4	4	4	5	2	2	4	5	3	4	5	4	4	4	2	5
55	4	4	3	2	4	2	4	2	5	3	5	4	4	5	5	4	5
56	5	5	3	4	4	5	2	4	5	4	5	5	1	4	3	5	4
57	4	3	3	4	4	2	4	3	5	4	4	4	3	5	4	4	4
58	2	4	2	2	2	2	1	3	4	4	4	5	4	2	3	4	4
59	4	1	5	2	2	1	1	4	5	5	4	5	2	2	4	2	5
60	4	5	4	3	5	4	4	5	4	4	2	4	4	2	5	5	5
61	4	1	1	2	4	2	4	5	4	2	3	5	1	3	2	4	1
62	4	1	2	2	4	4	4	4	5	3	3	5	1	4	3	3	4
63	4	2	1	2	4	2	5	4	5	3	3	5	2	3	3	4	5
64	5	2	4	4	4	5	5	1	4	2	2	4	2	4	4	4	5
65	4	4	4	3	3	4	2	2	5	3	4	3	2	4	3	3	5
66	5	2	2	2	2	4	2	4	4	2	4	2	2	4	4	4	2
67	5	2	3	2	3	2	4	2	4	4	5	3	2	2	2	4	2
68	2	2	2	3	2	4	2	3	4	2	4	4	2	4	4	4	4
69	4	4	2	2	3	2	3	3	4	2	4	4	3	4	4	4	5
70	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
71	4	4	4	2	4	2	2	4	4	4	4	4	2	4	4	4	4
72	4	3	4	3	2	4	3	4	4	4	4	4	4	2	4	2	4
73	2	4	2	4	4	4	2	2	4	3	4	4	2	4	3	3	4
74	4	2	3	2	4	4	3	4	4	4	4	4	4	4	4	4	2
75	4	4	4	4	4	4	4	4	4	4	5	2	2	2	3	2	4
76	4	2	3	3	2	4	2	4	4	2	4	4	2	4	4	4	4
77	4	2	2	2	4	4	2	4	4	4	3	4	2	4	4	4	4
78	4	2	2	3	4	4	2	4	5	3	4	4	2	3	4	4	2
79	2	2	4	2	4	3	2	4	4	2	4	4	4	2	3	4	2
80	5	4	4	2	4	2	5	4	4	2	4	4	2	5	4	4	4

Case	AOM	AOW	EXC	EDU	JRN	JSN	NSF	SBT	STP	SMK	SOT	TPM	WGT	WBV	WBS	WEP	WKH
81	4	5	4	4	4	2	2	4	5	2	5	4	4	5	4	4	5
82	2	4	4	4	4	3	4	3	2	2	4	4	2	2	4	4	4
83	4	3	3	4	2	4	2	4	4	2	4	4	2	4	4	4	4
84	4	2	2	2	2	4	2	2	4	3	4	4	2	4	4	4	2
85	4	3	4	4	4	4	4	2	4	3	4	4	2	4	4	3	4
86	4	4	4	4	2	4	4	4	4	2	4	4	2	4	4	4	4
87	4	4	4	3	2	4	4	4	4	2	4	4	2	4	4	4	4
88	4	2	4	4	2	4	2	4	4	2	4	4	2	2	4	4	4
89	4	2	4	4	3	4	4	4	5	3	4	4	2	4	4	4	5
90	4	4	4	4	4	5	5	4	4	2	2	4	2	4	4	4	2
91	4	4	2	2	4	4	5	4	4	2	5	4	4	4	4	4	5
92	4	4	4	4	4	4	2	3	4	2	4	2	2	4	4	4	5
93	2	2	4	4	4	4	4	2	4	2	4	4	4	4	4	4	4
94	2	2	4	2	4	4	4	4	4	2	4	4	2	2	4	4	4
95	2	2	4	2	4	2	2	2	4	2	4	4	2	4	4	4	4
96	3	2	4	2	4	2	4	4	4	2	4	4	2	2	4	2	4
97	4	3	3	2	2	4	2	4	4	2	4	4	2	4	4	4	4
98	4	4	4	2	4	2	4	4	4	2	4	4	4	4	4	2	4
99	4	4	4	2	2	2	4	4	4	2	4	4	2	4	4	4	4
100	3	2	4	2	4	4	4	4	4	2	4	4	4	4	4	4	4
101	4	3	2	2	4	2	2	4	4	2	2	4	2	2	4	4	4
102	4	3	2	2	2	2	2	4	4	2	4	4	2	4	4	4	4
103	2	2	3	2	4	2	4	4	4	2	2	4	3	4	4	2	4
104	4	4	2	2	4	2	2	4	4	2	2	4	4	4	4	4	4
105	3	2	4	2	4	4	2	2	4	2	2	4	2	2	4	4	2
106	4	4	4	2	4	4	2	4	4	2	2	4	2	4	4	4	2
107	4	2	4	2	4	4	4	4	4	2	4	4	2	2	4	4	2
108	2	2	2	2	4	2	2	4	4	2	2	4	2	2	4	4	4
109	4	2	4	2	2	4	3	4	4	2	4	4	2	4	4	4	4

Case	AOM	AOW	EXC	EDU	JRN	JSN	NSF	SBT	STP	SMK	SOT	TPM	WGT	WBV	WBS	WEP	WKH
110	4	2	4	2	2	4	2	4	4	2	4	4	2	2	4	3	2
111	2	2	2	2	2	4	2	4	4	2	4	4	2	2	4	4	4
112	4	2	4	2	4	4	2	3	4	3	4	4	2	2	4	2	2
113	4	2	4	3	4	4	2	3	5	2	4	3	2	4	4	4	4
114	4	2	4	3	2	2	4	4	4	4	4	4	4	4	4	4	4
115	4	2	4	2	4	4	2	2	2	4	2	4	4	4	4	4	2
116	3	4	4	2	4	2	4	4	4	4	4	4	4	4	4	4	4
117	4	2	4	2	4	2	2	4	4	2	4	3	2	4	4	3	4
118	4	3	4	2	4	2	4	4	4	2	2	2	4	4	4	4	4
119	4	2	4	3	4	2	2	4	2	2	2	4	2	3	4	2	4
120	4	2	4	4	4	2	4	4	5	2	4	4	2	4	4	4	4
121	4	2	3	3	5	4	4	4	4	2	4	4	4	4	4	4	4
122	4	4	4	3	2	4	3	4	4	3	4	4	4	4	4	2	4
123	4	2	4	3	4	2	2	4	4	2	2	4	2	4	4	2	4
124	4	2	4	4	4	2	2	4	4	2	4	4	2	4	4	4	2
125	4	4	4	3	4	4	2	4	4	3	4	4	4	4	4	4	4
126	4	4	4	3	4	4	4	4	4	2	2	4	2	4	4	3	4
127	2	2	4	3	4	4	2	4	2	2	2	4	2	4	4	4	4
128	4	4	4	3	4	4	2	4	4	2	4	4	2	4	4	4	4
129	4	2	2	2	4	2	4	4	4	2	4	2	2	2	4	4	4
130	2	4	4	4	4	4	4	4	2	2	4	4	2	4	4	4	4
131	4	4	4	3	4	4	2	4	4	4	4	4	4	4	4	4	4
132	4	4	4	3	4	2	2	4	5	2	4	4	2	5	4	4	4
133	4	2	2	2	2	4	4	4	4	2	4	4	2	4	4	4	4
134	4	2	3	2	4	2	4	4	4	2	4	4	2	4	4	4	2
135	2	2	2	2	4	2	2	4	2	2	2	4	2	4	4	4	4
136	4	4	4	3	4	4	4	4	4	2	4	4	2	4	4	4	4
137	4	4	2	3	4	4	3	4	4	2	4	4	2	4	4	4	2
138	4	2	4	3	4	4	4	4	4	4	4	4	2	4	4	4	4

Case	AOM	AOW	EXC	EDU	JRN	JSN	NSF	SBT	STP	SMK	SOT	TPM	WGT	WBV	WBS	WEP	WKH
139	4	4	4	3	4	2	2	4	4	2	4	4	4	4	4	4	4
140	4	4	4	3	4	4	4	4	4	3	2	4	2	2	4	4	2
141	4	4	4	3	2	2	2	4	4	2	4	4	2	3	4	4	2
142	4	2	4	3	4	4	4	4	2	2	4	4	4	2	4	4	4
143	2	4	4	3	4	4	2	4	4	2	4	4	4	4	4	4	4
144	4	2	2	3	4	3	4	4	2	4	4	4	2	4	4	4	4
145	4	2	4	2	4	4	2	2	4	2	4	4	2	4	4	4	4
146	4	4	4	4	4	4	2	4	4	2	4	4	4	4	4	4	4
147	4	2	4	3	4	4	2	2	4	4	4	3	2	2	4	4	4
148	4	2	4	3	4	4	4	4	4	2	3	4	2	2	4	4	4
149	2	2	4	4	4	4	2	4	4	2	4	4	2	2	4	4	4

Appendix F

Standardized Score (Z scores)

Case	ZAOM	ZAOW	ZEXC	ZEDU	ZJRN	ZJSN	ZNSF	ZSBT	ZSTP	ZSMK	ZSOT	ZTPM	ZWGT	ZWBV	ZWBS	ZWEP	ZWKH
1	1.5	0.7	0.7	-0.1	0.5	0.7	0.8	-3.0	1.2	0.3	0.3	0.1	1.2	1.4	0.1	0.2	0.2
2	0.3	0.7	-1.6	-1.1	0.5	0.7	-0.1	0.4	1.2	1.3	0.3	-1.4	-0.8	1.4	0.1	0.2	1.2
3	0.3	0.7	0.7	1.0	0.5	1.7	0.8	0.4	1.2	1.3	0.3	0.1	-0.8	0.3	1.8	-1.1	1.2
4	-2.0	-1.1	-0.5	-1.1	0.5	-1.3	0.8	-1.9	-0.1	-0.8	1.5	1.6	-0.8	0.3	-3.2	1.6	0.2
5	0.3	0.7	-0.5	1.0	-1.8	0.7	0.8	0.4	-0.1	1.3	0.3	0.1	1.2	0.3	0.1	0.2	0.2
6	0.3	-0.2	0.7	1.0	0.5	-1.3	-1.0	-1.9	-0.1	1.3	-0.9	0.1	0.2	0.3	0.1	1.6	0.2
7	0.3	0.7	0.7	1.0	1.6	-0.3	1.7	0.4	1.2	-0.8	0.3	0.1	1.2	1.4	0.1	0.2	1.2
8	0.3	0.7	-0.5	1.0	1.6	-0.3	0.8	-0.7	-0.1	-0.8	0.3	0.1	1.2	0.3	1.8	-1.1	1.2
9	1.5	1.6	-0.5	-1.1	0.5	0.7	1.7	-0.7	1.2	0.3	1.5	0.1	2.2	1.4	1.8	1.6	1.2
10	0.3	0.7	-0.5	-2.2	0.5	0.7	-1.0	-1.9	1.2	1.3	0.3	1.6	1.2	1.4	1.8	-1.1	0.2
11	0.3	1.6	0.7	1.0	-0.7	-2.3	-1.0	1.6	-0.1	-1.8	0.3	0.1	2.2	1.4	1.8	0.2	1.2
12	0.3	0.7	-1.6	1.0	-1.8	0.7	0.8	-0.7	1.2	1.3	-2.1	0.1	1.2	-0.9	0.1	-1.1	1.2
13	0.3	0.7	1.8	1.0	1.6	1.7	0.8	1.6	-0.1	2.4	1.5	1.6	1.2	0.3	0.1	1.6	1.2
14	-0.8	0.7	0.7	1.0	0.5	-1.3	-1.0	0.4	1.2	-0.8	1.5	0.1	1.2	0.3	0.1	0.2	1.2
15	1.5	0.7	-0.5	2.1	1.6	0.7	1.7	-0.7	-0.1	0.3	0.3	0.1	2.2	1.4	1.8	0.2	1.2
16	0.3	0.7	0.7	1.0	-1.8	0.7	-1.0	0.4	-0.1	0.3	0.3	0.1	-0.8	0.3	-1.5	0.2	0.2
17	1.5	1.6	-0.5	-0.1	0.5	1.7	1.7	1.6	1.2	1.3	1.5	0.1	0.2	0.3	-1.5	-1.1	1.2
18	1.5	1.6	-0.5	1.0	0.5	0.7	1.7	-0.7	1.2	0.3	1.5	0.1	0.2	1.4	0.1	1.6	-0.9
19	0.3	0.7	-0.5	1.0	0.5	0.7	-0.1	0.4	-1.4	1.3	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
20	0.3	-0.2	0.7	1.0	-0.7	0.7	-1.0	0.4	-0.1	0.3	0.3	0.1	0.2	0.3	0.1	0.2	-0.9
21	1.5	1.6	1.8	2.1	1.6	-0.3	-0.1	0.4	1.2	2.4	1.5	1.6	0.2	0.3	0.1	1.6	1.2
22	1.5	1.6	-1.6	2.1	1.6	-1.3	-1.0	-1.9	1.2	0.3	0.3	0.1	1.2	0.3	1.8	0.2	1.2
23	1.5	1.6	0.7	-0.1	-0.7	0.7	-1.0	0.4	1.2	0.3	0.3	0.1	-0.8	1.4	0.1	0.2	0.2

Case	ZAOM	ZAOW	ZEXC	ZEDU	ZJRN	ZJSN	ZNSF	ZSBT	ZSTP	ZSMK	ZSOT	ZTPM	ZWGT	ZWBV	ZWBS	ZWEP	ZWKH
24	1.5	0.7	0.7	1.0	0.5	-0.3	-1.0	0.4	1.2	0.3	-0.9	0.1	1.2	0.3	0.1	0.2	0.2
25	1.5	1.6	-1.6	1.0	-1.8	-1.3	-1.0	0.4	1.2	1.3	0.3	0.1	-0.8	1.4	-3.2	0.2	0.2
26	-0.8	-0.2	-1.6	-1.1	-1.8	0.7	0.8	0.4	-2.7	1.3	0.3	-2.9	1.2	0.3	0.1	0.2	0.2
27	-2.0	0.7	0.7	1.0	-1.8	0.7	0.8	-0.7	-0.1	0.3	0.3	1.6	1.2	0.3	0.1	0.2	1.2
28	-0.8	0.7	0.7	1.0	-0.7	0.7	-1.0	1.6	-1.4	-0.8	1.5	1.6	-0.8	0.3	0.1	1.6	-0.9
29	1.5	0.7	0.7	-0.1	0.5	1.7	1.7	1.6	-0.1	-1.8	0.3	1.6	-0.8	0.3	1.8	0.2	0.2
30	0.3	0.7	-1.6	-0.1	-0.7	-1.3	-1.0	1.6	1.2	-1.8	0.3	1.6	1.2	0.3	1.8	1.6	-2.0
31	0.3	0.7	-1.6	-1.1	-0.7	-0.3	0.8	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	-1.1	0.2
32	0.3	0.7	-1.6	1.0	0.5	-1.3	0.8	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	0.2	0.2
33	0.3	0.7	0.7	2.1	0.5	0.7	-0.1	-0.7	-1.4	1.3	0.3	1.6	-0.8	0.3	0.1	1.6	-0.9
34	-0.8	0.7	0.7	-0.1	0.5	-1.3	0.8	-0.7	-0.1	0.3	-0.9	-1.4	0.2	0.3	0.1	-1.1	0.2
35	-2.0	0.7	0.7	1.0	-0.7	0.7	1.7	0.4	-0.1	1.3	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
36	0.3	0.7	-0.5	1.0	0.5	0.7	1.7	1.6	-0.1	0.3	0.3	1.6	0.2	1.4	0.1	1.6	1.2
37	-0.8	0.7	0.7	-1.1	0.5	0.7	0.8	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	0.2	0.2
38	-0.8	0.7	-1.6	1.0	0.5	-0.3	0.8	-0.7	-0.1	1.3	-2.1	0.1	0.2	0.3	0.1	-1.1	0.2
39	0.3	0.7	0.7	1.0	0.5	0.7	0.8	0.4	1.2	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
40	0.3	1.6	1.8	1.0	1.6	-0.3	1.7	1.6	-0.1	0.3	0.3	1.6	0.2	1.4	1.8	1.6	1.2
41	0.3	0.7	-0.5	1.0	-0.7	1.7	-0.1	0.4	-0.1	1.3	-0.9	0.1	2.2	0.3	1.8	0.2	0.2
42	0.3	0.7	0.7	-0.1	0.5	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	0.2	0.2
43	0.3	0.7	-1.6	1.0	-0.7	-1.3	-1.0	0.4	-0.1	1.3	0.3	-2.9	1.2	0.3	0.1	0.2	0.2
44	-0.8	0.7	-0.5	1.0	0.5	-0.3	0.8	0.4	-0.1	0.3	0.3	0.1	0.2	0.3	0.1	0.2	0.2
45	-0.8	-0.2	-2.7	1.0	-1.8	-1.3	-1.0	0.4	1.2	0.3	0.3	-1.4	-0.8	-0.9	0.1	-2.5	-2.0
46	-3.1	1.6	0.7	2.1	-0.7	0.7	1.7	0.4	1.2	1.3	0.3	0.1	2.2	1.4	-3.2	0.2	0.2
47	-0.8	-1.1	0.7	-1.1	0.5	0.7	-1.0	-1.9	-2.7	1.3	0.3	0.1	-0.8	0.3	0.1	0.2	-2.0
48	1.5	1.6	0.7	-0.1	-1.8	-1.3	-0.1	-3.0	1.2	-1.8	-2.1	-2.9	-0.8	1.4	-3.2	1.6	0.2
49	0.3	-1.1	0.7	2.1	0.5	-1.3	0.8	-1.9	-1.4	-0.8	-2.1	-2.9	1.2	0.3	-3.2	0.2	1.2
50	0.3	-0.2	0.7	1.0	0.5	-1.3	0.8	-1.9	1.2	2.4	1.5	-2.9	1.2	0.3	-3.2	-2.5	0.2
51	0.3	-1.1	0.7	1.0	0.5	-0.3	-0.1	0.4	1.2	0.3	0.3	-1.4	-0.8	0.3	0.1	1.6	-2.0
52	-2.0	-1.1	0.7	-1.1	0.5	0.7	-1.0	0.4	-2.7	1.3	1.5	0.1	-0.8	0.3	0.1	0.2	0.2

Case	ZAOM	ZAOW	ZEXC	ZEDU	ZJRN	ZJSN	ZNSF	ZSBT	ZSTP	ZSMK	ZSOT	ZTPM	ZWGT	ZWBV	ZWBS	ZWEP	ZWKH
53	0.3	-1.1	0.7	-1.1	0.5	0.7	-1.0	-1.9	1.2	-0.8	0.3	0.1	1.2	1.4	0.1	0.2	1.2
54	0.3	0.7	0.7	1.0	1.6	-1.3	-1.0	0.4	1.2	0.3	0.3	1.6	1.2	0.3	0.1	-2.5	1.2
55	0.3	0.7	-0.5	-1.1	0.5	-1.3	0.8	-1.9	1.2	0.3	1.5	0.1	1.2	1.4	1.8	0.2	1.2
56	1.5	1.6	-0.5	1.0	0.5	1.7	-1.0	0.4	1.2	1.3	1.5	1.6	-1.8	0.3	-1.5	1.6	0.2
57	0.3	-0.2	-0.5	1.0	0.5	-1.3	0.8	-0.7	1.2	1.3	0.3	0.1	0.2	1.4	0.1	0.2	0.2
58	-2.0	0.7	-1.6	-1.1	-1.8	-1.3	-1.9	-0.7	-0.1	1.3	0.3	1.6	1.2	-2.0	-1.5	0.2	0.2
59	0.3	-2.0	1.8	-1.1	-1.8	-2.3	-1.9	0.4	1.2	2.4	0.3	1.6	-0.8	-2.0	0.1	-2.5	1.2
60	0.3	1.6	0.7	-0.1	1.6	0.7	0.8	1.6	-0.1	1.3	-2.1	0.1	1.2	-2.0	1.8	1.6	1.2
61	0.3	-2.0	-2.7	-1.1	0.5	-1.3	0.8	1.6	-0.1	-0.8	-0.9	1.6	-1.8	-0.9	-3.2	0.2	-3.1
62	0.3	-2.0	-1.6	-1.1	0.5	0.7	0.8	0.4	1.2	0.3	-0.9	1.6	-1.8	0.3	-1.5	-1.1	0.2
63	0.3	-1.1	-2.7	-1.1	0.5	-1.3	1.7	0.4	1.2	0.3	-0.9	1.6	-0.8	-0.9	-1.5	0.2	1.2
64	1.5	-1.1	0.7	1.0	0.5	1.7	1.7	-3.0	-0.1	-0.8	-2.1	0.1	-0.8	0.3	0.1	0.2	1.2
65	0.3	0.7	0.7	-0.1	-0.7	0.7	-1.0	-1.9	1.2	0.3	0.3	-1.4	-0.8	0.3	-1.5	-1.1	1.2
66	1.5	-1.1	-1.6	-1.1	-1.8	0.7	-1.0	0.4	-0.1	-0.8	0.3	-2.9	-0.8	0.3	0.1	0.2	-2.0
67	1.5	-1.1	-0.5	-1.1	-0.7	-1.3	0.8	-1.9	-0.1	1.3	1.5	-1.4	-0.8	-2.0	-3.2	0.2	-2.0
68	-2.0	-1.1	-1.6	-0.1	-1.8	0.7	-1.0	-0.7	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
69	0.3	0.7	-1.6	-1.1	-0.7	-1.3	-0.1	-0.7	-0.1	-0.8	0.3	0.1	0.2	0.3	0.1	0.2	1.2
70	-2.0	-1.1	0.7	1.0	0.5	0.7	0.8	0.4	-0.1	1.3	0.3	0.1	1.2	0.3	0.1	0.2	0.2
71	0.3	0.7	0.7	-1.1	0.5	-1.3	-1.0	0.4	-0.1	1.3	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
72	0.3	-0.2	0.7	-0.1	-1.8	0.7	-0.1	0.4	-0.1	1.3	0.3	0.1	1.2	-2.0	0.1	-2.5	0.2
73	-2.0	0.7	-1.6	1.0	0.5	0.7	-1.0	-1.9	-0.1	0.3	0.3	0.1	-0.8	0.3	-1.5	-1.1	0.2
74	0.3	-1.1	-0.5	-1.1	0.5	0.7	-0.1	0.4	-0.1	1.3	0.3	0.1	1.2	0.3	0.1	0.2	-2.0
75	0.3	0.7	0.7	1.0	0.5	0.7	0.8	0.4	-0.1	1.3	1.5	-2.9	-0.8	-2.0	-1.5	-2.5	0.2
76	0.3	-1.1	-0.5	-0.1	-1.8	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
77	0.3	-1.1	-1.6	-1.1	0.5	0.7	-1.0	0.4	-0.1	1.3	-0.9	0.1	-0.8	0.3	0.1	0.2	0.2
78	0.3	-1.1	-1.6	-0.1	0.5	0.7	-1.0	0.4	1.2	0.3	0.3	0.1	-0.8	-0.9	0.1	0.2	-2.0
79	-2.0	-1.1	0.7	-1.1	0.5	-0.3	-1.0	0.4	-0.1	-0.8	0.3	0.1	1.2	-2.0	-1.5	0.2	-2.0
80	1.5	0.7	0.7	-1.1	0.5	-1.3	1.7	0.4	-0.1	-0.8	0.3	0.1	-0.8	1.4	0.1	0.2	0.2
81	0.3	1.6	0.7	1.0	0.5	-1.3	-1.0	0.4	1.2	-0.8	1.5	0.1	1.2	1.4	0.1	0.2	1.2

Case	ZAOM	ZAOW	ZEXC	ZEDU	ZJRN	ZJSN	ZNSF	ZSBT	ZSTP	ZSMK	ZSOT	ZTPM	ZWGT	ZWBV	ZWBS	ZWEP	ZWKH
82	-2.0	0.7	0.7	1.0	0.5	-0.3	0.8	-0.7	-2.7	-0.8	0.3	0.1	-0.8	-2.0	0.1	0.2	0.2
83	0.3	-0.2	-0.5	1.0	-1.8	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
84	0.3	-1.1	-1.6	-1.1	-1.8	0.7	-1.0	-1.9	-0.1	0.3	0.3	0.1	-0.8	0.3	0.1	0.2	-2.0
85	0.3	-0.2	0.7	1.0	0.5	0.7	0.8	-1.9	-0.1	0.3	0.3	0.1	-0.8	0.3	0.1	-1.1	0.2
86	0.3	0.7	0.7	1.0	-1.8	0.7	0.8	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
87	0.3	0.7	0.7	-0.1	-1.8	0.7	0.8	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
88	0.3	-1.1	0.7	1.0	-1.8	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	-2.0	0.1	0.2	0.2
89	0.3	-1.1	0.7	1.0	-0.7	0.7	0.8	0.4	1.2	0.3	0.3	0.1	-0.8	0.3	0.1	0.2	1.2
90	0.3	0.7	0.7	1.0	0.5	1.7	1.7	0.4	-0.1	-0.8	-2.1	0.1	-0.8	0.3	0.1	0.2	-2.0
91	0.3	0.7	-1.6	-1.1	0.5	0.7	1.7	0.4	-0.1	-0.8	1.5	0.1	1.2	0.3	0.1	0.2	1.2
92	0.3	0.7	0.7	1.0	0.5	0.7	-1.0	-0.7	-0.1	-0.8	0.3	-2.9	-0.8	0.3	0.1	0.2	1.2
93	-2.0	-1.1	0.7	1.0	0.5	0.7	0.8	-1.9	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	0.2	0.2
94	-2.0	-1.1	0.7	-1.1	0.5	0.7	0.8	0.4	-0.1	-0.8	0.3	0.1	-0.8	-2.0	0.1	0.2	0.2
95	-2.0	-1.1	0.7	-1.1	0.5	-1.3	-1.0	-1.9	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
96	-0.8	-1.1	0.7	-1.1	0.5	-1.3	0.8	0.4	-0.1	-0.8	0.3	0.1	-0.8	-2.0	0.1	-2.5	0.2
97	0.3	-0.2	-0.5	-1.1	-1.8	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
98	0.3	0.7	0.7	-1.1	0.5	-1.3	0.8	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	-2.5	0.2
99	0.3	0.7	0.7	-1.1	-1.8	-1.3	0.8	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
100	-0.8	-1.1	0.7	-1.1	0.5	0.7	0.8	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	0.2	0.2
101	0.3	-0.2	-1.6	-1.1	0.5	-1.3	-1.0	0.4	-0.1	-0.8	-2.1	0.1	-0.8	-2.0	0.1	0.2	0.2
102	0.3	-0.2	-1.6	-1.1	-1.8	-1.3	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
103	-2.0	-1.1	-0.5	-1.1	0.5	-1.3	0.8	0.4	-0.1	-0.8	-2.1	0.1	0.2	0.3	0.1	-2.5	0.2
104	0.3	0.7	-1.6	-1.1	0.5	-1.3	-1.0	0.4	-0.1	-0.8	-2.1	0.1	1.2	0.3	0.1	0.2	0.2
105	-0.8	-1.1	0.7	-1.1	0.5	0.7	-1.0	-1.9	-0.1	-0.8	-2.1	0.1	-0.8	-2.0	0.1	0.2	-2.0
106	0.3	0.7	0.7	-1.1	0.5	0.7	-1.0	0.4	-0.1	-0.8	-2.1	0.1	-0.8	0.3	0.1	0.2	-2.0
107	0.3	-1.1	0.7	-1.1	0.5	0.7	0.8	0.4	-0.1	-0.8	0.3	0.1	-0.8	-2.0	0.1	0.2	-2.0
108	-2.0	-1.1	-1.6	-1.1	0.5	-1.3	-1.0	0.4	-0.1	-0.8	-2.1	0.1	-0.8	-2.0	0.1	0.2	0.2
109	0.3	-1.1	0.7	-1.1	-1.8	0.7	-0.1	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
110	0.3	-1.1	0.7	-1.1	-1.8	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	-2.0	0.1	-1.1	-2.0

Case	ZAOM	ZAOW	ZEXC	ZEDU	ZJRN	ZJSN	ZNSF	ZSBT	ZSTP	ZSMK	ZSOT	ZTPM	ZWGT	ZWBV	ZWBS	ZWEP	ZWKH
111	-2.0	-1.1	-1.6	-1.1	-1.8	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	-2.0	0.1	0.2	0.2
112	0.3	-1.1	0.7	-1.1	0.5	0.7	-1.0	-0.7	-0.1	0.3	0.3	0.1	-0.8	-2.0	0.1	-2.5	-2.0
113	0.3	-1.1	0.7	-0.1	0.5	0.7	-1.0	-0.7	1.2	-0.8	0.3	-1.4	-0.8	0.3	0.1	0.2	0.2
114	0.3	-1.1	0.7	-0.1	-1.8	-1.3	0.8	0.4	-0.1	1.3	0.3	0.1	1.2	0.3	0.1	0.2	0.2
115	0.3	-1.1	0.7	-1.1	0.5	0.7	-1.0	-1.9	-2.7	1.3	-2.1	0.1	1.2	0.3	0.1	0.2	-2.0
116	-0.8	0.7	0.7	-1.1	0.5	-1.3	0.8	0.4	-0.1	1.3	0.3	0.1	1.2	0.3	0.1	0.2	0.2
117	0.3	-1.1	0.7	-1.1	0.5	-1.3	-1.0	0.4	-0.1	-0.8	0.3	-1.4	-0.8	0.3	0.1	-1.1	0.2
118	0.3	-0.2	0.7	-1.1	0.5	-1.3	0.8	0.4	-0.1	-0.8	-2.1	-2.9	1.2	0.3	0.1	0.2	0.2
119	0.3	-1.1	0.7	-0.1	0.5	-1.3	-1.0	0.4	-2.7	-0.8	-2.1	0.1	-0.8	-0.9	0.1	-2.5	0.2
120	0.3	-1.1	0.7	1.0	0.5	-1.3	0.8	0.4	1.2	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
121	0.3	-1.1	-0.5	-0.1	1.6	0.7	0.8	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	0.2	0.2
122	0.3	0.7	0.7	-0.1	-1.8	0.7	-0.1	0.4	-0.1	0.3	0.3	0.1	1.2	0.3	0.1	-2.5	0.2
123	0.3	-1.1	0.7	-0.1	0.5	-1.3	-1.0	0.4	-0.1	-0.8	-2.1	0.1	-0.8	0.3	0.1	-2.5	0.2
124	0.3	-1.1	0.7	1.0	0.5	-1.3	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	-2.0
125	0.3	0.7	0.7	-0.1	0.5	0.7	-1.0	0.4	-0.1	0.3	0.3	0.1	1.2	0.3	0.1	0.2	0.2
126	0.3	0.7	0.7	-0.1	0.5	0.7	0.8	0.4	-0.1	-0.8	-2.1	0.1	-0.8	0.3	0.1	-1.1	0.2
127	-2.0	-1.1	0.7	-0.1	0.5	0.7	-1.0	0.4	-2.7	-0.8	-2.1	0.1	-0.8	0.3	0.1	0.2	0.2
128	0.3	0.7	0.7	-0.1	0.5	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
129	0.3	-1.1	-1.6	-1.1	0.5	-1.3	0.8	0.4	-0.1	-0.8	0.3	-2.9	-0.8	-2.0	0.1	0.2	0.2
130	-2.0	0.7	0.7	1.0	0.5	0.7	0.8	0.4	-2.7	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
131	0.3	0.7	0.7	-0.1	0.5	0.7	-1.0	0.4	-0.1	1.3	0.3	0.1	1.2	0.3	0.1	0.2	0.2
132	0.3	0.7	0.7	-0.1	0.5	-1.3	-1.0	0.4	1.2	-0.8	0.3	0.1	-0.8	1.4	0.1	0.2	0.2
133	0.3	-1.1	-1.6	-1.1	-1.8	0.7	0.8	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
134	0.3	-1.1	-0.5	-1.1	0.5	-1.3	0.8	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	-2.0
135	-2.0	-1.1	-1.6	-1.1	0.5	-1.3	-1.0	0.4	-2.7	-0.8	-2.1	0.1	-0.8	0.3	0.1	0.2	0.2
136	0.3	0.7	0.7	-0.1	0.5	0.7	0.8	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
137	0.3	0.7	-1.6	-0.1	0.5	0.7	-0.1	0.4	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	-2.0
138	0.3	-1.1	0.7	-0.1	0.5	0.7	0.8	0.4	-0.1	1.3	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
139	0.3	0.7	0.7	-0.1	0.5	-1.3	-1.0	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	0.2	0.2

Case	ZAOM	ZAOW	ZEXC	ZEDU	ZJRN	ZJSN	ZNSF	ZSBT	ZSTP	ZSMK	ZSOT	ZTPM	ZWGT	ZWBV	ZWBS	ZWEP	ZWKH
140	0.3	0.7	0.7	-0.1	0.5	0.7	0.8	0.4	-0.1	0.3	-2.1	0.1	-0.8	-2.0	0.1	0.2	-2.0
141	0.3	0.7	0.7	-0.1	-1.8	-1.3	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	-0.9	0.1	0.2	-2.0
142	0.3	-1.1	0.7	-0.1	0.5	0.7	0.8	0.4	-2.7	-0.8	0.3	0.1	1.2	-2.0	0.1	0.2	0.2
143	-2.0	0.7	0.7	-0.1	0.5	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	0.2	0.2
144	0.3	-1.1	-1.6	-0.1	0.5	-0.3	0.8	0.4	-2.7	1.3	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
145	0.3	-1.1	0.7	-1.1	0.5	0.7	-1.0	-1.9	-0.1	-0.8	0.3	0.1	-0.8	0.3	0.1	0.2	0.2
146	0.3	0.7	0.7	1.0	0.5	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	1.2	0.3	0.1	0.2	0.2
147	0.3	-1.1	0.7	-0.1	0.5	0.7	-1.0	-1.9	-0.1	1.3	0.3	-1.4	-0.8	-2.0	0.1	0.2	0.2
148	0.3	-1.1	0.7	-0.1	0.5	0.7	0.8	0.4	-0.1	-0.8	-0.9	0.1	-0.8	-2.0	0.1	0.2	0.2
149	-2.0	-1.1	0.7	1.0	0.5	0.7	-1.0	0.4	-0.1	-0.8	0.3	0.1	-0.8	-2.0	0.1	0.2	0.2

Appendix G
Measurement model result

Computation of degrees of freedom (Default model)

Number of distinct sample moments: 153

Number of distinct parameters to be estimated: 44

Degrees of freedom (153 - 44): 109

Result (Default model)

Minimum was achieved

Chi-square = 134.797

Degrees of freedom = 109

Probability level = .047

Notes for Group (Group number 1)

The model is recursive.

Sample size = 145

CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	44.00	134.80	109.00	0.05	1.24
Saturated model	153.00	0.00	0.00	-	-
Independence model	17.0	323.13	136.00	0.00	2.38

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	0.05	0.91	0.87	0.65

Model	RMR	GFI	AGFI	PGFI
Saturated model	0.00	1.00	-	-
Independence model	0.11	0.76	0.73	0.67

Baseline Comparisons

Model	NFI Delta 1	RFI rho1	IFI Delta 2	TLI rho2	CFI
Default model	0.58	0.48	0.88	0.83	0.86
Saturated model	1.00	-	1.00	-	1.00
Independence model	0.00	0.00	0.00	0.00	0.00

Parsimony-Adjusted Measures

Model	PRATIO	PNFI	PCFI
Default model	0.80	0.47	0.69
Saturated model	0.00	0.00	0.00
Independence model	1.00	0.00	0.00

NCP

Model	NCP	LO 90	HI 90
Default model	25.80	0.35	59.42
Saturated model	0.00	0.00	0.00
Independence model	187.13	138.39	243.57

FMIN

Model	FMIN	F0	LO 90	HI 90
Default model	0.94	0.18	0.00	0.41
Saturated model	0.00	0.00	0.00	0.00
Independence model	2.24	1.30	0.96	1.69

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	0.04	0.01	0.06	0.75
Independence model	0.10	0.08	0.11	0.00

Appendix H
Best fit model result

Computation of degrees of freedom (Default model)

Number of distinct sample moments: 153

Number of distinct parameters to be estimated: 44

Degrees of freedom (153 - 44):109

Result (Default model)

Minimum was achieved

Chi-square = 124.571

Degrees of freedom = 109

Probability level = .146

CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	44.00	124.57	109.00	0.14	1.14
Saturated model	153.00	0.00	0.00	-	-
Independence model	17.00	323.13	136.00	0.00	2.38

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	0.05	0.91	0.88	0.65
Saturated model	0.00	1.00	-	-
Independence model	0.11	0.76	0.73	0.67

Baseline Comparisons

Model	NFI Delta 1	RFI rho1	IFI Delta 2	TLI rho2	CFI
Default model	0.61	0.52	0.93	0.90	0.92

Model	NFI Delta 1	RFI rho1	IFI Delta 2	TLI rho2	CFI
Saturated model	1.00	-	1.00	-	1.00
Independence model	0.00	0.00	0.00	0.00	0.00

Parsimony-Adjusted Measures

Model	PRATIO	PNFI	PCFI
Default model	0.80	0.49	0.74
Saturated model	0.00	0.00	0.00
Independence model	1.00	0.00	0.00

NCP

Model	NCP	LO 90	HI 90
Default model	15.57	0.00	47.31
Saturated model	0.00	0.00	0.00
Independence model	187.13	138.39	243.57

FMIN

Model	FMIN	F0	LO 90	HI 90
Default model	0.87	0.11	0.00	0.33
Saturated model	0.00	0.00	0.00	0.00
Independence model	2.24	1.30	0.96	1.69

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	0.03	0.00	0.06	0.89
Independence model	0.10	0.08	0.11	0.00

Appendix I

Structuaral model result

Computation of degrees of freedom (Default model)

Number of distinct sample moments: 153

Number of distinct parameters to be estimated: 45

Degrees of freedom (153 - 45): 108

Result (Default model)

Minimum was achieved

Chi-square = 115.393

Degrees of freedom = 108

Probability level = .296

CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	45.00	115.39	108.00	0.30	1.07
Saturated model	153.00	0.00	0.00	-	-
Independence model	17.00	323.13	136.00	0.00	2.38

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	0.05	0.92	0.89	0.65
Saturated model	0.00	1.00	-	-
Independence model	0.11	0.76	0.73	0.67

Baseline Comparisons

Model	NFI Delta 1	RFI rho1	IFI Delta 2	TLI rho2	CFI
Default model	0.64	0.55	0.97	0.95	0.96
Saturated model	1.00	-	1.00	-	1.00
Independence model	0.00	0.00	0.00	0.00	0.00

Parsimony-Adjusted Measures

Model	PRATIO	PNFI	PCFI
Default model	0.79	0.51	0.76
Saturated model	0.00	0.00	0.00
Independence model	1.00	0.00	0.00

NCP

Model	NCP	LO 90	HI 90
Default model	7.39	0.00	37.42
Saturated model	0.00	0.00	0.00
Independence model	187.13	138.39	243.57

FMIN

Model	FMIN	F0	LO 90	HI 90
Default model	0.80	0.05	0.00	0.26
Saturated model	0.00	0.00	0.00	0.00
Independence model	2.24	1.30	0.96	1.69

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	0.02	0.00	0.05	0.96
Independence model	0.10	0.08	0.11	0.00

Appendix J

SD Equations of dynamic model of LBP prevention index

A_stock(t) = A_stock(t - dt) + (A_add_increase) * dt
INIT A_stock = 0

INFLOWS:
A_add_increase = AAHOs
B_stock(t) = B_stock(t - dt) + (B_add_increase) * dt
INIT B_stock = 0

INFLOWS:
B_add_increase = ABHOs
C_stock(t) = C_stock(t - dt) + (C_add_increase) * dt
INIT C_stock = 0

INFLOWS:
C_add_increase = ACHOs
ESB(t) = ESB(t - dt) + (IESB - EB - SB) * dt
INIT ESB = 0

INFLOWS:
IESB = LT

OUTFLOWS:
EB = PSR*SRBR
SB = IF(ESB>RBSS)THEN RBSS ELSE ROUND((ESB/PSS)-0.5)*PSS
Init_chances(t) = Init_chances(t - dt)
INIT Init_chances = Tot_C_chcnace
LAT(t) = LAT(t - dt) + (Leftover_increasing - additional_train_budget - LT) * dt
INIT LAT = 0

INFLOWS:
Leftover_increasing = ((TSBT)-(A_budget_spend_for_training+B_Budget_spend_for_training+C_Budget_spend_for_training))

OUTFLOWS:
additional_train_budget = Tot_extra_cost
LT = IF (Check_seat_and_equip= 4 AND Tot_extra_cost=0) THEN LAT ELSE IF (Check_seat_and_equip=4 AND (LAT-Tot_extra_cost)>0) THEN (LAT-Tot_extra_cost) ELSE 0
Max_JRF(t) = Max_JRF(t - dt) + (JRF_increase) * dt

INIT Max_JRF = 0

INFLOWS:
JRF_increase = IF DeltaJRF>Max_JRF THEN DeltaJRF ELSE 0
Max_ORF(t) = Max_ORF(t - dt) + (ORF_increase) * dt
INIT Max_ORF = 0

INFLOWS:
ORF_increase = IF DelataORF>Max_ORF THEN DelataORF ELSE 0
Max_PNF(t) = Max_PNF(t - dt) + (PNF_increase) * dt
INIT Max_PNF = 0

INFLOWS:
PNF_increase = IF DeltaPNF>Max_PNF THEN DeltaPNF ELSE 0
Max_SCF(t) = Max_SCF(t - dt) + (SCF_increase) * dt
INIT Max_SCF = 0

INFLOWS:
SCF_increase = IF DelataSCF>Max_SCF THEN DelataSCF ELSE 0
NCSs(t) = NCSs(t - dt) + (- suspension_seats_buying_rate) * dt
INIT NCSs = 200

OUTFLOWS:
suspension_seats_buying_rate = NSSs
Normal_A_Pop(t) = Normal_A_Pop(t - dt) + (Deduct_Over_A + A_normal_new) * dt
INIT Normal_A_Pop = 451

INFLOWS:
Deduct_Over_A = ROUND(0.2159*Over_A_pop)
A_normal_new = ROUND(New_A_per_year*0.6629+New_A_per_year*0.2022*0.2159)
Normal_B_pop(t) = Normal_B_pop(t - dt) + (Deduct_over_B + B_normal_new) * dt
INIT Normal_B_pop = 0.6667*112

INFLOWS:
Deduct_over_B = 0.25*Over_B_pop
B_normal_new = New_B_per_year*0.6667+New_B_per_year*0.1333*0.25
Normal_C_pop(t) = Normal_C_pop(t - dt) + (Deduct_over_C + C_under_new) * dt
INIT Normal_C_pop = 0*8

INFLOWS:
Deduct_over_C = 0.25*Over_C_pop
C_under_new = New_C_per_year*0
NPEXR(t) = NPEXR(t - dt) + (- never_reduction_rate) * dt

INIT NPEXR = 83.81/100

OUTFLOWS:
never_reduction_rate = (NPEXR*TR)
NSOs(t) = NSOs(t - dt) + (- DNSOs) * dt
INIT NSOs = Initial_operators

OUTFLOWS:
DNSOs = (AAHOs+ABHOs+ACHOs)*2
NSR(t) = NSR(t - dt) + (INSR) * dt
INIT NSR = 0

INFLOWS:
INSR = SRBR
NSS(t) = NSS(t - dt) + (suspension_seats_buying_rate) * dt
INIT NSS = 0

INFLOWS:
suspension_seats_buying_rate = NSSs
Obese_A_pop(t) = Obese_A_pop(t - dt) + (A_obese_new - Deduct_obese_A) * dt
INIT Obese_A_pop = 69

INFLOWS:
A_obese_new = ROUND(New_A_per_year*0.1011*(1-0.1896))

OUTFLOWS:
Deduct_obese_A = ROUND(0.1896*Obese_A_pop)
Obese_B_Pop(t) = Obese_B_Pop(t - dt) + (B_obese_new - Deduct_obese_B) * dt
INIT Obese_B_Pop = 0*112

INFLOWS:
B_obese_new = 0*New_B_per_year

OUTFLOWS:
Deduct_obese_B = 0.11*Obese_B_Pop
Obese_C_pop(t) = Obese_C_pop(t - dt) + (C_obse_new - Deduct_obese_C) * dt
INIT Obese_C_pop = 0*8

INFLOWS:
C_obse_new = New_C_per_year*0

OUTFLOWS:
Deduct_obese_C = 0.25*Obese_C_pop
Over_A_pop(t) = Over_A_pop(t - dt) + (Deduct_obese_A + A_over_new - Deduct_Over_A) * dt

INIT Over_A_pop = 137

INFLOWS:
Deduct_obese_A = ROUND(0.1896*Obese_A_pop)
A_over_new = ROUND(New_A_per_year*0.2022*(1-0.2159)+New_A_per_year*0.1011*0.1896)

OUTFLOWS:
Deduct_Over_A = ROUND(0.2159*Over_A_pop)
Over_B_pop(t) = Over_B_pop(t - dt) + (Deduct_obese_B + B_over_new - Deduct_over_B) * dt
INIT Over_B_pop = 0.1333*112

INFLOWS:
Deduct_obese_B = 0.11*Obese_B_Pop
B_over_new = New_B_per_year*0.1333*0.75

OUTFLOWS:
Deduct_over_B = 0.25*Over_B_pop
Over_C_pop(t) = Over_C_pop(t - dt) + (Deduct_obese_C + C_over_new - Deduct_over_C) * dt
INIT Over_C_pop = 0*8

INFLOWS:
Deduct_obese_C = 0.25*Obese_C_pop
C_over_new = New_C_per_year*0

OUTFLOWS:
Deduct_over_C = 0.25*Over_C_pop
RGJOSP(t) = RGJOSP(t - dt) + (R_decrease) * dt
INIT RGJOSP = Good_population

INFLOWS:
R_decrease = IF (RMJOSP<0.05) THEN (RRJOSP*S_Rate) ELSE 0
RMJOSP(t) = RMJOSP(t - dt) + (- M_decrease) * dt
INIT RMJOSP = Moderate_population

OUTFLOWS:
M_decrease = RMJOSP*S_Rate
RPEXR(t) = RPEXR(t - dt) + (increasing_regular) * dt
INIT RPEXR = 4.76/100

INFLOWS:
increasing_regular = decreasing_sometimes
RRJOSP(t) = RRJOSP(t - dt) + (M_decrease - R_decrease) * dt
INIT RRJOSP = Reasonable_population

INFLOWS:
M_decrease = RMJOSP*S_Rate

OUTFLOWS:
R_decrease = IF (RMJOSP<0.05) THEN (RRJOSP*S_Rate) ELSE 0
SOs(t) = SOs(t - dt) + (ISOs) * dt
INIT SOs = 0

INFLOWS:
ISOs = (AAHOs+ABHOs+ACHOs)*3+NHOs
SPEXR(t) = SPEXR(t - dt) + (increasing_sometimes - decreasing_sometimes) * dt
INIT SPEXR = 11.43/100

INFLOWS:
increasing_sometimes = IF(NPEXR>0.05) THEN never_reduction_rate ELSE 0

OUTFLOWS:
decreasing_sometimes = IF (NPEXR<0.05) THEN (SPEXR*TR) ELSE 0
SR(t) = SR(t - dt) + (SRBR) * dt
INIT SR = 200

INFLOWS:
SRBR = IF(EBY=0)THEN(ROUND((ESB/PSR)-0.5))ELSE(0)
Trained_workers_A(t) = Trained_workers_A(t - dt) + (STA) * dt
INIT Trained_workers_A = 0

INFLOWS:
STA = IF (TY=0) THEN (IF (ROUND (TPA)>ROUND ((TSBT /ATCPP)) -0.5) THEN (ROUND ((TSBT /ATCPP)-0.5)) ELSE (ROUND (TPA))) ELSE (0)
Trained_workers_B(t) = Trained_workers_B(t - dt) + (STB) * dt
INIT Trained_workers_B = 0

INFLOWS:
STB = IF (TY=2) THEN (IF (ROUND (TPB)>ROUND ((TSBT /BTCPP) -0.5)) THEN (ROUND ((TSBT /BTCPP)-0.5)) ELSE (ROUND (TPB))) ELSE (0)
Trained_workers_C(t) = Trained_workers_C(t - dt) + (STC) * dt
INIT Trained_workers_C = 0

INFLOWS:
STC = IF (TY=1) THEN (IF (ROUND (TPC)>ROUND ((TSBT/CTCPO))-0.5) THEN (ROUND (TSBT/CTCPO)-0.5) ELSE (ROUND (TPC))) ELSE (0)

AAHOs = ROUND((BHAOs/(WHRA*WEPerYear)))
ABC_detect = MOD(counter_y,3)
ABHOs = ROUND((BHBOs/(WHRB*WEPerYear)))
ACHOs = ROUND((BHCOs/(WHRC*WEPerYear)))
addictional_B_train_budget = IF B_Extra_cost>0 THEN (IF (LAT>B_Extra_cost) THEN (B_Extra_cost) ELSE LAT) ELSE 0
additional_A_train_budget = IF A_extra_cost>0 THEN (IF (LAT>A_extra_cost) THEN (A_extra_cost) ELSE LAT) ELSE 0
additional_C_train_budget = IF C_extra_cost>0 THEN (IF (LAT>C_extra_cost) THEN (C_extra_cost) ELSE LAT) ELSE 0
additional_tot = AAHOs+ABHOs+ACHOs
Annual_Improved_chances = IF (counter_y>1) THEN ((Init_chances-Tot_C_chcnace)/counter_y) ELSE 0
APop = A_stock+AAHOs+A_operators
APopR = APop/Tot_op
ATCPP = 100*TAIR
A_budget_spend_for_training = STA*ATCPP
A_EDU = (HAEDU*CHEDU)+(LAEDU*CLEDU)+(CMEDU*NMAEDU)
A_extra_cost = If TY=0 THEN (IF(TSBT>A_min_budget) THEN 0 ELSE (A_min_budget-TSBT)) ELSE 0
A_initial_pop = ROUND(Initial_operators*.85)
A_min_budget = (MIN(Minimum_train_A_portion,TPA))*ATCPP
A_normal_initial = ROUND(0.6629*680)
A_obese_initial = ROUND(0.1011*680)
A_operators = ROUND(A_initial_pop*(Net_Hireing_and_turnover_A+1)^(counter_y-1))
A_operator_adjust = ROUND(A_initial_pop*(Net_Hireing_and_turnover_A+1)^(counter_y))
A_over_initial = ROUND(0.2022*680)
BHAOs = IF (SBT>RMHAOs) THEN RMHAOs ELSE SBT
BHBOs = IF (LHAOs>RMHBOs) THEN RMHBOs ELSE LHAOs
BHCOs = IF (LHBOs>RMHCOs) THEN RMHCOs ELSE LHBOs
BHHEOs = (AAHOs*WHRA+ABHOs*WHRB+ACHOs*WHRC)*WEPerYear
BPop = B_stock+ABHOs+B_operators
BPopR = BPop/Tot_op
BTCPP = 127*TBIR
Budget_for_replece_existing_suspension_seats = PSS*NSS*SBY
Bud_check = IF (IntSBT>0) THEN 1 ELSE 0
Bud_check_3 = IF (IntSBT>0) THEN 1 ELSE 0
B_Budget_spend_for_training = STB*BTCPP
B_EDU = (HBEDU*CHEDU)+(LBEDU*CLEDU)+(CMEDU*NMBEDU)
B_Extra_cost = If TY=2 THEN (IF(TSBT>B_Min_budget) THEN 0 ELSE (B_Min_budget-TSBT)) ELSE 0
B_initial_pop = ROUND(Initial_operators*.14)

B_Min_budget = (MIN(minimum__train_B_portion,TPB))*BTCPP

B_opeator_adjust = ROUND(B_initial_pop*(Net_Hieing_and_turnover_B+1)^(counter_y))

B_operators = ROUND(B_initial_pop*(Net_Hieing_and_turnover_B+1)^(counter_y-1))

CAOM = (((1 -NSRR) *63) + (NSRR*30.40)) *1000

CAOW = ((48* APopR) + (54* BPopR) + (50* CPopR)) *1000

CEQF = (CAOM+CSOT+CSTP)*(1/3)

CEXR = ((50*RPEXR) + (70*SPEXR) + (82*NPEXR)) *1000

check2 = Init_chances-Tot_C_chcnace

CheckTrain = (IF (ABC_detect=1) THEN Check_C ELSE IF ABC_detect=2 THEN Check_B ELSE IF (ABC_detect=0) THEN Check_A ELSE 0)*1000

Check_A = IF((STA>DELAY(APop,3,0)) AND counter_y>3)THEN 0.304 ELSE 0.63

Check_B = IF((STB>DELAY(BPop,3,0)) AND counter_y>2)THEN 0.304 ELSE 0.63

Check_C = IF((STC>DELAY(CPop,3,0)) AND counter_y>1)THEN 0.304 ELSE 0.63

Check_JOR_NSF_&_WOH = (IF (Tot_op = SOs) THEN 0.304 ELSE 0.63)*1000*3

Check_machine = (IF (SR = NSR) THEN 0.304 ELSE 0.63)*1000

Check_seat = (IF (NSS = Total_seats) THEN 0.304 ELSE 0.63)*1000

Check_seat_and_equip = MOD(counter_y,5)

Check_train = IF (STA>0 OR STB >0 OR STC>0) THEN 1 ELSE 0

Check_train_3 = IF (STA=(TPA+TPB+TPC) OR STB =(TPA+TPB+TPC) OR STC=(TPA+TPB+TPC)) THEN 1 ELSE 0

CHEDU = 0.415

CJOR = ((80* RNSOs) + (1 -RNSOs*40)) * 1000

CJRF = (CEXR+CJOR+CNSF)*(1/3)

CLEDU = 0.646

CLWHO = 0.488

CMEDU = 0.458

CMWHO = 0.512

CNSF = ((42* RNSOs)+ (1 -RNSOs*21.5))* 1000

CORF = (CTPM+CVST+CWEP)*(1/3)

counter_y = COUNTER(1,201)

CPNF = (CAOW+CWGT+CWHO)*(1/3)

CPop = C_stock+ACHOs+C_operators

CPopR = CPop/Tot_op

CSCF = (EDU+JOS+CSMK)*(1/3)

CSMK = (((((1-RAPSMK)*0.4313)+(RAPSMK*0.5714)+((1-RBPSMK)*0.4313)+(RBPSMK*0.5714)+((1-RCPSMK)*0.4313)+(RCPSMK*0.5714))*1000))

CSOT = 630

CSR = NCSs/ (NCSs+NSS)

CSTP = ((30.4* (1 -CSR)) + (63*CSR)) *1000

CTCPO = 100*TCIR

CTPM = (((1-TR)*63) + ((1-TR)*48))*1000
cussion_seats_ratio = NCSs/Total_seats
CVST = ((Check_JOR_NSF_&_WOH + CheckTrain+ Check_seat+ Check_machine)
*1000)/6
CWEP = (55.60*RLWEP+44.3*RMWEP) *1000
CWGT = (((40.63*PNWGTR) + (58.62*PBWGTR) + (50*POWGTR) + (100*PUWGTR))) *1000
CWHO = (CMWHO*RNSOs) + (CLWHO*(1-RNSOs))*1000
C_Budget_spend_for_training = STC*CTCPO
C_EDU = (CHEDU*HCEDU)+(CLEDU*LCEDU)+(CMEDU*NMCEDU)
C_extra_cost = If TY=1 THEN (IF(TSBT>C_Min_budget) THEN 0 ELSE (C_Min_budget-TSBT)) ELSE 0
C_initil_pop = ROUND(Initial_operators*.01)
C_Min_budget = (MIN(minimum_train_C_portion,TPC))*CTCPO
C_operators = ROUND(C_initil_pop*(Net_Hiring_and_Turnover_C+1)^(counter_y-1))
C_operator_adjust = ROUND(C_initil_pop*(Net_Hiring_and_Turnover_C+1)^(counter_y))
DelataORF = (DELAY(CORF,1)-CORF)
DelataSCF = (DELAY(Final_SCF,1)-Final_SCF)
DeltaJRF = (DELAY(Final_JRF,1)-Final_JRF)
DeltaPNF = (DELAY(Final_PNF,1)-Final_PNF)
delta_JRF = -Max_JRF
delta_ORF = -Max_ORF
delta_PNF = -Max_PNF
delta_SCF = -Max_SCF
EBY = MOD(counter_y,10)
EDU = (A_EDU+B_EDU+C_EDU)*1000
EQFF = Final_EQF*0.6536
FCEQF = 1000-EQFF
FCJRF = 1000-Final_JRF
FCORF = 1000-CORF
FCPNF = 1000-Final_PNF
FCSCF = 1000-Final_SCF
Final_EQF = CEQF+((delta_PNF)-(delta_SCF*0.2)-(delta_JRF*0.13)-(delta_ORF*0.2))
Final_JRF = IF (CJRF+((delta_PNF*0.47)))>0 THEN CJRF+((delta_PNF*0.47)) ELSE 0
Final_LBP = (FCEQF+FCJRF+FCORF+FCPNF+FCSCF)/(5)
Final_PNF = CPNF+(delta_ORF*0.22)
Final_SCF = CSCF+((delta_PNF*0.55)+(delta_JRF*0.25))
Good_population = 0.28
HAEDU = IF (counter_y=0) THEN (1.05/100)*APopRELSE((1.05/100)*APopR)+(MAEDU*(0.2/100))

HBEDU = IF (counter_y=0) THEN (0*BPopR) ELSE
(0*BPopR+(MBEDU*(0.02/100)))
HCEDU = IF (counter_y=0) THEN (0*CPopR)
ELSE(0*CPopR+(MCEDU*(0.02/100)))
Health_index_2 = 1000-Tot_C_chcnace
Hire_check = IF (additional_tot>0) THEN 1 ELSE 0
Hire_check_3 = IF (additional_tot>(RAOs)) THEN 1 ELSE 0
HRO = IF(0.04+((counter_y-1)*0.5/100))<1 THEN
(0.04+((counter_y-1)*0.5/100)) ELSE 1
improvement_increse = DELAY(Tot_C_chcnace,1)-Tot_C_chcnace
initial_A_pop = 680
initial_B_pop = 112
initial_C_pop = 8
Initial_operators = 800
Initial_working_hours = Initial_operators*12*225
IntSBT = 252414
IRSBT = 1.02
JOS = ((19.48*RGJOSP) + (25.30*RRJOSP) + (34.78*RMJOSP))
*1000
JRFF = Final_JRF*0.68027
LAEDU = 4.44/100*APopR
LBEDU = 20/100*BPopR
LBP_prevention_index = Final_LBP
LCEDU = 1*CPopR
LHAOs = IF(SBT>BHAOs) THEN (SBT-BHAOs) ELSE 0
LHBOs = IF(LHAOs>BHBOs) THEN (LHAOs-BHBOs) ELSE 0
LHCOs = IF(LHBOs>BHCOs) THEN (LHBOs-BHCOs) ELSE 0
LWEP = RANDOM(0.2667,0.7333)
LWHOs = ROUND(Working_hours_with_12_hours/(8*225))
MAEDU = 94.51/100*APopR
Maturity_index = IF (LBP_prevention_index<200) THEN 1 ELSE (IF
(LBP_prevention_index=200 OR (LBP_prevention_index> 200 AND
LBP_prevention_index<400))THEN 2 ELSE(IF
(LBP_prevention_index=400 OR (LBP_prevention_index> 400 AND
LBP_prevention_index<600))THEN 3 ELSE IF
(LBP_prevention_index=600 OR (LBP_prevention_index> 600 AND
LBP_prevention_index<800))THEN 4 ELSE IF
(LBP_prevention_index=800 OR (LBP_prevention_index> 600 AND
(LBP_prevention_index<1000 OR LBP_prevention_index=1000)))THEN 5
ELSE 0))
MBEDU = 80/100*BPopR
MCEDU = 0*CPopR
Moderate_population = 0.07
MWEP = 1-LWEP
Net_Hieing_and_turnover_B = 0.04
Net_Hireing_and_turnover_A = 0.039
Net_Hiring_and_Turnover_C = 0.042

New_A_per_year = APop-DELAY(APop,1)
New_B_per_year = BPop-DELAY(BPop,1)
New_C_per_year = CPop-DELAY(CPop,1)
New_replces_sus = ROUND((Budget_for_suspension_replace/PSS))
new_suspension_ratio = NSS/Total_seats
NHOs = Operators-Initial_operators
NMAEDU = IF (counter_y=0) THEN MAEDU ELSE (MAEDU-(MAEDU*(0.2/100)))
NMBEDU =
IF (counter_y=0) THEN MBEDU ELSE (MBEDU-(MBEDU*(0.2/100)))
NMCEDU =
IF (counter_y=0) THEN MCEDU ELSE (MCEDU-(MCEDU*(0.2/100)))
Non_Standad_C_operators = NSOs*0.01
Non_standard_A_Operators = NSOs*0.85
Non_standard_B_operators = NSOs*0.14
Normal_A_popu = ROUND(Normal_A_Pop+A_normal_new)
Normal_B_popu = ROUND(Normal_B_pop+B_normal_new)
Normal_C_popu = ROUND(Normal_C_pop+C_under_new)
NSRR = NSR/(SR)
NSSs = ROUND ((SB/PSS)-1)
Obese_A_popu = ROUND(Obese_A_pop+A_obese_new)
Obese_B_popu = ROUND(Obese_B_Pop+B_obese_new)
Obese_C_popu = ROUND(Obese_C_pop+C_obse_new)
Operators = A_operators+B_operators+C_operators
Over_A_popu = ROUND(Over_A_pop+A_over_new)
Over_B_popu = ROUND(Over_B_pop+B_over_new)
Over_C_popu = ROUND(Over_C_pop+C_over_new)
PBWGT = Obese_A_popu+Obese_B_popu+Obese_C_popu
PBWGTR = PBWGT/Tot_op
percentage_improvement = IF (counter_y>1) THEN ((Init_chances-Tot_C_chcnace)/Init_chances) *100 ELSE 0
PNWGT = Normal_A_popu+Normal_B_popu+Normal_C_popu
PNWGTR = PNWGT/Tot_op
POWGT = Over_A_popu+Over_B_popu+Over_C_popu
POWGTR = POWGT/Tot_op
PSR = 100000
PSS = 700
PUWGT = Under_A_popu+Under_B_popu+Under_C_popu
PUWGTR = PUWGT/Tot_op
RAAOs = IF RAOs=0 THEN 0 ELSE IF counter_y=1THEN 0 ELSE ROUND(((RAOs*0.85*HRO)+0.5))
RABOs = IF RAOs=0 THEN 0 ELSE IF counter_y=1THEN 0 ELSE ROUND(((RAOs*0.14*HRO))-0.5)
RACOs = IF RAOs=0 THEN 0 ELSE IF counter_y=1THEN 0 ELSE ROUND(((RAOs*0.01*HRO))-0.5)
RAOs = IF((LWHOs-NSOs)>0) THEN(LWHOs-NSOs) ELSE 0

RAPSMK = IF((APopR*0.2444)-Reduction_of_A)>0.015THEN ((APopR*0.2444)-Reduction_of_A) ELSE 0.015
RBPSMK = IF((BPopR*0.40)-Reduction_of_B)>0.015THEN ((BPopR*0.40)-Reduction_of_B) ELSE 0.015
RBSS = NCSs*PSS*SBY
RCPSMK = IF((CPopR*1)-Reduction_of_C)>0.015THEN ((CPopR*1)-Reduction_of_C) ELSE 0.015
Reasonable_population = 0.65
Reduction_of_A = counter_y*0.01
Reduction_of_B = 0.0165*counter_y
Reduction_of_C = counter_y*0.0168
Remain_after_buying_cusion = ESB-SB
RLWEP = LWEP/TPop
RMHAOs = WHRA*WEPerYear*RAAOs
RMHBOs = WHRB*WEPerYear*RABOs
RMHCOs = WHRC*WEPerYear*RACOs
RMWEP = MWEP/ TPop
RNSOs = NSOs/(NSOs+SOs)
SBT = (IntSBT* IRSBT) ^ (counter_y)
SBY = IF(EBY =5 AND MOD(counter_y,5)=0) THEN 1 ELSE 0
SR_check = IF (SRBR>0) THEN 1 ELSE 0
SR_check_3 = IF (SRBR=(SR)) THEN 1 ELSE 0
SS_check = IF (NSS>0) THEN 1 ELSE 0
SS_check_3 = IF (NSS>(SR)) THEN 1 ELSE 0
S_Rate = (Bud_check+(2*Check_train)+(3*Hire_check)+SR_check+SS_check)
S_Rate_3 = (Bud_check_3+(2*Check_train_3)+(3*Hire_check_3)+SR_check_3+SS_check_3)
TAIR = IF TY=0 THEN 1.06 ^ROUND((counter_y/3)-0.5) ELSE 0
TBIR = IF TY=2 THEN 1.06 ^ROUND((counter_y/3)-0.5) ELSE 0
TCIR = IF TY=1 THEN 1.06 ^ROUND((counter_y/3)-0.5) ELSE 0
Total_seats = NSS+NCSs
Tot_A_train_budget = TSBT+additional_A_train_budget
Tot_C_chcnace = (EQFF+Final_JRF+CORF+Final_PNF+Final_SCF)/(5)
Tot_extra_cost = addictional_B_train_budget+additional_C_train_budget+additional_A_train_budget
Tot_op = NSOs+SOs
TPAY = IF (counter_y=3) THEN 0.54 ELSE (IF (counter_y=6) THEN 0.6433 ELSE(IF(counter_y= 9) THEN 0.7711 ELSE(0.80)))
TPBY = IF (counter_y=2) THEN 0.54 ELSE (IF (counter_y=5) THEN 0.6433 ELSE(IF(counter_y= 8) THEN 0.7711 ELSE(0.80)))
TPCY = IF (counter_y=1) THEN 0.54 ELSE (IF (counter_y=4) THEN 0.6433 ELSE(IF(counter_y= 7) THEN 0.7711 ELSE(0.80)))
TPop = APop+BPop+CPop

TR = (TTOs/Tot_op)
TSBT = IF (counter_y=1) THEN 0 ELSE IF(SBT-BHHEOs)<0 THEN 0 ELSE SBT-BHHEOs
TTOs = STA+STB+STC+DELAY(STA,1)+DELAY(STC,1)+DELAY(STC,2)+DELAY(STA,2)+DELAY(STB,1)+DELAY(STB,2)
TY = MOD(counter_y,3)
Under_A_popu = APop-(Normal_A_popu+Obese_A_popu+Over_A_popu)
Under_B_popu = BPop-(Normal_B_popu+Obese_B_popu+Over_B_popu)
Under_C_popu = CPop-(Normal_C_popu+Obese_C_popu+Over_C_popu)
WEPerYear = 52
WHRA = 18.1
WHRB = 20.63
WHRC = 21.19
Working_hours_with_12_hours = NSOs*225*12