PRODUCTIVITY ASSESSMENT AND SCHEDULE COMPRESSION INDEX
FOR CONSTRUCTION PROJECT PLANNING

SHAIFUL AMRI BIN MANSUR

A thesis submitted in fulfilment of the requirements for the award of the degree of
Doctor of Philosophy

Faculty of Civil Engineering
Universiti Teknologi Malaysia

DECEMBER 2004
To all who like to work smart.
ACKNOWLEDGEMENT

Alhamdulillah, I am very thankful to God that in preparing this thesis, I had received the support and assistance from many professionals from the construction industry, researchers, academicians, friends and family. Without their contributions, this thesis never would have come about. I express my deep appreciation to them:

- my supervisor, Associate Professor Dr Abd Hakim Mohammed for his advice, guidance and friendship;
- my ex-supervisor, Dr Che Wan Fadhil Che Wan Putra for his advice and friendship;
- UTM for the scholarship and opportunity given to me to study;
- my colleagues and friends for their supports and understandings;
- my wife for her complete support, encouragement and wisdom;
- my children for their patience, supports and prayers;

And finally, I also express my appreciation to many others whose contributions have made all the difference.
ABSTRACT

Productivity assessment and performance evaluation models identified from previous researches were normally performed separately to reduce complication and cost. However, performing both the productivity assessment and performance evaluation would benefit a project progress significantly. Furthermore, effective schedule compression methods should be identified to maximise productivity and reduce additional costs. The aim of the research was to develop a project management tool that combined productivity assessment and schedule compression methods for reporting productivity status and evaluating project performance. The report is produced based on the level of Factors Affecting Productivity (FAP) and Schedule Compression Methods (SCM) obtained from the project. The research was divided into three stages, which involved a pilot, first round, and second round questionnaire surveys. The respondents of the surveys were mostly project and site managers from registered construction firms in several states of the Malaysia Peninsular. The first stage of the research involved identifying the importance and optimum level of project planning, differences between productivity and performance, fundamentals of productivity assessments, plus FAP and SCM from literature review. The pilot survey was used to determine the relevance, suitability and applicability of the information obtained from literature review to the local building construction industry using index of importance method. The second stage of the research involved two rounds of surveys. The objective of the first round survey was to obtain the minimum and maximum limit for FAP and SCM elements weighting process, and to develop the questionnaire for second round survey. The objective of the second round survey was to obtain historical data from completed building construction projects. A table of predicted time performance ratio (TPR) was produced using fuzzy inference system, which was to be used as a project performance index table. The results showed that FAP and SCM were positively correlated, and so were FAP and TPR. In conclusions, there was a need for effective and cheaper project management tools. Productivity assessment and SCM were implemented only by less than fifty percent of the survey respondents. Correct selection of construction methods, scheduling implementation, starting work as planned, complexity of construction and contractor’s budget allocation were considered as having high impact on FAP, while the most effective SCM claimed by the respondents was staffing the project with most efficient crew members. A status report that contained both productivity and performance status of a project was successfully produced.
ABSTRAK

# TABLE OF CONTENTS

Title Page i
Declaration of Originality and Exclusiveness ii
Dedication iii
Acknowledgement iv
Abstract (English) v
Abstrak (Bahasa Malaysia) vi
Table of Contents vii
List of Tables xvi
List of Figures xxi
List of Symbols/Abbreviations/Notations/Terminologies xxvi
List of Appendices xxix

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1.1 Introduction</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1.2 Background of the Problem</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1.3 Statement of the Problem</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>1.4 Aims and Objectives</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1.5 Scope of Research</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>1.6 Methodology of the Research</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>1.7 Organisation of the Thesis</td>
<td>10</td>
</tr>
</tbody>
</table>
2 CONSTRUCTION PROJECT PLANNING

2.1 Introduction 12
2.2 The Importance of Project Planning 13
2.3 Finding the Correct Level of Planning 15
  2.3.1 Current Planning Practice 17
    2.3.1.1 Macro-Planning Process 19
    2.3.1.2 Micro-Planning Process 20
2.4 Pre-Project Planning 21
2.5 Planning Models 23
2.6 Project Scheduling 24
  2.6.1 Traditional Approach to Project Scheduling 28
  2.6.2 Work Package Scheduling 30
2.7 Decision Problems 34
  2.7.1 Decision-Making Process 35
2.8 Critical Path Method (CPM) 38
  2.8.1 Estimating Project Duration 39
  2.8.2 Planning Effectiveness 40
2.9 Automation in Planning 42
2.10 Planning Alignment in Organisations 45
2.11 Summary of Chapter 46

3 PRODUCTIVITY AND PROJECT PERFORMANCE 48

3.1 Introduction 48
3.2 Propositions to the Construction Industry 48
3.3 Productivity and Performance 50
3.4 Planning and Controlling Performance 51
3.5 Performance Measurement and Indicators 52
  3.5.1 Quantitative Performance Indicators 53
    3.5.1.1 Units per Man-Hour (UMH) 54
    3.5.1.2 Cost per Unit (CPU) 55
3.5.2. Qualitative Performance Indicators 57
3.5.3. Productivity Assessment and Performance Indicators 60
3.5.4. Time or Schedule Performance 61
3.5.5 Cost Performance 65
3.5.6 Quality Performance Indicators 70
3.5.7 Other Performance Indicators 75
  3.5.7.1 Disruption and Project Management Indices 75
  3.5.7.2 General Performance Index 76
  3.5.7.3 Risk Performance 80
  3.5.7.4 Key Performance Indicators 83
  3.5.7.5 Communication Performance Indicators 84
  3.5.7.6 Cost-Schedule Performance Indices 84
3.6 Summary of Chapter 85

4 PRODUCTIVITY ASSESSMENT 87

4.1 Introduction 87
4.2 Fundamental Aspects of Productivity 87
4.3 Productivity Defined 89
4.4 Approaches to Productivity Improvement 89
4.5 Methodologies for Direct Assessment of Productivity Rate 92
  4.5.1 Direct Observation Method 96
  4.5.2 Work Study 97
  4.5.3 Audio-Visual Methods 98
  4.5.4 Activity Sampling 99
  4.5.5 Craftsmen’s Questionnaire Survey 100
4.5.6 Foreman Delay Survey 100
4.5.7 Daily Visit Method 101

4.6 Indirect Productivity Assessment 103
4.6.1 Productivity Index 104

4.7 Factors Affecting Productivity (FAP) 105
4.7.1 Client 107
4.7.2 Consultants 109
4.7.3 Contractors 111
4.7.4 Material 112
4.7.5 Labour 112
4.7.6 Tools and Equipment 115
4.7.7 Contractual 116
4.7.8 External Factors 117
4.7.9 Other Factors 119

4.8 Disseminating Knowledge in the Construction Industry 120

4.9 Summary of Chapter 120

5 PRODUCTIVITY AND SCHEDULE COMPRESSION MODELS 122
5.1 Introduction 122

5.2 Productivity Models 122
5.2.1 Estimating Labour Productivity Using Probability Inference Neural Network 126
5.2.2 Conceptual Model for Measuring Productivity of Design and Engineering 126
5.2.3 Productivity Measurement: Untangling the White-Collar 127
5.2.4 Construction Baseline Productivity: Theory and Practice 128
5.2.5. Physiological Demands of Concrete Slab Placing and Finishing Work 128
5.2.6. Construction Labour Productivity Modelling with Neural Networks 129
5.2.7 Neural Network Model for Estimating Construction Productivity 130
5.2.8 Loss of Labour Productivity Due to Delivery Methods and Weather 130
5.2.9 Assignment and Allocation Optimisation of Partially Multi-skilled Workforce 131
5.2.10 Influence of Project Type and Procurement Method on Rework Costs in Building Construction Projects 132
5.2.11 Scheduled Overtime and Labour Productivity: Quantitative Analysis 132
5.2.12 Impact of Sub-contracting on Site Productivity: Lessons Learned in Taiwan 133
5.2.13 Reducing Variability to Improve Performance as a Lean Construction Principle 134
5.2.14 Using Machine Learning and Genetic Algorithms (GA) to Solve Time-Cost Trade-Off Problems 135
5.2.15 Incorporating Practicability into Genetic Algorithm-Based Time-Cost Optimisation 135
5.2.16 Site-level Facilities Layout Using Genetic Algorithms 136
5.2.17 Continuous Assessment of Project Performance 137
5.3 General Limitations of the Productivity Models 137
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4</td>
<td>Schedule Compression</td>
<td>138</td>
</tr>
<tr>
<td>5.4.1</td>
<td>The Proactive and Reactive Approaches</td>
<td>139</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Schedule Compression Methods (SCM)</td>
<td>141</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Level of Applicability of Concept</td>
<td>144</td>
</tr>
<tr>
<td>5.4.4</td>
<td>Selecting the Correct Method</td>
<td>144</td>
</tr>
<tr>
<td>5.5</td>
<td>Overview of the Malaysian Construction Industry</td>
<td>147</td>
</tr>
<tr>
<td>5.6</td>
<td>Propose Concept of Project Success</td>
<td>148</td>
</tr>
<tr>
<td>5.7</td>
<td>Summary of Chapter</td>
<td>151</td>
</tr>
<tr>
<td>6</td>
<td>RESEARCH METHODOLOGY</td>
<td>153</td>
</tr>
<tr>
<td>6.1</td>
<td>Introduction</td>
<td>153</td>
</tr>
<tr>
<td>6.2</td>
<td>Stages of the Research</td>
<td>153</td>
</tr>
<tr>
<td>6.3</td>
<td>The First Stage</td>
<td>155</td>
</tr>
<tr>
<td>6.3.1</td>
<td>Pilot Survey</td>
<td>155</td>
</tr>
<tr>
<td>6.3.1.1</td>
<td>Index of Importance</td>
<td>156</td>
</tr>
<tr>
<td>6.4</td>
<td>The Second Stage</td>
<td>158</td>
</tr>
<tr>
<td>6.4.1</td>
<td>First Round Survey - The Weighting Process</td>
<td>158</td>
</tr>
<tr>
<td>6.4.1.1</td>
<td>Normalising Process</td>
<td>163</td>
</tr>
<tr>
<td>6.4.1.2</td>
<td>Preliminary Weights</td>
<td>164</td>
</tr>
<tr>
<td>6.4.1.3</td>
<td>Data Screening using Box-plots</td>
<td>165</td>
</tr>
<tr>
<td>6.4.1.4</td>
<td>Mean for Maximum and Minimum Normalised Weights</td>
<td>167</td>
</tr>
<tr>
<td>6.4.1.5</td>
<td>Interpolating the Intermediate Normalised Weights</td>
<td>167</td>
</tr>
<tr>
<td>6.4.2</td>
<td>Second Round Survey – Obtaining Project Data</td>
<td>168</td>
</tr>
<tr>
<td>6.4.2.1</td>
<td>Questionnaire Development</td>
<td>168</td>
</tr>
<tr>
<td>6.4.2.2</td>
<td>Scoring Example</td>
<td>173</td>
</tr>
<tr>
<td>6.5</td>
<td>Model Fit</td>
<td>175</td>
</tr>
<tr>
<td>6.5.1</td>
<td>Acceptability of the Data</td>
<td>176</td>
</tr>
</tbody>
</table>
6.5.2 Scatter and Log Plots of the Residuals 177
6.5.3 Histograms 178

6.6 Determining the Relationship between FAP and SCM 179
6.6.1 Time Performance Indicator 180
6.6.2 Total FAP-SCM and TPR Relationships 181
6.6.2.1 Multiple Regression Method 181

6.7 Fuzzy Logic Network 182
6.7.1 Fuzzy Sets 183
6.7.2 Membership Functions 188
6.7.3 Logical Operations 190
6.7.4 If-Then Rules 192
6.7.5 Fuzzy Inference Systems 193

6.8 Estimating Project Risk 197
6.8.1 Quantitative Risk Analysis 197
6.8.2 Qualitative Risk Analysis 198
6.8.3 Decision Tree Analysis 200
6.8.4 Monte Carlo’s Simulation 202

6.9 Summary of Chapter 203

7 ANALYSES OF THE FINAL SCORE SHEET AND PASCI FACTORS 204

7.1 Introduction 204

7.2 Data Analyses – First Stage 204
7.2.1 Index of Importance 207

7.3 Data Analysis - Second Stage 210
7.3.1 First Round Survey - The Weighting Process 210
7.3.1.1 Analysis of the PASCI Parts and Categories 214
7.3.2 Second Round Survey – Obtaining Actual Project Data 216
  7.3.2.1 Sample Characteristics 216
  7.3.2.2 Scatter Plot of the Residuals 222
7.3.3 Histogram Plot of Standardised Residuals 226
7.4 Establishing PASCi Relationships 227
  7.4.1 Correlations and Linear Regressions 227
7.5 Projects Turning Points 230
7.6 Fuzzy Logic Network 232
7.7 Validating the Predicted Total TPR 239
7.8 Summary of Chapter 242

8 VALIDATING THE ASSESSMENT TOOL 244
  8.1 Introduction 244
  8.2 PASCi Category Analysis 245
  8.3 Productivity Assessment per Category 246
  8.4 Summary of Chapter 254
  8.5 Relationship with the Next Chapter 254

9 CASE STUDY: PASCi APPLICATION AND RISK ANALYSIS 255
  9.1 Introduction 255
  9.2 PASCi Application Process 255
    9.2.1 Overview of Sample Project 256
    9.2.2 Calculating the Volume of Work, Productivity Rate and Duration 257
    9.2.3 Assessment using the PASCi 260
  9.3 Project Risk Comparison 266
    9.3.1 Risk Scenario A 267
    9.3.2 Risk Scenario B 270
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Various other planning models</td>
<td>26</td>
</tr>
<tr>
<td>4.1</td>
<td>Factors affecting productivity</td>
<td>106</td>
</tr>
<tr>
<td>6.1</td>
<td>Data screening variables and weights</td>
<td>167</td>
</tr>
<tr>
<td>6.2</td>
<td>Logical operations</td>
<td>191</td>
</tr>
<tr>
<td>6.3</td>
<td>Altered logical operations</td>
<td>192</td>
</tr>
<tr>
<td>6.4</td>
<td>Comparison of reasoning tools (Han and Diekmann, 2001)</td>
<td>199</td>
</tr>
<tr>
<td>6.5</td>
<td>Risk scores</td>
<td>200</td>
</tr>
<tr>
<td>7.1</td>
<td>Types of company</td>
<td>205</td>
</tr>
<tr>
<td>7.2</td>
<td>Types of respondents</td>
<td>205</td>
</tr>
<tr>
<td>7.3</td>
<td>Working experience</td>
<td>206</td>
</tr>
<tr>
<td>7.4</td>
<td>Specialised areas</td>
<td>206</td>
</tr>
<tr>
<td>7.5</td>
<td>Location</td>
<td>206</td>
</tr>
<tr>
<td>7.6</td>
<td>Implementation of planning</td>
<td>206</td>
</tr>
<tr>
<td>7.7</td>
<td>Productivity assessment</td>
<td>206</td>
</tr>
<tr>
<td>7.8</td>
<td>Types of schedule compression</td>
<td>207</td>
</tr>
<tr>
<td>7.9</td>
<td>Implementation of SCM</td>
<td>207</td>
</tr>
<tr>
<td>7.10</td>
<td>Index of importance for FAP factors</td>
<td>209</td>
</tr>
<tr>
<td>7.11</td>
<td>Index of importance for SCM factors</td>
<td>210</td>
</tr>
<tr>
<td>7.12</td>
<td>Types of company</td>
<td>211</td>
</tr>
<tr>
<td>7.13</td>
<td>Types of respondents</td>
<td>211</td>
</tr>
<tr>
<td>7.14</td>
<td>Specialised in building projects</td>
<td>211</td>
</tr>
<tr>
<td>7.15</td>
<td>Working experience</td>
<td>212</td>
</tr>
<tr>
<td>7.16</td>
<td>Location</td>
<td>212</td>
</tr>
<tr>
<td>7.17</td>
<td>Implementation of planning</td>
<td>212</td>
</tr>
<tr>
<td>7.18</td>
<td>Productivity assessment</td>
<td>212</td>
</tr>
<tr>
<td>7.19</td>
<td>Types of schedule compression</td>
<td>212</td>
</tr>
<tr>
<td>7.20</td>
<td>Implementation of SCM</td>
<td>213</td>
</tr>
<tr>
<td>7.21</td>
<td>Frequency score calculations from data screening</td>
<td>214</td>
</tr>
<tr>
<td>7.22</td>
<td>PASC1 parts and categories sorted by weights</td>
<td>215</td>
</tr>
<tr>
<td>7.23</td>
<td>Highest weighted PASC1 factors</td>
<td>216</td>
</tr>
<tr>
<td>7.24</td>
<td>Types of company</td>
<td>216</td>
</tr>
<tr>
<td>7.25</td>
<td>Types of respondent</td>
<td>217</td>
</tr>
<tr>
<td>7.26</td>
<td>Specialised in building projects</td>
<td>217</td>
</tr>
<tr>
<td>7.27</td>
<td>Working experience</td>
<td>217</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>7.28</td>
<td>Location</td>
<td>217</td>
</tr>
<tr>
<td>7.29</td>
<td>Types of project</td>
<td>218</td>
</tr>
<tr>
<td>7.30</td>
<td>Project complexity</td>
<td>218</td>
</tr>
<tr>
<td>7.31</td>
<td>Implementation of planning</td>
<td>218</td>
</tr>
<tr>
<td>7.32</td>
<td>Implementation of CPM</td>
<td>218</td>
</tr>
<tr>
<td>7.33</td>
<td>Productivity assessment</td>
<td>219</td>
</tr>
<tr>
<td>7.34</td>
<td>Types of schedule compression</td>
<td>219</td>
</tr>
<tr>
<td>7.35</td>
<td>Unplanned schedule compression</td>
<td>219</td>
</tr>
<tr>
<td>7.36</td>
<td>Implementation of SCM</td>
<td>219</td>
</tr>
<tr>
<td>7.37</td>
<td>TPR</td>
<td>221</td>
</tr>
<tr>
<td>7.38</td>
<td>Data for TPR</td>
<td>221</td>
</tr>
<tr>
<td>7.39</td>
<td>Group statistics – Project durations</td>
<td>222</td>
</tr>
<tr>
<td>7.40</td>
<td>Independent samples test</td>
<td>222</td>
</tr>
<tr>
<td>7.41</td>
<td>Correlations total FAP-SCM</td>
<td>228</td>
</tr>
<tr>
<td>7.42</td>
<td>Regression coefficients</td>
<td>228</td>
</tr>
<tr>
<td>7.43</td>
<td>Correlations total FAP and TPR</td>
<td>229</td>
</tr>
<tr>
<td>7.44</td>
<td>Regression coefficients</td>
<td>230</td>
</tr>
<tr>
<td>7.45</td>
<td>Excluded variables</td>
<td>230</td>
</tr>
<tr>
<td>7.46</td>
<td>Group statistics</td>
<td>231</td>
</tr>
</tbody>
</table>
7.47 Independent samples test 231
7.48 Rules table 236
7.49 Project validation actual vs. fuzzy TPR 240
7.50 Descriptive statistics 241
7.51 Paired sample statistics 241
7.52 Paired sample correlations 241
7.53 Paired sample tests 241
7.54 TPR values 242
8.1 Correlation between PASCI categories and TPR score 246
8.2 Correlation coefficients for PASCI categories 247
8.3 Project performance groups 247
8.4 Scoring criteria for factor and group assessments 248
8.5 Categories and groups scores a) FAP, Projects 1 to 15, b) FAP, Projects 16 to 31, c) SCM, Projects 1 to 15, d) SCM, Projects 16 to 31, e) Groups, Projects 1 to 15, f) Groups, Projects 16 to 31 249
8.6 Group assessment correlation coefficients 250
8.7 Report of productivity assessments a) FAP, Projects 1 to 15, b) FAP, Projects 16 to 31, c) SCM, Projects 1 to 15, d) SCM, Projects 16 to 31, e) Groups, Projects 1 to 15, f) Groups, Projects 16 to 31 252
8.8 A complete productivity assessment and performance evaluation report 253
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1</td>
<td>Activity groupings</td>
<td>257</td>
</tr>
<tr>
<td>9.2</td>
<td>Calculating volume of work</td>
<td>259</td>
</tr>
<tr>
<td>9.3</td>
<td>Category duration</td>
<td>259</td>
</tr>
<tr>
<td>9.4</td>
<td>First review report</td>
<td>261</td>
</tr>
<tr>
<td>9.5</td>
<td>Second review report</td>
<td>264</td>
</tr>
<tr>
<td>9.6</td>
<td>Risk profile table</td>
<td>270</td>
</tr>
<tr>
<td>9.7</td>
<td>Risk profile table</td>
<td>272</td>
</tr>
<tr>
<td>9.8</td>
<td>Risk profile</td>
<td>277</td>
</tr>
<tr>
<td>9.9</td>
<td>Summary of the risk comparisons</td>
<td>280</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Methodology of the research</td>
<td>9</td>
</tr>
<tr>
<td>2.1</td>
<td>The optimum or planning saturation point (Neale and Neale, 1989)</td>
<td>16</td>
</tr>
<tr>
<td>2.2</td>
<td>Finding the correct planning (Firdman, 1991)</td>
<td>17</td>
</tr>
<tr>
<td>2.3</td>
<td>General vs. Optimal planning (Faniran et al., 1999)</td>
<td>25</td>
</tr>
<tr>
<td>2.4</td>
<td>Work package of the work plan (Choo et al., 1999)</td>
<td>32</td>
</tr>
<tr>
<td>2.5</td>
<td>Project planning process (Waly and Thabet, 2002)</td>
<td>36</td>
</tr>
<tr>
<td>2.6</td>
<td>Manual approach in current planning (Waly, Thabet and Wakefield, 1999)</td>
<td>37</td>
</tr>
<tr>
<td>2.7</td>
<td>Planned and actual effectiveness</td>
<td>41</td>
</tr>
<tr>
<td>3.1</td>
<td>Training performance evaluation methodology (Kuprenas et al., 2000)</td>
<td>54</td>
</tr>
<tr>
<td>3.2</td>
<td>Plan-do-check-act for performance measurement (Deming, 1986)</td>
<td>73</td>
</tr>
<tr>
<td>3.3</td>
<td>Benchmarking in the construction industry (Oakland and Sohal, 1996)</td>
<td>75</td>
</tr>
<tr>
<td>3.4</td>
<td>Conceptual model for predicting contractor performance (Alarcon and Mourgues, 2002)</td>
<td>78</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>3.5</td>
<td>Improved contractor selection model (Alarcon and Mourgues, 2002)</td>
<td>81</td>
</tr>
<tr>
<td>3.6</td>
<td>Ranges and scores for C/SPIs (Chang, 2001)</td>
<td>85</td>
</tr>
<tr>
<td>4.1</td>
<td>Off-site influences on the construction process (Sanvido, 1992)</td>
<td>92</td>
</tr>
<tr>
<td>4.2</td>
<td>Energy demand process in humans (Mohamed, 2002)</td>
<td>119</td>
</tr>
<tr>
<td>5.1</td>
<td>Planned and unplanned schedule compression methods (Noyce and Hanna, 1995)</td>
<td>143</td>
</tr>
<tr>
<td>5.2</td>
<td>Variables of project success</td>
<td>149</td>
</tr>
<tr>
<td>5.3</td>
<td>The assessment and evaluation process</td>
<td>150</td>
</tr>
<tr>
<td>5.4</td>
<td>Internal and external relationships</td>
<td>151</td>
</tr>
<tr>
<td>6.1</td>
<td>Flowchart of the research methodology</td>
<td>154</td>
</tr>
<tr>
<td>6.2</td>
<td>PASCI weighting process</td>
<td>159</td>
</tr>
<tr>
<td>6.3</td>
<td>An example of FAP weighting score sheet</td>
<td>162</td>
</tr>
<tr>
<td>6.4</td>
<td>An example of SCM weighting score sheet</td>
<td>162</td>
</tr>
<tr>
<td>6.5</td>
<td>Example of normalising minimum and maximum weights</td>
<td>163</td>
</tr>
<tr>
<td>6.6</td>
<td>Box-plots example of outliers and extremes</td>
<td>166</td>
</tr>
<tr>
<td>6.7</td>
<td>PASCI applicability in project life-cycle</td>
<td>170</td>
</tr>
<tr>
<td>6.8</td>
<td>PASCI – Example points of application</td>
<td>172</td>
</tr>
<tr>
<td>6.9</td>
<td>Scoring scales</td>
<td>173</td>
</tr>
<tr>
<td>6.10</td>
<td>Example of an empty score sheet</td>
<td>174</td>
</tr>
</tbody>
</table>
6.11 Example of scoring on a score sheet 174
6.12 Example of summing up a score sheet 174
6.13 Fuzzy inference process 184
6.14 Classical set 184
6.15 Non-classical set 186
6.16 Two-valued memberships 187
6.17 Multi-valued memberships 187
6.18 Continuous two-valued memberships 188
6.19 Continuous multi-valued memberships 188
6.20 Two-valued membership function 189
6.21 Multi-valued membership function 190
6.22 Varying range of truth 192
6.23 Fuzzy inference process 195
6.24 FIS in MATLAB 197
7.1 Scatter plot of residuals 223
7.2 Normal Q-Q Plot of FAP and SCM 224
7.3 Detrended normal Q-Q plot of FAP and SCM 225
7.4 Histogram of random errors 226
7.5 Scatter plot total FAP vs. total SCM 228
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.6</td>
<td>Scatter plot total FAP vs. TPR</td>
<td>229</td>
</tr>
<tr>
<td>7.7</td>
<td>FIS editor</td>
<td>232</td>
</tr>
<tr>
<td>7.8</td>
<td>MF editor – Total FAP</td>
<td>233</td>
</tr>
<tr>
<td>7.9</td>
<td>MF editor – Total SCM</td>
<td>234</td>
</tr>
<tr>
<td>7.10</td>
<td>MF editor – TPR</td>
<td>235</td>
</tr>
<tr>
<td>7.11</td>
<td>Rule editor</td>
<td>236</td>
</tr>
<tr>
<td>7.12</td>
<td>Rule viewer</td>
<td>237</td>
</tr>
<tr>
<td>7.13</td>
<td>Surface viewer</td>
<td>238</td>
</tr>
<tr>
<td>9.1</td>
<td>PASCI application process</td>
<td>256</td>
</tr>
<tr>
<td>9.2</td>
<td>Planned schedule</td>
<td>260</td>
</tr>
<tr>
<td>9.3</td>
<td>Predicted TPR inserted in schedule</td>
<td>262</td>
</tr>
<tr>
<td>9.4</td>
<td>Primavera global change feature</td>
<td>263</td>
</tr>
<tr>
<td>9.5</td>
<td>Target schedules</td>
<td>263</td>
</tr>
<tr>
<td>9.6</td>
<td>Second target bar</td>
<td>265</td>
</tr>
<tr>
<td>9.7</td>
<td>Decision tree – Scenario A</td>
<td>268</td>
</tr>
<tr>
<td>9.8</td>
<td>Risk profile graph – Accept project</td>
<td>269</td>
</tr>
<tr>
<td>9.9</td>
<td>Risk profile graph – Refuse project</td>
<td>269</td>
</tr>
<tr>
<td>9.10</td>
<td>Decision tree – Scenario B</td>
<td>271</td>
</tr>
<tr>
<td>9.11</td>
<td>Risk profile graph – Accept project</td>
<td>271</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>9.12</td>
<td>Risk profile graph – Refuse project</td>
<td>272</td>
</tr>
<tr>
<td>9.13</td>
<td>Decision tree – Scenario C</td>
<td>273</td>
</tr>
<tr>
<td>9.14</td>
<td>The data table</td>
<td>273</td>
</tr>
<tr>
<td>9.15</td>
<td>Probability density function</td>
<td>274</td>
</tr>
<tr>
<td>9.16</td>
<td>Cumulative distribution function</td>
<td>275</td>
</tr>
<tr>
<td>9.17</td>
<td>Decision tree – Scenario C</td>
<td>275</td>
</tr>
<tr>
<td>9.18</td>
<td>Risk profile graph – Accept project</td>
<td>276</td>
</tr>
<tr>
<td>9.19</td>
<td>Risk profile graph – Refuse project</td>
<td>276</td>
</tr>
<tr>
<td>9.20</td>
<td>Decision tree – Scenario D</td>
<td>278</td>
</tr>
<tr>
<td>9.21</td>
<td>Probability density function</td>
<td>278</td>
</tr>
<tr>
<td>9.22</td>
<td>Cumulative distribution function</td>
<td>279</td>
</tr>
<tr>
<td>9.23</td>
<td>Comparison of risk predictions</td>
<td>280</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>ACWP</td>
<td>Actual Cost of Work Performed</td>
<td></td>
</tr>
<tr>
<td>AHP</td>
<td>Analytical Hierarchy Process</td>
<td></td>
</tr>
<tr>
<td>ANFIS</td>
<td>Adaptive Neuro-Fuzzy Inference System</td>
<td></td>
</tr>
<tr>
<td>BCIS</td>
<td>Building Cost Information Service</td>
<td></td>
</tr>
<tr>
<td>BCWP</td>
<td>Budgeted Cost of Work Performed</td>
<td></td>
</tr>
<tr>
<td>BCWS</td>
<td>Budgeted Cost of Work Scheduled</td>
<td></td>
</tr>
<tr>
<td>CDF</td>
<td>Cumulative Distribution Functions</td>
<td></td>
</tr>
<tr>
<td>CICE</td>
<td>Construction Industry Cost Effectiveness Project</td>
<td></td>
</tr>
<tr>
<td>CII</td>
<td>Construction Industry Institute of America</td>
<td></td>
</tr>
<tr>
<td>CPM</td>
<td>Critical Path Method</td>
<td></td>
</tr>
<tr>
<td>CPF</td>
<td>Cost Performance Factor</td>
<td></td>
</tr>
<tr>
<td>CPI</td>
<td>Cost Performance Index</td>
<td></td>
</tr>
<tr>
<td>CPU</td>
<td>Cost per Unit</td>
<td></td>
</tr>
<tr>
<td>CSF</td>
<td>Critical Success Factors</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>Cost Variance</td>
<td></td>
</tr>
<tr>
<td>DEA</td>
<td>Data Envelopment Analysis</td>
<td></td>
</tr>
<tr>
<td>DI</td>
<td>Disruption Index</td>
<td></td>
</tr>
<tr>
<td>EMR</td>
<td>Experience Modification Ratings</td>
<td></td>
</tr>
<tr>
<td>EPC</td>
<td>Engineer-Procure-Construct</td>
<td></td>
</tr>
<tr>
<td>EV</td>
<td>Earned Value</td>
<td></td>
</tr>
<tr>
<td>FAP</td>
<td>Factors Affecting Productivity</td>
<td></td>
</tr>
<tr>
<td>FIS</td>
<td>Fuzzy Inference System</td>
<td></td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode And Effect Analysis</td>
<td></td>
</tr>
<tr>
<td>GA</td>
<td>Genetic Algorithms</td>
<td></td>
</tr>
<tr>
<td>GPM</td>
<td>General Performance Model</td>
<td></td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
<td></td>
</tr>
<tr>
<td>KPIs</td>
<td>Key Performance Indicators</td>
<td></td>
</tr>
<tr>
<td>MCS</td>
<td>Monte Carlo Simulation</td>
<td></td>
</tr>
<tr>
<td>MF</td>
<td>Membership Functions</td>
<td></td>
</tr>
<tr>
<td>MLGAS</td>
<td>Machine Learning and Genetic Algorithms based System</td>
<td></td>
</tr>
<tr>
<td>OCV</td>
<td>Original Contract Value</td>
<td></td>
</tr>
<tr>
<td>PASCIA</td>
<td>Productivity Assessment And Schedule Compression Index</td>
<td></td>
</tr>
<tr>
<td>PDCA</td>
<td>Plan-Do-Check-Act</td>
<td></td>
</tr>
<tr>
<td>PDF</td>
<td>Probability Density Functions</td>
<td></td>
</tr>
<tr>
<td>PDRI</td>
<td>Project Definition Rating Index</td>
<td></td>
</tr>
<tr>
<td>PERT</td>
<td>Program Evaluation and Review Technique</td>
<td></td>
</tr>
<tr>
<td>PMI</td>
<td>Project Management Index</td>
<td></td>
</tr>
<tr>
<td>PPC</td>
<td>Percent Of Planned Completed</td>
<td></td>
</tr>
<tr>
<td>PR</td>
<td>Performance Ratio</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Pearson Correlation Coefficient</td>
<td></td>
</tr>
<tr>
<td>R-square</td>
<td>Coefficient Of Determination</td>
<td></td>
</tr>
<tr>
<td>SCM</td>
<td>Schedule Compression Methods</td>
<td></td>
</tr>
<tr>
<td>SPF</td>
<td>Schedule Performance Factor</td>
<td></td>
</tr>
<tr>
<td>SPI</td>
<td>Schedule Performance Index</td>
<td></td>
</tr>
<tr>
<td>SV</td>
<td>Schedule Variance</td>
<td></td>
</tr>
<tr>
<td>TFP</td>
<td>Total Factor Productivity</td>
<td></td>
</tr>
<tr>
<td>TPR</td>
<td>Time Performance Ratio</td>
<td></td>
</tr>
<tr>
<td>TQM</td>
<td>Total Quality Management</td>
<td></td>
</tr>
<tr>
<td>UMH</td>
<td>Unit per Man-Hour</td>
<td></td>
</tr>
<tr>
<td>VTR</td>
<td>Videotapes Recording</td>
<td></td>
</tr>
<tr>
<td>ai</td>
<td>Weight Value</td>
<td></td>
</tr>
<tr>
<td>ei</td>
<td>Residual For The $i^{th}$ Observation In The Data Set</td>
<td></td>
</tr>
<tr>
<td>i</td>
<td>Response Index</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>Total Respondents</td>
<td></td>
</tr>
<tr>
<td>te</td>
<td>Expected Performance Time</td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>List Of Explanatory Variables</td>
<td></td>
</tr>
<tr>
<td>xi</td>
<td>$i^{th}$ Frequency Of Response</td>
<td></td>
</tr>
<tr>
<td>yi</td>
<td>$i^{th}$ Response In The Data Set</td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>Total Value Of Change Orders</td>
<td></td>
</tr>
</tbody>
</table>
\( E \) - Expected Project Performance Time

\( I \) - Index Of Importance

\( Y_i \) - Given Data Set

\( V_T \) - Variance In Total Project Performance

\( \beta \) - Parameters Estimated During Modeling Process
## LIST OF APPENDICES

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Pilot Survey</td>
<td>323</td>
</tr>
<tr>
<td>B</td>
<td>First Round Survey</td>
<td>329</td>
</tr>
<tr>
<td>C</td>
<td>Second Round Survey</td>
<td>335</td>
</tr>
<tr>
<td>D</td>
<td>The Weighted Score Sheet</td>
<td>342</td>
</tr>
<tr>
<td>E</td>
<td>PASCI Scoring Example</td>
<td>345</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Introduction

Construction projects are one-time and largely unique efforts of limited duration, which involve work of a non-standardised and variable nature. Field construction works can be greatly affected and influenced by events that are difficult to anticipate. High cost requirements and limited time to adjust can seriously worsen the situation. Proper co-ordination and communication can have significant effect on productivity and quality of construction projects (Sadri, 1994). This makes skilled and unremitting management efforts become not only desirable but also imperative for a satisfactory result. There is just too much risk to undertake a construction project without a well-thought plan. The risks can emerge in the forms of time variation, cost variation or litigations.

Productivity is one of the most important basic variables governing economic production activities (Alby, 1994). However, despite being so important, productivity has sometimes been relegated to second rank, neglected or ignored. In recent years, the pressures of an increasingly global economy have compelled companies in all industries including construction to focus on strategies for
productivity improvements. Unfortunately, issues related to productivity measurement or assessment have not received adequate attention by the relevant parties. The main reasons that made productivity assessment become complicated were (Belcher and John, 1984; Alby, 1994; Sudit, 1995):

- **Methodology**: Improvements in the methodology of productivity assessment were diversified and not performed as a whole.
- **Operational**: The implementations of productivity assessment procedures in most firms were not adequate.

Nevertheless, many construction development bodies have shown interest in the study of productivity in the construction industry. Over the past several years, the Construction Industry Institute of America (CII) has funded a number of research projects focused on productivity (CII, 1990a; CII, 1992; CII, 1994a; CII, 1994b). Findings from these investigations have somehow changed the degree of awareness of project management professionals toward the importance and benefits of productivity assessment.

There are two common problems related to the productivity issues. The first common problem faced by clients and contractors is project delay (Finke, 1999; Kartam, 1999; Al-Hammad, 2000). A project delay means a project that cannot be completed, partially or as a whole, on or before the scheduled completion date. There are many factors that can delay works and the project completion, such as unexpected events, hidden conditions or even additional work assigned during construction. In order to bring the project back on schedule, the contractor’s rate of performing the remaining activities must be increased because there is more work to be finished in a limited time. Even though the whole project schedule may look the same, the contractor’s individual schedule may have to be compressed.

The second problem, which usually troubles the contractor, is when the client decides to move in or use a facility earlier than planned, which makes the whole project schedule needs to be completed early (AGC, 1994; Al-Khalil and Al-Ghaflay, 1999). This may involve shortening or compressing the overall schedule duration by revising the project plan. Schedule compression can be performed during the planning process before the start of construction or anytime in between the
construction period (CII, 1988a & 1990b). The usual goal of schedule compression to the client is to shorten the overall schedule duration by the necessary amount at the least cost (AGC, 1994).

In both cases, productivity aspects of the project must be understood, so that productivity can be increased and effective methods of schedule compression can be applied in order to complete a construction project at the required time with least costs (CII, 1990b). Measuring project performance alone will not be very effective because the sources of improving performance come from productivity control and improvement, which cannot be done without productivity assessment (Allmon et al., 2000). In general, productivity assessment can provide an objective source of information about operating trends, draw attention to problems of performance and inspire a useful exchange of ideas.

1.2 Background of the Problem

It is the norm that all project participants would attempt to perform well when a construction project is first undertaken (McKim et al., 2000). However, construction projects must go through many complex steps, difficult site conditions and different individuals, which have caused some unavoidable delays, such as changing of the planned concepts or even rescheduling the project details (Faniran et al., 1999). It is highly desirable for contractors to deal with productivity objectively (Paulonis and Cox, 2003). Project managers and participants should implement techniques that are aimed at “doing things right the first time” and able to find, analyse and make corrections while the job is under way (Daffenbaugh, 1993; Jahren and Federle, 1999; Deming, 1986). Thus, there must be some appropriate ways to monitor tasks from deviations and to bring the schedule back on track when problems occur or delays happen.
An extensive literature review was performed on related topics, such as pre-project planning (Gibson and Hamilton, 1994; Gibson et al., 1993; Gibson et al., 1994; CII, 1995; CII, 1997), productivity (Motwani et al., 1995; Thomas and Zavrski, 1999; Allmon et al., 2000; Rojas and Aramvareekul, 2003a; Rojas and Aramvareekul, 2003b; Goodrum and Hass, 2004), schedule compression (Moselhi, 1993; Noyce and Hanna, 1998; CII, 1988, 1990 & 1998; Hanna et al., 1999a & 1999b) and project success (Chan et al., 2001; Griffith et al., 1999; Chua, 1999; Griffith and Gibson, 2001; Gao et al., 2002). The findings were used to provide background and support in developing the problem statement and methodology used in this study.

According to a study by CII (1994c), pre-project and project planning are very important in determining the success of a project. The better it is performed, the better the overall outcome of the project would be. In other words, there is a positive, quantifiable relationship between effort expended during the pre-project planning phase and the ultimate success of a project (Ottoman et al., 1999; McKim et al., 2000; Cox et al., 2003). By establishing lower third, middle third and upper third pre-project planning effort groups within the sample and evaluating each group against success variables, some broad conclusions can be made. At least, various parties involved in construction projects should understand the implications of pre-project planning in terms of project execution and the contracting environment that currently exists in the industry.

Many public and private sectors are investing significantly less money into preventive maintenance programmes in the construction industry. This lack of financial commitment towards construction projects is because of construction productivity and quality has not improved as much as in other industries and is regarded as low-priority investment (Christian and Hachey, 1995). However, the practice of giving low commitment to productivity and quality improvement should not be continued further because a successful project implementation should be accepted as a big return of an investment too.
1.3 Statement of the Problem

Delays in construction projects are very common, but not something that are unavoidable (Finke, 1999; Kartam, 1999; Carr, 2000). When delay happens, work output or productivity must be increased so that the initial schedule can be achieved. Although there are many methods suggested and commonly used to accelerate work productivity or to compress construction schedules, there is no clear and definitive answer on the effects of these method on certain important characteristics of a project, such as the capability of increasing the productivity rate of labour, reducing the schedule duration and whether the methods selected will increase the project costs (Christian and Hachey, 1995; Motwani, 1995; Noyce and Hanna, 1998; Crockett, 2000; Allmon et al., 2000, Marsh, 2002; Rojas and Aramvareekul, 2003a). For example, the initial reaction for most cases is probably to use more labour, increase the work period into overtime or use an additional shift (Noyce and Hanna, 1998). Yet, it is not clear if these methods will in fact reduce the duration and what the overall impact on cost will be. On the other hand, there are also many other schedule compression methods that are not commonly considered as equally or more effective in reducing the impacts on the financial status of contractors during schedule compression period (CII 1990).

However, there have been many studies performed and models developed by researchers in other countries that can be used as guides to this research (Perera, 1982; Coskunogula, 1984; Vrat and Kriengkrairut, 1986; Ritchie, 1990; CII, 1990; Moselhi, 1993; Senouci and Hanna, 1995; Noyce and Hanna, 1998). Some of the major problems with those existing models are that they have to be specially tailored or customised to the project local needs before they can be applied effectively (Hancher and Abd-ElKhalek, 1998). They can also be too complex to be understood and applied by general construction parties because they generally lack the emphasis and accountability on practical and effective concepts or the methods used in compressing the construction schedule itself (Thomas et al., 1999; Han and Diekmann, 2001).
Contractors and clients must be able to identify their resource constraints and apply the appropriate management decision process in the selection of the schedule compression approach or technique (Leu et al., 1999; Chelaka et al., 2001; Hegazy and Ersahin, 2001). There is a need to assess and evaluate the current or expected level of productivity and to identify the most effective methods of getting a project back on track. The need is to develop an improvised model of productivity assessment and schedule compression methods that is simple to understand and easy to apply, so that contractors and clients can be guided and informed about how to increase productivity and compress a schedule effectively with very little time to prepare and anticipate. The primary purpose of this study is to develop a practical tool or index that can be used by Malaysian project planning teams, including contractors and clients.

1.4 Aim and Objectives

The aim of the research is to develop a project management tool that combines productivity assessment and schedule compression methods for reporting productivity status and evaluating project performance. The objectives of this research are:

1. To establish the level of implementation of:
   a. Project planning.
   b. Productivity assessment.
   c. Schedule compression methods.

2. To identify elements of the followings that are relevant to the local building construction projects:
   a. Factors affecting productivity.
   b. Schedule compression methods.

3. To determine the correlations between factors affecting productivity, schedule compression methods and project time performance.
4. To perform productivity assessment and performance evaluation using single planning tool.
5. To compare estimated risks involved with and without productivity assessment tool.

1.5 Scope of Research

The chance of achieving a project success can be increased by performing assessment on project productivity and on the effectiveness of schedule compression methods. This is done by forecasting the probability in which certain construction activity will finish on time and the capability of compressing the project schedule. Because of insufficient project data and the requirement of additional planning costs, pre-project planning was typically not given enough emphasis in building construction projects in Malaysia. Therefore, an inexpensive management or planning tool that can be applied during pre-project and construction stage can be very useful, especially the one that is user-friendly, accurate and reliable.

In developing such a tool, a study was conducted to gather data on general building projects in Peninsular Malaysia that were completed within the last five years. The tool was developed and intended to be used in general building construction projects, such as schools, offices, shop-houses, hotels, residential, mosques and institutional buildings. In order to avoid significant discrepancies, the tool should be limited from being applied in other types of projects or in other countries.
1.6 Methodology of the Research

Figure 1.1 represents the methodology of the research, which was performed over a three years and six months period. The study was divided into stages, namely, the first, second and third stage. The first stage involved collecting data from literature review, setting research aims and objectives, and conducting a pilot survey. The second stage involved two rounds of survey, model fitting and data analyses. The third stage involved model validation, risk prediction, conclusion and recommendations for future research.

The initial steps in the first stage was identifying the importance and optimum level of project planning, the differences between productivity and performance, fundamentals of productivity assessments, Factors Affecting Productivity (FAP) and Schedule Compression Methods (SCM) from previous research found in the literature review. This was followed by a pilot survey, which objective was to determine the relevance, suitability and applicability of the information obtained from literature review to the local building construction industry using index of importance method.

In the second stage, the objective of the first round survey were to obtain the minimum and maximum limit for FAP and SCM elements weighting process, and develop the questionnaire for second round survey. The objective of the second round survey was to obtain historical data from completed projects. The data were analysed to determine the correlations between FAP, SCM and TPR. Once the correlations were determined, a prediction table for predicted TPR values was produced using fuzzy inference system. The table of predicted TPR values can be referred to as the project performance index table.
Figure 1.1: Methodology of the research
In the third stage, validation of the data was performed to test their accuracy and consistency. The predicted TPR values were validated using completed project data. An application of risk analysis was also demonstrated for an on-going project at the time of the research, as a case study. Lastly, conclusions of the research and recommendations for future research were made. More details on the research methodology can be found in Chapter 6.

1.7 Organisation of the Thesis

This thesis is divided into ten chapters. Chapter 1 gives the introduction and background to the existing problems, describes the research objectives and the research methodology.

Chapter 2 provides the overview of project planning. The importance of implementing and finding the correct level of planning are discussed. The existing planning models are identified.

Chapter 3 highlights the difference between productivity and performance. Existing performance measurement and performance indicators are identified.

Chapter 4 focuses on productivity assessment process. Methodologies for direct and indirect productivity assessment are identified. Factors affecting productivity are also identified, which are important to the development of the research.

Chapter 5 identifies productivity and schedule compression methods that have been developed and implemented in previous research. The strengths and limitations of the models are described.
Chapter 6 discusses in detail the methodology of the research. The research was discussed in accordance to stages of the research. Identification of survey elements, questionnaire development, data collection process and method of analysis are the main topics described in the chapter.

Chapter 7 describes the analyses that were performed on the data collected from different stages of the research. The results are displayed, analysed and discussed in order to obtain significant findings and fulfill the research objectives.

Chapter 8 discusses the data validation process. The model capabilities in performing productivity assessment and performance evaluation are demonstrated using data from completed projects. Actual project data were compared to the predicted values produced in this research.

Chapter 9 demonstrates the application of the research findings in predicting and reducing project risks. The demonstration is performed on a selected project as a case study.

Chapter 10 finally summarises the research work, provides the conclusions of this research and recommendations for future research.
e) Different versions of the PASCI namely for building, industrial and infrastructure projects are also recommended. The existing methodology and data should significantly reduce the research efforts of developing a new version of the PASCI.

f) Enhancing the application using information technology or other new technology can widen the interest in the application of this tool.
REFERENCES


*Construction Engineering and Management*. 116(1): 100-111.


Lee, J. D. (1997). *Validation of a Simulation Model to Evaluate Crew Size.* Santa Monica. CA.


Microsoft® Project. (2002). Copyright© Microsoft Corporation. Redmond. WA.


*International Environment Conscious Design Manufacturing*. ECDM Press. 2(6): 
25-32.


in Single Family Housing in Mid-Atlantic Rural University Towns*. Virginia Polytechnic Institute and State University: Masters Thesis.


and Build Contracts. *Proceedings Design and Build Procurement Systems 
Seminar*. 49–60.


 *Construction Engineering and Management*. 125(2): 69-75.


