

# **Hybrid Recommender Systems for Personalized Government-to- Business e-Services**

A Thesis Submitted for the Degree of  
Doctor of Philosophy

By

**Qusai Yousef Shambour**



University of Technology, Sydney

February, 2012

Copyright © 2012 by Qusai Shambour. All Rights Reserved

# CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

Production Note:

Signature removed prior to publication.

# ACKNOWLEDGEMENTS

First of all, I would like to express my sincere gratitude to my PhD principal supervisor, Prof. Jie Lu, for offering me an opportunity to begin my research study three and a half years ago. Thank you for your continuous support, encouragement, precious guidance and patience throughout my study. Thank you for your accurate critical comments and suggestions, which have strengthened this study significantly. Your strict academic attitude, generous personality and conscientious working style have influenced me deeply, and will be of great benefit to me in my future research work and life. I have learned a lot more from you than you realize. I also would like to address my sincere thanks to my co-supervisor, A/Prof. Guangquan Zhang for his knowledgeable suggestions and valuable advice, which have greatly improved the final quality of my PhD thesis.

Most of all, I would like to express my deepest appreciation to my family. To my parents, Yousef and Sana'a, thank you for supporting me and always being there for me during my ups and downs. Pursuing a PhD was always a long term challenge for me and a dream of my father's. This dream would have not been achieved without the love, great empathy and kind assistance of my father. Very special thanks to my father who believes in me more than I do in myself.

I would like to express my highest appreciation to my wife, Sara, for her unconditional love, encouragement, support and patience throughout my study. It would have been impossible for me to complete my study without her help. She shared all my pain, sorrow and depression in the most difficult time of my research. Her optimistic view of life encourages me a lot, not only in my research but also in my life. I am so grateful to have her as my lifelong partner. I would also like to

express my thanks and love to my three lovely daughters, Roa'a, Layan and Hala for their support, understanding, and patience with my anxiety through this journey.

I would like to thank Ms. Sue Felix for helping me to identify and correct grammar, syntax and presentation problems in my thesis. I am grateful to the School of Software in the Faculty of Engineering and Information Technology at the University of Technology, Sydney. This study was fully supported by a UTS Doctoral Research Scholarship (UTSD).

Finally, I wish to express my appreciation all my friends and the members of the Decision Systems & e-Service Intelligence (DeSI) Lab (especially Mr. Vahid Behbood) for their help, participation and valuable comments in every presentation I made during my study. The DeSI lab is one of five laboratories within the Centre for Quantum Computation and Intelligent Systems (QCIS), School of Software, Faculty of Engineering and Information Technology at the University of Technology, Sydney.

# TABLE OF CONTENTS

<i>ACKNOWLEDGEMENTS</i> .....	<i>ii</i>
<i>LIST OF FIGURES</i> .....	<i>ix</i>
<i>LIST OF TABLES</i> .....	<i>xv</i>
<i>ABSTRACT</i> .....	<i>xx</i>
<b>CHAPTER 1 Introduction</b> .....	<b>1</b>
<b>1.1 Background</b> .....	<b>1</b>
<b>1.2 Research Challenges</b> .....	<b>5</b>
<b>1.3 Research Objectives</b> .....	<b>8</b>
<b>1.4 Research Contributions</b> .....	<b>12</b>
<b>1.5 Research Methodology and Process</b> .....	<b>13</b>
1.5.1 Research Methodology.....	14
1.5.2 Research Process .....	16
<b>1.6 Formal Notations</b> .....	<b>17</b>
<b>1.7 Thesis Structure</b> .....	<b>18</b>
<b>1.8 Publications Related to This Thesis</b> .....	<b>20</b>
<b>CHAPTER 2 Literature Review</b> .....	<b>22</b>
<b>2.1 Government e-Services</b> .....	<b>22</b>
2.1.1 Government-to-Citizen (G2C) e-Services.....	23
2.1.2 Government-to-Business (G2B) e-Services .....	23
2.1.3 Government-to-Government (G2G) e-Services .....	24
2.1.4 Models of e-Government Development Stages .....	24
<b>2.2 Web Personalization</b> .....	<b>28</b>
2.2.1 Concept.....	28

2.2.2 Techniques .....	30
2.2.3 Government e-Service Personalization .....	32
<b>2.3 Recommender Systems: Classical Techniques .....</b>	<b>36</b>
2.3.1 Concept and Classification.....	36
2.3.2 Collaborative Filtering-based Recommendation Technique.....	38
2.3.3 Content-based Recommendation Technique.....	43
2.3.4 Knowledge-based Recommendation Technique .....	44
2.3.5 Hybrid-based Recommendation Technique .....	46
2.3.6 Evaluating Recommendation Techniques .....	48
<b>2.4 Recommender Systems: State-of-the-Art Techniques .....</b>	<b>49</b>
2.4.1 Fuzzy Set Technique in Recommender Systems .....	49
2.4.2 Semantic Technique in Recommender Systems .....	54
2.4.3 Trust Networks Technique in Recommender Systems .....	57
2.4.4 Multi-Criteria Technique in Recommender Systems.....	61
2.4.5 Fusion Technique in Recommender Systems .....	65
<b>2.5 Recommender Systems: Applications .....</b>	<b>66</b>
2.5.1 e-Commerce Recommender Systems.....	67
2.5.2 e-Learning Recommender Systems.....	68
2.5.3 e-Government Recommender Systems .....	70
<b><i>CHAPTER 3 Government-to-Business Recommendation Framework.....</i></b>	<b><i>77</i></b>
<b>3.1 Introduction .....</b>	<b>77</b>
<b>3.2 An Intelligent Business Partner Locator Recommendation Framework.....</b>	<b>78</b>
3.2.1 User Interface Layer.....	80
3.2.2 Recommendation Layer .....	84
3.2.3 Data Storage Layer.....	86
<b>3.3 Value Assessment of the IBPL Recommendation Framework .....</b>	<b>87</b>
<b>3.4 Summary .....</b>	<b>90</b>

<b>CHAPTER 4 Fuzzy-Semantic Recommendation Algorithm.....</b>	<b>91</b>
<b>4.1 Introduction .....</b>	<b>91</b>
<b>4.2 A Hybrid Fuzzy Semantic CF (FSCF) Algorithm .....</b>	<b>93</b>
4.2.1 Preliminaries.....	93
4.2.2 A Fuzzy Product Semantic Relevance Model.....	95
4.2.3 The Recommendation Computation Process .....	99
<b>4.3 A Case-based Example.....</b>	<b>106</b>
<b>4.4 Experimental Evaluations and Analysis.....</b>	<b>109</b>
4.4.1 Evaluation Dataset and Metrics.....	109
4.4.2 Benchmark Recommendation Approaches .....	110
4.4.3 Evaluation Results.....	111
<b>4.5 Summary .....</b>	<b>118</b>
<b>CHAPTER 5 Semantic-enhanced Recommendation Algorithm .....</b>	<b>119</b>
<b>5.1 Introduction .....</b>	<b>119</b>
<b>5.2 A Hybrid Semantic-enhanced CF (SeCF) Algorithm .....</b>	<b>120</b>
5.2.1 An Item-based Semantic Similarity Model.....	120
5.2.2 The Recommendation Computation Process .....	124
<b>5.3 A Case-based Example.....</b>	<b>129</b>
<b>5.4 Experimental Evaluations and Analysis.....</b>	<b>133</b>
5.4.1 Evaluation Dataset and Metrics.....	134
5.4.2 Benchmark Recommendation Approaches .....	134
5.4.3 Evaluation Results.....	135
<b>5.5 Summary .....</b>	<b>141</b>
<b>CHAPTER 6 Trust-enhanced Recommendation Algorithm.....</b>	<b>143</b>
<b>6.1 Introduction .....</b>	<b>143</b>
<b>6.2 A Hybrid Trust-enhanced CF (TeCF) Algorithm .....</b>	<b>145</b>

6.2.1 A User-based Implicit Trust Model .....	145
6.2.2 The Recommendation Computation Process .....	151
<b>6.3 A Case-based Example.....</b>	<b>158</b>
<b>6.4 Experimental Evaluations and Analysis.....</b>	<b>163</b>
6.4.1 Evaluation Dataset and Metrics.....	163
6.4.2 Benchmark Recommendation Approaches .....	163
6.4.3 Evaluation Results.....	164
<b>6.5 Summary .....</b>	<b>171</b>
<b><i>CHAPTER 7 Multi-Criteria Recommendation Algorithms .....</i></b>	<b><i>172</i></b>
<b>7.1 Introduction .....</b>	<b>172</b>
<b>7.2 Preliminaries.....</b>	<b>174</b>
<b>7.3 A Hybrid Multi-Criteria Semantic-enhanced CF (MC-SeCF) Algorithm.....</b>	<b>175</b>
7.3.1 The Recommendation Computation Process .....	175
7.3.2 A Case-based Example.....	180
7.3.3 Experimental Evaluations and Analysis.....	185
<b>7.4 A Hybrid Multi-Criteria Trust-enhanced CF (MC-TeCF) Algorithm.....</b>	<b>195</b>
7.4.1 The Recommendation Computation Process .....	195
7.4.2 A Case-based Example.....	202
7.4.3 Experimental Evaluations and Analysis.....	208
<b>7.5 Summary .....</b>	<b>217</b>
<b><i>CHAPTER 8 Fusion-Based Recommendation Algorithms .....</i></b>	<b><i>219</i></b>
<b>8.1 Introduction .....</b>	<b>219</b>
<b>8.2 A Fusion of Hybrid SeCF and Hybrid TeCF Recommendation Algorithms.....</b>	<b>220</b>
8.2.1 The Fusion Recommendation Process .....	221
8.2.2 A Case-based Example.....	225
8.2.3 Experimental Evaluations and Analysis.....	231



<b>8.3 A Fusion of Hybrid MC-SeCF and Hybrid MC-TeCF Recommendation</b>	
<b>Algorithms.....</b>	<b>239</b>
8.3.1 The Fusion Recommendation Process .....	239
8.3.2 A Case-based Example.....	244
8.3.3 Experimental Evaluations and Analysis.....	250
<b>8.4 Summary.....</b>	<b>256</b>
<b>CHAPTER 9 Conclusions And Future Study.....</b>	<b>257</b>
<b>9.1 Conclusions .....</b>	<b>257</b>
<b>9.2 Future Study .....</b>	<b>266</b>
<b>APPENDICES.....</b>	<b>268</b>
<b>Appendix A: Datasets Description.....</b>	<b>268</b>
<b>Appendix B: Screenshots of the ‘BizSeeker’ Prototype System.....</b>	<b>272</b>
<b>Appendix C: Abbreviations.....</b>	<b>274</b>
<b>REFERENCES.....</b>	<b>276</b>

# LIST OF FIGURES

<i>Figure 1-1 The general methodology of design research.....</i>	<i>14</i>
<i>Figure 1-2 Thesis structure.....</i>	<i>19</i>
<i>Figure 2-1 EU progress achievement on five-stage sophistication model .....</i>	<i>34</i>
<i>Figure 2-2 Framework for the analysis and classification of recommender systems</i>	<i>38</i>
<i>Figure 2-3 An example of a product taxonomy tree .....</i>	<i>55</i>
<i>Figure 2-4 An example of a trust social network.....</i>	<i>57</i>
<i>Figure 2-5 CF in a multi-criteria rating setting .....</i>	<i>62</i>
<i>Figure 2-6 An example of multi-criteria ratings in Epinions .....</i>	<i>64</i>
<i>Figure 2-7 An example of multi-criteria ratings in Yahoo! Movies .....</i>	<i>65</i>
<i>Figure 3-1 The IBPL recommendation framework.....</i>	<i>79</i>
<i>Figure 4-1 Fuzzy sets and membership functions for Table 4-1.....</i>	<i>97</i>
<i>Figure 4-2 Fuzzy sets and membership functions for Table 4-2.....</i>	<i>98</i>
<i>Figure 4-3 An example of product taxonomy with semantic relevance weights.....</i>	<i>99</i>
<i>Figure 4-4 A hybrid FSCF recommendation algorithm diagram.....</i>	<i>100</i>
<i>Figure 4-5 Impact of neighborhood size on recommendation accuracy .....</i>	<i>111</i>
<i>Figure 4-6 Impact of <math>\omega</math> on recommendation accuracy.....</i>	<i>112</i>
<i>Figure 4-7 Recommendation accuracy comparison between the hybrid FSCF algorithm and other benchmark approaches on different number of neighbors (MovieLens dataset).....</i>	<i>113</i>
<i>Figure 4-8 Recommendation accuracy comparison between the hybrid FSCF algorithm and other benchmark approaches on different number of neighbors (Yahoo Webscope dataset) .....</i>	<i>113</i>
<i>Figure 4-9 Recommendation accuracy comparison between the hybrid FSCF algorithm and other benchmark approaches on different number of neighbors (BizSeeker dataset).....</i>	<i>114</i>

<i>Figure 4-10 Recommendation accuracy comparison between the hybrid FSCF algorithm and other benchmark approaches on different Sparsity levels .....</i>	<i>115</i>
<i>Figure 4-11 Recommendation coverage comparison between the hybrid FSCF algorithm and other benchmark approaches on different Sparsity levels .....</i>	<i>116</i>
<i>Figure 4-12 Recommendation accuracy comparison between the hybrid FSCF algorithm and other benchmark approaches on different number of ratings for CS Items .....</i>	<i>117</i>
<i>Figure 4-13 Recommendation coverage comparison between the hybrid FSCF algorithm and other benchmark approaches on different number of ratings for CS Items .....</i>	<i>117</i>
<i>Figure 5-1 An example of business taxonomy .....</i>	<i>121</i>
<i>Figure 5-2 A hybrid SeCF recommendation algorithm diagram .....</i>	<i>124</i>
<i>Figure 5-3 Recommendation accuracy comparison between the hybrid SeCF algorithm and other benchmark item-based CF approaches on different number of neighbors (MovieLens dataset) .....</i>	<i>136</i>
<i>Figure 5-4 Recommendation accuracy comparison between the hybrid SeCF algorithm and other benchmark item-based CF approaches on different number of neighbors (Yahoo Webscope dataset) .....</i>	<i>136</i>
<i>Figure 5-5 Recommendation accuracy comparison between the hybrid SeCF algorithm and other benchmark approaches on different number of neighbors (BizSeeker dataset) .....</i>	<i>137</i>
<i>Figure 5-6 Recommendation accuracy comparison between the hybrid SeCF algorithm and other benchmark approaches on different Sparsity levels .....</i>	<i>138</i>
<i>Figure 5-7 Recommendation coverage comparison between the hybrid SeCF algorithm and other benchmark approaches on different Sparsity levels .....</i>	<i>139</i>
<i>Figure 5-8 Recommendation accuracy comparison between the hybrid SeCF algorithm and other benchmark approaches on different number of CS Items ratings .....</i>	<i>140</i>

<i>Figure 5-9 Recommendation coverage comparison between the hybrid SeCF algorithm and other benchmark approaches on different number of CS Items ratings</i>	141
<i>Figure 6-1 Trust relations in recommender systems</i>	146
<i>Figure 6-2 A hybrid TeCF recommendation algorithm diagram</i>	152
<i>Figure 6-3 Examples of the trust propagation process</i>	160
<i>Figure 6-4 Recommendation accuracy comparison between the hybrid TeCF algorithm and other benchmark recommendation approaches on different number of neighbors (MovieLens dataset)</i>	165
<i>Figure 6-5 Recommendation accuracy comparison between the hybrid TeCF algorithm and other benchmark recommendation approaches on different number of neighbors (Yahoo Webscope dataset)</i>	166
<i>Figure 6-6 Recommendation accuracy comparison between the hybrid TeCF algorithm and other benchmark recommendation approaches on different number of neighbors (BizSeeker dataset)</i>	166
<i>Figure 6-7 Recommendation accuracy comparison between the hybrid TeCF algorithm and other benchmark recommendation approaches on different Sparsity levels</i>	168
<i>Figure 6-8 Recommendation coverage comparison between the hybrid TeCF algorithm and other benchmark recommendation approaches on different Sparsity levels</i>	168
<i>Figure 6-9 Recommendation accuracy comparison between the hybrid TeCF algorithm and other benchmark recommendation approaches on different number of ratings for CS users</i>	170
<i>Figure 6-10 Recommendation coverage comparison between the hybrid TeCF algorithm and other benchmark recommendation approaches on different number of ratings for CS users</i>	170
<i>Figure 7-1 A hybrid MC-SeCF recommendation algorithm diagram</i>	176

<i>Figure 7-2 Recommendation accuracy comparison between the hybrid MC-SeCF algorithm and other benchmark item-based CF approaches on different number of neighbors.....</i>	<i>187</i>
<i>Figure 7-3 Recommendation accuracy comparison between the hybrid MC-SeCF algorithm and the hybrid SC-SeCF algorithm on different number of neighbors....</i>	<i>188</i>
<i>Figure 7-4 Recommendation accuracy comparison between the hybrid MC-SeCF algorithm and other benchmark item-based CF approaches on different Sparsity levels .....</i>	<i>190</i>
<i>Figure 7-5 Recommendation coverage comparison between the hybrid MC-SeCF algorithm and other benchmark item-based CF approaches on different Sparsity levels .....</i>	<i>190</i>
<i>Figure 7-6 Recommendation accuracy comparison between the hybrid MC-SeCF algorithm and the hybrid SC-SeCF algorithm on different Sparsity levels.....</i>	<i>191</i>
<i>Figure 7-7 Recommendation coverage comparison between the hybrid MC-SeCF algorithm and the hybrid SC-SeCF algorithm on different Sparsity levels.....</i>	<i>191</i>
<i>Figure 7-8 Recommendation accuracy comparison between the hybrid MC-SeCF algorithm and other benchmark item-based CF approaches on different number of ratings for CS items .....</i>	<i>193</i>
<i>Figure 7-9 Recommendation coverage comparison between the hybrid MC-SeCF algorithm and other benchmark item-based CF approaches on different number of ratings for CS items .....</i>	<i>193</i>
<i>Figure 7-10 Recommendation accuracy comparison between the hybrid MC-SeCF and the hybrid SC-SeCF algorithm on different number of ratings for CS items.....</i>	<i>194</i>
<i>Figure 7-11 Recommendation coverage comparison between the hybrid MC-SeCF algorithm and the hybrid SC-SeCF algorithm on different number of ratings for CS items.....</i>	<i>194</i>
<i>Figure 7-12 A hybrid MC-TeCF recommendation algorithm diagram.....</i>	<i>196</i>
<i>Figure 7-13 Examples of the trust propagation process .....</i>	<i>205</i>

<i>Figure 7-14 Recommendation accuracy comparison between the hybrid MC-TeCF algorithm and other benchmark user-based CF approaches on different number of neighbors.....</i>	<i>209</i>
<i>Figure 7-15 Recommendation accuracy comparison between the hybrid MC-TeCF algorithm and the hybrid SC-TeCF on different number of neighbors .....</i>	<i>210</i>
<i>Figure 7-16 Recommendation accuracy comparison between the hybrid MC-TeCF algorithm and other benchmark user-based CF approaches on different Sparsity levels .....</i>	<i>212</i>
<i>Figure 7-17 Recommendation coverage comparison between the hybrid MC-TeCF algorithm and other benchmark user-based CF approaches on different Sparsity levels .....</i>	<i>212</i>
<i>Figure 7-18 Recommendation accuracy comparison between the hybrid MC-TeCF algorithm and the hybrid SC-TeCF algorithm on different Sparsity levels.....</i>	<i>213</i>
<i>Figure 7-19 Recommendation coverage comparison between the hybrid MC-TeCF algorithm and the hybrid SC-TeCF algorithm on different Sparsity levels.....</i>	<i>213</i>
<i>Figure 7-20 Recommendation accuracy comparison between the hybrid MC-TeCF algorithm and other benchmark user-based CF approaches on different number of ratings for CS users .....</i>	<i>215</i>
<i>Figure 7-21 Recommendation coverage comparison between the hybrid MC-TeCF algorithm and other benchmark user-based CF approaches on different number of ratings for CS users .....</i>	<i>216</i>
<i>Figure 7-22 Recommendation accuracy comparison between the hybrid MC-TeCF algorithm and the hybrid SC-TeCF algorithm on different number of ratings for CS users.....</i>	<i>216</i>
<i>Figure 7-23 Recommendation coverage comparison between the hybrid MC-TeCF algorithm and the hybrid SC-TeCF algorithm on different number of ratings for CS users.....</i>	<i>217</i>
<i>Figure 8-1 A diagram of the Fusion SC-STCF recommendation algorithm .....</i>	<i>221</i>
<i>Figure 8-2 The Fusion MC-STCF recommendation algorithm.....</i>	<i>240</i>

*Figure 9-1 The 'BizSeeker' home page ..... 272*

*Figure 9-2 The 'BizSeeker' recommendations list of "Food & Beverage" businesses  
as potential business partners ordered by prediction values..... 273*

# LIST OF TABLES

<i>Table 2-1 Summary and comparison of e-government development models .....</i>	<i>28</i>
<i>Table 2-2 Summary of recommender systems applications.....</i>	<i>73</i>
<i>Table 3-1 Definition and value of each concept in the metadata model .....</i>	<i>82</i>
<i>Table 3-2 Industry classification listed by Austrade.....</i>	<i>83</i>
<i>Table 3-3 The value assessment of the proposed IBPL recommendation framework</i>	<i>89</i>
<i>Table 4-1 Linguistic terms for users' preferences .....</i>	<i>97</i>
<i>Table 4-2 Linguistic terms for product relevance degrees .....</i>	<i>97</i>
<i>Table 4-3 Supplier-Buyer linguistic rating matrix.....</i>	<i>106</i>
<i>Table 4-4 Supplier-Supplier fuzzy semantic similarity matrix.....</i>	<i>107</i>
<i>Table 4-5 Supplier-Supplier fuzzy CF similarity matrix.....</i>	<i>107</i>
<i>Table 4-6 Supplier-Supplier total weighted similarity matrix.....</i>	<i>108</i>
<i>Table 4-7 Hybrid FSCF predicted Supplier-Buyer rating matrix .....</i>	<i>108</i>
<i>Table 4-8 Closeness Coefficient of FPV.....</i>	<i>109</i>
<i>Table 5-1 An example of Supplier-Buyer rating matrix.....</i>	<i>121</i>
<i>Table 5-2 Raw Supplier-Buyer rating matrix .....</i>	<i>129</i>
<i>Table 5-3 Supplier-Supplier category vector matrix.....</i>	<i>130</i>
<i>Table 5-4 Supplier-Supplier semantic similarity matrix.....</i>	<i>130</i>
<i>Table 5-5 Supplier-Supplier Jaccard similarity matrix.....</i>	<i>131</i>
<i>Table 5-6 Supplier-Supplier enhanced item-based CF similarity matrix.....</i>	<i>131</i>
<i>Table 5-7 Neighbors selection .....</i>	<i>131</i>
<i>Table 5-8 Item-based semantic predicted Supplier-Buyer rating matrix .....</i>	<i>132</i>
<i>Table 5-9 Enhanced item-based CF predicted Supplier-Buyer rating matrix.....</i>	<i>132</i>
<i>Table 5-10 Hybrid SeCF predicted Supplier-Buyer rating matrix.....</i>	<i>133</i>
<i>Table 6-1 Raw Supplier-Buyer rating matrix .....</i>	<i>158</i>
<i>Table 6-2 Buyer-Buyer Jaccard similarity matrix.....</i>	<i>159</i>



Table 6-3 Buyer-Buyer direct implicit trust matrix .....	159
Table 6-4 Buyer-Buyer propagated implicit trust matrix .....	160
Table 6-5 Buyer-Buyer enhanced user-based CF similarity matrix.....	161
Table 6-6 Neighbors selection .....	161
Table 6-7 Implicit trust-based predicted Supplier-Buyer matrix.....	162
Table 6-8 Enhanced user-based CF-based predicted Supplier-Buyer matrix.....	162
Table 6-9 Hybrid TeCF predicted Supplier-Buyer matrix.....	162
Table 7-1 Raw Supplier-Buyer multi-criteria rating matrix.....	181
Table 7-2 Buyers weights on the four criteria .....	181
Table 7-3 Supplier-Supplier category vector matrix .....	181
Table 7-4 Supplier-Supplier semantic similarity matrix.....	182
Table 7-5 Supplier-Supplier Jaccard similarity matrix.....	182
Table 7-6 Supplier-Supplier enhanced MC item-based CF similarity matrix (according to Buyer B1 criteria' weights) .....	183
Table 7-7 Neighbors selection .....	183
Table 7-8 Item-based semantic predicted Supplier-Buyer matrix.....	184
Table 7-9 Enhanced MC item-based CF predicted Supplier-Buyer matrix .....	184
Table 7-10 Hybrid MC-SeCF Predicted Supplier- Buyer matrix .....	184
Table 7-11 Raw Supplier-Buyer multi-criteria rating matrix.....	203
Table 7-12 Buyers weights on the four criteria .....	203
Table 7-13 Buyer-Buyer Jaccard similarity matrix.....	203
Table 7-14 Buyer-Buyer direct implicit trust matrix .....	204
Table 7-15 Buyer-Buyer propagated implicit trust matrix .....	205
Table 7-16 Buyer-Buyer MC user-based CF similarity matrix (according to each Buyer criteria' weights) .....	205
Table 7-17 Neighbors selection .....	206
Table 7-18 Implicit trust-based predicted Supplier-Buyer matrix.....	207
Table 7-19 Enhanced MC user-based CF predicted Supplier-Buyer matrix .....	207
Table 7-20 Hybrid MC-TeCF predicted Supplier-Buyer matrix .....	207

<i>Table 8-1 Raw Supplier-Buyer rating matrix .....</i>	<i>225</i>
<i>Table 8-2 Supplier-Supplier category vector matrix .....</i>	<i>226</i>
<i>Table 8-3 Supplier-Supplier semantic similarity matrix.....</i>	<i>226</i>
<i>Table 8-4 Supplier-Supplier enhanced item-based CF similarity matrix.....</i>	<i>227</i>
<i>Table 8-5 Neighbors selection .....</i>	<i>227</i>
<i>Table 8-6 SC-SeCF predicted Supplier-Buyer rating matrix .....</i>	<i>228</i>
<i>Table 8-7 Buyer-Buyer direct implicit trust matrix .....</i>	<i>228</i>
<i>Table 8-8 Buyer-Buyer propagated implicit trust matrix .....</i>	<i>228</i>
<i>Table 8-9 Buyer-Buyer enhanced user-based CF similarity matrix.....</i>	<i>229</i>
<i>Table 8-10 Neighbors selection .....</i>	<i>229</i>
<i>Table 8-11 SC-TeCF predicted Supplier-Buyer matrix.....</i>	<i>230</i>
<i>Table 8-12 Fusion SC-FSTCF predicted Supplier-Buyer rating matrix .....</i>	<i>230</i>
<i>Table 8-13 Recommendation accuracy (MAE) comparison between the Fusion SC-STCF algorithm with benchmark CF-based, hybrid SC-SeCF and hybrid SC-TeCF algorithms on different number of neighbors (MovieLens dataset).....</i>	<i>233</i>
<i>Table 8-14 Recommendation accuracy (MAE) comparison between the Fusion SC-STCF algorithm with benchmark CF-based, hybrid SC-SeCF and hybrid SC-TeCF algorithms on different number of neighbors (Yahoo Webscope dataset).....</i>	<i>234</i>
<i>Table 8-15 Recommendation accuracy (MAE) comparison between the Fusion SC-STCF algorithm with benchmark CF-based, hybrid SC-SeCF and hybrid SC-TeCF algorithms on different number of neighbors (BizSeeker dataset) .....</i>	<i>234</i>
<i>Table 8-16 Recommendation accuracy (MAE) comparison between the Fusion SC-STCF algorithm with benchmark CF-based, hybrid SC-SeCF and hybrid SC-TeCF algorithms on different levels of Sparsity .....</i>	<i>235</i>
<i>Table 8-17 Recommendation coverage comparison between the Fusion SC-STCF algorithm with benchmark CF-based, hybrid SC-SeCF and hybrid SC-TeCF algorithms on different levels of Sparsity .....</i>	<i>235</i>

<i>Table 8-18 Recommendation accuracy (MAE) comparison between the Fusion SC-STCF algorithm with benchmark item-based CF and hybrid SC-SeCF algorithms on different number of ratings for CS items.....</i>	<i>236</i>
<i>Table 8-19 Recommendation coverage comparison between the Fusion SC-STCF algorithm with benchmark item-based CF and hybrid SC-SeCF algorithms on different number of ratings for CS items.....</i>	<i>237</i>
<i>Table 8-20 Recommendation accuracy (MAE) comparison between the Fusion SC-STCF algorithm with benchmark user-based CF and hybrid SC-TeCF algorithms on different number of ratings for CS users.....</i>	<i>238</i>
<i>Table 8-21 Recommendation coverage comparison between the Fusion SC-STCF algorithm with benchmark user-based CF and hybrid SC-TeCF algorithms on different number of ratings for CS users.....</i>	<i>238</i>
<i>Table 8-22 Raw Supplier-Buyer multi-criteria rating matrix.....</i>	<i>244</i>
<i>Table 8-23 Buyers weights on the four criteria .....</i>	<i>245</i>
<i>Table 8-24 Supplier-Supplier category vector matrix .....</i>	<i>245</i>
<i>Table 8-25 Supplier-Supplier semantic similarity matrix.....</i>	<i>245</i>
<i>Table 8-26 Supplier-Supplier enhanced MC item-based CF similarity matrix (according to Buyer B<sub>1</sub> criteria' weights).....</i>	<i>246</i>
<i>Table 8-27 Neighbors selection .....</i>	<i>246</i>
<i>Table 8-28 MC-SeCF predicted Supplier-Buyer rating matrix.....</i>	<i>247</i>
<i>Table 8-29 Buyer-Buyer direct MC implicit trust matrix .....</i>	<i>247</i>
<i>Table 8-30 Buyer-Buyer propagated implicit trust matrix .....</i>	<i>248</i>
<i>Table 8-31 Buyer-Buyer enhanced MC user-based CF similarity matrix.....</i>	<i>248</i>
<i>Table 8-32 Neighbors selection .....</i>	<i>248</i>
<i>Table 8-33 MC-TeCF predicted Supplier-Buyer matrix.....</i>	<i>249</i>
<i>Table 8-34 Fusion MC-FSTCF predicted Supplier-Buyer rating matrix.....</i>	<i>249</i>
<i>Table 8-35 Recommendation accuracy (MAE) comparison between the Fusion MC-STCF algorithm with benchmark CF-based, hybrid MC-SeCF and hybrid MC-TeCF algorithms on different number of neighbors .....</i>	<i>252</i>

<i>Table 8-36 Recommendation accuracy (MAE) comparison between the Fusion MC-STCF algorithm with benchmark CF-based, hybrid MC-SeCF and hybrid MC-TeCF algorithms on different levels of Sparsity .....</i>	<i>253</i>
<i>Table 8-37 Recommendation coverage comparison between the Fusion MC-STCF algorithm with benchmark CF-based, hybrid MC-SeCF and hybrid MC-TeCF algorithms on different levels of Sparsity .....</i>	<i>253</i>
<i>Table 8-38 Recommendation accuracy (MAE) comparison between the Fusion MC-STCF algorithm with benchmark item-based CF and hybrid MC-SeCF algorithms on different number of ratings for CS items.....</i>	<i>254</i>
<i>Table 8-39 Recommendation coverage comparison between the Fusion MC-STCF algorithm with benchmark item-based CF and hybrid MC-SeCF algorithms on different number of ratings for CS items.....</i>	<i>254</i>
<i>Table 8-40 Recommendation accuracy (MAE) comparison between the Fusion MC-STCF algorithm with benchmark user-based CF and hybrid MC-TeCF algorithms on different number of ratings for CS users.....</i>	<i>255</i>
<i>Table 8-41 Recommendation coverage comparison between the Fusion MC-STCF algorithm with benchmark user-based CF and hybrid MC-TeCF algorithms on different number of ratings for CS users.....</i>	<i>256</i>
<i>Table 9-1 Comparative analysis of the effectiveness of the proposed SC-based recommendation algorithms .....</i>	<i>264</i>
<i>Table 9-2 Comparative analysis of the effectiveness of the proposed MC-based recommendation algorithms .....</i>	<i>265</i>

# ABSTRACT

As e-Governments around the world face growing pressures to improve the quality of service delivery and become more efficient and cost-effective, their initiatives currently focus on providing users with a seamless service delivery experience. Web-based technologies offer governments more efficient and effective means than traditional physical channels to provide high quality e-Service delivery to their users, which include citizens and businesses. Government-to-Business (G2B) e-Services involve information distribution, transactions, and interactions with businesses in varying ways via e-Government websites and portals. The G2B e-Services aim to reduce burdens on businesses and to provide effective and efficient access to information for business users. One of the most important e-Services of G2B is the promotion of local businesses goods and services to consumers (i.e., local and overseas businesses) by providing online business directories. However, with the rapid growth of information and unreliable search facilities, business users, who are seeking 'one-to-one' e-Services from government in highly competitive markets, struggle with online business directories and increasingly find it difficult to locate business partners according to their needs and interests. How, then, can business users be provided with information and services specific to their needs, rather than an undifferentiated mass of information? An effective solution proposed in this research is the development of personalized G2B e-Services using recommender systems. It is worth mentioning that the adoption of recommender systems in the context of e-Government to provide personalized services has received very limited attention in the literature.

Recommender systems aim to suggest the right items (products, services or information) that best match the needs and interests of particular users based on their explicit and implicit preferences. In current recommender systems, the Collaborative

Filtering (CF) approaches are the most popular and widely adopted recommendation approaches. Regardless of the success of CF-based approaches in various recommendation applications, they still suffer from data uncertainty, data sparsity, cold-start item and cold-start user problems, resulting in poor recommendation accuracy and reduced coverage. An effective solution proposed in this research to alleviate such problems is the development of hybrid and fusion-based recommendation algorithms that exploit and incorporate additional knowledge about users and items. Such knowledge can be extracted from either the users' trust social network or the items' semantic domain knowledge.

This research explores the adoption of recommender systems in an e-Government context for the provision of personalized G2B e-Services. Accordingly, a G2B recommendation framework for providing personalized G2B e-Services (particularly personalized business partner recommendations) for Small-to-Medium Businesses (SMBs) is proposed. Novel hybrid and fusion-based recommendation models and algorithms are also proposed and developed to overcome the limitations of existing CF-based recommendation approaches. Experimental results on real datasets show that our proposed recommendation algorithms significantly outperform existing recommendation algorithms in terms of recommendation accuracy and coverage when dealing with data sparsity, cold-start item and cold-start user limitations inherent in CF-based recommendation approaches.