MODELLING THE COMPLEXITY OF THE UAE NUCLEAR POWER PLANT OPERATIONAL READINESS PROGRAMME

نمذجة التعقيد لبرنامج الاستعداد التشغيلي لمحطات الطاقة النووية في دولة الإمارات العربية المتحدة

by

YOUSEF MOHAMMED QTEIT

A thesis submitted in fulfilment

of the requirements for the degree of

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Abstract

Network analysis was used to model the complexity of the UAE nuclear power plant operational readiness programme. The success of the Nuclear Power Plant Operational Readiness depends on how information travels throughout the programme via a network of complex interactions at different levels. In most cases, complex interactions that occur within nuclear power plant operational readiness programmes are poorly understood and unmanaged. This study aimed to demystify the complexity of nuclear operational project processes and stakeholders of the UAE nuclear sector.

Secondary data obtained for this research and was followed by in-depth interviews and multiple iterations of data quality check and results validation. These data were configured in the form of adjacencies matrices, transformed into Nodes and Edges, and were analyzed using Gephi Network Analysis software. This produced 13 networks that are mutually exclusive and collectively exhaustive of all interactions in the UAE Nuclear Power Plant Operational Readiness Program. Also, statistical reports on interdependencies, information flow structures, and the nature of influence have been produced. Findings revealed issues with network density; interactions turned out to be low, indicating a limited number of information sharing channels established among different actors. Findings also highlighted a structural configuration of the Hub and Spoke model, distinctive clusters, and Influential nodes in each interaction, which to great extent affect the information flow and the structural integrity of interactions explored in this study.

This study has demonstrated the utility of network analysis for Nuclear Power Plants Operational Readiness programs. The methodology achieved the purpose of modeling the complexity of nuclear operational project processes and stakeholders of the UAE nuclear sector and evaluating

interdependencies within detailed interactions and identifying key influential components that affect the Operating License achievement. Additional research is needed to test network analysis methods on different nuclear organizational context and ecosystem setup.

الملخص

تم استخدام منهجيات واليات تحليل الشبكات لنمذجة مدى تعقيد برنامج الاستعداد التشغيلي لمحطات الطاقة النووية الإماراتية. يعتمد نجاح الجاهزية التشغيلية لمحطة الطاقة النووية على كيفية انتقال المعلومات في جميع أنحاء البرنامج عبر شبكة من التفاعلات والترابطات المعقدة على مستويات مختلفة. في معظم الحالات، تكون التفاعلات المعقدة التي تحدث ضمن برامج الاستعداد التشغيلي لمحطة الطاقة النووية غير مفهومة وغير مُدارة بشكل ممنهج ومنظم. هدفت هذه الدراسة إلى إزالة الغموض عن تعقيد عمليات المشاريع التشغيلية النووية وأصحاب المصلحة في القطاع النووي الإماراتي.

تم الحصول على البيانات الثانوية لهذا البحث وتبعها مقابلات متعمقة وتكرارات متعددة لفحص جودة البيانات والتحقق من صحة النتائج. تم تكوين هذه البيانات في شكل مصفوفات متجاورة، وتحويلها إلى عقد وروابط، وتم تحليلها باستخدام برنامج "Gephi ". نتج عن ذلك 13 شبكة حصرية وشاملة لجميع التفاعلات في برنامج الاستعداد التشغيلي لمحطة الطاقة النووية الإماراتية. كما تم إنتاج تقارير إحصائية عن الترابطات، وهياكل تدفق المعلومات، وطبيعة التأثير. كشفت النتائج عن مشاكل تتعلق بكثافة الشبكة؛ تبين أن تفاعلات الترابط كانت منخفضة، مما يشير إلى عدد محدود من قنوات تبادل المعلومات التي تم إنشاؤها بين مختلف الجهات الفاعلة. أبرزت النتائج أيضًا التكوين الهيكلي لنموذج "Hub and Spoke "، والمجموعات المميزة، والعقد المؤثرة في كل تفاعل، والتي تؤثر إلى حد كبير على تدفق المعلومات والسلامة الهيكلية للتفاعلات التي تم استكشافها في هذه الدراسة.

أظهرت هذه الدراسة فائدة استخدام منهجية تحليل الشبكات لبرامج الاستعداد التشغيلي لمحطات الطاقة النووية. حققت المنهجية الغرض من نمذجة تعقيد عمليات المشاريع التشغيلية النووية وأصحاب المصلحة في القطاع النووي الإماراتي وتقييم الترابطات ضمن تفاعلات مفصلة وتحديد المكونات الرئيسية التي تؤثر على تحقيق رخصة التشغيل. هناك حاجة إلى مزيد من البحث لاختبار طرق تحليل الشبكة على سياق تنظيمي نووي مختلف ونظام تشغيلية متنوعة.

DEDICATION

I am dedicating this thesis to four beloved people who have meant and continue to mean so much to me. Although one of them is no longer with us in this world, his legacy continues to guide me through my life. First and foremost, to my grandfather Mustafa Khalil Qteit whose love for me knew no bounds and, who taught me the value of hard work. Thank you so much “ya seed”, I will never forget you.

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Contents

Chapter 1: Research Agenda 1
1.1. Research background 1
1.2. Research aim and objectives 3
1.3. Research questions 4
1.4. Novelty and theoretical significance 8
1.5. Outline of the thesis 10
Chapter 2: Review of Commissioning and Nuclear Power Plant Operational Readiness Literature 12
2.1 Introduction 12
2.2 UAE energy sector and the need for nuclear power generation 14
2.3 ..... Commissioning process and the organizational theory 16
2.3.1 Commissioning nuclear power plants 22
2.4 ..... Review of systems thinking, complexity and network analysis literature 29
2.4.1 Demystifying systems thinking and network analysis 30
2.4.2 Systems thinking and Network analysis application in the nuclear industry and other comparative fields 35
2.5 Chapter summary 43
Chapter 3: Conceptual Model 44
3.1 Introduction 44
3.2 Theoretical framework 45
3.2.1 Complexity in nuclear power plant operational readiness 47
3.2.2 Information use in the nuclear power plant operational readiness 48
3.2.3 Network analysis 49
3.3 Nuclear power plant operational readiness program components and interactions mapping 50
3.4 Chapter summary 57
Chapter 4: Research Methodology 57
4.1. Introduction 57
4.2. Research method process 58
4.3. Research paradigms 60
4.4. Research approach 62
4.5. Research methods 63
4.6. The rationale for the research design 65

4.7. Data collection methods 69
4.8. Data analysis 78
4.9. Confidentiality and accessibility 86
4.10. Data validity and reliability 88
4.11. Chapter summary 89
Chapter 5: Results 89
5.1. Introduction 90
5.2. Interactions between level 0 processes and regulatory requirements within the nuclear power plant operational readiness program 91
5.2.1 Network diagrams 91
5.2.2 General characteristics 102
5.2.3 Network density 103
5.2.4 Network clustering coefficient and modularity analysis 104
5.2.5 Network centrality measures 105
5.3. Interactions between level 0 processes and strategic programs within the nuclear power plant operational readiness program 110
5.3.1 Network diagrams 111
5.3.2 General characteristics 115
5.3.3 Network density 116
5.3.4 Network clustering coefficient and modularity analysis 117
5.3.5 Network centrality measures 118
5.4. Interactions amongst level 1 processes in the nuclear power plant operational readiness program 124
5.4.1 General characteristics 128
5.4.2 Network density 128
5.4.3 Network clustering coefficient and modularity analysis 129
5.4.4 Network centrality measures 131
5.5. Interactions between level 0 processes and stakeholders in the nuclear power plant operational readiness program 136
5.5.1 General characteristics 140
5.5.2 Network density 141
5.5.3 Network clustering coefficient and modularity analysis 142
5.5.4 Network centrality measures 144
5.6. Interactions between level 1 processes and stakeholders in the nuclear power plant operational readiness program 149
5.6.1 General characteristics 155
5.6.2 Network density 156

5.6.3 Network clustering coefficient and modularity analysis 156
5.6.4 Network centrality measures 158
5.7. Interactions between level 0 processes and nuclear power plant systems 164
5.7.1 General characteristics 168
5.7.2 Network density 169
5.7.3 Network clustering coefficient and modularity analysis 171
5.7.4 Network centrality measures 173
5.8. Interactions between level 0 processes and implementing procedures 179
5.8.1 General characteristics 198
5.8.2 Network density 199
5.8.3 Network clustering coefficient and modularity analysis 200
5.8.4 Network centrality measures 202
5.9. Interactions between level 0 processes in the nuclear power plant operational readiness 207
5.9.1 General characteristics 208
5.9.2 Network density 209
5.9.3 Network clustering coefficient and modularity analysis 210
5.9.4 Network centrality measures 211
5.10. Interactions between strategic programs and regulatory requirements in the nuclear power plant operational readiness program 216
5.10.1 General characteristics 219
5.10.2 Network density 219
5.10.3 Network clustering coefficient and modularity analysis 220
5.10.4 Network centrality measures 222
5.11. Interactions between strategic programs and roles in the nuclear power plant operational readiness program 227
5.11.1 General characteristics 236
5.11.2 Network density 236
5.11.3 Network clustering coefficient and modularity analysis 237
5.11.4 Network centrality measures 238
5.12. Interactions between strategic programs in the nuclear power plant operational readiness program 244
5.12.1 General characteristics 247
5.12.2 Network density 247
5.12.3. Network clustering coefficient and modularity analysis 248
5.12.4 Network centrality measures 249

5.13. Interactions between strategic programs and plant systems in the nuclear power plant operational readiness program 255
5.13.1 General characteristics 257
5.13.2 Network density 257
5.13.3 Network clustering coefficient and modularity analysis 259
5.13.4 Network centrality measures 261
5.14. Nuclear power plant operational readiness program full network 266
5.14.1 Nuclear power plant operational readiness program overview 268
5.14.2 General characteristics 269
5.14.3 Network density 270
5.14.4 Network clustering coefficient and modularity analysis 271
5.14.5 Network centrality measures 273
5.14.6 Quality assurance process ego network 277
5.14.7 Environmental services process ego network 281
5.14.8 Operating license (OL) requirements ego network 286
5.15. Linking findings to research objectives 290
5.16. Chapter summary 294
Chapter 6: Discussion of results 295
6.1 Introduction 295
6.2 Research objective 1 295
6.2.1 Interactions between level 0 processes and regulatory requirements within the nuclear power plant operational readiness program 295
6.2.2 Interactions between level 0 processes and strategic programs within the nuclear power plant operational readiness program 297
6.2.3 Interactions amongst level 1 processes in the nuclear power plant operational readiness program 299
6.2.4 Interactions between level 0 processes and stakeholders in the nuclear power plant operational readiness program 300
6.2.5 Interactions between level 1 processes and stakeholders in the nuclear power plant operational readiness program 301
6.2.6 Interactions between level 0 processes and nuclear power plant systems 303
6.2.7 Interactions between level 0 processes and implementing procedures 304
6.2.8 Interactions between level 0 processes in the nuclear power plant operational readiness 306
6.2.9 Interactions between strategic programs and regulatory requirements in the nuclear power plant operational readiness program 306
6.2.10 Interactions between strategic programs and roles in the nuclear power plant operational readiness program 307

6.2.11 Interactions between strategic programs in the nuclear power plant operational readiness program 308

6.2.12 Interactions between strategic programs and plant systems in the nuclear power plant operational readiness program........ 309

6.3 Research objective 2 311

6.3.1 Interactions between level 0 processes and regulatory requirements within the nuclear power plant operational readiness program........ 311

6.3.2 Interactions between level 0 processes and strategic programs within the nuclear power plant operational readiness program........ 314

6.3.3 Interactions amongst level 1 processes in the nuclear power plant operational readiness program 317

6.3.4 Interactions between level 0 processes and stakeholders in the nuclear power plant operational readiness program........ 320

6.3.5 Interactions between level 1 processes and stakeholders in the nuclear power plant operational readiness program........ 323

6.3.6 Interactions between level 0 processes and nuclear power plant systems........ 325

6.3.7 Interactions between level 0 processes and implementing procedures 328

6.3.8 Interactions between level 0 processes in the nuclear power plant operational readiness 331

6.3.9 Interactions between strategic programs and regulatory requirements in the nuclear power plant operational readiness program........ 334

6.3.10 Interactions between strategic programs and roles in the nuclear power plant operational readiness program........ 336

6.3.11 Interactions between strategic programs in the nuclear power plant operational readiness program 338

6.3.12 Interactions between strategic programs and plant systems in the nuclear power plant operational readiness program........ 341

6.4 Research objective 3 344

6.5 Research objective 4 348

6.5.1 Quality assurance process Ego network 348

6.5.2 Environmental services process Ego network 350

6.5.3 Operating license (OL) requirements Ego network........ 352

Chapter 7: Conclusions........ 355

7.1 Introduction........ 355

7.2 Accomplishing the research objectives........ 355

7.2.1 To Evaluate the interdependencies and the nature of influence within detailed interactions between the components of the nuclear power plant operational readiness program in UAE;355

7.2.2 Understand identify the key influential components of nuclear operational project processes and readiness in the UAE nuclear sector;........ 357

7.2.3 To model the complexity (interactions and the structure of information flow) of nuclear operational project processes and stakeholders of the UAE nuclear sector; 359

7.3 Research limitations 360

7.4 Knowledge contributions 361

7.5 Recommendations for further research 365

References 367

List of Figures

Figure 3. 1 Theoretical framework..46
Figure 4. 1 Research process..59
Figure 4. 2 The relationship between research paradigm, interpretative frameworks , methodology and research methods (Adopted from Crotty 1998). 60
Figure 4. 3 The research onion adopted from Saunders, Lewis and Thornhill (2011)..61
Figure 4. 4 *The dependency matrix structure* 72
Figure 4. 5 *Data collection and analysis process*..75
Figure 5. 1 *Level 0 processes and regulatory requirements network*..101
Figure 5. 2 Modularity class size distribution in the interactions between L0 processes and the regulatory requirements 105
Figure 5. 3 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and the regulatory requirements..107
Figure 5. 4 Ego network of ENV-L0 109
Figure 5. 5 L0 Processes and strategic programs network 114
Figure 5. 6 Modularity class size distribution in the interactions between L0 processes and strategic programs..118
Figure 5. 7 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and strategic programs 120
Figure 5. 8 Ego network of quality assurance process interactions with strategic programs 123
Figure 5. 9 Level-1 processes network..127
Figure 5. 10 L1 processes network modularity class size distribution..130
Figure 5. 11 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions amongst L1 processes..132
Figure 5. 12 Ego network of plant chemistry monitoring and control process 135
Figure 5. 13 Level 0 processes and stakeholders network 140
Figure 5. 14 Clusters size distribution in the interactions between L0 processes and stakeholders 143
Figure 5. 15 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and stakeholders..145
Figure 5. 16 Ego network of the process of managing statutory and regulatory requirements 147
Figure 5. 17 Level 1 processes and stakeholders network 150
Figure 5. 18 Clusters size distribution in the interactions between L1 processes and stakeholders 157
Figure 5. 19 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L1 processes and stakeholders..160
Figure 5. 20 Ego network of finance process..162
Figure 5. 21 L0 and nuclear power plant systems network..168
Figure 5. 22 Clusters size distribution in the interactions between L0 processes and plant systems, structures and components..172
Figure 5. 23 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and plant systems, structures or components. 174
Figure 5. 24 Ego network of structures, systems and components operations and monitoring process 177

Figure 5. 25 L0 Processes and implementing procedures network 198
Figure 5. 26 Modularity class size distribution in the interactions between L0 processes and implementing procedures 201
Figure 5. 27 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and implementing procedures 203
Figure 5. 28 Ego network of environmental services process 205
Figure 5. 29 Level 0 processes network 208
Figure 5. 30 Modularity class size distribution in the interactions amongst L0 processes 211
Figure 5. 31 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes 213
Figure 5. 32 Ego network of communication process 214
Figure 5. 33 Strategic programs and regulatory requirements network 218
Figure 5. 34 Clusters size distribution in the interactions between L0 processes and regulatory requirements 221
Figure 5. 35 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between strategic programs and the regulatory requirements 223
Figure 5. 36 Ego network of quality assurance program 225
Figure 5. 37 Strategic programs and roles network 235
Figure 5. 38 Clusters size distribution in the interactions between programs and roles 238
Figure 5. 39 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between strategic programs and roles 239
Figure 5. 40 Ego network of quality assurance program (PG43) 242
As per the network graph in Figure (5. 40), looking at the clustering of distinctive communities within the Quality Assurance Program Ego Network, we can observe four clusters with majority of nodes falling in the second cluster as show in figure (5.41) 243
Figure 5. 41 Clusters distribution of the Quality Assurance Program Ego Network 244
Figure 5. 42 Strategic programs network 246
Figure 5. 43 Clusters size distribution in the interactions between strategic programs 249
Figure 5. 44 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between strategic programs 250
Figure 5. 45 Ego network of maintenance program 253
Figure 5. 46 Clusters distribution of the maintenance program Ego network 255
Figure 5. 47 Strategic programs and plant systems network 256
Figure 5. 48 Modularity class size distribution in the interactions between strategic programs, plant systems, structures and components 260
Figure 5. 49 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between strategic programs, plant systems, structures and components. 262
Figure 5. 50 Ego network of quality assurance program 264
Figure 5. 51 Clusters distribution of the quality assurance program Ego network 266
Figure 5. 52 Nuclear power plant operational readiness program full network 267
Figure 5. 53 Clusters size distribution in the interactions between different components of the nuclear power plant operational readiness program 272

Figure 5. 54 a) Betweenness centrality distribution b) Closeness centrality distribution in the nuclear power plant operational readiness program 275
Figure 5. 55 Ego network of quality assurance process 278
Figure 5. 56 a) Betweenness centrality distribution b) Closeness centrality distribution in the quality assurance Ego network 280
Figure 5. 57 Clusters size distribution in the interactions between quality assurance process and other components of the nuclear power plant operational readiness program 281
Figure 5. 58 Ego network of environmental services process 282
Figure 5. 59 a) Betweenness centrality distribution b) Closeness centrality distribution in the environmental services process Ego betwork 284
Figure 5. 60 Clusters size distribution in the interactions between environmental services process and other components of the nuclear power plant operational readiness program 285
Figure 5. 61 Ego network of operating license (OL) requirements 286
Figure 5. 62 a) Betweenness centrality distribution b) Closeness centrality distribution in the operating license (OL) requirements Ego network 288
Figure 5. 63 Clusters size distribution in the interactions between operating license (OL) requirements and other components in NPP 289
Figure 6. 1 Statistical comparison of top nodes influencing processes and the regulatory requirements network 312
Figure 6. 2 Statistical comparison of top nodes influencing level 0 processes and strategic programs network 315
Figure 6. 3 Statistical comparison of top nodes influencing level 1 processes network 318
Figure 6. 4 Statistical comparison of top nodes influencing level 0 processes and stakeholders network 321
Figure 6. 5 Statistical comparison of top nodes influencing level 1 processes and stakeholders network 324
Figure 6. 6 Statistical comparison of top nodes influencing level 0 processes and plant systems network 326
Figure 6. 7 Statistical comparison of top nodes influencing level 0 processes and implementing procedures network 329
Figure 6. 8 Statistical comparison of top nodes influencing L0 processes network 332
Figure 6. 9 Statistical comparison of top nodes influencing strategic programs and regulatory requirements network 335
Figure 6. 10 Statistical comparison of top nodes influencing strategic programs and roles network 337
Figure 6. 11 Statistical comparison of top nodes influencing strategic programs network 339
Figure 6. 12 Statistical comparison of top nodes influencing strategic programs and plant systems network 342
Figure 6. 13 Statistical comparison of most influential nodes in the nuclear power plant operational readiness program 347
Figure 6. 14 Ego network of quality assurance process 349
Figure 6. 15: Ego network of environmental services process 351
Figure 6. 16 Ego network of operating license (OL) requirements 353

Figure 6. 1 Statistical comparison of top nodes influencing processes and the regulatory requirements network 312
Figure 6. 2 Statistical comparison of top nodes influencing level 0 processes and strategic programs network 315
Figure 6. 3 Statistical comparison of top nodes influencing level 1 processes network 318
Figure 6. 4 Statistical comparison of top nodes influencing level 0 processes and stakeholders network 321
Figure 6. 5 Statistical comparison of top nodes influencing level 1 processes and stakeholders network 324
Figure 6. 6 Statistical comparison of top nodes influencing level 0 processes and plant systems network 326
Figure 6. 7 Statistical comparison of top nodes influencing level 0 processes and implementing procedures network 329
Figure 6. 8 Statistical comparison of top nodes influencing L0 processes network 332
Figure 6. 9 Statistical comparison of top nodes influencing strategic programs and regulatory requirements network 335
Figure 6. 10 Statistical comparison of top nodes influencing strategic programs and roles network 337
Figure 6. 11 Statistical comparison of top nodes influencing strategic programs network 339
Figure 6. 12 Statistical comparison of top nodes influencing strategic programs and plant systems network 342
Figure 6. 13 Statistical comparison of most influential nodes in the nuclear power plant operational readiness program 347
Figure 6. 14 Ego network of quality assurance process 349
Figure 6. 15: Ego network of environmental services process 351
Figure 6. 16 Ego network of operating license (OL) requirements 353

List of Tables

Table 4. 1: Key network statistical measures and their contextual relevance to this research 83
Table 5. 1 List of level 0 processes 92
Table 5. 2 List of regulatory requirements.. 93
Table 5. 3 Structural characteristics of the L0 to regulatory requirements intersections........................ 102
Table 5. 4 L0 Processes with highest betweenness centrality 108
Table 5. 5 Ego network of ENV-L0 characteristic 110
Table 5. 6 Ego network of ENV-L0 statistics.. 110
Table 5. 7 List of strategic programs 112
Table 5. 8 Structural characteristics of the L0 to strategic programs intersections 115
Table 5. 9 L0 Processes with highest betweenness centrality 121
Table 5. 10 Characteristic of quality assurance process ego network 123
Table 5. 11 Statistics of quality assurance ego network 124
Table 5. 12 List of L1 processes.. 124
Table 5. 13 Characteristic of L1 processes network.. 128
Table 5. 14 L1 processes with highest betweenness centrality 133
Table 5. 15 Characteristic of plant chemistry monitoring and control Ego network.............................. 135
Table 5. 16 Statistics of plant chemistry monitoring and control Ego network 136
Table 5. 17 List of stakeholders identified for this study 137
Table 5. 18 Structural characteristics of the L0 to stakeholders intersections...................................... 141
Table 5. 19 L0 processes with highest betweenness centrality 146
Table 5. 20 Characteristic of ‘Statutory and Regulatory Requirements Process’ Ego Network 148
Table 5. 21 Statistics of ‘Statutory and Regulatory Requirements Management Process’ Ego Network 148
Table 5. 22 Structural characteristics of the L1 processes interactions with stakeholders...................... 155
Table 5. 23 L1 Processes with highest betweenness centrality 161
Table 5. 24 Characteristic of finance process Ego network 163
Table 5. 25 Statistics of finance process Ego network.. 163
Table 5. 26 List of plant systems, structures and components.. 164
Table 5. 27 Structural characteristics of the L0 to nuclear power plant systems intersections.............. 169
Table 5. 28 L0 Processes with highest betweenness centrality 175
Table 5. 29 Characteristic of finance process Ego network 177
Table 5. 30 Statistics of structures, systems and components process Ego network 178
Table 5. 31 List of implementing procedures 180
Table 5. 32 Structural characteristics of L0 processes and implementing procedures intersections 198
Table 5. 33 L0 Processes with highest betweenness centrality 204
Table 5. 34 Characteristic of environmental services process Ego network 205
Table 5. 35 Statistics of environmental services process Ego network 206
Table 5. 36 Structural characteristics of the L0 processes network 209
Table 5. 37 L0 Processes with highest betweenness centrality 213
Table 5. 38 Characteristic of communication process Ego network.. 215

Table 5. 39 Statistics of communication process Ego network 215
Table 5. 40 Structural characteristics of strategic programs and regulatory requirements interactions 219
Table 5. 41 Strategic programs with highest betweenness centrality............ 224
Table 5. 42 Characteristic of quality assurance program Ego network 225
Table 5. 43 Statistics of quality assurance program Ego network 226
Table 5. 44 List of established roles in the nuclear power plant operational readiness program 227
Table 5. 45 Structural characteristics of strategic programs and roles intersections 236
Table 5. 46 Programs with highest betweenness centrality............ 240
Table 5. 47 Characteristic of Quality Assurance Program Ego Network............ 242
Table 5. 48 Statistics of Quality Assurance Program Ego Network............ 243
Table 5. 49 Structural characteristics of the strategic programs network 247
Table 5. 50 Strategic programs with highest betweenness centrality............ 252
Table 5. 51 Characteristic of maintenance program Ego network 253
Table 5. 52 Statistics of maintenance program Ego network 254
Table 5. 53 Structural characteristics of the strategic programs and plant systems network 257
Table 5. 54 Programs with the highest betweenness centrality............ 263
Table 5. 55 Characteristic of quality assurance program Ego network 264
Table 5. 56 Statistics of quality assurance program Ego network 265
Table 5. 57 Structural characteristics of nuclear power plant operational readiness program network 269
Table 5. 58 L0 Processes with highest betweenness centrality 276
Table 5. 59 Ego network of quality assurance process characteristics............ 278
Table 5. 60 Ego network of L0 quality assurance process statistics 278
Table 5. 61 Ego network of environmental services process characteristics 282
Table 5. 62 Ego network of environmental services process statistics 283
Table 5. 63 Ego network of operating license (OL) requirements characteristics............ 287
Table 5. 64 Ego network of operating license (OL) requirements statistics 287
Table 6. 1 Researcher’s observations on influential nodes in level 0 processes and regulatory requirements network 313
Table 6. 2 Researcher’s observations on influential nodes in L0 process and strategic programs network 316
Table 6. 3 Researcher’s observations on influential nodes in L1 processes network 319
Table 6. 4 Researcher’s observations on influential nodes in L0 processes and the stakeholder’s network 322
Table 6. 5 Researcher’s observation on influential nodes 1 processes and stakeholders network 325
Table 6. 6 Researcher’s observations on influential nodes in L0 processes and plant systems network 327
Table 6. 7 Researcher’s observations on influential nodes in L0 processes and implementing procedures network 330
Table 6. 8 Researcher’s observations on influential nodes in Level 0 processes network 333
Table 6. 9 Researcher’s observations on influential nodes in programs and regulatory requirements network 336
Table 6. 10 Researcher’s observations on influential nodes in strategic programs and roles network... 338

Table 6. 11 Researcher’s observations on influential nodes in strategic programs in the nuclear power plant operational readiness program 340
Table 6. 12 Researcher’s observations on influential nodes in strategic programs and plant systems network 343
Table 7. 1 Most influential actor in the nuclear power plant operational readiness 357

Acronyms

ABM: Agent-based modeling ... 6
ADSSC: Abu Dhabi Sewage Services Company ... 95
AERB:Atomic Energy Review Board-India ... 4
ANS: American National Standard ... 96
ANSI: American National Standard Institute ... 96
AOV: Air Operated Valve ... 111
APR: Advanced Pressurized Reactor ... 8
ASHRAE: American Society of Heating, Refrigerating and Air Conditioning Engineers ... 18
ASME: American Soceity of Mechanical Engineers ... 93
BAC: Boric Acid Corrosion ... 111
BAU: Business as Usual ... 101
BUiD: The British University in Dubai ... 73
CAS: complex adaptive systems ... 1
CCC: California Commissioning Collaborative ... 18
COBIT: Control Objectives for information and related Technologies ... 98
DCRM: Document Control and Records Management ... 138
DSM: Design Structure Matrix ... 68
EAD: Environment Agency of Abu Dhabi ... 53
ECMS: Electronic Content Management System ... 164
EHS: Environmental Health and Safety ... 96
ENEC: Emirates Nuclear Energy Corporation ... 8
ERO: Emergency Response Organization ... 138
FANR: Federal Authority for Nuclear Regulation ... 53
FME: Foreign Material Exclusion ... 229
FSAR: First Safety Assessement Report ... 93
IAEA: International Atomic Energy Agency ... 4
ICC: International Code Council ... 18
ICT: Information and Communications Technology ... 138
IMS: Integrated Management System ... 50
INPO: Institute of Nuclear Power Operations ... 13
IPS: Integrated Project Schedule ... 1
ISO: International Organization of Standardization ... 98
ITIL: Information Technology Infrastructure Library ... 98
M&TE: Measuring and Test Equipment ... 111
MOV: Motor Operated Valve ... 112
MW:Megawatt ... 14
MWe: Megawatt electricity ... 53
NFPA: National Fire Protection Association ... 94
NPP: Nuclear Power Plant ... 9
NQA: Nuclear Quality Assurance ... 93

OEMP: Operation Environmental Management Plan 95
OHSAS: Occupational Health and Safety Management system 93
OMS: Operations Management System 164
PGD: Program Description 50
PGTC: Procurement Governance and Tendering Committee 136
PMG: Procedure Management Group 138
PMI-PMBOK: Project Management Institute- Project Management Body of Knowledge 2
PRA: Probabilistic Risk Assessment 94
PSD: Process Description 50
QA: Quality Assurance 115
SSC: Systems, Structures and Components 54
STUK: Radiation and Nuclear Safety Authority-Finland 4
UAE: United Arab Emirates 4
USNRC: United States Nuclear Regulatory Commission 98
VP: Vice President 137
WANO: World Association of Nuclear Operators 13

Chapter 1: Research Agenda

1.1.Research background

Despite the fact that commissioning is a critical and complex phase of operating any new power plant and is a crucial step in any plant-modification project, the way the commissioning process is managed across different industries and sectors is yet seen as ad hoc and lacks integration (Lawry and Pons 2013). In the context of the Nuclear industry, commissioning is included as one phase of the Integrated Project Schedule (IPS) for any nuclear new build and managed as a program, so it is not that nuclear professionals are ignorant of commissioning. Rather, the problem is that there is a lack of comprehensive understanding and systematic management of commissioning as a system that is constantly changes based on the influence (Feedback) and interdependencies between activities and actors involved. Understanding and effectively managing the complexity of the commissioning programs is critical to the success of plant safe and reliable start-up. During the commissioning phase, the inability to address complex issues and take timely and effective decisions based on a comprehensively understanding of all involved stakeholders and interfaces usually leads to errors and delays (Cagno, Caron, and Mancini 2002).

Nuclear commissioning (Operational Readiness) shares the characteristics of complex adaptive systems (CAS). Operational Readiness is a dynamic phase of any nuclear new build that is governed by the influence (Feedback) from one activity, milestone, or stakeholder to another Operational readiness milestones are interdependent and the Operational readiness programs adapt based on the progress and experience (IAEA 2014, AERB 1998, STUK 2003). Phenomena of phase transitions, feedback loops, scale-free networks, and emergent behavior are typical characteristics of any nuclear power plant operational readiness program. The current practice of managing the commissioning of new nuclear power plants by only using the project management methodology might result in unpredictable outcomes (Lawry and Pons 2013). Those unpredictable outcomes might range from a minor delay in operating the nuclear power plant to critical safety and security issues, or in some cases to catastrophes like what happened in the disaster of Chernobyl nuclear power plant in 1986.

There is a general agreement in the literature on the importance of the “Integration” and the role integration plays as a key success factor for effective and efficient management of any Commissioning program (Bernhardt 1997, Brown et al. 2001, Gikas 2008, Horsley 1998, Kirsilä, Hellström, and Wikström 2007). However, traditional project management practices are not sufficient to comprehensively cover all internal and external factors and stakeholders involved in the operational readiness programs in a way that facilitates effective and timely decision making. According to the PMI-PMBOK 6th edition, “the complexity within projects is a result of the organization’s system behavior, human behavior, and the uncertainty at work in the organization or its environment”. This research attempts to investigate the complexity of interaction between Programs, Processes, Procedures, Systems, and Stakeholders of the UAE Nuclear power plant operational Readiness program applying the theory and tools of Systems Thinking. Namely, network graph modeling and analysis.

The Operational Readiness Programs for Nuclear new build projects involve thousands of activities and ‘commissionable objects’ such as instruments, equipment, skids, modules, circuits, loops, subsystems, and systems (IAEA 2018). However, the current implemented practices like project management or establishing management systems are seen as insufficient to manage the large volume and complexity of commissioning data. The US Ministry of Energy standard for the Planning and Conducting Readiness Reviews (2010) emphasized the importance of identifying and evaluating the complexity of the startup or restart of any nuclear power plant. however, no structured approach is used or even proposed, but rather left for the nuclear professionals to decide based on their experience and known industry practices. Studies showed that in many cases engineers during the commissioning phase carry out unnecessary activities because of lacking the comprehensive system view of the commissioning (Kirsilä, Hellström and Wikström 2007).

Even though complexity is well recognized in the academic literature as a key feature of the commissioning phase in any nuclear new build project, there is limited rigorous academic research addressing how to fully comprehend and effectively manage that complexity. Published articles dealing with the issue of understanding and managing the complexity of Nuclear power plants Operational Readiness programs are extremely rare, almost non-existent.

Therefore, addressing the complexity of interfaces and interaction between Programs, Processes, Procedures, Systems, and Stakeholders of Nuclear Power Plants Operational Readiness programs is seen as a gap in the literature from a *knowledge point of view*. Applying a structured and systematic approach to investigate the nature of that complexity is seen also as a gap from *a methodological point of view*.

1.2. Research aim and objectives

The research aimed to model the complexity of nuclear operational project processes and stakeholders of the UAE nuclear sector. Moreover, the research aimed to examine the readiness and interactions of nuclear operational project processes and their impact on achieving the operating License requirements; and propose a methodology that can be adopted by the UAE energy sector to manage complexity. Along with this overall aim, the objectives of this study were:

1. Evaluate the interdependencies and the nature of influence within detailed interactions between the components of the nuclear power plant operational readiness program in UAE;
2. Identify the key influential components of nuclear operational project processes and readiness in the UAE nuclear sector;
3. Model the complexity (interactions and the structure of information flow) of nuclear operational project processes and stakeholders of the UAE nuclear sector;
4. Propose a methodology that can be adopted by the UAE energy sector to manage complexity.

1.3. Research questions

A critical and comprehensive review of the literature in the field of Nuclear Power Plants commissioning and Systems Thinking was conducted as a base for defining the research questions. Summary of the key resources reviewed related to commissioning nuclear power plants and their main arguments used to build the case were as follows:

1. IAEA (2014), AERB (1998), and STUK (2003): Nuclear commissioning shares the characteristics of complex adaptive systems (CAS). Operational Readiness is a dynamic phase of any nuclear new build that is governed by the influence (Feedback) from one activity, milestone, or stakeholder to another Operational readiness milestones are interdependent and the Operational readiness programs adapt based on the progress and experience. Phenomena of phase transitions, feedback loops, scale-free networks, and emergent behavior are typical characteristics of any nuclear power plant's operational readiness program.

2. International Atomic Energy Agency, Commissioning Guidelines for Nuclear Power Plants, IAEA Nuclear Energy Series NP-T-2.10, IAEA, Vienna (2018).

3. Lawry and Pons (2013): the way the commissioning process is managed across different industries and sectors is yet seen as ad hoc and lacks integration. Not approaching the commissioning programs as a comprehensive system might result in unpredictable outcomes

4. Bernhardt (1997), Brown et al. (2001), Gikas (2008), Horsley (1998), Kirsilä, Hellström, and Wikström (2007): the crucial role of the "Integration and dependencies management" as a key success factor for the successful delivery of Commissioning program

And for the Systems Thinking were:

1. Catastrophe theory (Poston & Stewart 1987): Minor changes in specific variables of a nonlinear CAS can lead to abrupt and significant changes in the overall behavior of the system.

2. Cybernetics (Ashby 1956): the nature of communication and control of regulatory feedback affects the systems dynamics and overall behavior.

3. Chaos theory (Strogatz 2018): small changes in setup settings (initial conditions) of any dynamic system is highly likely to produce wildly different outcomes. Such changes follow well established and predefined rules about changing relationships, and with minimum room for randomness.

4. General systems theory (van Bertalanffy 1976): a systematic inquiry of finding a general theory to explain systems behavior.

5. Learning organizations theory (Senge 2006): organizational learning can be understood through applying the tools and techniques of Systems thinking

6. Path dependency theories (Arthur 1994) processes can have similar starting points yet lead to different outcomes, even if they follow the same rules, and outcomes are sensitive not only to initial conditions but also to bifurcations and choices made along the way.

7. Punctuated equilibrium (Baumgartner & Jones 1993): Theory that explains how long periods of stability can be interrupted by rapid and radical change with a specific focus as decision and policy changes.

8. Agent-based modeling (Epstein 2006): ABM is used to create a virtual representation of a complex system, modeling of variables and actors and their interactions within the system and with the external environment.

9. Network Analysis or Social Network Analysis (Newman 2013, Valente 2010): Demonstrate relations between different actors within a dynamic system (Stakeholders (People), groups, organizations), represent through nodes and ties and uses a wide range of tools to display the network and the nature of the relationships between system's actors.

And based on the systematic review of the literature, the following questions were chosen as the research questions:

1. What are the <u>Interactions (the Information flow structure)</u> between different actors involved in the UAE Nuclear Power Plants Operational Readiness Program (Programs, Processes, Procedures, systems, and stakeholders)?
    1) Level 0 Process to Requirement

2) Level 0 Process to Program

3) Level 1 Process to another level 1 process

4) Level 0 Process to Stakeholders

5) Level 1 Process to Stakeholders

6) Level 0 Process to Plant Systems

7) L0 process to Implementing procedure

8) Level 0 Process to L0 Process

9) Programs to Requirement

10) Programs to Role

11) Program to Program

12) Program to Plant System

13) And Finally, one network graph analysis for the operational readiness program level

2. What are the <u>Interdependencies and the nature of influence</u> between individual actors <u>within detailed interactions</u> between the components of the nuclear power plant operational readiness program in UAE?

3. What are the Interdependencies <u>between the five key components</u> of the UAE Nuclear Power Plant Operational Readiness Program (Full Network Level)?

4. What are the most influential components of different Programs, Processes, Procedures, systems, and stakeholders on achieving the Operating License requirements?

Those research questions when answered will help in addressing the identified gap in the academic literature from a knowledge point of view through modeling interactions between Programs, Processes, Procedures, Systems, and Stakeholders of Nuclear Power Plants Operational Readiness.

Furthermore, research questions will address the gap from a methodological point of view through the application of a structured and systematic approach to investigate the nature of that complexity using network analysis. In totality, answering research questions will contribute to the theory and practice of both nuclear commissioning and project management disciplines.

1.4. Novelty and theoretical significance

This study is considered the first of its kind to address the challenge of modeling the complexity of nuclear power plant operational readiness programs. It is not significant only because it is covering an under-researched area as was highlighted in the Literature Review Chapter but also because it is addressing knowledge and methodological gap in the academic literature related to Nuclear power plant's operational readiness. The Nuclear Power Plant Operational Readiness Programs for new build projects involve thousands of activities, processes, systems, stakeholders, and 'commissionable objects' such as instruments, equipment, skids, modules, circuits, loops, subsystems, and systems (IAEA 2018). *However, the available theoretical knowledge does not address how to manage such complexity. This study aims to close this theoretical gap.*

Also, there are a unique set of corporate and institutional factors that affect how operational readiness is managed within the Emirates Nuclear Energy Corporation (ENEC) that might enrich the analysis and advance our knowledge on how to better manage such programs in the future. Those factors include the magnitude of the Emirates Nuclear Energy Corporation (ENEC) program as the largest worldwide by building four typical nuclear power plants simultaneously and adopting the most advanced nuclear technology (APR1400). Therefore, this study contributes to theoretical knowledge by:

1. Original testing of Network Analysis (borrowed from graph and complexity theory) on the Nuclear Power Plants Operational Readiness Programs domain. There has been limited use of network methods in the Nuclear Industry. Application has been limited to studies of Safety and Security. Nuclear Power Plants Operational Readiness Programs share the characteristics of Complex Adaptive Systems (CAS). Thus, the use of Network Analysis has been identified as a fundamental need for NPP commissioning programs to better analyze complexity and develop its Information flow structure.
2. Conducting the first of its kind empirical work to demystify the complexity and info. Structure of a Nuclear Power Plants Operational Readiness Program by applying network analysis on the largest and most advanced nuclear power program worldwide.
3. Original testing of how network analysis might address the shortcomings of the Information Processing Theory of not counting for the non-linearity and Interorganizational perspective by applying network analysis in the context of NPP.

Furthermore, this study contributes significant practical knowledge in both domains; Nuclear Commissioning and Project Management, because it:

1. Produces graphical models that describe the complex network and info. structure that exists between the 5 key components in the world's largest and most advanced Nuclear Power Plant Operational Readiness Program. This model helps practitioners/engineers and decision-makers to:

    b) Simulate and better understand distal impacts of decisions

    c) Provide insights into more effective and efficient Organizational Design.

    d) Provide another perspective to help resources deployment

2. Provides insight into how the flow of information might influence achieving operating License requirements
3. Demonstrates the utility of network analysis for demystifying complexity and managing information in Nuclear Power Plant operational readiness.
4. Provides a practical methodology for addressing the shortcomings of the conventional project management functions of planning and control in examining and modeling megaproject complexity and dynamics.

Therefore, research findings will be valuable for practitioners and decision-makers in the nuclear industry organizations worldwide, local and international nuclear regulators, and other similar high reliable and complex industries.

1.5. Outline of the thesis

Chapter one: this chapter provides the background to this study, including the context and the of the research. Also, the research problem has been mentioned; based on it, the research questions, aim, and objectives have been developed. The chapter ends with the research outline.

Chapter two: this chapter summarizes the literature that is relevant to this research, highlights the gaps in the literature, and explains how your research helps to fill identified gaps. Also, this chapter explains the alignment with the UAE energy sector and provides a review of how comparative industries tackled complexity problems.

Chapter three: this chapter focuses on the definition of the key components of the UAE Nuclear power plant operational readiness program. Furthermore, it provides a justification derived from the literature review on the interactions mapping adopted to answer research questions. In addition, this chapter summarizes and illustrates key theories and concepts from the literature as the theoretical framework which is used to explain relationships among these ideas and how they relate to the research study.

Chapter four: explains the methodology of this research in detail. Furthermore, it outlines the data collection and analysis used to achieve the research aim. Furthermore, this chapter describes how ethics was carried out and explain data validation techniques used in this study.

Chapter five: in this chapter, the interaction networks are developed, analyzed, and elaborated on for all the thirteen networks. Network Statistical analysis is used to measure the network diameters, average length paths, network density, centrality of the different components, and modularity class analysis. Ego network topologies are applied and the data are analyzed for the most influential actors identified in the thirteen networks.

Chapter six: this chapter discusses the main results and answers to the research questions.

Chapter seven: this chapter concludes the research; it explains the research contributions, provides recommendations for further research, and highlights the research limitations.

Chapter 2: Review of Commissioning and Nuclear Power Plant Operational Readiness Literature

2.1 Introduction

The objective of this chapter is to provide a theoretical foundation and explanation for the research study, based on the systematic and critical review of the available literature which forms the theoretical basis for the conceptual model described in Chapter 3. This chapter consists of three main elements: Systems thinking, Complexity and network analysis and their foundations; information flow structure and use in nuclear power plants operational readiness programs; and how these two are coupled toward the goal of demystifying the complexity of nuclear operational project processes and stakeholders of the UAE nuclear sector, as well as, examining the readiness and interactions of nuclear operational project processes and their impact on achieving the operating License requirements.

This chapter introduces a systematic, critical, and comprehensive review of the literature in the field of commissioning with a focus on Nuclear Power Plants commissioning and operational readiness, Complexity and network analysis, and organizational information processing. The selection criteria for the literature included is explained due to the fact that rigorous academic researches addressing nuclear power plants commissioning and operational readiness are very rare, almost not-existent. Substantive and thorough researches are built on a substantive systematic review of the literature around the topic of interest. The substantive and thorough literature review should advance our collective knowledge and support address a methodological or knowledge gap in the existing literature related to a specific subject of interest. Boote and Beile (2005) have built on Creswell's (1994) three criteria of effective literature review and expanded it into 12 attribute criteria measured across five different categories of coverage, synthesis, methodology, significance, and rhetoric. Each criterion is measured against three levels of maturity (1 is the lowest and 3 is the highest) where the first criterion is having justified criteria for inclusion and exclusion from the literature review. In this research, publications selection for inclusion was based on multiple criteria. First, any relevant publication from the International Agency of Atomic Energy (IAEA) and other international associations in the field of nuclear energy like the World Association of Nuclear Operators (WANO) and the Institute of Nuclear Power Operations (INPO). International Agency of Atomic Energy (IAEA) is one of the united nations' organizations that work as a global center for collaboration for the peaceful use of nuclear energy through a network of partners and member states. Within the context of this role, the International Agency of Atomic Energy (IAEA) issues scientific and technical publications in the forms of safety standards, book series, nuclear energy series, conference proceedings, data publications, and others that serve as a reference for state members operators and regulators while managing nuclear power programs. IAEA publications reflect an international consensus on different areas covered and they often serve as regulatory documents in different areas related to NPPs construction and operations.

All relevant IAEA publications related to commissioning nuclear power plants were included as part of this research. The second criteria for inclusion were any relevant publication from nuclear operators and regulators in any of the member states like Canada, India, Russia, etc. The third criteria were any relevant published work in any reputable high-ranking journals.

This chapter summarizes and informs the reader on the previous investigations conducted in the field of nuclear power plants commissioning, Systems thinking, network analysis, and organizational information processing and provides a state of the current research. Thus, as a result of this comprehensive review, the research gap has been determined, and accordingly, to fill this knowledge gap, the research aim has been set. In addition, this research uses the literature review as a foundation and to explain the new knowledge about the complexity of the nuclear power plant's operational readiness.

2.2 UAE energy sector and the need for nuclear power generation

Based upon projections that the annual growth rate of electricity demand in the UAE is likely to be around 9% and that the UAE annual peak demand for electricity is likely to rise to more than 40,000 MW's by 2020, the UAE government has evaluated viable options to meet this high demand. As part of this evaluation, it was determined that known volumes of natural gas that could be made available to the nation's electricity sector would be insufficient to meet increasing future demand, providing adequate fuel for only 20,000-25,000 MW's of power generation capacity by 2020. While the burning of liquids (crude oil and diesel) was found to be logistically viable, evaluation of this option revealed that heavy future reliance on liquids would entail extremely high economic costs, as well as a significant degradation in the environmental performance. Similarly, although coalfired power generation establishes its lower relative price compared to liquids-fired power generation, its widespread use within the UAE would have a devastating impact on environmental performance, while also raising major concerns on the security of supply. Evaluation of alternative energies, including solar and wind, suggested that, massive development could only supply 6-7% of peak electricity demand. However, this contribution is not dependable since renewable energy sources are not baseload (The United Arab Emirates' Government portal 2020). Accordingly, nuclear energy emerged as a proven, environmentally promising, and commercially competitive option that could make a significant base-load contribution to the UAE's economy and future energy security. Therefore, the UAE launched a national "Energy Strategy 2050" in January 2017 with the target to increase the total capacity mix of nuclear energy to 6% by 2050. However, constructing and operating a nuclear power plant is a very complex task from both the structural and dynamic complexity perspectives. Structural complexity is characterized by the interdependence and diversity of components (Baccarini, 1996). Nuclear Power plant operational readiness shares the same characteristics. It includes thousands of activities, systems, subsystems, processes, and other ‘commissionable objects’ such as circuits, loops, modules, instruments, and equipment. Multiple interdependencies and interfaces between processes, procedures systems, and stakeholders where relationships between different components are governed by continuous feedback loops. Due to the large volume of commissionable items, multiple interfaces, multiple stakeholders, and complexity of commissioning data, structural complexity is seen as a key feature of nuclear power plant operational readiness (IAEA 2018, IAEA 2014, AERB 1998, STUK 2003).

Dynamic complexity is characterized by continuous changes and evolutions over time as a result of dynamic interactions between the multiple actors and components within themselves and with their operating environment (Geraldi et al., 2011). Commissioning and start-up of new nuclear power plant shares the characteristics of complex adaptive systems (CAS). Operational Readiness is a dynamic phase of any nuclear new build that is governed by the influence (Feedback) from one activity, milestone, or stakeholder to another Operational readiness milestones are interdependent and the Operational readiness programs adapt based on the progress and experience (IAEA 2014, AERB 1998, STUK 2003). Phenomena of phase transitions, feedback loops, scale-free networks, and emergent behavior are typical characteristics of any nuclear power plant operational readiness program. (Daniel and Daniel 2019).

2.3 Commissioning process and the organizational theory

Operational readiness programs are part of the organizational setting. There are different views in the academic literature on what an organization is and what comprises its entity. However, there is a general agreement one key feature that differentiates an organization from other collections of people is the collective commitment to achieve a certain mutual goal. This collective marching behind a common goal is governed by a stable structure of task allocations, roles, and responsibilities (Starbuck, 1965). The classic organizational theory defines an organization as a structure of relationships, roles, power where the chain of command prevails and the manager's primary function is to control performance. On the other side, new organizational forms are described as complex systems that are governed by information sharing and informed by chaos and complexity theories.

The blow table summarizes the schools of thought on organizational theory evolvement by decade. (Wertheim, 2001).

School of thought	Decade	Description
Authoritarian	Before 1900	Emphasizes division of labor and the importance of machinery to facilitate labor
Scientific management	1910s-	Describes management as a science with employers having specific responsibilities; encourages scientific selection, training of workers and equal division of work between workers and management
Classical school	1910s-	Lists duties of manager for controlling performance; called for specialization, the chain of command
Human relations	1920s-	Emphasizes the importance of attitudes and feelings of workers; informal roles and norms impact performance
Classical school revisited	1930s	Re-emphasizes the classical principles
Group dynamics	1940s	Encourages individual participation in decision making; impact of the workgroup on

		performance
Bureaucracy	1940s	Emphasizes order, system, rationality, uniformity, and consistency in management; led to equitable treatment for all employees by management
Leadership	1950s	Stresses the importance of groups having both social task leaders
Decision theory	1960s	Suggests that individuals "satisfice" when they make decisions; so-called garbage can model
Socio-technical school	1960s	Calls for considering technology and workgroups when understanding a work system
Environmental and technical system	1960s	Describes mechanistic and organic structures and their effectiveness w/ specific environmental conditions and technological resources
Systems theory	1970s	Represents organizations as open systems with inputs, internal transformations, outputs, and feedback; systems strive for equilibrium
Contingency theory	1980s	Emphasizes fit between organization processes and characteristics of the situation
Relational	1980s	Cites communication as a basis for human organizing
Postmodern organization theory	1990s Onward	New organizational forms mediated by technology and informed by chaos and complexity theories, e.g. virtual organizations, self-organizing systems, networked organizations.

Schools of organizational thought and their components by decade (Wertheim, 2001)

The same description of the postmodern organizational theory applies to the nuclear power plant's operational readiness. Nuclear power plant operational readiness shares the characteristics of complex adaptive systems (CAS). Operational Readiness is a dynamic phase of any nuclear new build that is governed by the influence (Feedback) from one activity, milestone, or stakeholder to another Operational readiness milestones are interdependent and the Operational readiness programs adapt based on the progress and experience (Daniel and Daniel 2019, IAEA 2018, IAEA 2014, AERB 1998, STUK 2003).

Commissioning has different meanings for different engineering disciplines. However, there is a general consensus in the academic and technical published work on a general definition of commissioning as a structured and systematic quality assurance process implemented across all construction projects' delivery phases and facility lifecycle with an overall objective of ensuring compliance of the new building's performance with owner's expectations (CCC 2006, ASHRAE 2013, NECA 2009, Lawry and Pons 2013, ICC 2012). Along the same line, the guidelines of the US National Institute of building sciences (2012) defines the building enclosure commissioning as the process of verifying the performance of materials, systems, and components to the design specifications and owner -defined performance criteria outlined in the contract documents. The International Electrical Testing Association (2013) complemented the definition and articulation of California Commissioning Collaborative and the American Society of Heating, Refrigerating and Air Conditioning Engineers by developing specific inspection and testing guidelines on how to determine electrical power equipment's suitability for initial energization and their operational performance capability against user's acceptance criteria. The formal development of commissioning guidelines started in 1982 by ASHRAE as an effort intended to document commissioning good practices required to ensure compliance with the owner's specifications and expectations.

Commissioning is characterized by being multiphase, cross-functional and an integrated set of activities with predefined sequences and dependencies (IPENZ 2007). Effective and top-quality commissioning is key to the success of any project. Commissioning Activities are often included in projects and/or programs plans and managed using the traditional project management approach where governance and control functions are applied to each activity to ensure realizing commissioning deliverables on time, within budget, and up to the quality standard required (Lawry and Pons 2013, IPENZ 2007).

There is a general agreement in the literature on the importance of the “Integration” and the role integration plays as a key success factor for effective and efficient management of any Commissioning program (Bernhardt 1997, Brown et al. 2001, Gikas 2008, Horsley 1998, Kirsilä, Hellström, and Wikström 2007). However, traditional project management practices are not sufficient to comprehensively manage the huge number of interactions between all Programs, Processes, Procedures, systems, and stakeholders involved in the operational readiness programs in a way that fosters a deeper understanding of the nature of interactions and roles of different actors on realizing the key milestones of such critical programs through practicing effective and timely decision making. According to the PMI-PMBOK 6th edition, “the complexity within projects is a result of the organization’s system behavior, human behavior, and the uncertainty at work in the organization or its environment”.

The complexity of commissioning has been always a distinguishing feature of the commissioning process and a real challenge for conducting top-quality commissioning process (Doty 2007, Cagno, Caron, and Mancini 2002). this complexity is a result of the huge number of interactions between multiple actors within and outside the nuclear power plant operational readiness program. Those actors are mainly the Programs, Processes, Procedures, Plant systems, and Stakeholders (People). Therefore, the Complexity of the commissioning project is recognized as an essential factor that engineers, practitioners, and decision makers should take into consideration while managing commissioning activities. Furthermore, commissioning professionals need to fulfill an essential competency requirement in providing relevant experience and qualifications in relation to the complexity of the same type of commissioning activities or projects they are managing or planning to manage (ICC 2012, USDVA 2013, Tribe and Johnson 2008). Understanding the complexity of the commissioning through training and qualification only is not enough because every project has its unique circumstances and environment. Therefore, a systematic, comprehensive, and future-oriented methodology needs to be implemented to model the complexity of interactions between all Programs, Processes, Procedures, Systems, and Stakeholders involved in the nuclear power plant operational readiness. Such methodology is also needed to make effective decisions needed to handle uncertainties associated with commissioning since complexity has been always a challenge for effective risk management during the commissioning phase (Cagno, Caron, and Mancini 2002).

Increasing information interdependence during the commissioning life cycle is also an essential feature of its complexity. The complex and interdependent information flow between different processes, programs, and systems during commissioning cuts through different project's stages, process and involve multiple internal and external stakeholders. Fiatech's Capital Facilities Information Handover Guide (2006) emphasized on the critical role of information flow and handover for the success of commissioning activities and developed a methodology for defining the full life cycle of information requirements as a prerequisite for managing information flow and implementing interphases information handover. Understanding the information flow between different actors of the nuclear power plant operational readiness program through modeling the interaction between those actors and linking it to achieving regulatory requirements and other safety-related commitments is vital to the success of such programs. Galbraith explained how evolvement in organizational design emerges from efforts for enhancing decision-makers and middle management pre-planning ability by equipping them with the right information at the right time to achieve the strategic outcomes for organizations (Galbraith, 1973). There are several strategies that organizations can use to reduce information uncertainty by finding the right balance between the amount of information processed and the ability to handle more information (Galbraith, 1977). These strategies include:

1. Creation of slack resources, such as extending delivery times, adding more money to the budget, and building inventory. All strategies have inherent costs.

2. Creation of self-contained tasks to simplify management of exceptions in routine procedures.

3. Investment in vertical integration systems to condense the flow of information (e.g., computer and decision support systems).

4. Creation of lateral relationships to move decision making to where the information exists.

One of the shortcomings of Galbraith's theory was the focus on the interior of the organization and overlooking the relationship with the external stakeholders. Interdependence makes coordination indispensable, because of the dependability of one actor on the other. Previous studies (Cooper and Wolfe 2005; Daft and Lengel 1986) contrasted Galbraith (1973) and pointed out the external environment, interdepartmental relations, and technology as sources of uncertainty. Another shortcoming stemmed from the fact that the relationship between information processing and outcomes is not linear. Fairbank et al. (2006) point out that the relationship between information processing designs or strategies and performance is not linear as explained by Galbraith (1973). It is a lot more complex. Commissioning effective information management is a critical enabler for the success of the nuclear power plant's operational readiness. Effective use of commissioning data enables commissioning engineers to identify design and construction non-conformances and take the required action of repair or modification accordingly (IAEA 2016, AERB 1998). However, even though the importance and significance of effective commissioning have been well recognized and appreciated in the academic and professional domains, the general methodology and the detailed process of commissioning and starting-up capital plants is often poorly understood and poorly executed by engineers (IPENZ 2007). According to Dvir (2005), the planning for commissioning activities as part of the project handover has not been receiving proper attention from practitioners and engineers to ensure efficient and effective execution of this critical phase of the project life cycle. Commissioning is not only an essential and critical phase of operating any new plant or facility. It is also a crucial step in any plant-modification project. However, the way the commissioning process is managed across different industries and sectors is yet seen as ad hoc and lacks integration (Lawry and Pons 2013).

2.3.1 Commissioning nuclear power plants

Commissioning within the nuclear industry is defined as the process of operationalizing systems and components of the constructed nuclear facility and verify them against the design and the required performance criteria (IAEA 2008, IAEA 2016, ONR 2016, AERB 1998, ASN 2013). Understanding the critical role of the commissioning phase in making systems, components, or a facility operated following specific design requirements and performance criteria has been always a focus of engineers and decision-makers in different sectors across different industries. The importance of commissioning is not only coming from the fact that it's a very vital step to ensure compliance with the design parameters and meeting specific performance criteria that allow for safe and reliable operations (the backward view that focus on historical data), but also because of the probability of putting systems, components or a facility in an abnormal future state based on the output of this phase. The commissioning phase follows the construction phase of any facility. The success of construction projects is usually measured by their adherence to the schedule quality and budget. However, the success of the commissioning phase is not necessarily measured using the same parameters due to the unpredictability of test results and their impact on the rework that has to be done. Unlike the plant operation phase that is characterized by being a steady-state phenomenon, Cagno, Caron, and Mancini (2002) described Plant commissioning as "a transient state phenomenon during which every single sub-system continually varies over time in function of the sequence in which operations are carried out". The complexity of the commissioning varies based on the type and volume of systems and components included. In the case of Nuclear power plants, there are thousands of activities, systems, subsystems, and other 'commissionable objects' such as circuits, loops, modules, instruments, and equipment. Due to the large volume of commissionable items, multiple interfaces, multiple stakeholders, and complexity of commissioning data, the complexity of commissioning nuclear power plants is very high and involves multiple interdependencies and interfaces between processes, procedures systems, and stakeholders. In such dynamic and complex systems, there is a critical need to model and understand sufficiently all interacting forces in an exhaustive fashion. According to the IAEA Safety Standards Series No. SSR-2/2 (Rev. 1) regarding commissioning and operation of nuclear power plants "The operating organization shall ensure that the interfaces and the communication lines between different groups (i.e. groups for design, groups for construction, contractors, groups for commissioning and groups for operations) shall be clearly specified and controlled".

In its simplest form, Commissioning is a verification and confirmation that systems, subsystems, and components are installed as per the design requirements and function according to the acceptable performance specifications. The basic commissioning process includes the following:

1. Verification of the current state of the systems, subsystems, or components to the design drawings and specifications.

2. Initiating action or operation and waiting for the right response
3. Reverse the action of operation and waiting for the right response or corrective response from the system, subsystem, or component.
4. Document all commissioning data as a baseline for future use by the operating entity.

The International Electrotechnical Commission standard 62382 (IEC 2012) highlighted that this verification process includes two main phases: cold commissioning phase and hot commissioning phase. Cold commissioning is the phase during which facility, systems, and equipment testing areare conducted using test media while the hot commissioning phase is the phase during which the verification and testing process of facility, systems, and equipments are performed using the actual process chemicals. Some national regulatory bodies like AERB include hot and cold functional tests as part of Pre-operational commissioning tests (AERB 1998). However, both phases include multiple stakeholders and generate a large amount of commissioning data that serve as a baseline for future utilization in the commercial operation phase. According to the IAEA Nuclear Energy Series No. NP-T-3.5 the most frequent cause of engineering structure failures in nuclear projects is designing errors or poor-quality construction. Commissioning data is a critical enabler for the effective review of concrete material quality in the nuclear power plant. Effective use of commissioning data enables commissioning engineers to identify design and construction non-conformances and take the required action of repair or modification accordingly (IAEA 2016, AERB 1998). According to Galbraith (1973, 1974, 1977), Organizations are information processing entities where the inadequacy of information usually leads to uncertainty. That uncertainty is defined as the delta between information needed to perform a certain task or to make a timely decision and the information available. Therefore, there is a need to comprehensively map all interactions between programs, processes, procedures, systems, and stakeholders at different levels to enhance our understanding of the information flow between different actors and identify players who could influence the speed and quality of information sharing within the nuclear power plant operational readiness program.

It is very important to recognize that planning for commissioning starts in the project planning phase and intersects with the design, procurement, construction, and operation phases. Hence, the timeline of commissioning exceeds its formal stage and includes activities in multiple phases of any project. In the case of nuclear power plants, Commissioning activities continue through fuel loading, first criticality, and power ascension test (IAEA 2018, STUK 2003). In addition, systems modifications during the life cycle of any facility require commencing specific commissioning activities to ensure compatibility to the design modification specifications and operability in accordance with a defined acceptance criteria.

In the context of the Nuclear industry, commissioning is included as one phase of the Integrated Project Schedule (IPS) for any nuclear new build and managed as a program, Commissioning follows a sequence of activities and an orderly process, the scope of which is defined in a schedule (ONR 2016). This usually starts with developing a commissioning strategy, which defines the intended testing scope and performance acceptance criteria. So, it is not that nuclear professionals are ignorant of commissioning. Rather, the problem is that there is a lack of comprehensive understanding and systematic management of commissioning as a system that is constantly changes based on the influence (Feedback) and interdependencies between processes and actors involved. Understanding and effectively managing the complexity of the commissioning programs is critical to the success of plant safe and reliable signed off for commercial operation (Rosenergoatom 2017). According to the office of nuclear regulation, the complexity and safety criticality of the commissioning should be a determining factor in the scope of commissioning.

“the more complex or safety-critical, the wider the scope” (ONR 2016). During the commissioning phase, the inability to address complex issues and take timely and effective decisions based on a comprehensively understanding of all involved stakeholders and interfaces usually leads to errors and delays (Cagno, Caron, and Mancini 2002).

Commissioning is crucial to the safe and reliable operation of any nuclear power plan (IAEA 2018, AERB 1998). Performing top quality commissioning programs provide all involved stakeholders with assurance on meeting all applicable requirements needed to get the operational license agreement and move the nuclear plant to the commercial operation phase. The essence of this assurance is provided by robust and effective commissioning integrated management system. The integrated Management System is a set of interrelated processes that are designed to interact with each other in a synchronized fashion that enables achieving an overall objective. The integrated Management System (IMS) for commissioning should comprehensively cover all processes and activities and their interactions required for achieving the commissioning objectives from the pre-commissioning planning phase moving to the operation phase and any later plant modifications. Such a management system should evolve over time to accommodate for the continuous changes in its components including changes in the organizational culture, stakeholders influence, resources, structures, and the interactions between humans and systems which have been radically altered by technological innovations (IAEA 2006, IAEA 2009). The same notion applies to commissioning, the evolving and dynamic view of the Complex interaction between commissioning activities and multiple processes’ interfaces and stakeholders involved is fundamental to ensure realizing all aspects affecting the achievement of the commissioning goals and nuclear power plant operational readiness. This complexity needs to be fully comprehended with all aspects including processes, systems, and stakeholders to enable practitioners and decisions maker to analyze near and distal impacts and consequences of any intended change affecting the commissioning and plant operational readiness activities.

IAEA Nuclear Energy Series No. NP-T-2.7 (IAEA 2012) highlighted key lessons learned related to project management in construction and commissioning of nuclear power plants based on analyzing reports from different member states like Japan, Canada, Republic of Korea, China, India, Russia, and others. Some of these lessons Learned included:

1. Adapt an agile and adaptive commissioning schedule and Improve on it based on learning and context.

   Effective collaboration between different stakeholders especially of operations and engineering staff

2. Effective management of intercedences, interfaces, and commissioning roles and responsibilities.

In addition, IAEA Member States' experience on construction and commissioning of evolutionary water-cooled reactors highlighted the positive impact of adopting modeling and simulation on adhering to the construction schedule and budget (IAEA 2004). Modeling the complexity of interaction between processes, systems, and stakeholders involved in the commissioning phase can also achieve the same benefits if not more.

As typically done, Decisions affecting commissioning are taking based on the progress of project activities and completion of the agreed deliverables. In today's highly sophisticated work environment where one deliverable or activity can be affected by multiple internal and external explicit or implicit factors, looking at commissioning as a sequential set of activities with timeline and resources assigned without the ability to recognize other factors like multiple interfaces and interactions between processes and systems, the flow of information, the influence of stakeholders involved, complex interdependencies and interaction between systems and stakeholders involved in the commissioning process might hinder decision makers ability to take effective and timely decisions required to deliver top-quality commissioning outcomes. This narrow view overlooks some critical organizational dynamics that might have significant negative unintended consequences on delayed and distal impacts of decisions, which will ultimately affect the critical milestones and deliverables of the commissioning process. These unintended consequences might range from a recoverable delay in completion or environmental pollution to delay in operations and serious adverse conditions to safety and security.

The current practice of managing the commissioning of new nuclear power plants by only using the project management methodology might result in unpredictable outcomes (Lawry and Pons 2013). Those unpredictable outcomes might range from a minor delay in operating the nuclear power plant to critical safety and security issues, or in some cases to catastrophes like what happen in the disaster of Chernobyl nuclear power plant in 1986. Such disasters highlighted an imminent need for considering new analytical methods and approaches to advance our understanding of technology-organizational dynamic interaction.

Commissioning and start-up of new nuclear power plant shares the characteristics of complex adaptive systems (CAS). Operational Readiness is a dynamic phase of any nuclear new build that is governed by the influence (Feedback) from one activity, milestone, or stakeholder to another Operational readiness milestones are interdependent and the Operational readiness programs adapt based on the progress and experience (IAEA 2014, AERB 1998, STUK 2003). Phenomena of phase transitions, feedback loops, scale-free networks, and emergent behavior are typical characteristics of any nuclear power plant operational readiness program.

Commissioning and Operational Readiness Programs for Nuclear new build projects involve thousands of activities, commissionable objects, commissioning data, and complex interfaces and dependencies (IAEA 2018, IAEA 2014). However, the current implemented practices like project management or establishing management systems are seen as insufficient to manage the large volume and complexity of commissioning data. The US Ministry of Energy standard for the Planning and Conducting Readiness Reviews (2010) emphasized the importance of identifying and evaluating the complexity of the startup or restart of any nuclear power plant. however, no structured approach is used or even proposed, but rather left for the nuclear professionals to decide based on their experience and known industry practices. Studies showed that in many cases engineers during the commissioning phase carry out unnecessary activities because of lacking the comprehensive system view of the commissioning (Kirsilä, Hellström and Wikström 2007).

Despite the fact that complexity is well recognized in the academic literature as a key feature of the commissioning phase in any nuclear new build project. There is limited rigorous academic research addressing how to fully comprehend and effectively manage that complexity. Published articles dealing with the issue of understanding and managing the complexity of Nuclear power plant operational Readiness programs are extremely rare, almost non-existent. Therefore, addressing the complexity of interfaces and interaction between processes, systems, and stakeholders of Nuclear power plant operational Readiness programs is seen as a gap in the literature from a knowledge point of view. Applying a structured and systematic approach to model and demystify that complexity is seen also as a gap from a methodological point of view.

2.4 Review of systems thinking, complexity and network analysis literature

This section will introduce the systematic review of literature in the field of systems thinking, complexity and network analysis. Also, it highlights how other comparative industries like public health, software engineering, supply chain and Research and development tackled complexity problems. To ensure eliminating any confusion between the area of systems thinking and other areas like systems theory, systems methods, and systems sciences, this chapter discusses the common and differentiating factors between these terms. The criteria for including publications in developing this chapter was firstly, any relevant academic work published in a reputable academic journal like Safety Science, IEEE systems journal, System Dynamics Review, Civil Engineering, and Environmental Systems, International Journal of Energy Sector Management. secondly, Relevant open access articles from reputable universities like MIT, Iowa State University, and Pennsylvania University and thirdly, any relevant publication cited the set of publications generated from the first criteria based on their network of citations and citation numbers. This chapter will also discuss the application of Systems Thinking in the context of Nuclear energy in line with what has been discussed in chapter two.

2.4.1 Demystifying systems thinking and network analysis

The fundamental underpinnings of the systems thinking were developed at the beginning of the 20th century (Capra 1996). Since then, the term Systems Thinking has been used interchangeably with other terms like systems concept, systems knowledge and systems sciences. The inconsistent use of systems thinking term with other terms is also evident in the seminal work in the field. However, different definitions of systems thinking that can be found in the existing academic literature share key components and underpinnings of a universal definition (Arnold and Wade 2015). In general, Systems thinking is perceived by scholars and practitioners as a conceptual framework or a structured-systematic way of thinking about certain phenomenon or behavior rather than being science by itself. This understanding is deeply rooted in the existing academic literature related to Systems Thinking and complexity science. According to Bertalanffy (1969) in his articulation of the General Systems Theory, Systems Thinking is a structured methodology of systematic inquiry into finding a general conceptual framework that explains systems behaviors in different fields of science. However, like many other scholars, Bertalanffy used the term systems thinking and systems interchangeably and in some other cases inconsistently by confusing the ontological stance of the term being "Knowledge about systems" and the epistemological underpinning of Systems Thinking as a systematic inquiry method for understanding systems behavior. Capra (1983) in his famous book The Turning Point: science, society, and the Rising Culture also used different terms like ecological thinking and Holistic thinking referring to systems thinking. However, along the same line with Bertalanffy's articulation of systems thinking as a universal-systematic method of inquiry, Capra depicted systems thinking as the new paradigm shift in the worldview of modern physics describing it as "a holistic view of fundamental interrelatedness and interdependence of all phenomena". Wheatley (2011) has used both terms of Systems Thinking and Ecological Thinking to offer a new leadership paradigm through the adoption and implementation of systems thinking concepts and tools. Some other scholars looked at systems thinking from different angles. Peter Senge in his famous book The Fifth Discipline: The Art and Practice of the Learning Organization, looked at systems thinking as the conceptual basis for understanding and describing how an organization facilitates effective and continuous learning and how it transforms itself to adapt to its environment to cultivate the learning process on the individual and process levels.

The scholarly work on Systems thinking also overlaps with the ontological stance of knowledge about systems and systems behavior. This overlap is more evident in the field of science. Strogatz (2018) have discussed the application of Systems Thinking to explain how small variation in the initial set up conditions of any system can significantly affect the outputs produced by the same system. He applied Systems thinking in the field of Mathematics explaining how changes in the system's dynamics take place through fixed rules so relationships and interdependencies follow in organized patterns. Furthermore, Arthur (1994) in his contribution to the Path dependency theories explained that processes with the same initial setup conditions can also yield different outcomes based on decisions and bifurcations made during the execution. Some other scholars like Ashby (1956) through his contribution to the Cybernetics "A synonym for Systems Theory" has applied Systems Thinking as a conceptual framework for communicating regulatory information, managing its flow, and controlling feedback within organizations and machines (Mingers and White 2010).

Although most scholars and scientists in the field of systems and systems thinking refer to the general definition of Systems Thinking as articulated by top gurus in the field like Bertalanffy, Arthur, Strogatz, and Ashby, it is very important to note that some others don't use the term "systems thinking" per se to refer to what Systems Thinking entails. Wheatley, for example, in her book: Leadership and the New Science has used terms like "new sciences", "Chaos" and "Complexity" and applied them to the business discipline. However, all are sharing (more or less) the same attributes to be considered as systems-oriented sciences. Strogatz also did not use the term "systems thinking" explicitly in their published work. instead, he used terms like complex systems sciences, systems synchronizations, and chaos. Similarly, the work of other scholars like Senge explicitly refers to systems thinking but also adapts the term to fit with the overall context and purpose of their specific field of study like using "systems view" as synonyms for systems thinking.

In line with the same notion of Collins and Porras (2005) on rejecting the tyranny of "either/or" and enforce the benefits of "and/both", Systems thinking provide a holistic, balanced, factual view of complex interrelationships, dependencies, patterns and distal impacts within a specific studied system. This view covers multiple perspectives and provides a variety of nonlinear analytical stances to the phenomenon under study that is characterized by being multi-dimensional, participatory, adaptive, and predictive. Network analysis enables researchers to comprehend and illustrate information flow structures by exploring relational data and investigating the nature and attributes of those relations. The key underlying principles of the network perspective include the following (Hanneman, 2001; Wasserman & Faust, 1994):

1. Actors (Nodes) and actions are viewed as interdependent rather than autonomous and independent units.
2. Relational links between actors (Nodes) are channels for the flow of resources (including the information and data assets).
3. Network modeling demystifies and decomposes the interactions structural environment to provide opportunities for or constraints on individual node actions.
4. Network models present structure (such as social, economic, political) as lasting patterns of relations among actors.

Complexity science as a harmonious collection of theories, approaches, and tools that are derived from multiple disciplines like engineering, mathematics, and social sciences provides a universal-common language to analyze and manage complex phenomena and issues. At its core, systems thinking as a conceptual model aims to provide a holistic view of how multiple variables or actors interact with each other under certain circumstances to produce a collective response to certain changes or shape a holistic behavior. Network analysis is a tool used in system thinking and complexity science to unravel organizational complexity. It is an empirical descriptive and quantitative research method derived from social science and graph theory which allows researchers to model, illustrate, quantify, and analyze interrelated relationships and information flow in the organizational system. Applying network analysis fosters a better understanding of the deeply rooted causes of complex behaviors and allows for better prediction and, ultimately, adjustment of variables for better outcomes (Forrester 1968&1970, Arnold and Wade 2015, Mingers and White 2010).

The field of systems thinking and complexity has received more attention from scholars and practitioners due to the potential promises it offers on facilitating a better understanding of complex phenomena and systems. This attention created two major bodies of the literature related to systems thinking; the first is the literature available of systems thinking as a systematic inquiry model or conceptual framework (The Epistemological stance) and the other is the literature available on knowledge about systems (The Ontological stance). Midgley as a top writer in the field of systems thinking in his four-volume collection (Midgley 2003) and jointly with a forty-seven-member international advisory board from different disciplines have studied ninety-seven seminal papers on different areas of systems thinking. While Midgley is of great importance, it still can be seen as a historical summary of the evolution of systems ideas and systems movement with no clear contribution on developing a general model (Conceptual Framework) for systems thinking. On contrary, the work of other scholars like Senge, Bertalanffy, Ashby, and Wheatley have contributed more in advancing our knowledge on the epistemological aspects of inquiring how systems behave under certain circumstances and based on specific initial set-up conditions. This epistemological view also includes demystifying complex interactions, interfaces, and interdependencies. In fact, both views are necessary. However, the epistemological stance of how scientists and practitioners can investigate and understand systems behavior is a prerequisite for advancing their knowledge on how systems in their fields of specialty works (The ontological stance of knowledge about systems).

In today's dynamic and Interconnected world, the complexity of the organizational environment becomes a norm where nonlinear interactions of individual actors are intimately linked to a lagging effect especially with the increasingly interconnected internal and external politics, social, environmental, legal, economic, and technological driving forces (Arthur 1994; Beinhocker 1997). Therefore, systems thinking becomes a real necessity for better management in addressing the pressing complex of issues of our era. In fact, Systems Thinking should be a paradigm shift in the way we comprehend the complexity and interconnectedness of different organizational aspects across different disciplines to enable effective decision making and better problem solving (Richmond 1993). In fact, organizations have been seen as information processing entities (Galbraith,1973, 1974, 1977). Galbraith explained how the inadequacy of information usually leads to uncertainty. That uncertainty is defined as the delta between information needed to perform a certain task or to make a timely decision and the information available. Inadequacy in information sharing negatively affects decision-maker's ability to take effective and timely decisions. Galbraith also highlighted that for organizations to reduce uncertainty, they need to better understand, design, and coordinate the information flow structure, often by rules, hierarchy, or goals.

2.4.2 Systems thinking and Network analysis application in the nuclear industry and other comparative fields

Systems thinking was discussed and referred to in many publications related to nuclear energy. Monat and Gannon (2015) explained how Gerald Weinberg in his book entitled "An Introduction to General Systems Thinking" provides very interesting examples of how systems thinking can enable decision-makers to foresee future intended and untended sequences of the decision they made today. One of these examples was the unintended impacts of waste heat from nuclear power plants. Along the same line, a recent study by Chroust and Finlayson (2017) has discussed the role of systems thinking in fostering anticipation and support analyzing system disturbance and disasters. The study has referred to the Fukushima nuclear disaster that happened in Japan in 2011. I tend to agree with this view as most of the events, deviations from the quality or safety standards, and incidents in the nuclear industry share the same attributes of complex adaptive systems. Therefore, should be analyzed differently.

Network analysis enabled researchers in different comparative fields to demystify the complexity of interactions and quantify the properties of those interactions (Monge et al., 2003). The underlying principles for the network analysis methods include the following (Hanneman, 2001; Wasserman & Faust, 1994):

1 Actors and actions are seen as autonomous units where interdependency between both is a key feature.
2 Connections between actors are channels for resources flow. Information is a good example.
3 Network models illustrate the interaction's structural complexity highlighting constraints on actors' action.
4 Network models present network structure as long-lasting architectures of relations among actors.

One industry that has faced a similar challenge of complexity and was characterized (as a whole or in parts) as a complex adaptive system is a public health. It is noticeable that researchers in the field of Public health are increasingly recognizing the utility of network methods to examine and manage complex issues and phenomena like disease transmission patterns, information sharing structures and to predict potential effects of disease control policies (De et al., 2004; Pourbohloul, et al., 2005). Network analysis also has been applied to manage the complexity of relationships among public health organizations at the state and community levels. Knauss and colleagues examined inter-organizational relationships within state tobacco control networks (Mueller, Krauss, and Luke, 2004). Provan and colleagues developed a framework for evaluating public-sector organizational networks (Provan & Milward, 2001). The framework proposes that network analysis may be applied at several levels to evaluate the effectiveness of public sector agencies at the community level, at the inter-agency level, and at the intra-organizational level. In the literature, to date, no network studies were found examining Intra Intra organizational structure in a public health department.

Another industry that suffered from the complexity issue is the supply chain industry. Battini, Persona, and Allesina (2007) investigated and quantified the complex supply chain ecosystem by measuring flows of goods and interaction costs between different sectors of activity within the supply chain borders. The network of flows were built and successively investigated by network analysis and the result supported the idea that the uses of systems thinking approach provided a conceptual perspective for the modern supply network, and that network analysis can handle these issues in practice.

Mote (2005) examined the impact of complexity in an R&D setting which adopts the approach that collaboration and involvement of a wide range of specialties and skills. Mote (2005) used the network analysis technique to explore and comprehend the R&D context complexity and found it very helpful in examining the interrelationships of competencies within a cluster of

R&D projects in a large multi-disciplinary national laboratory. Networks analysis helped in exploring and understanding structural characteristics, which impact on the productivity of research projects. Mote concluded that network structure and complexity should be given more attention in the of R&D field.

Another industry that benefited from the network analysis to model and manage complexity is the software development industry. That was primarily due to its essential role in system development (Xia and Lee, 2005). Complexity has been seen as one of the most contributing factors for software project failure. According to Nguyen (2014), the inability to understand complexity attributes to nearly around 35% of the software project's failure. Network analysis techniques were used in the software development industry to manage the complexity challenge. Using network analysis to understand software project complexity is vital for the success of IT project management (Petkova and Petkov 2015).

Systems Thinking and network analysis was found beneficial in analyzing complex energy issues and phenomena. For example, it was used for analyzing wind energy sustainability and found very helpful in fostering a better holistic understanding of the wind energy sustainability behavior and the interaction between different elements affecting it through using causal models and feedback loops (Tejeda and Ferreira 2014). Narrowing our discussion to the nuclear energy sector, Systems Thinking was applied to the overriding priorities of nuclear Safety and Nuclear security. Young and Leveson (2013) presented a use case for network analysis in nuclear cybersecurity and safety fields. They have described how systems thinking can be suitable for addressing the challenge of securing complex systems against cyber-attacks. In addition, they have proposed a new framework that shifts practitioner's focus away from threats as an individual immediate cause of losses to more comprehensive focuses and understanding of the system structure and behavior that allowed for such a loss. In fact, this mental shift is also required in different business and technical areas of managing nuclear power plants. One of those areas can be commissioning and operational readiness for the nuclear new builds. Along the same line, systems thinking was used and found beneficial to quantify the dynamics of the physical security in the Nuclear Power Plants where the same logic of analyzing the impact of the interaction between several external driving forces (Political, Economic, Social, Technological, Legal, etc.) and their collective delayed impact on the physical security objectives and the defense against possible terror attack (Woo 2013). Also, System dynamics has been seen as one of the most appropriate tools for analyzing and addressing the complexity of developing radiation and emergency preparedness plans in the Nuclear Power Plants (binti Ab Hamid et.al 2001). Therefore, Systems thinking as an analysis framework is highly recommended to be adopted in different areas of managing Nuclear power plants as it provides a common-structured thinking perspective and language that meets the complex nature of socio-technical aspects of key areas like safety, security, and reliability. Along the same line, systems thinking was perceived as the only valid approach for understanding uncertainty and the unintended consequences of human actions during the construction projects on schedules, budget, and quality (Pidgeon 2010).

Systems thinking was also applied in the field of reliability and learning from past events that took place in the nuclear power plants with the same overall emphasis on safety. Leveson (2011) has discussed the methodological pitfall of investigating events and learning from them in the traditional ways used in the nuclear industry like root causes analysis and a new model of causality based on the application of systems thinking tools and methods. He explicitly highlighted that traditional methods of accident analysis do not serve the purpose when applied within the context of complexity and therefore, there is an imminent need for adopting new methods and techniques that address the complexity and foster a holistic understanding of systems behaviors. Leveson mentioned, “As long as we continue to base our accident analysis and learning from events on assumptions that no longer hold for today’s systems, we should not be surprised that our accident analysis and prevention efforts are of limited usefulness”. Also, Systems thinking was perceived as a beneficial analysis method for some complex problems like nuclear capacity.

Schlange (1995) highlighted the useful adoption of systems thinking as a comprehensive analysis framework for defining, controlling, and testing relationships and relevant assumptions affecting the dynamics and behavior of phenomena or systems.

According to Leveson's (2011) discussion in her book titled “Engineering a Safer World”, Systems Thinking is a more comprehensive and powerful approach to safety and security because it analyzes inter-relationships and interdependencies rather than just linear causality relationships, which support in identifying root causes of flaws and errors. Therefore, considered more suitable for analyzing complex systems more than traditional safety analysis approaches

Organizations are nothing but systems. Especially in the high-reliability industries where organizations are structured as a complex architecture of many subsystems with interrelated tasks and multiple interdependencies on internal and external factors and forces. These tasks can range from routinely conducted tasks like strategy development and supply chain management to huge and complex tasks like commissioning and operational readiness. A very important study for Sireli and Mengers (2009) that was published in the IEEE Systems Journal examined the relevance and value of using systems thinking for analyzing the trend of extended operation of U.S. nuclear reactors and concluded with the fact that U.S. nuclear power plants are good examples of complex systems in need of a change from a traditional managerial view to a system thinking approach. This paradigm shift in the way Nuclear Power Plants are managed has become a necessity more than a choice not only to address the complexity of Nuclear power plant's processes and interactions but also to address the unprecedented complexity of the external operating environment of today’s world. Sireli and Mengers (2009) have suggested some future lines of research within the context of Nuclear Power Plants based on the conclusion of the relevance of Systems Thinking to the Nuclear industry and its challenges. Those suggestions included the following:

1. To thoroughly investigate new emerging issues and apply Forecasting methods to ensure effective decision making and better management of risks and issues.
2. To investigate the complex interaction and combined impacts of technical and non-technical Issues on the focal subject under study.

In the Nuclear industry, commissioning is included as one phase of the Integrated Project Schedule (IPS) for any nuclear new build and managed as a program, Commissioning follows a sequence of activities and an orderly process, the scope of which is defined in a schedule (ONR 2016). Basic methods and practices such as cost-benefit analysis and traditional project management are still used in Most nuclear power companies (Sireli and Mengers 2009). Although these methods are widely used to support the decisions making process for strategic and operational tasks, they are understood to be inadequate for a complex problem. Therefore, network analysis is seen as the fit-for-purpose alternative to traditional analysis methods of complex issues and systems in the nuclear industry.

In summary, the life cycle stages of a nuclear power plant (NPP) include Design, Construction, Commissioning (Operational Readiness), Operations, and decommissioning. The commissioning phase is one of the most interesting and important phases in the lifetime of a nuclear power plant (NPP). It is a short but very intense and complex period, typically encompassing 1–2 years in the total lifetime of an NPP. However, the way the commissioning process is managed across different industries and sectors is yet seen as ad hoc and lacks integration (Lawry and Pons 2013, IAEA 2018). The current practice of managing the commissioning of new nuclear power plants by only using the project management methodology might result in unpredictable outcomes (Lawry and Pons 2013). During the commissioning phase, the inability to address complex issues and take timely and effective decisions based on a comprehensive understanding of all involved stakeholders and interfaces usually leads to errors and delays (IAEA 2014, Cagno, Caron, and Mancini 2002). During the commissioning phase, unnecessary activities are carried out because of lacking the comprehensive system view of the commissioning (Kirsilä, Hellström, and Wikström 2007). Nuclear commissioning (Operational Readiness) shares the characteristics of complex adaptive systems (CAS). Operational Readiness is a dynamic phase of any nuclear new build that is governed by the influence (Feedback) from one activity, milestone, or stakeholder to another Operational readiness milestones are interdependent and the Operational readiness programs adapt based on the progress and experience (Daniel and Daniel 2019, IAEA 2018, IAEA 2014, AERB 1998, STUK 2003). The US Ministry of Energy standard for the Planning and Conducting Readiness Reviews (2010) emphasized on the importance of identifying and evaluating the complexity of the startup or restart of any nuclear power plant. however, no structured approach is used or even proposed, but rather left for the nuclear professionals to decide based on their experience and known industry practices. Understanding and effectively managing the complexity of the commissioning programs is critical to the success of plant safe and reliable signed off for commercial operation (Rosenergoatom 2017). Even though complexity is well recognized in the academic literature as a key feature of the commissioning phase in any nuclear new build project, there is limited rigorous academic research addressing how to fully comprehend and effectively manage that complexity. Published articles dealing with the issue of understanding and managing the complexity of Nuclear power plants Operational Readiness programs are extremely rare, almost non-existent. Therefore, addressing the complexity of interfaces and interaction between Programs, Processes, Procedures, Systems, and Stakeholders of Nuclear Power Plants Operational Readiness programs is seen as a gap in the literature from a knowledge point of view (IAEA 2018, Rosenergoatom 2017, ONR 2016, Doty 2007, STUK 2003). Applying a structured and systematic approach to investigate the nature of that complexity is seen also as a gap from a methodological point of view (Daniel and Daniel 2019, IAEA 2016, IAEA 2012, USDOE 2010, Sireli and Mengers 2009).

2.5 Chapter summary

This chapter has defined complexity and has also clarified what complexity and system thinking . It has also explained how the nuclear power plant operational readiness is recognized as a complex adaptive system and established the need to investigate the complexity of interactions and information flow structures based on the reviewed the relationship between complexity and serious implications on the success of the nuclear power plant operational readiness. Furthermore, this chapter highlighted the methodological and ontological gap in the existing literature which was used to demonstrate the original contribution to theoretical and practical knowledge.

Chapter 3: Conceptual Model

3.1Introduction

this chapter defined key components of the UAE Nuclear power plant operational readiness program and provided a justification from the literature review on the interactions mapping adopted to answer research questions. In addition, this chapter summarized and illustrated key theories and concepts from the literature as the theoretical framework which is used to explain relationships among these ideas and how they relate to the research study.

3.2 Theoretical framework

This study is based on the relationship between three key concepts derived from four main theories. The first is the concept of complexity of interactions and information flow in the nuclear power plant operational readiness programs. The second is the concept of network analysis, a method for evaluating and understanding complexity and dynamic interactions. The third is the application of the network analysis on nuclear power plant operational readiness programs which creates a means to examine aspects of Influence and Interdependencies towards achieving the Operating License requirements. These concepts are discussed fully in chapter 2 and illustrated in the theoretical framework displayed in figure 3.1.

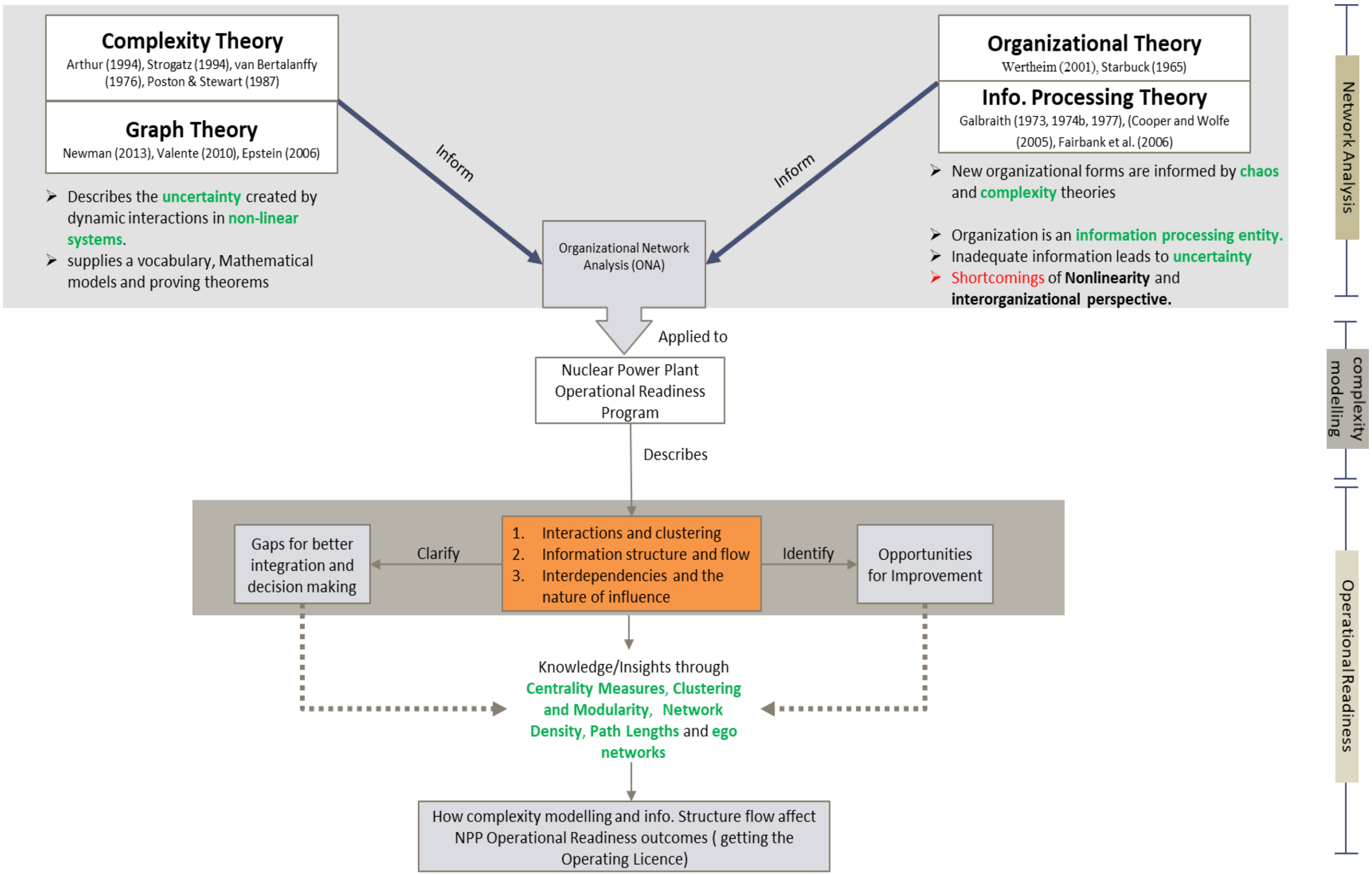


Figure 3. 1 Theoretical framework

3.2.1 Complexity in nuclear power plant operational readiness

Life cycle stages of a nuclear power plant (NPP) include Design, Construction, Commissioning (Operational Readiness), Operations, and decommissioning. The commissioning phase is one of the most interesting and important phases in the lifetime of a nuclear power plant (NPP). It is a short but very intense and complex period, typically encompassing 1–2 years in the total lifetime of an NPP. However, the way the commissioning process is managed across different industries and sectors is yet seen as ad hoc and lacks integration (Lawry and Pons 2013, IAEA 2018). The current practice of managing the commissioning of new nuclear power plants by only using the project management methodology might result in unpredictable outcomes (Lawry and Pons 2013). During the commissioning phase, the inability to address complex issues and take timely and effective decisions based on a comprehensively understanding of all involved stakeholders and interfaces usually leads to errors and delays (IAEA 2014, Cagno, Caron, and Mancini 2002). During the commissioning phase, unnecessary activities are carried out because of lacking the comprehensive system view of the commissioning (Kirsilä, Hellström, and Wikström 2007). Nuclear commissioning (Operational Readiness) shares the characteristics of complex adaptive systems (CAS). Operational Readiness is a dynamic phase of any nuclear new build that is governed by the influence (Feedback) from one activity, milestone, or stakeholder to another Operational readiness milestones are interdependent and the Operational readiness programs adapt based on the progress and experience (Daniel and Daniel 2019, IAEA 2018, IAEA 2014, AERB 1998, STUK 2003). The US Ministry of Energy standard for the Planning and Conducting Readiness Reviews (2010) emphasized on the importance of identifying and evaluating the complexity of the startup or restart of any nuclear power plant. Understanding and effectively managing the complexity of the commissioning programs is critical to the success of plant safe and reliable signed off for commercial operation (Rosenergoatom 2017). Complexity theory describes the uncertainty created by dynamic interactions in non-linear systems, where cause and effect are not proportional. Graph theory complements the complexity theory by supplying a vocabulary for denoting interactions and information structural properties (Nodes, edges, Hubs, clusters, Ego networks, etc.). also, graph theory provides statistical and mathematical tests and models to quantify these network properties. Furthermore, graph theory (through network analysis) establishes a method for proving theorems about networks that help in drawing reliable insights on how well ident fed network properties network represent the measured systems.

3.2.2 Information use in the nuclear power plant operational readiness

Increasing information interdependence during the commissioning life cycle is also an essential feature of its complexity. The complex and interdependent information flow between different processes, programs, and systems during commissioning cuts through different project's stages, process and involve multiple internal and external stakeholders. Fiatech's Capital Facilities Information Handover Guide (2006) emphasized on the critical role of information flow and handover for the success of commissioning activities and developed a methodology for defining full life cycle e information requirements as a prerequisite for managing information flow and implementing interphases information handover. Understanding the information flow between different actors of the nuclear power plant operational readiness program through modeling the interaction between those actors and linking it to achieving regulatory requirements and other safety-related commitments is vital to the success of such programs. Galbraith explained how evolvement in organizational design emerges from efforts for enhancing decision-makers and middle management pre-planning ability by equipping them with the right information at the right time to achieve the strategic outcomes for organizations (Galbraith, 1973). Commissioning effective information management is a critical enabler for the success of the nuclear power plant's operational readiness. Effective use of commissioning data enables commissioning engineers to identify design and construction non-conformances and take the required action of repair or modification accordingly (IAEA 2016, AERB 1998).

3.2.3 Network analysis

Network analysis enables researchers to comprehend and illustrate information flow structures by exploring relational data and investigating the nature and attributes of those relations (Hanneman, 2001; Wasserman & Faust, 1994). Network analysis views actors (Nodes) and actions as interdependent rather than autonomous units. It helps in understanding relational links between actors (Nodes) as channels for information flow (Newman 2013, Valente 2010, Epstein 2006). When network analysis is applied in an organizational context, it's usually referred to as organizational network analysis. The network analysis method takes into account the Intra organizational perspective as well (the relationship between organizational actors and the external operating environment). Network Analysis demonstrates relations between different actors within a dynamic system (Stakeholders (People), groups, organizations), represent through nodes and ties, and uses a wide range of graphical and statistical models to display the network and the nature of the relationships between system’s actors. (Newman 2013, Valente 2010). The results produce knowledge and insights through network statistics (like centrality measures, clustering and modularity, network density, path lengths, and ego networks) into systems’ behavior and complexity comprehension.

3.3 Nuclear power plant operational readiness program components and interactions mapping

Commissioning is an essential and critical phase of operating any new power plant. It is also a crucial step in any plant-modification project. However, the way the commissioning process is managed across different industries and sectors is yet seen as ad hoc and lacks integration (Lawry and Pons 2013). In the context of the Nuclear industry, commissioning is included as one phase of the Integrated Project Schedule (IPS) for any nuclear new build and managed as a program, so it is not that nuclear professionals are ignorant of commissioning. Rather, the problem is that there is a lack of comprehensive understanding and systematic management of commissioning as a system that is constantly changes based on the influence (Feedback) and interdependencies between activities and actors involved. Understanding and effectively managing the complexity of the commissioning programs is critical to the success of plant safe and reliable start-up. During the commissioning phase, the inability to address complex issues and take timely and effective decisions based on a comprehensiveunderstanding of all involved stakeholders and interfaces usually leads to errors and delays (Cagno, Caron, and Mancini 2002).

Nuclear power plant operational Readiness shares the characteristics of complex adaptive systems (CAS). Operational Readiness is a dynamic phase of any nuclear new build that is governed by the influence (Feedback) from one activity, milestone, or stakeholder to another Operational readiness milestones are interdependent and the Operational readiness programs adapt based on the progress and experience (IAEA 2014, AERB 1998, STUK 2003). Phenomena of phase transitions, feedback loops, scale-free networks, and emergent behavior are typical characteristics of any nuclear power plant operational readiness program.

This research investigated the complexity of interaction between Processes, Programs, Procedures, Plant Systems, and Stakeholders of the UAE Nuclear power plant operational Readiness program. Within this context, this research described and model the interaction between all elements included in the UAE Nuclear power plant operational readiness program which covers the 5 Ps (Programs, Processes, Procedures, Stakeholders and Plant) within the hierarchy of the Integrated Management System (IMS) Architecture as per the following mapping that was derived from IAEA (2009), IAEA (2006) and STUK (2003):

1. Level 0 Process (Main Process or Process Description-PSD) to the Regulatory Requirement linked to each Level 0 process (PSD). Those requirements are set by the Nuclear Regulator and considered the minimum requirements that the nuclear plant operator needs to demonstrate full compliance to to be eligible to receive the nuclear power plant Operating License.
2. Level 0 Process (Process Description-PSD) to the Program (PGD) dependency mapping. This mapping explained which Program each Process directly supports according to each Process Description document.
3. Level 1 Process to another level 1 process Interfaces. This mapping illustrated the process interfaces identified for each Level 1 Sub Process with other L1 Sub Processes. Some interfaces also made to the L2 process to provide more information if required.
4. Level 0 Process (PSD) to Stakeholders (People) dependencies. This mapping explained all Stakeholders (People) who being involved in the implementation of each L0 Process. This mapping included a mixture of functions, organizational Units, and positions
5. Level 1 Process to Stakeholders (People) dependencies. This mapping showed all Stakeholders (People) who being involved in the implementation of each L1 Process. This mapping included a mixture of functions, organizational units, and positions.

6. Level 0 Process (PSD) to Plant Systems dependencies. This mapping illustrated dependency relationships between the main Plant systems and L0 processes in terms of which Plant system supports the implementation of which L0 Process as depicted in management system documents.
7. Level 0 process (PSD) to Implementing procedure dependencies. This mapping explained the implementing Procedures required to ensure the systematic execution of L0 processes (PSD. This mapping was extended to cover owning Functions and accountable owners.
8. Level 0 Process (PSD) to other Level 0 Process (PSD). This mapping explained how each main process in the Nuclear Power Plant Operational Readiness is linked to and/or interacting with other Level 0 Process (PSD) directly or indirectly.
9. Programs to Requirements mapping. This mapping explained interactions between the Statutory, regulatory, and Non-Regulatory requirements and strategic Programs.
10. Programs to Roles mapping. This mapping illustrated interactions between roles and responsibilities and Functions, persons and/or other entities involved in the Nuclear power plant operational Readiness Program at all levels.
11. Program to Program Interface mapping. This mapping illustrated program to program interfaces and dependencies.
12. Program to Plant Systems dependency mapping. This mapping illustrated interactions between all main Plant systems and all strategic Programs in the master Operational Readiness Program.
13. Comprehensive network mapping all components of the Nuclear Power Plant Operational Readiness.

The scope of this study included all Programs and Processes related to the operational readiness interfaces with stakeholders, Plant systems, and implementing procedure documents. The scope of this study also covered any other artifacts that emerged during the learning experience of maintaining the Integrated Management System and therefore, deemed necessary to support the delivery of the IMS in terms of its architecture including the following:

1. ENEC Enterprise Vision and Mission
2. Nuclear Safety Culture
3. ENEC Enterprise core Values
4. Operating Model of ENEC Enterprise and its operating subsidiary
5. Any relevant Standards

The study considered the following definition for each process level:

a) Level 1 is the High-Level Overview and defined as an overview of how the organization and its management system are designed to meet its policies and objectives. This High-Level Overview is typically used by management as a primary channel of communicating to individuals' expectations, their strategies for success, and methods for achieving the operational readiness objectives.
b) Level 2 are the Programs and Processes designed to achieve regulatory and organizational objectives and specify which organizational unit is to carry them out. Processes are used to structure what we do, sequence how we do them, understand the interactions, and manage them effectively. Programs are specific packages of work, supported by processes that implement requirements
c) Level 3 are Implementing Procedures. These are the detailed instructions and guidance that enable the processes to be carried out and specification of the individual or unit that is to

perform the works. Detailed working documents to prescribe the specific details for the performance of tasks by individuals or by small functional groups or teams. The conceptual model of this study is developed based on the above-mentioned three-level structure for IMS information documentation, as described in IAEA GS-G-3.1 “Application of the Management System for Facilities and Activities Safety Guide”. The study will also investigate the integrates with all statutory and regulatory requirements that relate to FANR-REG-01, "Regulation for Management Systems for Nuclear Facilities", as well as other UAE laws and regulations for example; the Environment Agency of Abu Dhabi (EAD), Federal Law by Decree No.6 (2009) and will incorporate the interfaces of key stakeholders and interested parties including the public and local communities, employees, governmental organizations, and the global nuclear industry.

In the context of the development of a peaceful nuclear program, the UAE is committed to implementing the highest regulatory and safety management standards in all areas (Ref: UAE Federal Law No6. of 2009). These measures include reactor design, required safety equipment, and emergency-response measures, with numerous safety-related regulatory requirements. These design features enhance safety and reliability and assist in the prevention of any accidental radiological releases. The Advanced Power Reactor 1400 MWe (APR1400) was developed in the Republic of Korea in 2002. APR1400 utilizes state-of-the-art proven technology and incorporates several advanced design features to meet the utility’s needs for enhanced economic goals, and to address the new licensing safety issues and requirements for improved plant safety. The APR1400 was designed with additional safety margins to improve defense-in-depth, as well as the protection of the public. Systems referred to in this study covered Plant Systems, Structures, and Components

(SSC). These included software applications, supporting hardware, safety-related equipment, and buildings.

Programs are a planned, coordinated group of activities, processes, and/or procedures, developed for a specific purpose to accomplish a clear safety objective, with details on what work is to be done, by whom, at what periodicity, and what means, or resources will be used. Programs are characterized by the following criteria:

1. Programs require specific technical expertise.
2. Programs are required by reference documents (e.g. FANR regulations, Technical Specifications, FSAR, standard nuclear industry practice, or expert judgment)
3. Program data collection activities are repeated at regular intervals.
4. There is a continuity of data where the output and inputs of each data collection cycle are compared to each other.

Processes support the safe and reliable operations of the plant. They consist of a structured set of activities, which produce a measurable output. Processes are designed to facilitate the execution of repetitive work to ensure requirements are met effectively and efficiently, through a sequence of sub-processes and activities showing the operation of a Function or service. Processes aim to meet Nuclear Power Plant Operational Readiness strategic and regulatory objectives under the categories of:

1. Management Processes are used to provide oversight, review performance, and provide opportunities to improve Core and Support Processes. These Processes are Management Oversight, Independent Oversight, and Performance Improvement.

2. Core Processes are used to deliver key products and services, by taking input and transforming it into a value-adding output. They are Operate Plant, Work Management, Configuration Management, Equipment Reliability, and Materials and Services.
3. Support Processes are used to provide support for our Core Processes. They are Loss Prevention, Nuclear Fuel, Talent Management, and Support Services.

The study covered all procedures developed to meet safety and quality requirements. those support the implementation of our Programs and Processes and specify or describe how an activity is to be performed. The term procedure in this study will also include instructions and drawings including the following key areas:

a. Calibration and Test Procedures
b. Chemical and Radiochemical Control Procedures
c. Emergency Operating Procedures
d. Emergency Plan Implementing Procedures
e. Fire Protection Procedures
f. Fuel Handling Procedures
g. Maintenance Procedures
h. Power Operation and Load Changing Procedures
i. Process Monitoring Procedures
j. Radiation Control Procedures
k. Shutdown Procedures
l. Start-up Procedures
m. System Procedures
n. Temporary Procedures

3.4 Chapter summary

In this chapter, the researcher has explained the complexity of interactions and information flow in the nuclear power plant operational readiness programs. This chapter highlighted the gap in the existing literature related to the ontological stance of what nuclear power plant operational readiness complexity looks like, as well as, the methodological stance of how complexity can be demystified and understood. Furthermore, this chapter explained the concept of network analysis as a method for evaluating and understanding complexity and dynamic interactions and established the theoretical basis for applying the network analysis on nuclear power plant operational readiness programs to examine the nature of interactions, Influence, and Interdependencies between different actors towards achieving the Operating License requirements. Finally, this chapter discussed components of the Nuclear power plant operational readiness program and explained the detailed interactions mapping that this study has covered.

Chapter 4: Research Methodology

4.1. Introduction

This chapter provides an overview of the commonly used interpretive frameworks and available scientific research methods and explains the rationale behind adopting the Network

Analysis Design and in-depth interviews as a fit for purpose method for this research. Furthermore, this chapter explains in detail the research process, data collection, and data analysis methods.

4.2. Research method process

This research followed Saunders, Lewis, and Thornhill's (2011) multi-stage research process to complete the research project and address research questions and objectives. This process covered the stages of defining the research scope and objectives, reviewing the Literature, adopting the right research philosophy and approach, formulating the research design, data collection, data analysis, and finally draw conclusions and future recommendations. This process was managed as an iterative process where the researcher ensured alignment and integration between different stages. This research process is depicted in Figure 4.1 below with a dotted line indicating the alignment and integration aspects.

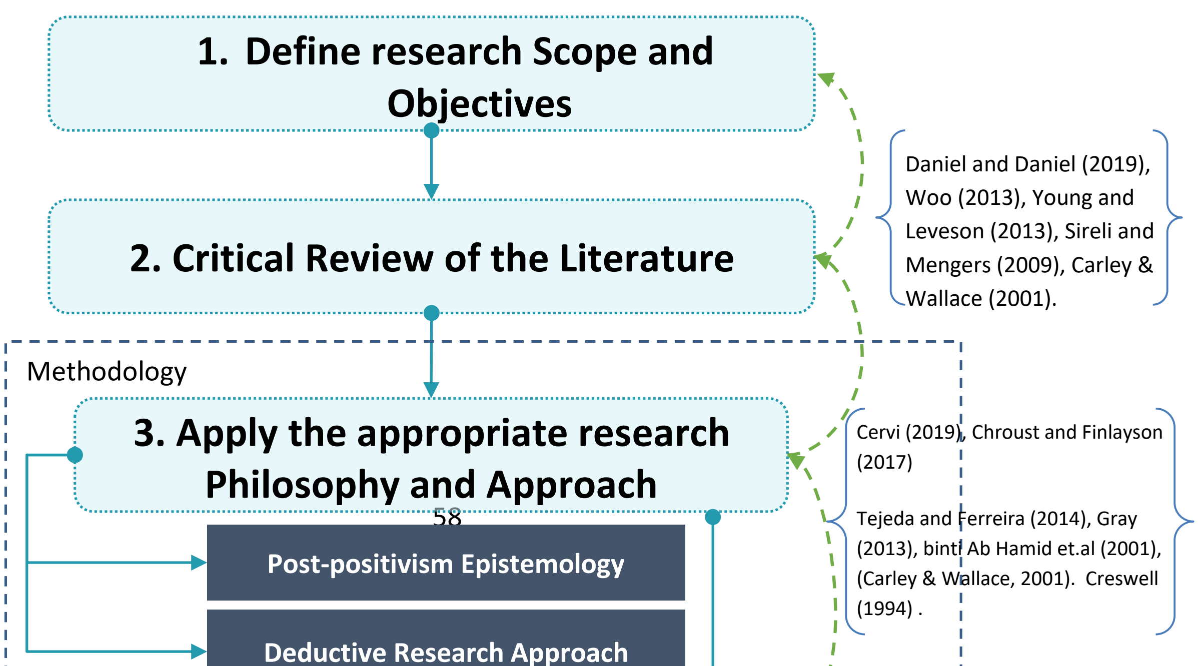


Figure 4. 1 Research process

Previous chapters have discussed in detail the research scope, objectives, questions, and systematic review of the literature on both Nuclear power plant operational Readiness, Systems Thinking, and network analysis. The next section of this chapter discusses the relevant research paradigms (world views) and the epistemological and ontological implications of the selected research paradigm on the selected research approach which covers the third phase of the research process adopted. For phase 4, the three commonly used research designs were discussed in line with the research questions and the epistemological stance adopted by the researcher. Phase 5 and 6 were covered through the discussion of the best fit-for-purpose data collection and analysis methods in line with decisions and work made in the previous steps

4.3. Research paradigms

The research paradigm is the underpinning model that steers and guides the research process. It is defined as the philosophical framework on which the research will be conducted accordingly (Collis and Hussy 2013). Creswell (2014) called them worldviews of Post-positivism, Constructivism, Pragmatism, and Transformative. Crotty (1998) highlights the importance of establishing linkage and integration between the theoretical stance adopted by the researcher, the epistemological view adopted, research methodology, and research methods to produce valid and sound conclusions as depicted in figure 1.2 below.

Figure 4. 2 The relationship between research paradigm, interpretative frameworks , methodology and research methods (Adopted from Crotty 1998).

Along the same line, the research onion (Figure 4.3) depicted by Saunders, Lewis, and Thornhill (2011) highlights the interrelationship and dependencies between the research philosophy adopted by the researcher and the relevant research approach and the methods needed to address the research questions in line with the adopted philosophy. In fact, each research philosophy comes with certain assumptions about the way the researcher views and comprehend phenomena. These assumptions are the underpinnings of the research strategy and the research methods. Research philosophy determines the researcher's view of reality

(Creswell 2014). It is a logical structure that encompasses Epistemological and Ontological stances on how to approach certain inquiries (Gray 2013). Therefore, it was vital for the researcher to choose the right research philosophy and establish proper linkage and integration with the adopted research philosophy and the research approach and methods to ensure the robustness of the research structure and validity of the research outputs.

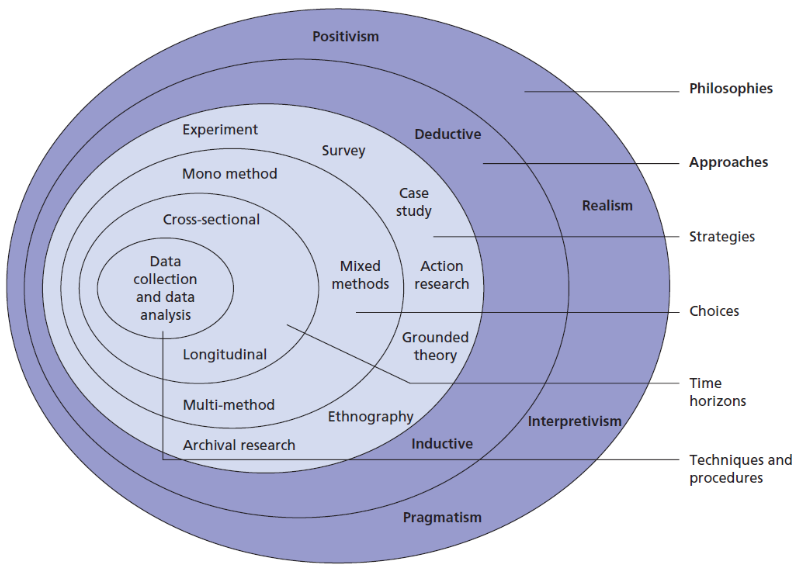


Figure 4. 3 The research onion adopted from Saunders, Lewis and Thornhill (2011)

Ontology is defined as the study of being (Gray 2013, Creswell 2014), That is, the study of what entails and constitutes reality and existence. Therefore, the ontological stance of the researcher between subjectivity and objectivity dictates to a great extent the research approach. For example, the Postpositivist world view of the existence of one reality that is independent of the actor's perception and influence necessitates holding a deterministic philosophy of causality reasoning in which causes determines outcomes, effects, and results. While on the other hand, the Constructionist world view assumes the existence of multiple realities and that the subjective meanings of individuals can produce different realities of the same phenomenon.

Epistemology on the other side is the researcher's view of what can be qualified as legitimate, acceptable, and adequate knowledge (Saunders, Lewis, and Thornhill 2011, Gary 2013). The Post-positivism epistemology as a theoretical stance enables the researcher to apply science and rationalism to investigate and comprehend meanings and how they have been constructed within a specific context (Creswell 2014). The interpretive framework of Post-positivism epistemology was used to model the complexity of interaction between Processes, Systems, and stakeholders of the UAE Nuclear power plant operational Readiness program. Adopting the post-positivism epistemology lens as an interpretive framework enabled the researcher to understand and model the complexity of interaction between Processes, Systems, and stakeholders in great detail and enhanced the ability to tap onto the intangible aspects of the relationships and complexity of interactions with the different actors of the investigated system.

4.4. Research approach

In the pursuit to contribute to the academic body of Knowledge, searchers adopt different approaches based on the type of inquiry and the aim of the research. There are two major known research approaches, the Deductive approach and the Inductive approach (Creswell 2014, Gray 2013). The deductive research approach is primarily tied to scientific research and it is all about testing existing theories (Creswell 2014). According to Robson (2002), deductive reasoning goes into different steps that include:

1. Deducing a hypothesis from a theory
2. Operationalize the hypothesis through developing the research conceptual model that includes all variables and relationships related to the hypothesis

3. Conduct the research and analyze the results
4. Reflect research findings on the theory if applicable.

The deductive research approach dictates full independence between the research and the phenomenon under study.

The inductive research approach focuses on building new theories. On the opposite of the deductive research approach, the inductive approach pays relatively low attention to the pre-existing theories and start with data collection and analysis as a base for finding patterns and valid conclusions that might qualify to generalize or even theorize. According to Saunders, Lewis, and Thornhill (2011) "deduction owes more to positivism and induction to interpretivism".

4.5. Research methods

The known research methods in social and scientific sciences cover a wide range of Quantitative, Qualitative, Mixed methods, simulation, modeling, and experimentations. The qualitative research methods are primarily linked to the inductive reasoning with a wide range of methods like the grounded theory and the work of Corbin and Strauss (2007) and Charmaz (2006) to develop the procedure for this method, case study method (Yin 2009, 2012; Stake 1995), Ethnography, and phenomenological research. On the other hand, The Quantitative research methods are invoked by the postpositivist research paradigm and tied primarily to the deductive research approaches. According to Creswell (2014), quantitative research methods include Experimental research design, Quasi-experimental design, and Non-experimental research designs. One form of the non-experimental quantitative research design in the Network Analysis Design in which the researcher used statistics and mathematical equations to model and describe the relationships, associations, and degrees of interdependencies between different actors involved in this study. This study utilized various statistical tests and techniques provided by Network Analysis. Those tests included centrality measures, clustering and modularity, network density, path lengths, and ego network analysis. Network analysis is linked with the scientific research paradigm which ties mostly with deductive reasoning as the essence for testing theories and hypotheses through rigorous methods like simulation, modeling, and experimentation (Chroust and Finlayson 2017, Carley & Wallace, 2001). For the purposes of this study and in line with the research problem and aim of modeling the complexity of the UAE nuclear sector operational project processes and stakeholders while examining the readiness and interactions of nuclear operational project processes and their impact on achieving the operating License requirements, the Network Analysis Design will be used as a research method in conjunction with the in-depth interviews with processes owners and nuclear experts to further strengthen the validity of the secondary data usage. Network analysis design is based on analyzing organizations as complex systems where multiple actors interact in dynamic and non-linear relationships that shape the overall behavior and performance of the organization (Daniel and Daniel 2019, Woo 2013, Young and Leveson 2013, Sireli and Mengers 2009). One key factor dynamic relationship is the information flow structure represented by interactions between those actors. Network analysis provides an overall collective analysis accompanied by both a visual illustration and a statistical analysis that is not possible using probability-based statistical methods (Carley & Wallace, 2001). Therefore, the adopted research design will also support closing the methodological gap identified in the literature review chapter.

The third method is the mixed research method where the researcher adopts different techniques from both qualitative and qualitative methods to form a balanced approach between closed-ended questions and predetermined nature from one side and the opened-ended and emerging nature from the other side. In many cases, academics have perceived the use of mixed methods as a supporting factor that enhances the researcher's ability to strengthen his research outcomes (Amaratunga et al. 2002). According to Creswell (2014), the researcher can make inferences and validation across the data collected through the qualitative technique or secondary data through conducting in-depth confirmatory interviews which were used in this study.

4.6. The rationale for the research design

Network analysis design is based on analyzing organizations as complex systems where multiple actors interact in dynamic and non-linear relationships that shape the overall behavior and performance of the organization (Daniel and Daniel 2019, Woo 2013, Young and Leveson 2013, Cervi 2019, Chroust and Finlayson 2017, Tejeda and Ferreira 2014, binti Ab Hamid et.al 2001). One key factor dynamic relationship is the information flow structure represented by interactions between those actors. Network analysis provides an overall collective analysis accompanied by both a visual illustration and a statistical analysis that is not possible using probability-based statistical methods (Carley & Wallace, 2001). The use of data triangulation in data collection has become popular in recent research. The term triangulation refers to the use of secondary and primary data as the two sources of data collection

Furthermore, the use of secondary data helps the researcher to enhance the reliability of Network analysis (Newman 2003). In fact,

Therefore, network analysis complemented by confirmatory in-depth interviews and supported by secondary data review ensured addressing the following research questions:

5. What are the Interactions (the Information flow structure) between different actors involved in the UAE Nuclear Power Plants Operational Readiness Program (Programs, Processes, Procedures, systems, and stakeholders)?

    14) Level 0 Process to Requirement

    15) Level 0 Process to Program

    16) Level 1 Process to another level 1 process

    17) Level 0 Process to Stakeholders

    18) Level 1 Process to Stakeholders

    19) Level 0 Process to Plant Systems

    20) L0 process to Implementing procedure

    21) Level 0 Process to L0 Process

    22) Programs to Requirement

    23) Programs to Role

    24) Program to Program

    25) Program to Plant System

    26) And Finally, one network graph analysis on the operational readiness program level

6. What are the Interdependencies and the nature of influence between individual actors within detailed interactions between the components of the nuclear power plant operational readiness program in UAE?

7. What are the Interdependencies between the five key components of the UAE Nuclear Power Plant Operational Readiness Program (Full Network Level)?

8. What are the most influential components of different Programs, Processes, Procedures, systems, and stakeholders on achieving the Operating License requirements?

The research design of this study is consistent with the work of Young and Leveson (2013) where they have presented a use case for systems thinking in nuclear cybersecurity describing how network analysis can be suitable for addressing the challenge of securing complex systems against cyber-attacks. Accordingly, they have proposed a new framework that shifts practitioner's focus away from threats as an individual immediate cause of losses to more comprehensive focuses and understanding of the system structure and behavior that allowed for such a loss. Moreover, the adoption of network analysis is consistent with Woo (2013) where it was used and found beneficial to quantify the dynamics of the physical security in the Nuclear Power Plants where the same logic of analyzing the impact of the interaction between several external driving forces (Political, Economic, Social, Technological, Legal, etc.) and their collective delayed impact on the physical security objectives and the defense against a possible terror attack. Additionally, Network analysis and systems dynamics were also adopted binti Ab Hamid et.al (2001) and have been seen as one of the most appropriate tools for analyzing and addressing the complexity of developing radiation and emergency preparedness plans in the Nuclear Power Plants. Furthermore, network graph analysis was adopted by Tejeda and Ferreira (2014) for analyzing wind energy sustainability which was found very helpful in fostering a better holistic understanding of the wind energy sustainability behavior and the interaction between different elements affecting it through using causal models and feedback loops. Along the same line, some recent studies like Chroust and Finlayson (2017) have discussed the role of network analysis in fostering anticipation and support analyzing system disturbance and disasters like Fukushima nuclear disaster. Most importantly, the research design is consistent with the recommendations of one of the most important studies for Sireli and Mengers (2009) that was published in the IEEE Systems Journal that examined the relevance and value of using systems thinking and network analysis for analyzing the trend of extended operation of U.S.

nuclear reactors and concluded with the fact that U.S. nuclear power plants are good examples of complex systems in need of a change from a traditional managerial view to a system thinking approach. Sireli and Mengers (2009) has suggested some future lines of research within the context of Nuclear Power Plants based on the conclusion of the relevance of Systems Thinking and network analysis to the Nuclear industry and its challenges. Those suggestions included the following which goes in line with the research agenda and methodology:

1. To thoroughly investigate new emerging issues and apply Forecasting methods to ensure effective decision making and better management of risks and issues.
2. To investigate the complex interaction and combined impacts of technical and non-technical Issues on the focal subject under study.

As discussed earlier in this chapter, the Network Analysis Design in the form of system modeling using Gephi software was used as a research method in conjunction with the in-depth interviews with processes owners and Nuclear experts to validate and confirm the relationships, interdependencies, and the strength of influence between all Programs, Processes, Procedures, Plant Systems and Stakeholders involved in the development and management of the UAE Nuclear power plant operational Readiness Program. The adopted research is seen as the perfect fit for purposes since it directly answers the research questions and addresses the research aim. Additionally, it supports both methodological triangulation and data triangulation which both enhances the researcher's ability to balance out any of the potential weaknesses in each data collection method and therefore enhance the quality and validity of the research outputs (Saunders, Lewis, and Thornhill 2011, Easterby-Smith et al. 2002). This study depended heavily on reviewing and collecting secondary data from different inputs like engineering standards, regulatory and statutory requirements, management systems policies, process maps, management systems procedures, systems architectures, programs and projects documentation, performance reports, assessment reports, enterprise architecture, stakeholders' maps, etc. and transform them into the form of 'Dependency Matrices'. The secondary data when utilized before the in-depth interviews enabled the researcher to develop a preliminary understanding of the situation/phenomenon under study. This preliminary understanding was the basis for capturing key focus areas and emerging themes for further discussion and analysis during the in-depth interviews.

4.7. Data collection methods

Dependency matrices were used to collect secondary data from all relevant sources like engineering standards, regulatory and statutory requirements, management systems policies, process maps, management systems procedures, systems architectures, programs and projects documentations, performance reports, assessment reports, enterprise architecture, stakeholders' maps, etc. using the Design structure matrix (Adjacency matrix structure) depicted in Figure 1.4. Design structure matrix (DSM) emerged as a data collection technique from diverse origins. DSM is essentially the square matrix, long used by systems engineers to represent complex architectural components and interfaces. A design structure matrix (DSM) provides a simple, concise, and visual representation of a complex system that supports analyzing dynamic complex behaviors through decomposition into smaller subsets that can be studied in depth (Eppinger and Browning 2012, Browning 2001, Tang, Zhang and Dai 2009). The advantages of Design structure matrices (DSM) compared to alternative system representation and analysis techniques have led to their increasing use in a variety of contexts including complex organization design and mega projects (Browning 2001). Tang, Zhang, and Dai, 2009). Design structure matrix (DSM) is a powerful tool to identify and model inexpediencies between different tasks and actors with a process or a complex system (Eppinger and Browning 2012, Carrascosa, Eppinger, and Whitney 1998).

To ensure capturing all required details of interactions from different angles, this mapping will take place on the following levels:

1. Level 0 Process (Main Process or Process Description-PSD) to the Regulatory Requirement linked to each Level 0 process (PSD). Those requirements are set by the Nuclear Regulator and considered the minimum requirements that the nuclear plant operator needs to demonstrate full compliance to be eligible to receive the nuclear power plant Operating License.
2. Level 0 Process (Process Description-PSD) to the Program (PGD) dependency mapping. This mapping explained which Program each Process directly supports according to each Process Description document.
3. Level 1 Process to another level 1 process Interfaces. This mapping illustrated the process interfaces identified for each Level 1 Sub Process with other L1 Sub Processes. Some interfaces also made to the L2 process to provide more information if required.
4. Level 0 Process (PSD) to Stakeholders (People) dependencies. This mapping explained all Stakeholders (People) who being involved in the implementation of each L0 Process. This mapping included a mixture of functions, organizational Units, and positions
5. Level 1 Process to Stakeholders (People) dependencies. This mapping showed all Stakeholders (People) who being involved in the implementation of each L1 Process. This mapping included a mixture of functions, organizational units, and positions.
6. Level 0 Process (PSD) to Plant Systems dependencies. This mapping illustrated dependency relationships between the main Plant systems and L0 processes in terms of which Plant system

supports the implementation of which L0 Process as depicted in management system documents.

7. Level 0 process (PSD) to Implementing procedure dependencies. This mapping explained the implementing Procedures required to ensure the systematic execution of L0 processes (PSD. This mapping was extended to cover owning Functions and accountable owners.
8. Level 0 Process (PSD) to other Level 0 Process (PSD). This mapping explained how each main process in the Nuclear Power Plant Operational Readiness is linked to and/or interacting with other Level 0 Process (PSD) directly or indirectly.
9. Programs to Requirements mapping. This mapping explained interactions between the Statutory, regulatory, and Non-Regulatory requirements and strategic Programs.
10. Programs to Roles mapping. This mapping illustrated interactions between roles and responsibilities and Functions, persons and/or other entities involved in the Nuclear power plant operational Readiness Program at all levels.
11. Program to Program Interface mapping. This mapping illustrated program to program interfaces and dependencies.
12. Program to Plant Systems dependency mapping. This mapping illustrated interactions between all main Plant systems and all strategic Programs in the master Operational Readiness Program.

Dependency Matrix

X when row depends on column.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 6	Attribute 7	Attribute 8	Attribute 9	Attribute 10	Attribute 11	Attribute 12	Attribute 13	Attribute 14
1	Attribute 1										x		x		
2	Attribute 2	x													
3	Attribute 3								x			x			
4	Attribute 4			x											
5	Attribute 5									x			x		
6	Attribute 6					x									
7	Attribute 7														
8	Attribute 8														
9	Attribute 9														
10	Attribute 10														
11	Attribute 11														
12	Attribute 12														
13	Attribute 13														
14	Attribute 14		x		x		x								

Figure 4. 4 *The dependency matrix structure*

Plant Systems referred to in this study covered Plant Systems, Structures, and Components (SSC). These included software applications, supporting hardware, safety-related equipment, and buildings.

Programs referred above were those which were a planned, coordinated group of activities, processes, and/or procedures, developed for a specific purpose to accomplish a clear safety objective, with details on what work is to be done, by whom, at what periodicity, and what means, or resources will be used. Programs included in this study followed the management system definition which was characterized by the following criteria:

1) Programs require specific technical expertise.
2) Programs are required by reference documents (e.g. FANR regulations, Technical Specifications, FSAR, standard nuclear industry practice, or expert judgment)
3) Program data collection activities are repeated at regular intervals.

4) There is a continuity of data where the output and inputs of each data collection cycle are compared to each other.

Processes referred to above were those processes that support the safe and reliable operations of the plant. They consist of a structured set of activities, which produce a measurable output. Processes are designed to facilitate the execution of repetitive work to ensure requirements are met effectively and efficiently, through a sequence of sub-processes and activities showing an operation of a function or service. Processes aim to meet Nuclear Power Plant Operational Readiness strategic and regulatory objectives under the categories of:

1. Management Processes are used to provide oversight, review performance, and provide opportunities to improve Core and Support Processes. These Processes are Management Oversight, Independent Oversight, and Performance Improvement.

2. Core Processes are used to deliver key products and services, by taking input and transforming it into a value-adding output. They are Operate Plant, Work Management, Configuration Management, Equipment Reliability, and Materials and Services.

3. Support Processes are used to provide support for our Core Processes. They are Loss Prevention, Nuclear Fuel, Talent Management, and Support Services.

The study covered all procedures developed to meet safety and quality requirements. those support the implementation of our Programs and Processes and specify or describe how an activity is to be performed. The term procedure in this study also included instructions and drawings including the following key areas:

a. Calibration and Test Procedures

b. Chemical and Radiochemical Control Procedures

c. Emergency Operating Procedures

d. Emergency Plan Implementing Procedures

e. Fire Protection Procedures

f. Fuel Handling Procedures

g. Maintenance Procedures

h. Power Operation and Load Changing Procedures

i. Process Monitoring Procedures

j. Radiation Control Procedures

k. Shutdown Procedures

l. Start-up Procedures

m. System Procedures

n. Temporary Procedures

Even though this study is a whole-network analysis and does not require to use of any sampling technique for developing and analyzing the networks (Marsden, 2005). A validation interview structure was assembled using standard network analysis questions to strengthen the validity of findings drawn from network analysis (Cross et al., 2004; Newman, 2003). The selected interview questions were reviewed with a network methods expert from BUiD and the wording of some questions was modified. Those interviews covered all process owners and subject matter experts as defined in the list of Functional Element Leads in ENEC management systems. A total of 46 process owners and 62 subject matter experts were interviewed as part of developing the adjacency matrices, quality check, and the validation interviews. These questions were selected using the recognition technique to support respondents in identifying all interactions by providing the initial view developed based on the secondary data review and organized as per the structure derived from the literature and explained in detail in chapter 2. The recognition technique produces a more accurate evaluation of network structure compared to the free recall techniques (Hlebec & Ferligoj, 2002). After finalizing all dependency matrices as per the above description and based on the secondary data review, a one-to-one meeting was conducted with business process owners and Subject Matter Experts to validate the data and ensure accuracy. The adoption of in-depth interviews on top of the secondary data as another independent data source will also support the triangulation and corroboration of research findings within this study. The data collection and analysis process is depicted in figure (4.5).

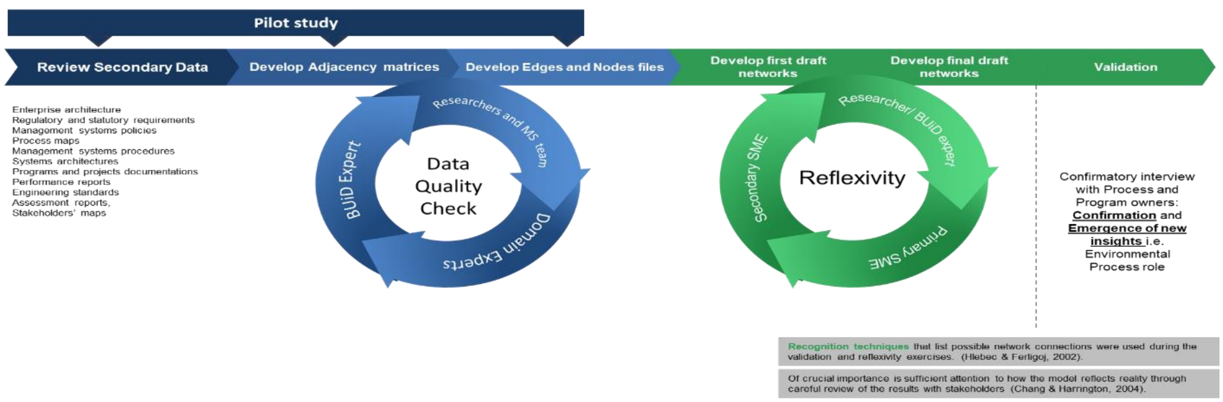


Figure 4. 5 *Data collection and analysis process*

According to Schrieber & Carley (2003), the validity of network analysis can be examined by correlating network graphs and statistics with observed data. Data triangulation techniques, which refers to the uses of both; secondary as two sources for data collection using multiple methods such as, interviews, observation, or collection of records. It is very essential to pay attention to how the network models reflect reality by adopting multiphase iterative review processes that involve relevant stakeholders (Chang & Harrington, 2006). This study has adopted an iterative, collaborative interpretation as shown in figure (4.5) to improve the robustness of this study's findings. This process ensured that results are interpreted in the right context given the structure and operations of the UAE nuclear power plant operational readiness. The use of secondary data coupled with detailed stakeholders review of the network models enhance the reliability of findings derived from network analysis (Scott, 2000). Furthermore, the use of secondary data as the starting point in developing network graphs helps the research produces reliable and accurate models that survey methods usually fails to procedure due to the well-known issue of expansiveness bias, a type of bias defined as a tendency of survey responders to indicate extra relational connections (Marsden, 2005). Also, this design that has been adopted for this study aligns with the use of the recognition technique as a mechanism to produces a more accurate evaluation of network structure rather than the free recall techniques (Hlebec & Ferligoj, 2002).

Internal validity in network analysis has been defined as error-free code (Borgatti and Fosteret 2003). Significant efforts were made to ensure accurate data collection, entry, and conversion in this study. Two methods have been used as part of this study to research to ensure adherence to the highest standards of quality, data validity, and data reliability. Reflexivity and Quality checks (Saunders, Lewis, and Thornhill 2011). Reflexivity means that the insider researcher assesses his or her association with the research setting and the impact such association might have on research outcomes. An iterative review process was adopted as part of this research to ensure addressing the issue of self-biases. This process included iterative reviews of the network's development and analysis by different subject matter experts (Primary and secondary) from the nuclear field in addition to network analysis experts from the British University in Dubai to ensure eliminating any chance for insider biases towards certain assumptions. Quality checks were also implemented using two techniques. First, the researchers created the first draft of dependency matrices and individual networks. Those dependency matrices and individual networks were separately analyzed to spot any discrepancies so that all corrections were made before running the network analysis. Secondly, another member with extensive nuclear experience reviewed the networks while being developed before considering the draft of dependency matrices and individual networks as final.

A pilot study was carried out as part of his study to test the accuracy and reliability of data collection and analysis. In particular, to address and stress test aspects like the accuracy of adjacency matrices, data tabulation into the nodes and edges lists, recognition technique to face validate the first draft of graphs developed, and finally to cross-validate final networks with reality on the ground. Creswell (2014) emphasized the essential role pilot studies play in enabling researchers to detect and avoid any defects or shortcomings associated with the data collection method and tool. Pilot studies enhance the researcher's ability to enhance data validity and reliability. Debriefing and note-taking were used to document feedback from subject matter experts and process owners on each step of the data collection and analysis of the first two networks. Namely; interactions between Level-0 Processes and Regulatory Requirements and interactions between Level-0 Processes and Strategic Programs. Notes were used to build a better understanding of secondary data transformation into the accuracy of adjacency matrices, the data tabulation into the nodes and edges lists, the validation through recognition technique, and final network validation with process owners. As a result, a secondary subject matter expert was added to the data collection and validation processes. Furthermore, an introduction about network statics measure was added as an awareness material to participants, and interview questions were simplified to eliminate any confusion and to prevent any misinterpretation. Saunders, Lewis, and Thornhill (2011) highlighted that the pilot study should support designing a data collection tool that is easy for participants to understand and complete.

4.8. Data analysis

Each Data Analysis procedures have their own strengths and weaknesses. Data analysis methods differ and depend widely on the research problem and aim. The ability to fully and accurately answer the research questions depends on the researcher's ability to choose and conduct the appropriate data analysis method (Weber 1990). Therefore, the analysis method should be consistent with the previous research stages. most importantly, to provide the necessary reliable output that fully addresses the research questions. This research, as has been mentioned, adopted the Network Analysis method in conjunction with the confirmatory interviews to answer the research questions. Network Analysis was identified as the best-fit analysis method to model the complexity of interaction between Processes, Programs, Stakeholders (People), and Systems of the Nuclear power plant operational Readiness Program. In order to explore the complexity of interactions between the different components of the nuclear power plant operational readiness, this research used the network statistic results from the Gephi software. Key reasons for selecting Gephi software were the following:

1. The powerful data processing and visualization functions. Instant visual feedback is a central feature of Gephi's identity. The best position to do is making things visible when you apply an algorithm to the network. Gephi provides more various layout algorithms to present the network. Besides, they have a better edit-ability than Citespace on a generated network (Wajahat et al., 2020, Yang et al., 2017).

2. Interactive exploration of different types of networks with a set of features that are not too specific, and that scale to a large number of nodes and edges. Large magnitude networks (Shen et al., 2019)
3. It can be understood by non-experts.
4. Gephi does not require coding experience
5. Gephi was cited and used heavily by scholars in different fields to address similar research problems like the one for this study. (as per google scholar +22,000, around 3000 this year only)

Based on the systematic review of the literature, the following mappings were chosen to answer the research questions:

1) Level 0 Process to Requirement
2) Level 0 Process to Program
3) Level 1 Process to another level 1 process
4) Level 0 Process to Stakeholders
5) Level 1 Process to Stakeholders
6) Level 0 Process to Plant Systems
7) L0 process to Implementing procedure
8) Level 0 Process to L0 Process
9) Programs to Requirement
10) Programs to Role
11) Program to Program
12) Program to Plant System

13) And Finally, one network graph analysis on the operational readiness program level

Accordingly, the Network Analysis was conducted at the 12 sub-networks individually before apply the same on the whole Nuclear power plant operational Readiness Program. General characteristics were provided for each sub-network in terms of the general characteristics of centrality measures. The two different levels of analysis identified explored Processes, Programs, Stakeholders, and Systems that are most central and important. These elements were further investigated through network statistics. Starting with network density, network diameter, and average length path. Additionally, the centrality measures were applied to identify those elements which have more influence on the Nuclear power plant's operational Readiness. This measure was divided into two sub-measure; Closeness centrality and betweenness centrality. The Closeness centrality identified those elements which can reach other factors in the most efficient way among other elements of the Nuclear power plant operational Readiness. The Betweenness centrality measured the number of times each element/actor occurs on the shortest geodesic' paths connecting other elements /actors. In other words, this measure identified the most controlling or the shortest paths across other elements of the Nuclear power plant operational Readiness program. Additionally, modularity class analysis was applied to detect subset and clustering within the 13 networks. Moreover, to investigate in-depth, the complexity of interaction in the 13 networks developed, the general characteristics have been provided for another 13 ego networks, each one of them focused on the most influential node identified through betweenness centrality. The below table describes the network general parameter and its meaning in the context of the nuclear power plant operational readiness program.

A systematic process has been developed and strictly followed to provide a structured mechanism and ensure consistency while transforming raw data captured from reviewing o management systems documentation and interviews to the final published network graphs, especially because we had multiple network graphs to be created to be able to answer research questions. After validating all adjacency matrices with subject matter experts across different domains in the Nuclear Power Plant Operational Readiness Program, the following steps have been followed for developing each of the 13 Network graphs:

1. <u>Formatting the data for Gephi:</u> The validated data has been transformed into nodes and edges. To follow Gephi naming conventions, the following fields have been created as required by the nodes and edges sheets:
    - For Nodes: Nodes ID and label
    - For Edges: Edge Source and target.

2. <u>Importing data into Gephi:</u> Two CSV files, one file for nodes and another for edges have been created for each network. Both spreadsheets were imported to create edges and nodes tables as undirected networks.
3. <u>Assess the initial graph layout:</u> The initial graph was used as a starting point to assess some basic features inherent in the Data uploaded into Gephi to address the following points:
    a. Are all nodes fully connected, or are there several disconnected nodes?
    b. Does the graph look dense or disperse?
    c. Is there any observable pattern or clusters? Any specific network structures?

Some instances of Data duplication have been observed and corrected at this stage.

4. <u>Selecting the network layout:</u> The focus of this step was on selecting the most suitable layout that helps to demystify relationships between defined nodes and support the researcher to provide effective analysis. Even though all layouts can perform similar basic

functions of graph visualization, Network complexity and structure are the two main factors that would determine researchers' choice of the proper layout. Taking into account those two factors and after running multiple scenarios, Force Atlas was found to be the most suitable graph layout to explore and discover the interactions between Nuclear Power Plant Operational Readiness actors (Nodes). algorithms based on spring mechanisms such as repulsion and attraction are probably far more useful in drawing the network.

5. <u>Exporting the graph with all associated graph statistics conducted</u>
6. <u>Analyzing the graph:</u> There are many statistical analysis measures and techniques that can be used for Network analysis. to understand the patterns and behaviors within each individual network related to this research, we shall try to answer the following key questions:

1. What does the overall structure of the network look like? Is it densely connected, or is the network rather sparse?
2. Does our network have a high level of randomness, exemplified by a few distinct patterns? Or are there very pronounced groups within the network that exhibit advanced levels of clustering?
3. Do we see evidence of high degree hubs in the network, with many smaller nodes surrounding the hubs?
4. Are certain nodes critical within the structure of the network, perhaps acting as bridges between otherwise disconnected groups?

The graph statistics mentioned in the table (4.1) with their contextual interpretation of the Nuclear Power industry will be used to answer each of these. During the analysis phase, the research team will investigate which statistics to use and when to ensure measuring various behaviors and structures of a network accurately and reliably.

When it comes to Centrality measures, the research will address the following four critical views:

a) As a starting point, the research will analyze how central a specific node is relative to the entire network. If any node is highly connected and centrally positioned within any of the 13 networks, or are they all on the peripheries with just a few connections?

b) secondly, the research will analyze if any node within the 13 networks is surrounded by highly connected neighbors, without necessarily being directly linked to a large number of nodes within the network.

c) Thirdly, investigate if any node within the 13 networks is most likely to be connected to other key influential modes within the network, thus affirming its influence and importance.

d) and finally, analyze if any node within the 13 networks forms a bridge between otherwise unconnected portions of the network. This can be measured by how often a node appears on the shortest path between other nodes.

Table 4. 1: Key network statistical measures and their contextual relevance to this research

Measure	Definition	Contextual Relevance to the research
Network Diameter	The maximum number of connections required to traverse the graph *OR* How many steps it takes for the two most distant nodes in the network to reach one another	Understanding the network diameter will help in comprehending the structure of a network and whether any nodes within the network is essential (of strategic importance) when we assess using another measure like Eccentricity.

Eccentricity	The number of steps required for an individual node to cross the network.	Provide a perspective on the relative importance and influence of a node compared with other nodes usually when combined with other statistical measures
Network Density	The degree nodes are interconnected within the network. Usually calculated as the proportion of connected edges relative to the total possible number of connections and returned as a decimal value between zero and one. 1 is dense 0 is sparse	Density measure would help in understanding how the individual 13 networks (mentioned above) are structured and might help identify gaps or holes within those networks or/and the bigger network of the nuclear power plant operational readiness program as a whole.
Average path length	the maximum path length between nodes.	A measure of how efficient is the communication and information flow for an entire network. lower numbers might indicate that the network is relatively more efficient and the info. The flow between different players in the Nuclear Power plant Operational Readiness is timely and smooth, while high average numbers might signify a relatively inefficient cross-functional communication between process and programs owners and/or inefficient information flow between systems and programs.
Edge betweenness	How often specific edges reside within the shortest paths between network nodes	**Edge betweenness** will help in identifying the most frequently used paths within each of the 13 networks. Therefore, illustrate the most efficient paths for traversing each network and ultimately allowing for making comparisons between the 13 networks.
Centrality Measures	*the relative influence of individual nodes within the network*	Centrality would help in identifying which components of the nuclear power plant operational readiness (5Ps) have more influence over other components in terms of achieving the strategic targets of the program (Safety, reliability, cost, schedule, etc.) Centrality is an essential measure of the information flows within the network. However, it should be assessed using a combination of the mentioned measures to form a comprehensive and accurate understanding of info. Flow within

		the nuclear power plant operational readiness program.
Degree Centrality **a) In-degree centrality** **b) Out-degree centrality**	The total number of direct connections (degrees) one node has (In or out)	The higher the degree of centrality the higher the importance or influence of the node within the network. This statistical measure will be considered carefully in this research after validating the underlying assumption that "the number of connections is a key measure of importance or influence within the network".
Closeness centrality	The average farness (inverse distance) to all other nodes. Nodes with a high closeness score have the shortest distances to all other nodes	Closeness centrality might help in detecting nodes that can send communications and share information in a very efficient and fast manner through the network. Therefore, support timely decision making related to any of the processes, programs, or systems included in the Nuclear Power plant Operational Readiness.
Eigenvector centrality	The degree nodes are highly connected to other influential/important nodes	A Higher Eigenvector centrality score for a node will provide a perspective into the influence that node has on the network. This influence can be interpreted in many forms like the relative importance of the node to the communication effectiveness and info. Sharing. It might also provide a perspective of the degree of interdependencies of influential nodes on the node with a high Eigenvector centrality score which might shift the focus on management towards a different type of action to address business challenges.
Betweenness centrality	The degree nodes offer the most direct path/Bridges between otherwise disconnected Clusters.	A higher betweenness centrality score for a node will provide a perspective on how critical that node to maintain the structure of the network. into the influence, that node has on the network. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. This also might shift the focus on management towards a different type of action to address business challenges.
Modularity	Assessment of the number of distinct groupings within a network.	This network statistic will help in grouping nodes based on the strength of their relationships into distinct clusters. Understanding clusters within the 13 networks of the Nuclear Power Plant Operational Readiness Program will help to characterize the behavior of each network by

	using modularity value as a predictor of cluster and network future response to certain parameters like the speed of information transfer. It will also provide an additional perspective on the influence of certain nodes when combined with other measures like centrality measures.

After exploring and illustrating interactions in the form of 13 networks, this research validated the preliminary analysis of all networks against experts' opinions via a one-to-one interview with process owners. Network graphs need more than face validation, which can be determined by asking the question "is it a reasonable representation of reality?" (Chang & Harrington, 2006). Therefore, after exploring detailed interactions and producing detailed network graphs, the interviews protocol focused on answering three questions:

1) Looking at this network, can you identify any missing connections? Or any overstated ties?
2) Does this network graph provide an accurate representation of reality on the ground?
3) What practical insights you can generate from this network illustration and statistics?

4.9. Confidentiality and accessibility

This study applied the essential principles of ethical conduct; informed consent and the protection of confidentiality. All activities associated with this study started with an introductory paragraph and an explanation of its purpose to assure confidentiality. Despite the fact that network data are sensitive in terms of describing detailed interactions and relationships between actors. Network data are not traditional data where attribute and subject can be separated and still retain meaning

(Eppinger and Browning 2012, Browning 2001). Therefore, for data analysis and network presentations during the data quality check and the validation interviews, all actors (Nodes) involved in this study were coded (given an ID and Label) with letters and numbers. During phases of data quality check, reflexivity, and validation interviews, process owners and subject matter experts were able to identify some additional items that were classified as confidential. Therefore, those items were removed from the analysis. At that time, process owners and subject matter experts agreed that labeling and coding used in this study are sufficient to ensure the protection of confidentiality.

This study also was governed under the terms and conditions of the standard non-disclosure undertaking of the Emirates Nuclear Energy Corporation (ENEC). The researcher undertakes to use solely for the purpose of conducting this study and not for any other purposes. This study has maintained the confidentiality of all confidential information and kept them secure, safe, and protected from any unauthorized access. The researcher didn't disclose any confidential information to any person or entity, including the network analysis expert supported this study from the British university in Dubai. faculty members assigned for this study. The following confidential information has been excluded from the researcher undertaking agreement:

a) Any confidential information which is generally made available publicly by the Emirates Nuclear Energy Corporation (ENEC) without restriction on disclosure.

b) Any information which is independently developed by the researcher who had no direct or indirect access to, or knowledge of, such confidential information.

As part of this study, the researcher hasn't expunged confidential information from any computer, word processor, or other similar devices storing confidential information in electronic format, provided that the confidentiality of such electronically stored information. No confidential information was included in the final thesis in its original format (without coding). This study has not discussed or included any export-controlled information.

4.10. Data validity and reliability

There are two different views in the academic literature pertaining to the researcher being an insider to the setting, context, or organization where the research is being conducted. Some academics have seen this association between the research and the research setting as a drawback that might jeopardize the validity and reliability of the research output since the insider researcher has a personal stake and substantive emotional association in the setting that might hinder his ability to attain the required distance and objectivity needed to obtain impartial and valid insights and analysis. Brannick and Coghlan (2007) have challenged that view and explained the benefit of being an insider researcher and how insider research is not only valid and reliable but also provides important knowledge about what organizations are really like, which traditional approaches may not be able to uncover due to the restrictions of data accessibility and the real understanding of the research setting and context. Internal validity in network analysis has been defined as error-free code (Borgatti and Fosteret 2003). Significant efforts were made to ensure accurate data collection, entry, and conversion in this study. Two methods have been used as part of this study to research to ensure adherence to the highest standards of quality, data validity, and data reliability. Reflexivity and Quality checks. Reflexivity means that the insider researcher assesses his or her association with the research setting and the impact such association might have on research outcomes. Therefore, reflexivity should be an integral part of the research process to ensure that the association and involvement of the researcher with the research setting will not bias the research assumptions and hence analysis of findings and research outcomes. An iterative review process has been adopted as part of this research to ensure addressing the issue of self-biases. This process included iterative reviews of the network's development and analysis by different subject matter experts from the nuclear field in addition to network analysis experts from the British University in Dubai to ensure eliminating any chance for insider biases towards certain assumptions. In addition, quality checks were also implemented using two techniques. First, the researchers created the first draft of dependency matrices and individual networks. Those dependency matrices and individual networks were separately analyzed to spot any discrepancies so that all corrections were made before running the network analysis. Secondly, another member with extensive nuclear experience reviewed the networks while being developed before considering the draft of dependency matrices and individual networks as final.

4.11. Chapter summary

In this chapter, the researcher has provided an overview of the methodology and research techniques adopted and highlighted the main reasons behind using this methodology, and has provided justification for the use of Design Structure Matrix (DSM) and Network Analysis. In addition, this chapter explained how the data has been analyzed using Gephi software, as well as, discussed the contribution of the validation interviews to the research reliability.

Chapter 5: Results

5.1. Introduction

This chapter discusses in detail the findings of the network analysis. It provides an overview of the 13 network diagrams in regards to network general characteristics, network density, network clustering coefficient and modularity analysis, network centrality measures, and ego networks. Also, this chapter provides a preliminary interpretation of the main observations that emerged from the network analysis. Key reasons for selecting Gephi software were the following:

1. The powerful data processing and visualization functions. Instant visual feedback is a central feature of Gephi's identity. The best position to do is making things visible when you apply an algorithm to the network. Gephi provides more various layout algorithms to present the network. Besides, they have a better edit-ability than Citespace on a generated network (Wajahat et al., 2020, Yang et al., 2017).
2. Interactive exploration of different types of networks with a set of features that are not too specific, and that scale to a large number of nodes and edges. Large magnitude networks (Shen et al., 2019)
3. It can be understood by non-experts.
4. Gephi does not require coding experience
5. Gephi was cited and used heavily by scholars in different fields to address similar research problems as the one for this study. (as per google scholar +22,000, around 3000 this year only)

5.2. Interactions between level 0 processes and regulatory requirements within the nuclear power plant operational readiness program

Main Processes (referred to in this study as L0 processes) support the safe and reliable operations of any Nuclear Power Plant. They consist of a structured set of activities, which produce a measurable output. Processes are designed to facilitate the execution of repetitive work to ensure requirements are met effectively and efficiently, through a sequence of sub-processes and activities showing an operation of a function or service. Processes aim to meet Nuclear Power Plant Operational Readiness strategic and regulatory objectives under the categories of:

1. *Management Processes:* those are L0 Processes that are used to provide oversight, review performance, and provide opportunities to improve Core and Support Processes. Examples of these Processes are Management Oversight, Independent Oversight, and Performance Improvement.
2. *Core Processes*: those are L0 Processes that are used to deliver key products and services, by taking input and transforming it into a value-adding output. Examples of these Processes are Operate Plant, Work Management, Configuration Management, Equipment Reliability, and Materials, and Services.
3. *Support Processes*: those are L0 Processes that are used to provide support for our Core Processes. Examples of these Processes are Loss Prevention, Nuclear Fuel, Talent Management, and Support Services.

5.2.1 Network diagrams

This network aimed to identify and depict all interactions between all L0 processes (Main Processes) forming the structure of Integrated Management System for the Nuclear Power Plant

Operational Readiness Program and the regulatory requirements set by the Nuclear Regulator that need to be fulfilled at minimum to issue the Operating License. The list of L0 processes covered all Management System processes and each L0 process was given a code and a node label as per the table (5.1).

Table 5. 1 List of level 0 processes

Process	Node Label	Node ID
Manage Configuration	ENG1-L0	1
Manage Equipment Reliability and Performance	ENG2-L0	2
Manage External Assessments	NOS-L0	3
Manage Quality Assurance	QA-L0	4
Manage Internal Audit	IAD-L0	5
Manage Governance Controls	LGL2-L0	6
Provide Security Measures	SNS-L0	7
Provide Industrial Safety Services	HNS-L0	8
Maintain License and Permits	LRA-L0	9
Perform Emergency Planning	EP1-L0	10
Provide Fire Protection	FP2-L0	11
Manage Nuclear Risk	NRM-L0	12
Provide Environmental Services	ENV-L0	13
Execute the Integrated Management System	NIMS-L0	14
Manage Statutory and Regulatory Requirements	LGL3-L0	15
Manage Enterprise Risk	PMD1-L0	16
Materials and Services	PSC-L0	17
Fuel Management Services- a subsidiary	RE-L0	18
Provide and Transport Fuel	FCM-L0	19
Provide Handling, Storage, and Disposal of Fuel	RE-L0	20
Operate and Monitor Structures, Systems, and Components	OP-L0	21
Monitor and Control Effluents	RW-L0	22
Monitor and Control Plant Chemistry	CHE-L0	23
Manage Corrective Actions	NPI1-L0	24
Manage Self-Assessment and Benchmarking	NPI2-L0	25
Manage Knowledge and Utilize Operating Experience	NPI3-L0	26
Manage Human Performance	NPI4-L0	27
Manage Culture of Safety	NPI5-L0	28
Manage Enterprise Performance	PMD2-L0	29
Manage Project Controls and Project Delivery	PMD3-L0	30

Manage Finance	FIN-L0	31
Provide Legal Services	LGL1-L0	32
Perform Commissioning Oversight	COS-L0	33
Perform Decommissioning	DEC-L0	34
Manage Documentation and Records	DCM-L0	35
Maintain Facilities	FAC-L0	36
Support Community and Government Relations	COM1-L0	37
Manage Communications	COM2-L0	38
Provide Information Technology Services	ICT-L0	39
Talent Management	HR-L0	40
Planning and Scheduling	WM-L0	41
Perform Maintenance	MNT-L0	42
Monitor and Control Radiation Exposure	RP2-L0	43
Monitor and Control Contamination	RP1-L0	44
Manage Site Projects	PRJ-L0	45
Manage Outage	OUT-L0	46

Similarly, all Regulatory Requirements have been labeled and given IDs as per the table (5.2).

Table 5. 2 List of regulatory requirements

Regulatory Requirement	Node Label	Node ID
FANR-REG-01 Article (10), Process Implementation	Req.1	109
FANR-REG-16 Article (12), Control of Nuclear Facility Configuration	Req.2	110
FANR-REG-16 Article (13), Management of Modifications	Req.3	111
QA-MAN-0001, Quality Assurance Manual	Req.4	112
INPO AP-929, Configuration Management Process Description	Req.5	113
1&2 FSAR Chapter 13 (Conduct of Operations), subsection 13.5 (Plant Procedures)	Req.6	114
FANR-REG-01, Regulation for Management Systems for Nuclear Facilities	Req.7	115
FANR-REG-16, Article (30), Maintenance, Testing, Surveillance, and Inspection Programs	Req.8	116
1&2 FSAR Chapter 17(Management of Safety and Quality Assurance Program), subsection 17.7.2.3 (System and Equipment Health)	Req.9	117
INPO AP-913, Equipment Reliability Process Description	Req.10	118
Managerial, Administrative, and Quality Assurance Controls for the Operational Phase of Nuclear Power Plants	Req.11	119
Regulation for Management System for Nuclear Facilities	Req.12	120
Operational Safety including Commissioning, Article 11	Req.13	121
Quality Assurance Manual	Req.14	122

Quality Assurance Policy	Req.15	123
Managerial, Administrative, and Quality Assurance Controls for the Operational Phase of Nuclear Power Plants	Req.16	124
ASME NQA-1: 1994 (with 1995 Addenda) Quality Assurance Requirements for Nuclear Facility Applications	Req.17	125
Final Safety Analysis Report (FSAR), Chapter 17, Management of Safety and Quality Assurance Program	Req.18	126
United Arab Emirates (UAE) Federal Law by Decree No 6 Concerning Peaceful Uses of Nuclear Energy	Req.19	127
FANR-REG-16, Operational Safety Including Commissioning	Req.20	128
FANR REG-01, Regulation for Management Systems for Nuclear Facilities	Req.21	129
Internal Audit Guidance and Standards issued by the Abu Dhabi Accountability Authority (ADAA)	Req.22	130
International Professional Practices Framework and Standards by The Institute of Internal Auditors	Req.23	131
FANR-REG-08, Physical Protection for Nuclear Materials and Nuclear Facilities	Req.24	132
Abu Dhabi Environment, Health and Safety Management System (AD EHSMS) Regulatory Framework	Req.25	133
Final Safety Analysis Report (FSAR), Chapter 13	Req.26	134
FANR-REG-11, Regulation for Radiation Protection and Predisposal Radioactive Waste Management in Nuclear Facilities	Req.27	135
Health & Safety Program Description	Req.28	136
Nuclear Safety Policy	Req.29	137
OHSAS 18001, Occupational Health and Safety Management system	Req.30	138
WANO Guidance (INPO) 16-011, Industrial Safety for Nuclear Power Stations.	Req.31	139
FANR-REG-09, Regulation on the Export and Import Control of Nuclear Material, Nuclear Related Items and Nuclear Related Dual-Use Items	Req.32	140
FANR-REG-10, System of Accounting for and Control of Nuclear Material and Application of Additional Protocol - for reporting requirements	Req.33	141
FANR-REG-16, Operational Safety including Commissioning,	Req.34	142
Federal Law by Decree No. 13 of 2007, Concerning the Commodities Subject to Control of Import and Export	Req.35	143
Federal Law by Decree No. 6 of 2009, Concerning the Peaceful Uses of Nuclear Energy	Req.36	144
Federal Law by Decree No. 63 of 2010, Additional Protocol Ratification	Req.37	145
123 Agreement - Agreement for Cooperation between the Government of the United States of America & the Government of the United Arab Emirates Concerning Peaceful uses of Nuclear Energy	Req.38	146
FANR-RG-001, Content of Nuclear Facility Construction and Operating License Application	Req.39	147
IAEA INFCIRC/622/Add.1, Protocol Additional to the Agreement between the United Arab Emirates and the International Atomic Energy Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, dated 19 January 2011	Req.40	148
Licensing policy and FANR Interface Policy	Req.41	149
NPP Public Protective Actions [2013], Actions to protect the public in an emergency due to Severe Conditions at a Light Water Reactor, IAEA, Vienna, 2013	Req.42	150

External Affairs and Communication Group Emergency Communication Plan	Req.43	151
FANR REG-12, Emergency Preparedness	Req.44	152
FANR REG-15, Requirements for Off-Site Emergency Plans for Nuclear Facilities	Req.45	153
FANR REG-16, Operational Safety Including Commissioning	Req.46	154
FANR-REG-03, Regulation for the Design of the Nuclear Power Plants. Federal Authority for Nuclear Regulation (FANR)	Req.47	155
FANR-REG-04, Regulation for Radiation Dose Limits and Optimization of Radiation Protection for Nuclear Facilities	Req.48	156
FANR-REG-08, Regulation for the Physical Protection for Nuclear Material and Nuclear Facilities	Req.49	157
Federal Law by Decree No. 2 of 2011 Establishing the National Emergency Crisis and Disaster Management Authority	Req.50	158
Federal Law Decree 6 of 2009 Concerning the Peaceful Uses of Nuclear Energy	Req.51	159
IAEA No. Part 7, Preparedness and Response for a Nuclear or Radiological Emergency	Req.52	160
NEI 99-01, Development of Emergency Action Levels for Non-Passive Reactors, Revision 6, 2012	Req.53	161
Criteria for the Development of Evacuation Time Estimate Studies, NRC, Revision 0, 2011	Req.54	162
Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants. NRC, Revision 1, 1980	Req.55	163
Functional Criteria for Emergency Response Facilities, 1981	Req.56	164
5 U.S. NRC Regulatory Guide 1.189, Fire Protection for Nuclear Power Plants	Req.57	165
Final Safety Analysis Report (FSAR), Chapter 9.5.1, Fire Protection System	Req.58	166
FANR-REG-01, Regulation for Management Systems for Nuclear Facilities, Article 10, Process Implementation	Req.59	167
FANR-REG-03, Regulation for the Design of Nuclear Power Plants	Req.60	168
FANR-REG-16, Regulation for Operational Safety Including Commissioning	Req.61	169
National Fire Protection Association (NFPA) Codes and Standards	Req.62	170
U.S. NRC BTP CMEB 9.5-1	Req.63	171
FANR-REG-05, Regulation for the Application of Probabilistic Risk Assessment (PRA) at Nuclear Facilities	Req.64	172
FANR-REG-16, Operational Safety including Commissioning, Article (19)	Req.65	173
FANR-RG-003, Probabilistic Risk Assessment: Scope, Quality, and Applications	Req.66	174
FANR-RG-004, Evaluation Criteria for Probabilistic Safety Target and Design Requirements	Req.67	175
Final Safety Analysis Report (FSAR)	Req.68	176
Decree No. (42) of 2009, Concerning the Environment, Health and Safety Management System in Abu Dhabi Emirate	Req.69	177
Executive Order issued by Council of Ministers Decree No. (12) of 2006, for Protection of Air from Pollution	Req.70	178
Executive Order issued by Council of Ministers Decree No. (37) of 2001, Executive Guidelines for Federal Law No. (24) of 1999	Req.71	179
FANR-REG-04, Regulation for Radiation Dose Limits and Optimization of Radiation Protection for Nuclear Facilities	Req.72	180
Federal Law No. (11) of 2002, Concerning Regulating and Controlling the International Trade in Endangered Species of Wild Fauna and Flora	Req.73	181

Federal Law No. (23) of 1999, concerning Exploitation, Protection and Development of the Living Aquatic Resources in the Waters of the State of the United Arab Emirates	Req.74	182
Federal Law No. (24) of 1999, Protection and Development of the Environment	Req.75	183
Law No. (17) of 2005, Establishment of the Abu Dhabi Sewage Services Company (ADSSC)	Req.76	184
Law No. (18) of 2007, primarily enabling other Wastewater and Sewerage Services entities other than ADSSC to be licensed by the Bureau and allowed these entities to connect to ADSSC's Sewerage Services network Company (ADSSC)	Req.77	185
Law No. (2) of 1998, Regulation of the Water and Electricity Sector in the Emirate of Abu Dhabi	Req.78	186
Law No. (21) 2005, for Waste Management in Abu Dhabi Emirate	Req.79	187
Law No. (6) of 2006, concerning Organization of Drilling of Groundwater Wells	Req.80	188
Recycled Water and Biosolids Regulations 2010, (The Regulation and Supervision Bureau for the water, wastewater, and electricity sector in the Emirate of Abu Dhabi)	Req.81	189
The Fuel Storage Tank Regulations 2009, (The Regulation and Supervision Bureau for the water, wastewater, and electricity sector in the Emirate of Abu Dhabi)	Req.82	190
EAD (2014), Environment Agency-Abu Dhabi Standard Operating Procedure for Permitting of Industrial, Commercial, and Light Industrial Projects in Abu Dhabi	Req.83	191
Environment Agency-Abu Dhabi Technical Guidance Document Standards and Limits for Pollution to Air and Marine Environments Occupational Exposure Pesticides and Chemical Use (2003)	Req.84	192
Environment Agency-Abu Dhabi Technical Guidance Document for Operation Environmental Management Plan (OEMP) (2014)	Req.85	193
Environment Agency-Abu Dhabi Technical Guideline for Environmental Audit Reports (2014)	Req.86	194
Environment Agency-Abu Dhabi Technical Guideline for Fish Entrainment and Impingement Studies (2014)	Req.87	195
Environment Agency-Abu Dhabi Technical Guideline for Monitoring Reports (2014)	Req.88	196
Environment Agency-Abu Dhabi Technical Guideline for Storage of Hazardous Materials (2014)	Req.89	197
Environment Agency-Abu Dhabi Technical Guideline for Submission of Environmental Applications and Reports (2014)	Req.90	198
Environment Agency-Abu Dhabi Technical Guideline for Wastewater and Marine Water Quality Monitoring (2014)	Req.91	199
Environment Agency-Abu Dhabi Technical Guideline for Wastewater Treatment Plant Permit Discharge Management Plan (2014)	Req.92	200
IAEA General Safety Requirements No. GSR Part 2, Leadership and Management for Safety	Req.93	201
International Finance Corporation-World Bank Group Environmental and Social Performance Standards	Req.94	202
International Finance Corporation-World Bank Group Environmental, Health, and Safety Guidelines for Thermal Power Plants (2008)	Req.95	203
International Finance Corporation-World Bank Group General Environmental Health and Safety (EHS) Guidelines (2007)	Req.96	204

International Finance Corporation-World Bank Group Performance Standards on Environmental and Social Sustainability (2012)	Req.97	205
FANR-REG-01, Management Facilities for Nuclear Facilities	Req.98	206
FANR-REG-16, Regulation on Operational Safety including Commissioning	Req.99	207
ASME NQA-1: 1994, Quality Assurance Requirements for Nuclear Facility Applications, with 1995 Addenda, Parts I, II and III.	Req.100	208
FANR-REG-01, Regulation for Management Systems for Nuclear Facilities.	Req.101	209
FANR-REG-1, Regulation for Management Systems for Nuclear Facilities	Req.102	210
FANR-REG-3, Regulation for the Design of Nuclear Power Plants	Req.103	211
FANR-REG-9, Regulation on the Export and Import Control of Nuclear Material, Nuclear Related Items and Nuclear Related Dual-Use Items	Req.104	212
ASME NQA-1-1994 Quality Assurance Requirements for Nuclear Facility Applications and 1995 Addenda	Req.105	213
FANR-REG-01, Regulation for Management Systems for Nuclear Facilities, Articles 10, 11 and 12	Req.106	214
FANR-REG-03, Regulation for the Design of Nuclear Power Plants, Articles 48, 49, 86 and 87	Req.107	215
FANR-REG-09, Regulation on the Export and Import Control of Nuclear Material, Nuclear Related Items and Nuclear Related Dual-Use Items, Article 7	Req.108	216
FANR-REG-10, Regulation for the System of Accounting for and Control of Nuclear Material and Application of Additional Protocol	Req.109	217
FANR-REG-16, Operational Safety including Commissioning, Article 29	Req.110	218
ANSI/ANS-3.2, Administrative Controls and Quality Assurance for the Operational Phase of Nuclear Power Plants	Req.111	219
FANR-REG-01, Management Systems for Nuclear Facilities Article 21	Req.112	220
Barakah NPP Units 1&2 Final Safety Analysis Report (FSAR) Chapter 11	Req.113	221
Barakah Offsite Dose Calculation Manual.	Req.114	222
FANR-REG-04, Regulation for Radiation Dose Limits & Optimization of Radiation Protection for Nuclear Facilities	Req.115	223
FANR-REG-06, Regulation for an Application for a License to Construct a Nuclear Facility	Req.116	224
FANR-REG-13, Regulation for the Safe Transport of Radioactive Materials	Req.117	225
FANR-REG-14, Regulation for an Application for a License to Operate a Nuclear Facility	Req.118	226
FANR-REG-01, Regulation for Management Systems of Nuclear Facilities	Req.119	227
FANR-REG-16, Operational Safety including Commissioning, Article (28)	Req.120	228
ANSI/ASME NQA-1, Quality Assurance Requirements for Nuclear Facility Applications	Req.121	229
FANR-REG-01, Regulation for Management Systems of Nuclear Facilities, Article 22	Req.122	230
IAEA GS-G-3.1, Application of the Management System for Facilities and Activities Safety Guide	Req.123	231
IAEA GS-G-3.5, The Management System for Nuclear Installations	Req.124	232
FANR-REG-01, Regulation for Management Systems of Nuclear Facilities, Article 19	Req.125	233
FANR-REG-01, Regulation for Management Systems of Nuclear Facilities, Article 9 (including letter FANR-ENA-15-0273L.)	Req.126	234
FANR-REG-01 Article 10 – Process Implementation	Req.127	235
FANR-REG-16, Operational Safety including Commissioning, Article 23	Req.128	236

FANR-REG-01, (Version 0), Regulation for Management Systems of Nuclear Facilities, Article 4	Req.129	237
FANR-REG-16, (Version 0), Operational Safety including Commissioning, Article 7, Article10, and Article 11, Item 2	Req.130	238
IAEA GS-G-3.5, The Management System for Nuclear Installations	Req.131	239
Nuclear Safety Policy	Req.132	240
Performance Improvement Program Description	Req.133	241
Integrated Management System	Req.134	242
NPP 1&2 Final Safety Analysis Report Chapter 13 & 17	Req.135	243
FANR-REG-16, (Version 0), Operational Safety including Commissioning	Req.136	244
FANR-REG-01, (Version 0), Regulation for Management Systems of Nuclear Facilities	Req.137	245
FANR-REG-01, Management Systems for Nuclear Facilities, Article 10 and Article 11	Req.138	246
WANO Performance Objectives & Criteria (PO&C)– 2013-02	Req.139	247
Best practice financial management and reporting.	Req.140	248
FANR Reg [LATER] requires funds to be made available to ensure the safe operation and maintenance of	Req.141	249
FANR-REG-01, Regulation for Management Systems of Nuclear Facilities, Article 10	Req.142	250
UAE Company Law requires the preparation of audited financial statements and the maintaining of books, records, and systems to in support of the statements	Req.143	251
A Legal Department must be staffed by an adequate number of competent staff members to provide the level and quality of legal support needed by the organization	Req.144	252
FANR-REG-06, Application for a License to Construct a Nuclear Facility	Req.145	253
FANR-REG-11, Radiation Protection and Predisposal Radioactive Waste Management in Nuclear Facilities	Req.146	254
FANR-REG-14, Regulation for an Application for a License to Operate a Nuclear Facility	Req.147	255
FANR-REG-21, Decommissioning of Nuclear Facilities	Req.148	256
Federal Law by Decree no. 6 (2009) - Concerning the Peaceful Uses of Nuclear Energy	Req.149	257
FANR-REG-01, Regulation for Management Systems of Nuclear Facilities, Article 10 – Process Implementation	Req.150	258
FANR-REG-01, Regulation for Management Systems of Nuclear Facilities, Article 12 - Control of Documents	Req.151	259
FANR-REG-01, Regulation for Management Systems of Nuclear Facilities, Article 14 - Control of Records	Req.152	260
FSAR Chapter 17	Req.153	261
FANR-REG-13, Safe Transport of Radioactive Materials	Req.154	262
COBIT 5	Req.155	263
ISO/IEC 27001:2013 Standard	Req.156	264
ITIL (V3)	Req.157	265
FANR-REG 17, Certification of Operating Personnel at Nuclear Facilities	Req.158	266
IAEA Nuclear Power Plant Personnel Training and its Evaluation-Technical Report 380	Req.159	267
IAEA Recruitment, Qualification and Training of Personnel for Nuclear Power Plants, Safety Standards Series No N-SG-2.8	Req.160	268

UAE Civil Law	Req.161	269
UAE Federal Law by Decree No 6 of 2009	Req.162	270
UAE Labor Law	Req.163	271
FANR-REG-16, Article (30), Maintenance, Testing, Surveillance and Inspection Program	Req.164	272
FANR-RG-002, Application of Management Systems for Nuclear Facilities	Req.165	273
FSAR Unit 1&2	Req.166	274
Maintenance Program Description	Req.167	275
NPP Units 1&2 Final Safety Analysis Report (FSAR) Chapter 12	Req.168	276
Regulations for the Safe Transport of Radioactive Material	Req.169	277
Regulation for a License to Operate a Nuclear Facility	Req.170	278
Transportation Safety Guide	Req.171	279
Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material	Req.172	280
USNRC Regulatory Guide 1.97, Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident	Req.173	281
USNRC Regulatory Guide 8.8, Information Relevant to ensure that Occupational Radiation Exposures at Nuclear Power Stations will be as Low as is Reasonably Achievable	Req.174	282
USNRC Regulatory Guide 8.15, Acceptable Programs for Respiratory Protection	Req.175	283
USNRC Regulatory Guide 8.27, Radiation Protection Training for Personnel at Light-Water-Cooled Nuclear Power Plants	Req.176	284
USNRC Regulatory Guide 8.38, Control of Access to High and Very High Radiation Areas in Nuclear Power Plants	Req.177	285
FANR-REG-01, Article 3, 7 and 10, Regulation for Management Systems for Nuclear Facilities	Req.178	286
FANR-REG-16, Article 31, Clause 1 (d) – 2 and Article (31), Clause 4 (refer CB observation – 5 in the document), Regulation on Operational Safety including Commissioning	Req.179	287

Subsequently, data for this network was imported into Gephi using the above-mentioned structure, Force atlas algorithm was applied, graph statistics were applied the initial graph layout was assessed and elimination of unconnected nodes that were irrelevant to this network was done. Finally, the final network graph was produced (Figure 5.1). The Force Atlas layout algorithm was used for two main reasons:

1. It is made to spatialize small worlds and Scale-Free Networks specifically. That algorithm design fits with the characteristics of the nuclear power plant operational

readiness being a complex adaptive system. Therefore, The Force Atlas layout algorithm was seen as the best fit.

2. The Force Atlas layout algorithm is focused on Quality and is known for being the best fit to explore real data with the fewest biases possible and statistical constraints. It fits with research design as an empirical study that is relied on secondary data.

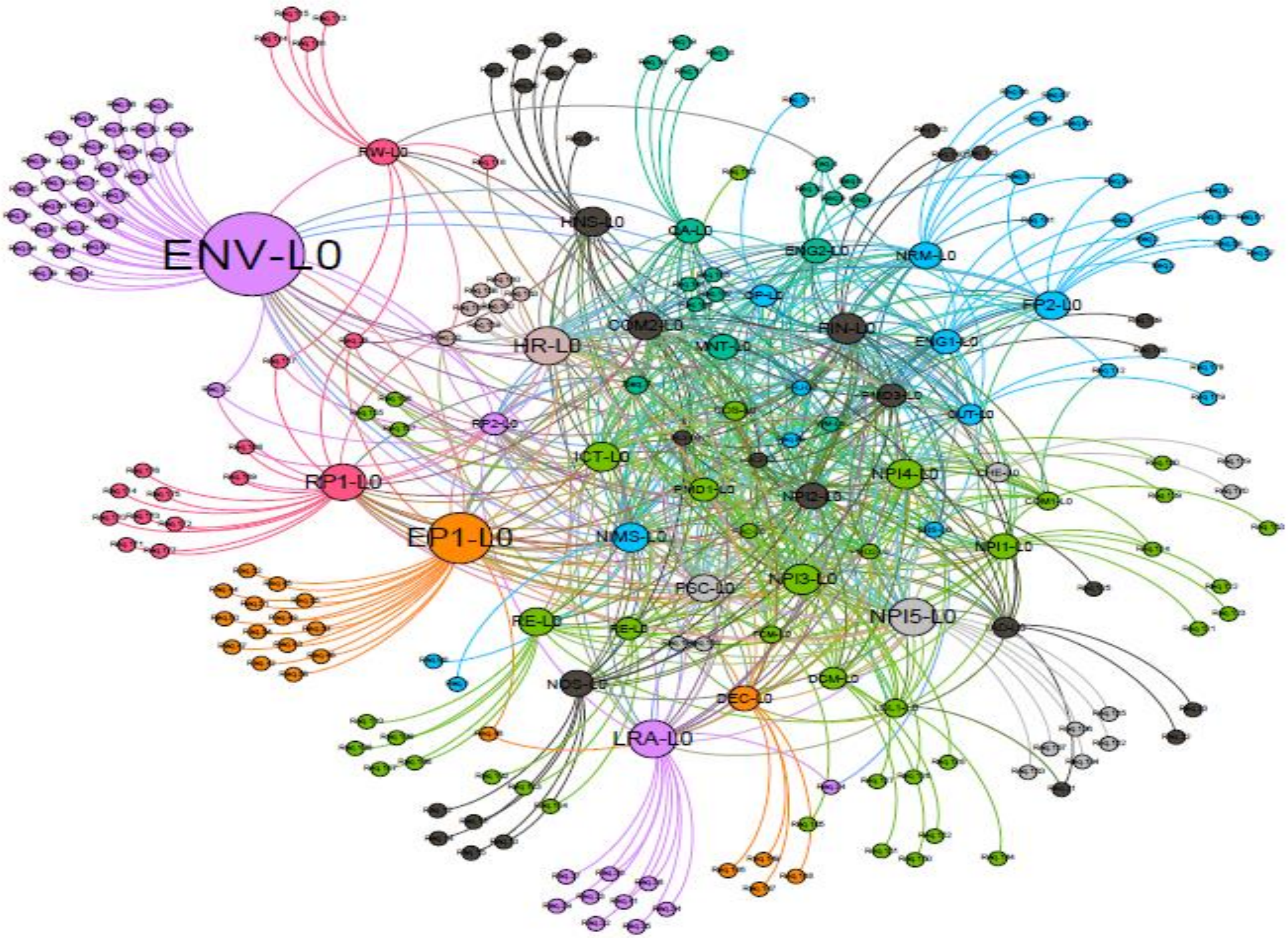


Figure 5. 1 *Level 0 processes and regulatory requirements network*

From the first look on figure 5.1, it is noticeable that the interactions between Level 0 Processes and Regulatory Requirements within the Nuclear Power Plant Operational Readiness Program looks cluttered and a bit concentrated near the center. This nature of this interaction forms multiple distinct and large hubs around main processes like Provide Environmental Services (ENV-L0), Monitor and Control Contamination (RP1-L0), Perform Emergency Planning (EP1-L0), Provide Handling, Storage and Disposal of Fuel (RE-L0), Manage External Assessments (NOS-L0) and Maintain License and Permits (LRA-L0). The depicted layout interactions between Level 0 Processes and Regulatory Requirements support to a great extent the fact that Nuclear Power plants Operational Readiness Programs are designed and structured using process-based models. Furthermore, the hub and spoke pattern prevailed in this interaction explains how each L0 process is designed to fulfill specific Regulatory Requirements and ultimately instilling those requirements in the Business as Usual (BAU) by design.

5.2.2 General characteristics

The structural characteristics of the L0 to Regulatory Requirements network are shown in Table (5.3).

Table 5. 3 Structural characteristics of the L0 to regulatory requirements intersections

Characteristic	Value
Total number of L0 and Regulatory Requirements nodes	228
Total number of undirected interactions (Edges)	691

The interaction between the L0 processes and regulatory requirements seems to be efficient and the flow of information seems to be seamless as indicated by a relatively low dense network. The maximum number of connections required to traverse the interaction between L0 to Regulatory Requirements or in other words the number of steps taken between the two most distant nodes in this interaction to reach one another is 5 nodes as indicated by the Network Diameter. Combining this observation with the fact that the maximum path length between L0 to Regulatory Requirements is 3.03 as indicated by the average path length for a graph, we can conclude that the graph is efficient from a communication standpoint since the maximum path length between L0 to Regulatory Requirements is less than the network diameter.

5.2.3 Network density

Graph density is a network statistical measure of how tightly interconnected a network. It is calculated by examining the proportion of existing edges relative to the possible total number of connections. A high degree of interaction across the network will have higher density levels while weak interactions result in low Network Density. Two networks with identical numbers of nodes might have very different density levels; even the same network measured at different time intervals is likely to have differing density measures as links are formed or broken over time. In this network, density measures the linkage between L0 Processes and Regulatory Requirements. The value of network density ranges from 0 to 1. A density close to 1 indicates that all L0 Processes are strongly linked to Regulatory Requirements within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interaction between L0 Processes and Regulatory requirements. A value close to 0 will indicate the existence of weak interaction between L0 Processes and Regulatory Requirements. Additionally, the density of the interaction in this network can be used to measure the cohesiveness and robustness of the interaction between L0 Processes and Regulatory Requirements, as well as, the inclusiveness and coverage of all regulatory requirements as part of the BAU design within the nuclear power plant. The density of interaction between L0 Processes and the Regulatory Requirements is 0.028 which suggests that there is a low level of interaction among L0 processes and corresponding regulatory requirements.

5.2.4 Network clustering coefficient and modularity analysis

This network statistic will help in grouping nodes based on the strength of their relationships into distinct clusters. Clustering coefficient provides the ability to measure the level at which L0 processes and Regulatory requirements are grouped, as opposed to being equally or randomly connected across the network. Clustering coefficient Scores have an inverse correlation with other statistics, including several of the centrality measures, mainly when we are analyzing at the global level (the entire network). Clustering coefficient calculation is based on measuring the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available amongst L0 processes and Regulatory requirements interactions. in essence, this measures the degree to which second-tier L0 processes or a regulatory requirement are connected to one another (Friends of friends). High Clustering coefficient scores are highly anticipated from tightly knit hubs and distinctive communities, whereas dispersed and remotely scattered networks might be expected to produce lower scores. The average Clustering Coefficient for this network is 0.23 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis showed that L0 Processes and Regulatory Requirements are distributed across 10 distinct communities. The size distribution of the 10 clusters is shown in figure (5.2). This property strongly correlates with the network's robustness to failure. It turned out that the 10 major hubs are concentrated around specific L0 processes which are linked to a unique group of regulatory requirements. This structural configuration allows for a fault-tolerant behavior and fosters resilience in the interaction between L0 Processes and Regulatory Requirements.

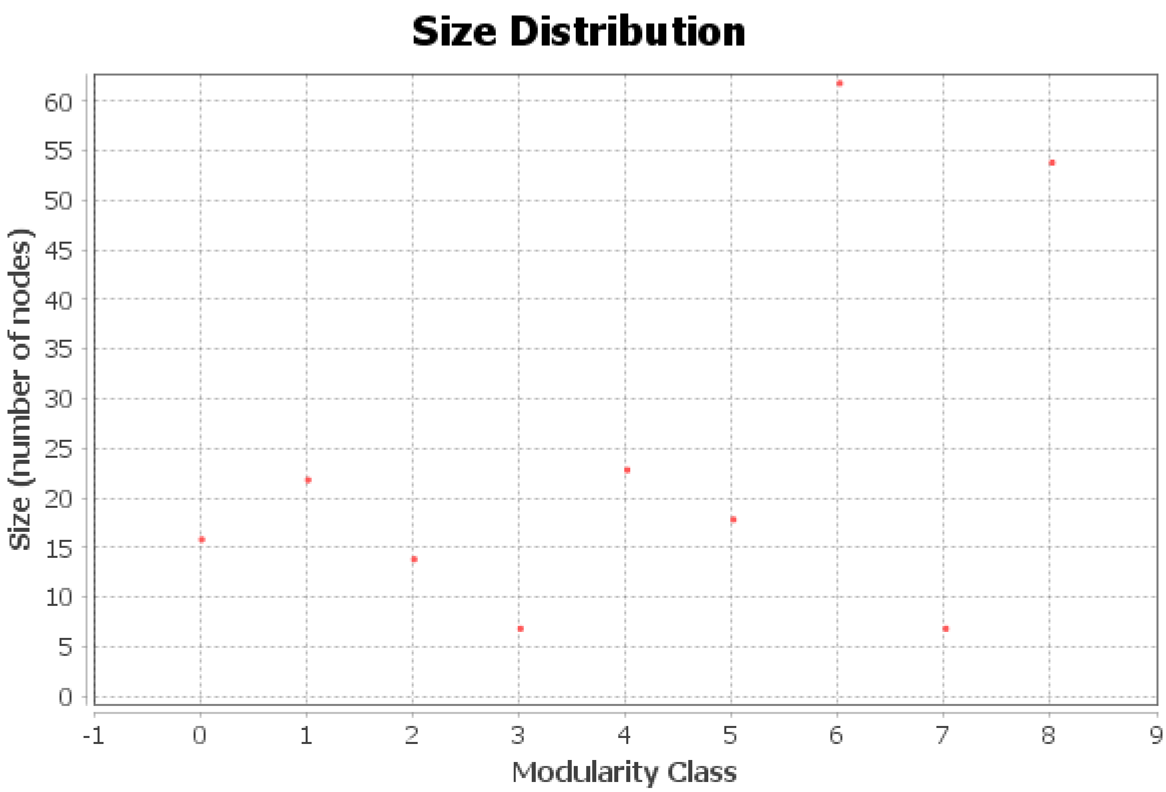
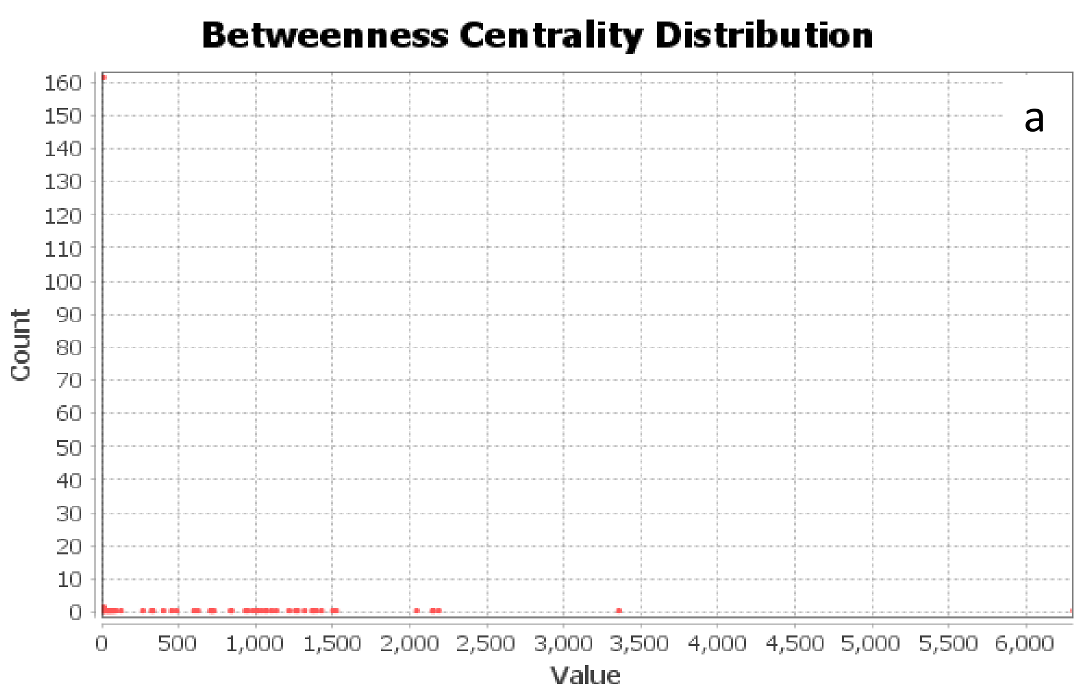


Figure 5. 2 Modularity class size distribution in the interactions between L0 processes and the regulatory requirements

5.2.5 Network centrality measures

Centrality measures help to demystify certain characteristics in the interactions between L0 processes and the Regulatory Requirements. There are many ways to measure centrality and each of these approaches help in understanding a specific type of centrality, as opposed to offering competing versions of the same measurement. Centrality measures help in identifying which components of the nuclear power plant operational readiness (5Ps) have more influence over other components in terms of achieving the strategic targets of the program (Safety, reliability, cost, schedule, etc.). Furthermore, Centrality is an essential measure of the information flows between

L0 processes and Regulatory Requirements when assessed jointly with other statistics to form a comprehensive and accurate understanding of information flow and efficiency of interaction. The Closeness Centrality is the inverse of the mean shortest path between a node and all other nodes in the network that is reachable from it. This metric reflects the ability of L0 Processes and Regulatory Requirements to access and transmit information through the network quickly. It also indicates how close a L0 Process or a Regulatory Requirement is from every other node in this network. Nodes with high closeness centrality have a central position in the network since they're close to other nodes. Betweenness centrality measures the degree L0 Processes and Regulatory Requirements offer the most direct path/Bridges between otherwise disconnected Clusters. A higher betweenness centrality score for a node will provide a perspective on how critical that node to maintain the structure of the network. into the influence, that node has on the network. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. Figure (5.3) presents the results of the analysis of Betweenness and closeness centrality in interactions between L0 processes and the regulatory Requirements



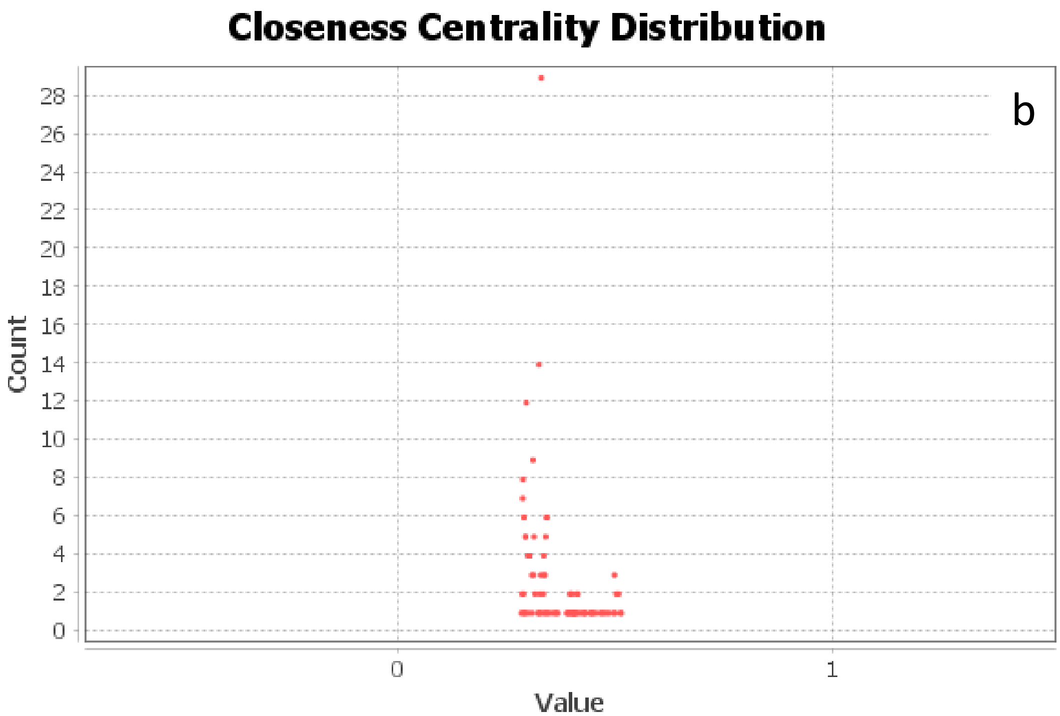


Figure 5. 3 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and the regulatory requirements

Figure 5.3 shows that the distributions of L0 processes and the regulatory Requirements based on their Betweenness Centrality and Closeness Centrality do not follow the normal distribution. As one can see, the majority of the L0 processes and the regulatory requirements have the same closeness (around 0.5), meaning that they're seen from this angle as having the same influence over this network, while a few of them tend to have a high closeness value. L0 processes and the regulatory Requirements tend to be distributed across a straight continuum. Table (5.4) below highlights L0 processes with the highest Betweenness Centrality. ENV-L0, RP1-L0, EP1-L0, RE-L0, NOS-L0, and LRA-L0 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between L0 processes and Regulatory requirements intact. Those nodes seem to serve as bridges between other L0 processes to satisfy the majority of regulatory requirements. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction between L0 process and Regulatory Requirements.

Table 5. 4 L0 Processes with highest betweenness centrality

Node Id	Label	Closeness centrality	Betweenness centrality
13	ENV-L0	0.480519	6295.033
10	EP1-L0	0.468354	3344.057
40	HR-L0	0.506849	2175.978
28	NPI5-L0	0.509174	2139.915
9	LRA-L0	0.439604	2137.048
44	RP1-L0	0.40884	2032.332
31	FIN-L0	0.494432	1510.9
26	NPI3-L0	0.502262	1488.915
27	NPI4-L0	0.502262	1416.282
39	ICT-L0	0.493333	1382.02
8	HNS-L0	0.397849	1361.716
14	NIMS-L0	0.497758	1357.177
11	FP2-L0	0.406593	1305.681
20	RE-L0	0.403636	1261.08
38	COM2-L0	0.493333	1246.04
17	PSC-L0	0.49115	1204.486
3	NOS-L0	0.394316	1121.095
12	NRM-L0	0.422857	1091.326
22	RW-L0	0.39292	1059.362
25	NPI2-L0	0.497758	1049.915
24	NPI1-L0	0.436149	1023.586

The main focus of this work is to understand the interaction between L0 processes and Regulatory requirements. So, it is important to have a deeper look at the nature of influence the Environmental Services process has in this network. To do so, the ego network technique will be used. An Ego Network consists of a focal node (also called the “ego”) and all the nodes that have some relationship to it. This relationship can be direct, meaning that the nodes are adjacent, or it can be established as a second level relationship (friend of a friend). Using Ego Network Analyses help to model and study the influence of central modes by applying network statistics on that focused snapshot of the bigger network.

The below graph (5.4) was produced by Gephi using the Ego Network.

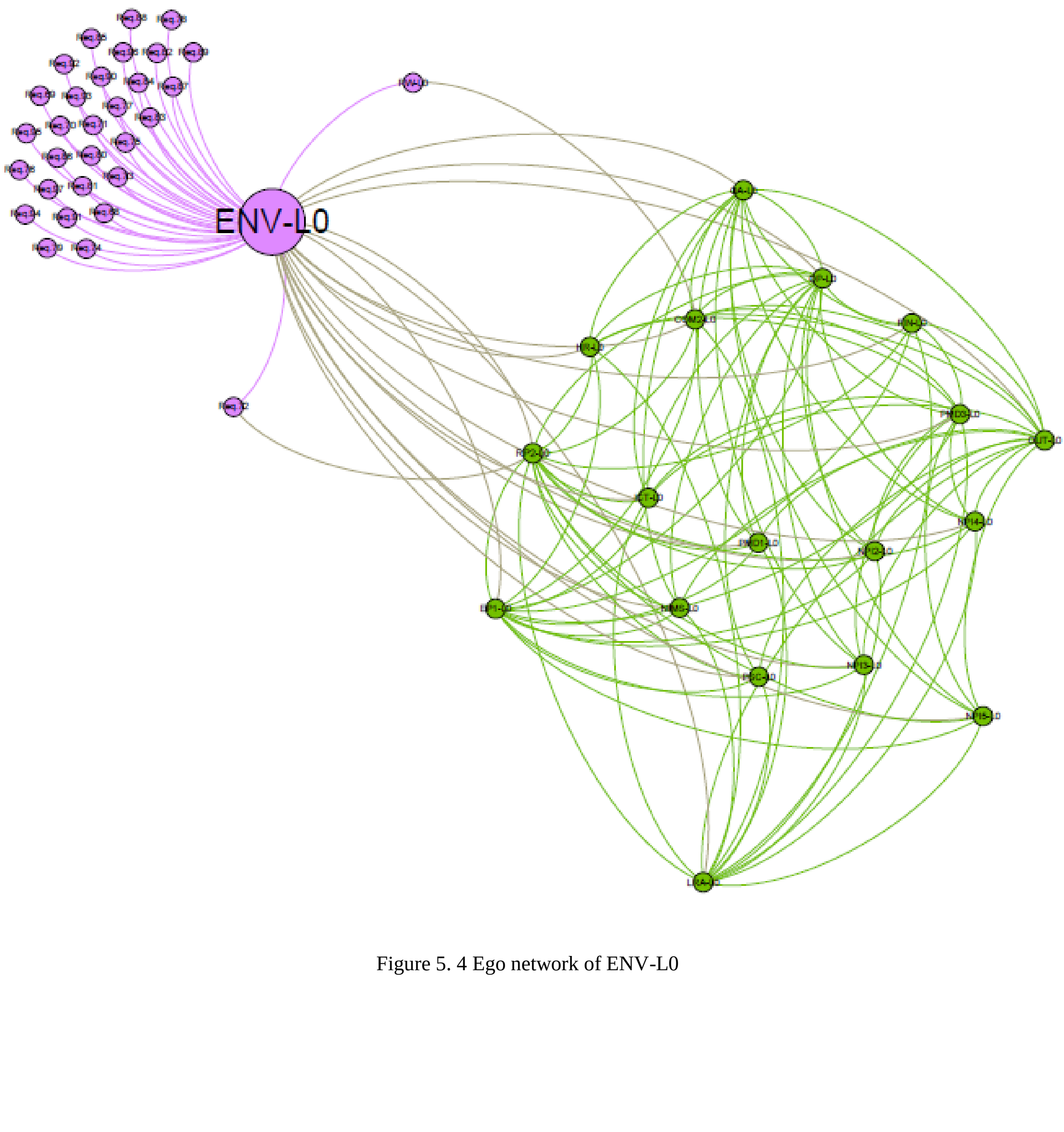


Figure 5. 4 Ego network of ENV-L0

The structural characteristics of the of ENV-L0 Ego Network are shown in Table (5.5).

Table 5. 5 Ego network of ENV-L0 characteristic

Characteristic	Value	% Visible
Total number nodes	50	22.42%
Total number of Edges	135	19.54%

The interaction between ENV-L0 and other L0 processes and regulatory requirements seems to be an inefficient and forming a low level of interactions as indicated by the below network statistical measures. The maximum path length between in this ego network is 1.89 as indicated by the average path length for a graph, we can conclude that the graph is inefficient from a communication standpoint since the maximum path length is almost the same as the network diameter. The interaction between ENV-L0 and other L0 processes and regulatory requirements is clustered across two distinctive Communities.

Table 5. 6 Ego network of ENV-L0 statistics

Network statistic	Value
Graph density	0.11
Network diameter	2
Average Path length	1.89
Average Clustering Coefficient	0.559

5.3. Interactions between level 0 processes and strategic programs within the nuclear power plant operational readiness program

This interaction looks at the relationship between Nuclear Power Plant L0 Processes and the Strategic Programs established to deliver certain agreed benefits for the Nuclear Power Plant Operational Readiness. Those Programs are strategic in nature, extend for a relatively long period of time (3-5 years), and aim to establish certain organizational capability and/or fulfill certain Regulatory Requirements. Programs are a planned, coordinated group of activities, processes, and/or procedures, developed for a specific purpose to accomplish a clear safety objective, with details on what work is to be done, by whom, at what periodicity, and what means, or resources will be used. Programs are characterized by the following criteria:

1. Programs require specific technical expertise.
2. Programs are required by reference documents (e.g. FANR regulations, Technical Specifications, FSAR, standard nuclear industry practice, or expert judgment)
3. Program data collection activities are repeated at regular intervals.
4. There is a continuity of data where the output and inputs of each data collection cycle are compared to each other. The list of L0 process covered all Management Systems processes and each L0 process was given a code and a node label (Table 5.1). On the other hand, each Program associated with the Nuclear Power Plant Operational Readiness was identified and given a code and a node label as per the below table (5.7)

5.3.1 Network diagrams

This network aimed to identify and depict all interactions between all L0 processes (Main Processes) forming the structure of Integrated Management System for the Nuclear Power Plant Operational Readiness Program and the Strategic Programs designed to realize strategic Benefits and close strategic value gaps needed to satisfy the Nuclear Regulator and fulfill minimum requirements needed to receive the Operating License. The list of L0 processes covered all Management System processes and each L0 process was given a code and a node label as per the below table (5.1). Similarly, the list of Strategic Programs has been identified and every Strategic Program was given a code and a node label as per the below table (5.7).

Table 5. 7 List of strategic programs

Node Label	Program	Node ID
PG1	Core Monitoring program	288
PG2	Other affecting SSCs	289
PG3	Maintenance Program Description	290
PG4	Maintenance Rule Program Description	291
PG5	Preventive Maintenance Program	292
PG6	Program Catalog	293
PG7	System Health Program Description	294
PG0	None-Confidential	295
PG8	Accident Management	296
PG9	Ageing Management	297
PG10	Air Operated Valves (AOVs)	298
PG11	Boric Acid Corrosion (BAC) Control	299
PG12	Chemistry	300
PG13	Containment Leak Rate Testing	301
PG14	Control Room Envelope Habitability	302
PG15	Core Monitoring	303
PG16	Corrective Action	304
PG17	Counterfeit, Fraudulent, Suspect Items	305
PG18	Cyclic and Transient Monitoring	306
PG19	Diesel Fuel Oil Testing	307
PG20	Document Control and Records Management	308
PG21	Emergency Preparedness	309
PG22	Employee Concerns	310
PG23	Equipment Qualification	311
PG24	Erosion and Corrosion Monitoring	312
PG25	Export Control	313
PG26	Fire Protection	314
PG27	Foreign Material Exclusion	315
PG28	Fuel Integrity	316
PG29	Health & Safety	317
PG30	In-Service Inspection	318
PG31	In-Service Testing	319
PG32	Maintenance	320
PG33	Maintenance Rule	321
PG34	Measuring and Test Equipment (M&TE)	322

PG35	Meteorological Monitoring	323
PG36	Motor Operated Valves (MOVs)	324
PG37	Off Site Dose Calculation Program	325
PG38	Operational Radiation Protection	326
PG39	Performance Improvement	327
PG40	Primary Coolant Outside of Containment	328
PG41	Probabilistic Risk Assessment	329
PG42	Process control	330
PG43	Quality Assurance	331
PG44	Radioactive Waste Management	332
PG45	Reactor Coolant Pressure Boundary Material Surveillance	333
PG46	Safeguards	334
PG47	Site Security	335
PG48	Steam Generator Management	336
PG49	Surveillance	337
PG50	System Health Evaluation	338
PG51	Training and Personnel Qualification	339
PG52	Site Security Program,	340
PG53	Emergency Preparedness Program.	341
PG54	Export Control Program	342
PG55	Meteorological Monitoring Program	343
PG56	Offsite Dose Calculation Manual Program	344
PG57	Quality Assurance Program	345
PG58	Health and Safety Program	346
PG59	Training and Personnel Qualification Program	347
PG60	Performance Improvement Program	348
PG61	Corrective Action Program	349
PG62	Counterfeit, Fraudulent and Suspect Items Program	350
PG63	Diesel Fuel Oil Testing Program	351
PG64	Export Control Program	352
PG65	Equipment Qualification Program	353
PG66	Measuring and Test Equipment (M&TE) Program	354
PG67	Document Control and Records Management Program	355
PG68	Primary Coolant Outside Containment	356
PG69	Process Control Program Description	357
PG70	Radioactive Waste Management Program Description	358
PG71	Radiation Protection Program	359
PG72	Offsite Dose Calculation Automated Program	360
PG73	Quality Assurance	361
PG74	Training and Personnel Qualifications	362
PG75	Performance Improvement Program	363
PG76	All programs	364
PG77	Emergency Preparedness	365
PG78	Training and Personnel Qualification Program	366
PG79	Employee Concerns Program	367
PG80	Radiation Protection Program-1	368

PG81	Radiation Protection Program-2	369

Data for this network was imported into Gephi using the above-mentioned structure, the Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced in figure 5.5.

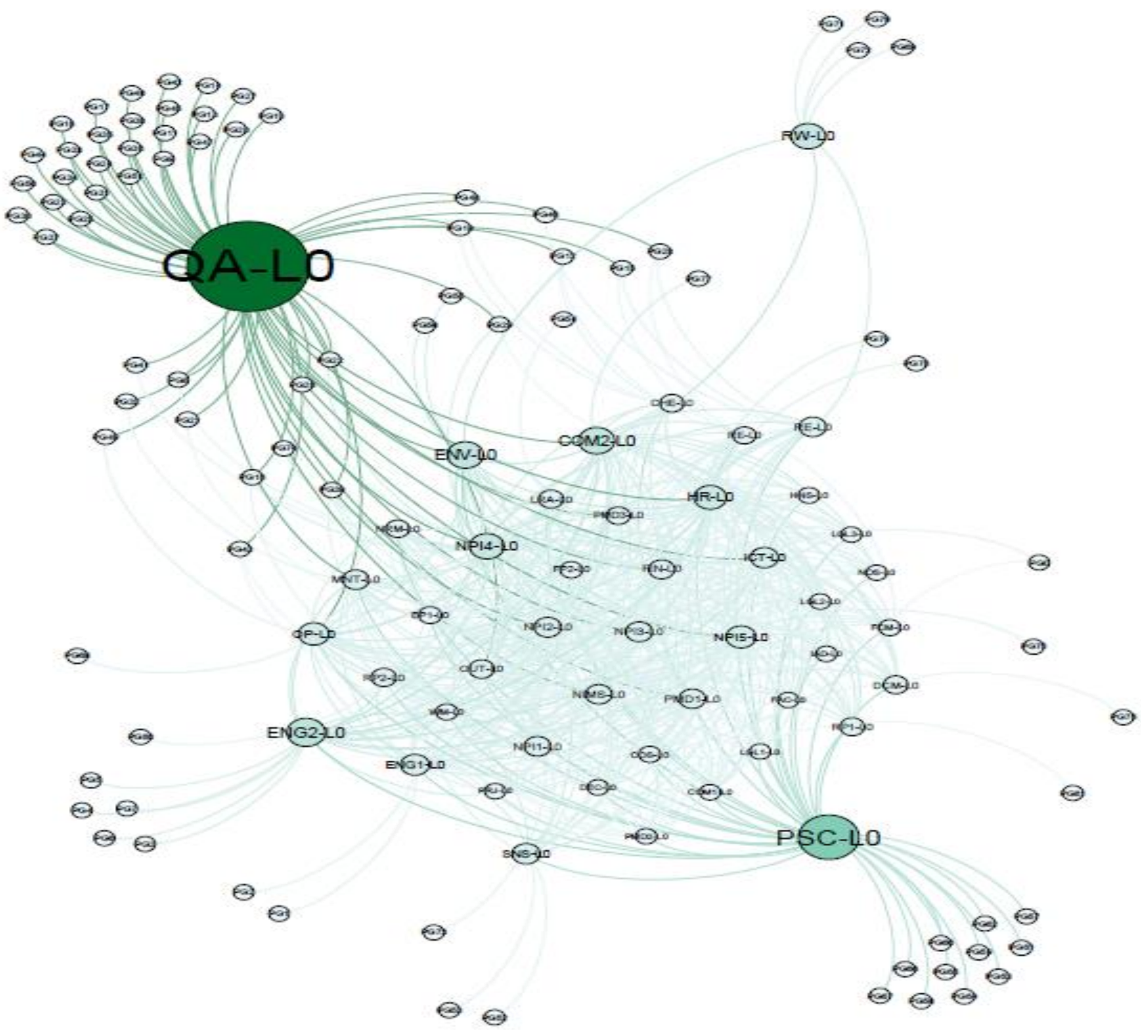


Figure 5. 5 L0 Processes and strategic programs network

5.3.2 General characteristics

The structural characteristics of the L0 Processes and Strategic Programs network are shown in Table (5.).

Table 5. 8 Structural characteristics of the L0 to strategic programs intersections

Characteristic	Value
Total number of L0 Processes and Strategic Programs nodes	128
Total number of undirected interactions (Edges)	570

As shown in figure 5.5, the interaction between L0 process and Strategic Programs appear to be efficient and the flow of information seems to be seamless as indicated by a relatively low dense network. The number of steps taken between the two most distant nodes in interactions between L0 processes and strategic Programs (the maximum number of connections required to traverse this interaction) to reach one another is 5 nodes as indicated by the Network Diameter. Combining this observation with the fact that the maximum path length between L0 processes and Strategic Programs is 2.6 as indicated by the average path length for a graph, we can conclude that the graph is efficient from a communication standpoint since the maximum path length between L0 to Strategic Programs is less than the network diameter. Furthermore, the graph revealed some interesting facts about the interaction between Management Systems L0 Process and Established Program in the Nuclear Power Plant Operational Readiness. The Quality Assurance Process acts as a central hub for the majority of the Programs and has the highest Betweenness Centrality. This can be attributed to the key influence the Quality Assurance Process has on the design and execution of Nuclear Power Plant Operational Readiness Programs. This relationship can be understood from two different perspectives. Firstly, the oversight role was delivered by the Quality Assurance on certain Programs during the Nuclear Power Plant Operational Readiness phase to ensure compliance with the ASMI Standard and other Regulatory Requirements. This role will require establishing multiple Interfaces, Validation & Verification points, and surveillance activities with a large number of Programs. Secondly, the establishment of QA- specific Programs needed to establish certain organizational capabilities needed to ensure safe and reliable operations of the Nuclear Power Plant. The hub and spoke pattern shown in this network explains how some Programs are tagged to specific L0 processes and primarily aim to build specific organizational capabilities related to the L0 process domain. Similar to the influence the Quality Assurance Process has on interactions between L0 Process and Programs, the Procurement Process seems to be central to this interaction. This observation also can be interpreted from two angles. First, the dependencies most of the programs have on the Procurement Process to supply goods and services required to realize programs benefits. secondly, programs needed to ramp up the Procurement capacity to manage Operational Phase requirements related to Maintenance and outage management. Some examples might be the Operational Spare parts supply, Inventory and Warehouse Management and integrations for enabling preventive maintenance.

5.3.3 Network density

As mentioned earlier, Graph density is a network statistical measure of how tightly interconnected a network and is calculated by examining the proportion of existing edges relative to the possible total number of connections. A high degree of interaction across the network will have higher density levels while weak interactions result in low Network Density. In this network, density measures the linkage between L0 Processes and Strategic Programs. The value of network density ranges from 0 to 1. A density close to 1 indicates that all L0 Processes are strongly linked to

Strategic Programs within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interaction between L0 Processes and Strategic Programs. A value close to 0 will indicate the existence of weak interaction between L0 Processes and Strategic Programs. Additionally, the density of the interaction in this network can be used to measure how cohesive and robust is the interaction between L0 Processes Strategic Programs. The density of interaction between L0 Processes and the Strategic Programs is 0. 070 which suggests that there is a low level of interaction among L0 processes and Strategic Programs within the Nuclear Power Plant Operational Readiness.

5.3.4 Network clustering coefficient and modularity analysis

As discussed earlier, this graph statistic helps in grouping nodes based on the strength of their relationships into distinct clusters. The clustering coefficient provides the ability to measure the level at which L0 processes and Strategic Programs are grouped together, as opposed to being equally or randomly connected across the network. As highlighted earlier, Clustering coefficient Scores have an inverse correlation with other statistics, including several of the centrality measures, mainly when we are analyzing at the global level (the entire network). Clustering coefficient calculation is based on measuring the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available amongst Interactions between L0 processes and Strategic Programs. in essence, this measures the degree to which second-tier L0 processes or a Strategic Program are connected to one another (Neighbors of neighbors). High Clustering coefficient scores are highly anticipated from tightly knit hubs and distinctive communities, whereas dispersed and remotely scattered networks might be expected to produce lower scores. The average Clustering Coefficient for this network is 0.269 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis showed that L0 Processes and strategic Programs are distributed across 6 distinct communities. The size distribution of the 6 clusters is shown in figure 5.6. It turned out that the 6 major hubs are concentrated around specific L0 processes which are linked to a unique group of Strategic Programs. To some extent, this structural layout provides a fault-tolerant behavior and fosters resilience in the interaction between L0 Processes and Strategic Programs.

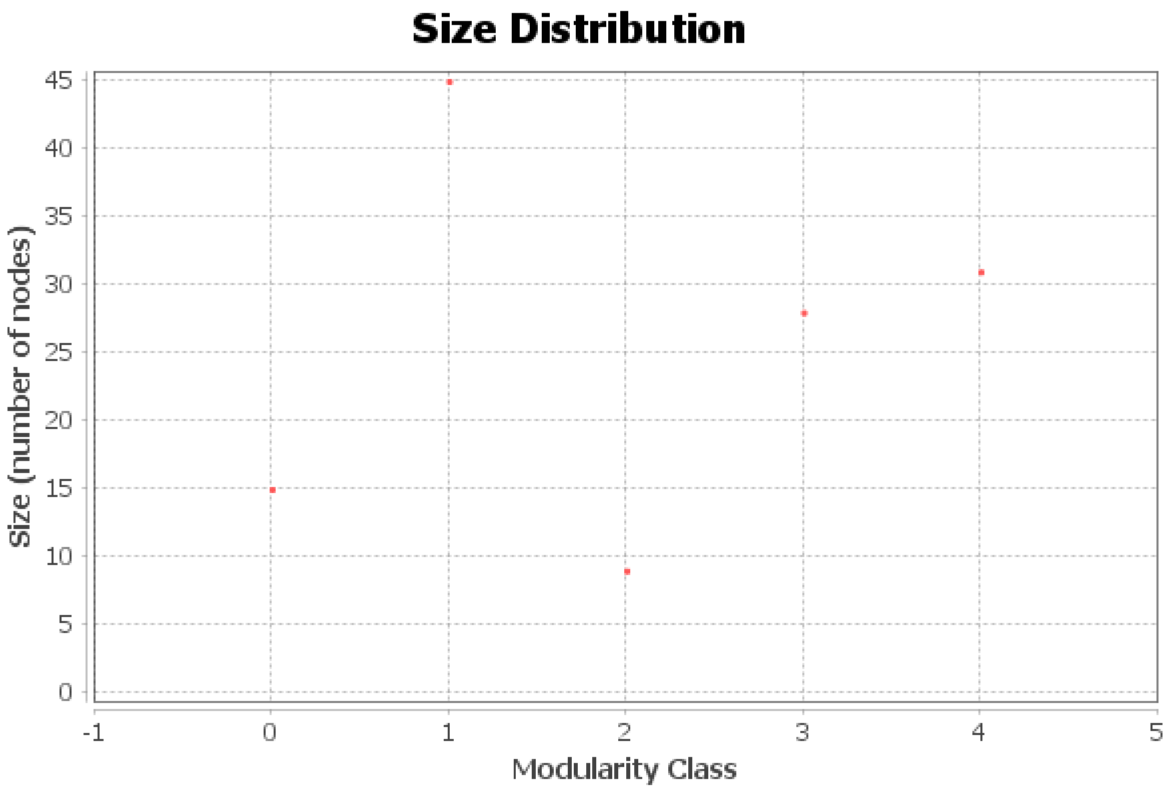
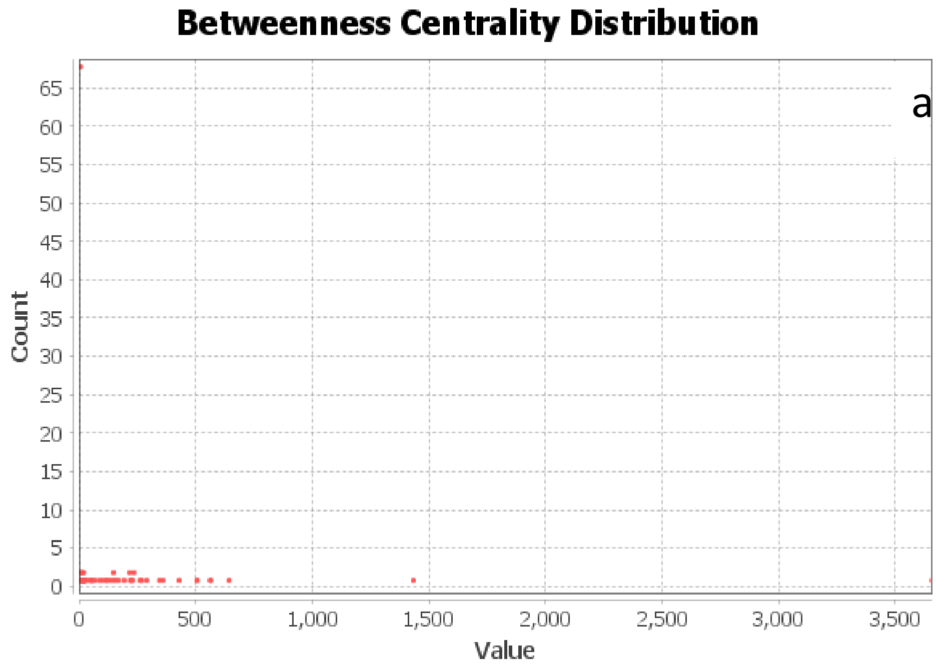


Figure 5. 6 Modularity class size distribution in the interactions between L0 processes and strategic programs

5.3.5 Network centrality measures

Centrality measures help to demystify certain characteristics of the interaction between the different players in the Nuclear Power Plant Operational Readiness Program. In this case, the interactions between L0 processes and the Strategic Programs. As explained earlier, there are many ways to measure centrality and each of these approaches helps in understanding a specific type of centrality, as opposed to offering competing versions of the same measurement. Centrality measures help in identifying which components of the Interactions between the L0 Processes and Strategic Programs have more influence over other components. Furthermore, Centrality is an essential measure to assess the efficiency of interactions and information flow between L0 processes and Strategic Programs especially when assessed and supported by other network statistics to form a comprehensive understanding. The Closeness Centrality is the inverse of the mean shortest path between a node and all other nodes in the network that is reachable from it. This metric reflects the ability of L0 Processes and Strategic Programs to access and transmit information through the network quickly. It also indicates how close a L0 Process or a Strategic Program is from every other node in this network. Betweenness centrality measures the degree L0 Processes and Strategic Programs offer the most direct path/Bridges between otherwise disconnected Clusters. A higher betweenness centrality score for a node will provide a perspective on how critical that node to maintain the structure of the network. into the influence, that node has on the network. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. Figure (5.7) presents the results of the analysis of Betweenness and closeness centrality in interactions between L0 processes and Strategic Programs.



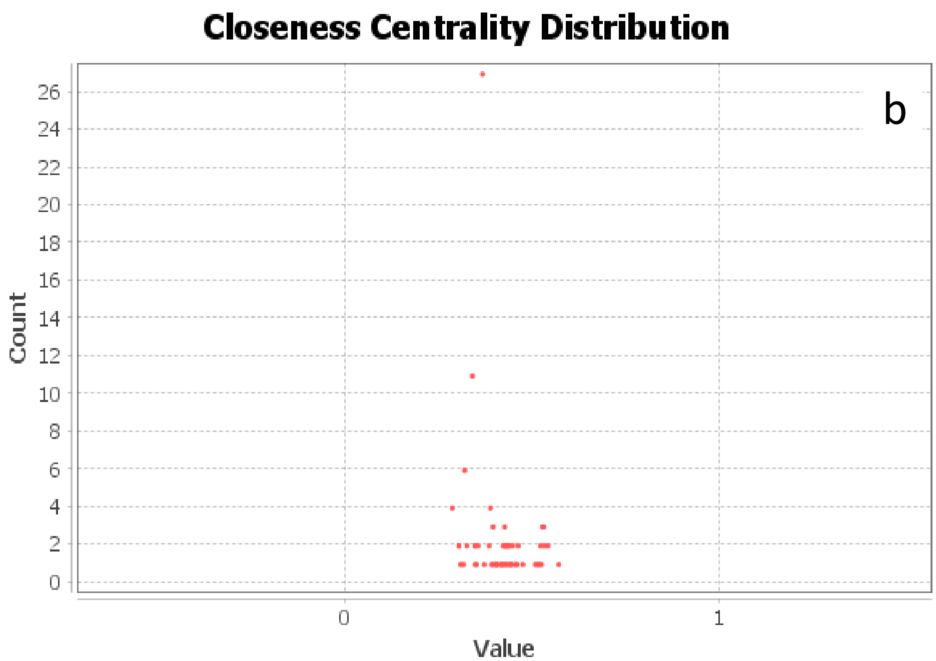


Figure 5. 7 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and strategic programs

As shown in figure (5.7), the distributions of L0 processes and Strategic Program based on their Betweenness Centrality and Closeness Centrality do not follow the normal distribution. As one can see, the majority of the L0 processes and strategic Programs have the same closeness (around 0.5), indicating that they're having almost the same influence over this network, while a few of them tend to have a high closeness value. L0 processes and the regulatory Requirements tend to be distributed across a straight continuum. Table (5.9) below highlights L0 processes with the highest Betweenness Centrality. It turned out that the Quality Assurance and Procurement Process are critical to maintaining the interaction between L0 processes and Strategic Programs intact and efficient due to their high Betweenness Centrality. Some other nodes like RW-L0 is a bit peripheral to the network structure because the Radioactive Waste management Process at this phase of the development of the Nuclear Power Program is managed as a second priority compared to other processes like Operations, Maintenance, and Capacity Building, and work Management. However, interfaces with other L0 processes and Strategic Programs should be considered and established at the commissioning phase to ensure satisfying regulatory requirements by incorporating RW requirements in all relevant processes. Otherwise, some rework and major adjustments might be needed to ensure fulfilling onsite and off-site radiological waste. Decision-makers and Subject Matter Experts in the Nuclear Power Plant Operational Readiness Program should pay attention to the impactful role Quality Assurance and Procurement processes play in maintaining the robust structure and efficient and effective interaction between L0 process and strategic Programs. They also might need to rethink the relationship and interfaces of the Radiological Waste Management Process with other operational Readiness Processes and Strategic Programs.

Table 5. 9 L0 Processes with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality

4	QA-L0	0.566964	3650.906502
17	PSC-L0	0.503968	1426.11794
2	ENG2-L0	0.458484	636.28615
13	ENV-L0	0.518367	556.723132
38	COM2-L0	0.520492	555.622752
27	NPI4-L0	0.538136	499.451334
22	RW-L0	0.390769	498.25
40	HR-L0	0.522634	422.420025

The main focus of this work is to understand the interaction between L0 processes and Strategic Programs. So, it is important to understand in detail the nature of influence the Quality Assurance process has in this network. To do so, the ego network technique will be used. An Ego Network consists of a focal node (also called the "ego") and all the nodes that have some relationship to it. This relationship can be direct, meaning that the nodes are adjacent, or it can be established as a second level relationship (friend of a friend). Using Ego Network Analyses help to model and study the influence of central modes by applying network statistics on that focused snapshot of the bigger network. The below graph (5.8) was produced by Gephi using the Quality Assurance Ego Network.

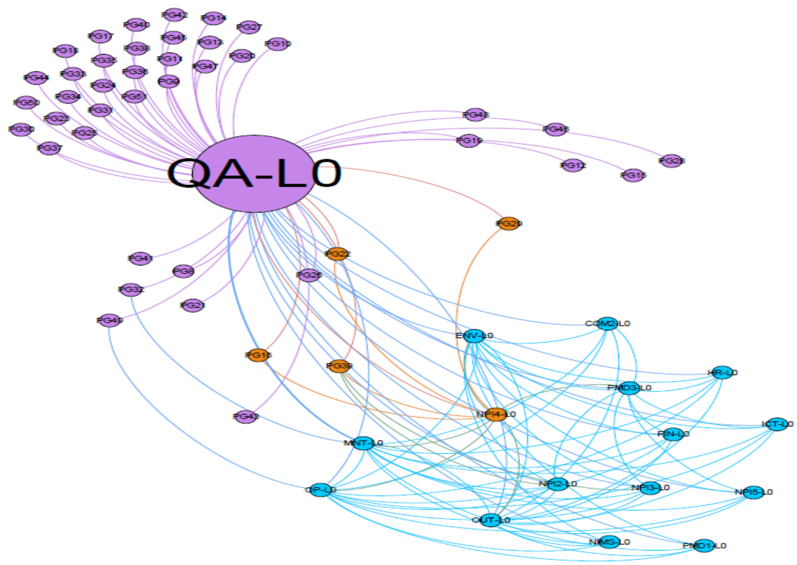


Figure 5. 8 Ego network of quality assurance process interactions with strategic programs

The structural characteristics of the L0 to Regulatory Requirements network are shown in Table (5.10).

Table 5. 10 Characteristic of quality assurance process ego network

Characteristic	Value	% Visible
Total number nodes	60	46.88%
Total number of Edges	120	21.05%

As shown in figure (5.8), The interaction between the Quality Assurance process with other L0 processes, as well as, strategic Programs seems to be inefficient and forming a low level of interactions as indicated by the below network statistical measures. The maximum path length between in this ego network is 1.93 as indicated by the average path length for a graph, we can conclude that the graph is inefficient from a communication standpoint since the maximum path length is almost the same as the network diameter. The interaction between the Quality Assurance process with other L0 processes, as well as, strategic Programs are clustered across three distinctive Communities. Table 5.11 provides the general characteristics of the quality assurance ego network.

Table 5. 11 Statistics of quality assurance ego network

Network statistic	Value
Graph density	0.068
Network diameter	2
Average Path length	1.93
Average Clustering Coefficient	0.627

5.4. Interactions amongst level 1 processes in the nuclear power plant operational readiness program

The Third Network looks at the next level of details. It maps all interactions between Level 1 Processes in the Nuclear Power Plant Operational Readiness. L1 Processes form the fundamental structural component of the Management System in any Nuclear Power plant. They are sub-processes from L0 and understanding the nature of the interactions between them is very crucial to comprehend the behavior of the whole Management System and its effectiveness in delivering its purpose of supporting the achievements of Strategic Goals and Objectives of the Nuclear Power Plant Operational Readiness. All Level1 processes included in the Management Systems have been given a code and a node label as highlighted in table 5.12.

Table 5. 12 List of L1 processes

L1 Process	Node Label	Node ID
Evaluate Identified Problem or Desired Change	CM001	47
Design Requirements Change Process	CM002	48
Physical Configuration Change Authorization	CM003	49
Facility Configuration Information Change Process	CM004	50
Scoping and Identification of Critical Components	ER001	51
Performance Monitoring	ER002	52
Continuing Equipment Reliability Improvement	ER003	53
Lifecycle Management	ER004	54
Manage External Assessments	IO001	55
Manage Quality Assurance	IO002	56
Manage Internal Audit	IO003	57
Manage Governance Controls	IO004	58
Provide Security Measures	LP001	59
Provide Industrial Safety Services	LP002	60
Maintain License and Permits	LP003	61
Perform Emergency Planning	LP004	62
Provide Fire Protection	LP005	63
Manage Nuclear Risk	LP006	64
Provide Environmental Services	LP007	65
Execute Integrated Management System	MO001	66
Manage Statutory and Regulatory Requirements	MO002	67
Manage Enterprise Risk	MO003	68
Manage Strategic Sourcing	MS001	69
Procure Materials & Services	MS002	70
Manage Warehouse & Logistics	MS003	71
Manage Procurement Engineering	MS004	72
Provide Fuel Management Services	NF001	73
Provide and Transport Fuel	NF002	74
Provide Handling, Storage and Disposal of Fuel	NF003	75
Operate and Monitor Structures, Systems and Components	OP001	76
Monitor and Control Effluents	OP002	77
Monitor and Control Plant Chemistry	OP003	78
Manage Corrective Actions	PI001	79
Manage Self-Assessment and Benchmarking	PI002	80
Manage Knowledge and Utilize Operating Experience	PI003	81
Manage Human Performance	PI004	82
Manage Culture of Safety	PI005	83
Manage Enterprise Performance	PI006	84
Manage Project Controls and Project Delivery	SS001	85
Manage Finance	SS002	86
Provide Legal Services	SS003	87

Perform Commissioning Oversight	SS004	88
Perform Decommissioning	SS005	89
Manage Documentation and Records	SS006	90
Maintain Facilities	SS007	91
Support Community and Government Relations	SS008	92
Manage Communications	SS010	93
Provide Information Technology Services	SS011	94
Talent Acquisition	TM001	95
Capacity Building	TM002	96
Learning & Capability Development (Training)	TM003	97
Career Management	TM004	98
Perform Planning	WM001	99
Perform Scheduling	WM002	100
Perform Preventive Maintenance	WM003	101
Perform Corrective Maintenance	WM004	102
Perform Predictive Maintenance	WM005	103
Monitor and Control Radiation Exposure	WM007	104
Monitor and Control Contamination	WM008	105
Perform Minor Maintenance/Fix-it-now Maintenance	WM009	106
Manage Site Projects	WM010	107
Manage Outages	WM011	108

Following the Data Analysis process for this study, Data for this network was imported into Gephi using the above-mentioned structure, Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced (Figure 5.9)

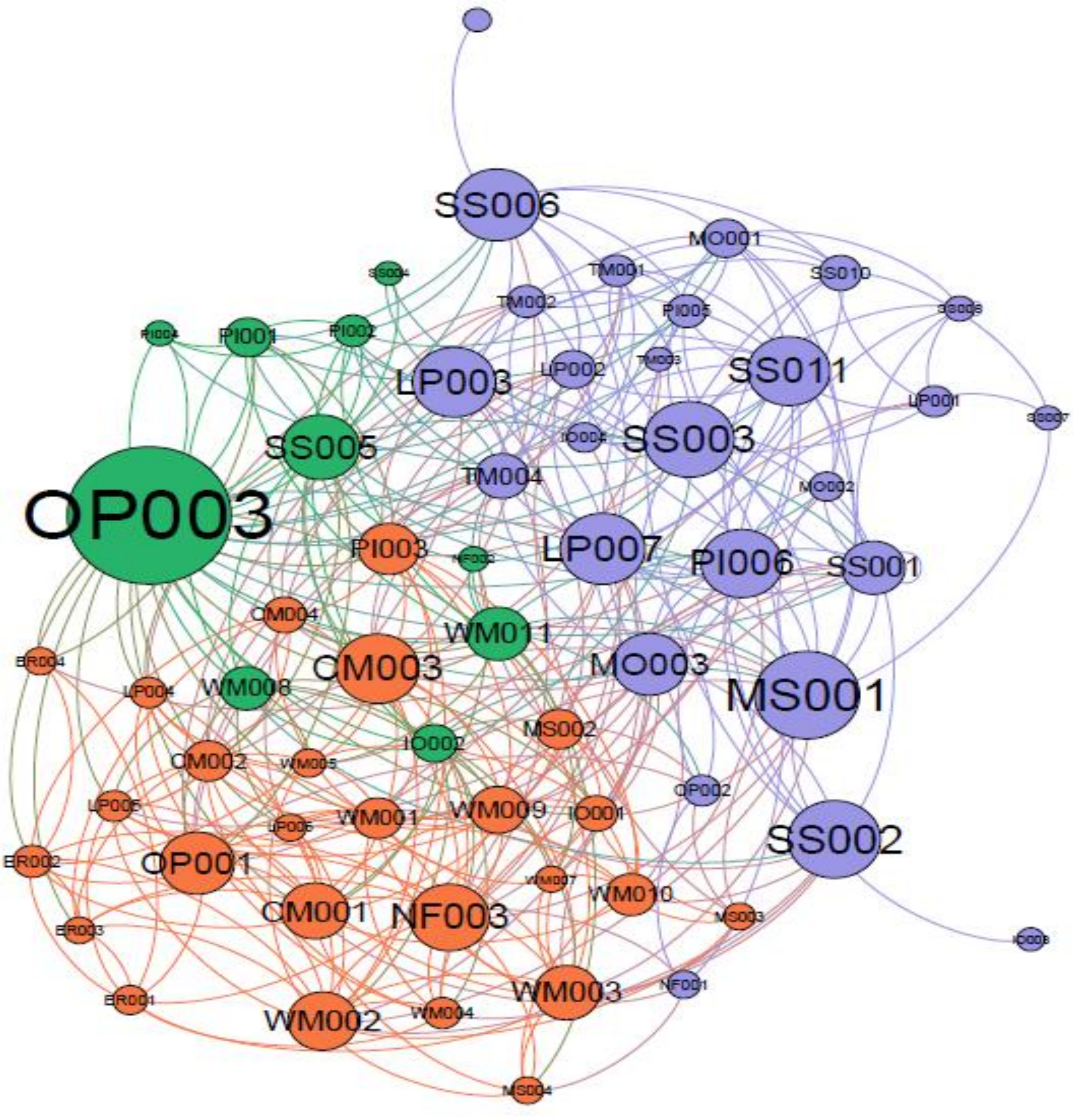


Figure 5. 9 Level-1 processes network

5.4.1 General characteristics

The structural characteristics of the L1 processes network are shown in Table (5.13).

Table 5. 13 Characteristic of L1 processes network

Characteristic	Value
Total number of L1 Processes	62
Total number of undirected interactions (Edges)	356

The maximum number of connections required to traverse the interaction between L1 Processes is 4 as indicated by the Network Diameter. Therefore, the interaction between L1 processes seems to be efficient and the flow of information appears to be flowing smoothly. In addition to being a low dense network, the maximum path length between L1 Processes is 2.01 as indicated by the average path length. Thus, we can conclude that the interaction among L1 processes within the Nuclear Power Plant Operational Readiness is efficient from a communication and information sharing standpoint since the maximum path length is less than the network diameter.

5.4.2 Network density

Graph density measures how tightly interconnected is the interaction amongst the L1 processes network by calculating the proportion of existing established connections relative to the possible total number of connections. A high degree of interaction amongst L1 processes will have higher density levels while weak interaction amongst L1 processes results in low Network Density. It is worth mentioning that two networks of L1 processes with identical numbers of processes might have very different density levels; even the same L1 processes network measured at different time intervals is likely to have differing density measures as links are formed or broken over time. In this network, density measures the linkages between L1 Processes. The value of network density ranges from 0 to 1. A density close to 1 indicates that all L1 Processes are strongly linked together within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interactions between. A value close to 0 will indicate the existence of weak interaction between L1 Processes. Furthermore, the density of the interaction in this network can indicate how cohesive and robust is the interaction between L1. The density of interactions between L1 Processes is 0.02 which suggests that there is a low level of interaction among L1 processes. This finding indicates that interactions between L1processes in the Nuclear Power Plant Operational Readiness Program might be fragile and to some extent not resilient enough to absorb any future unanticipated disruptive events.

5.4.3 Network clustering coefficient and modularity analysis

This network statistic will help in grouping L1 processes based on the strength of their relationships into distinct communities within the overall Nuclear Power Plant Operational Readiness Program. The clustering coefficient provides the ability to measure the level at which L1 processes are grouped together, as opposed to being equally or randomly connected across the network. The average Clustering Coefficient for this network is 0.268 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis showed that L1 Processes are distributed across three distinct communities. The size distribution of the three clusters is shown in figure 5.10.

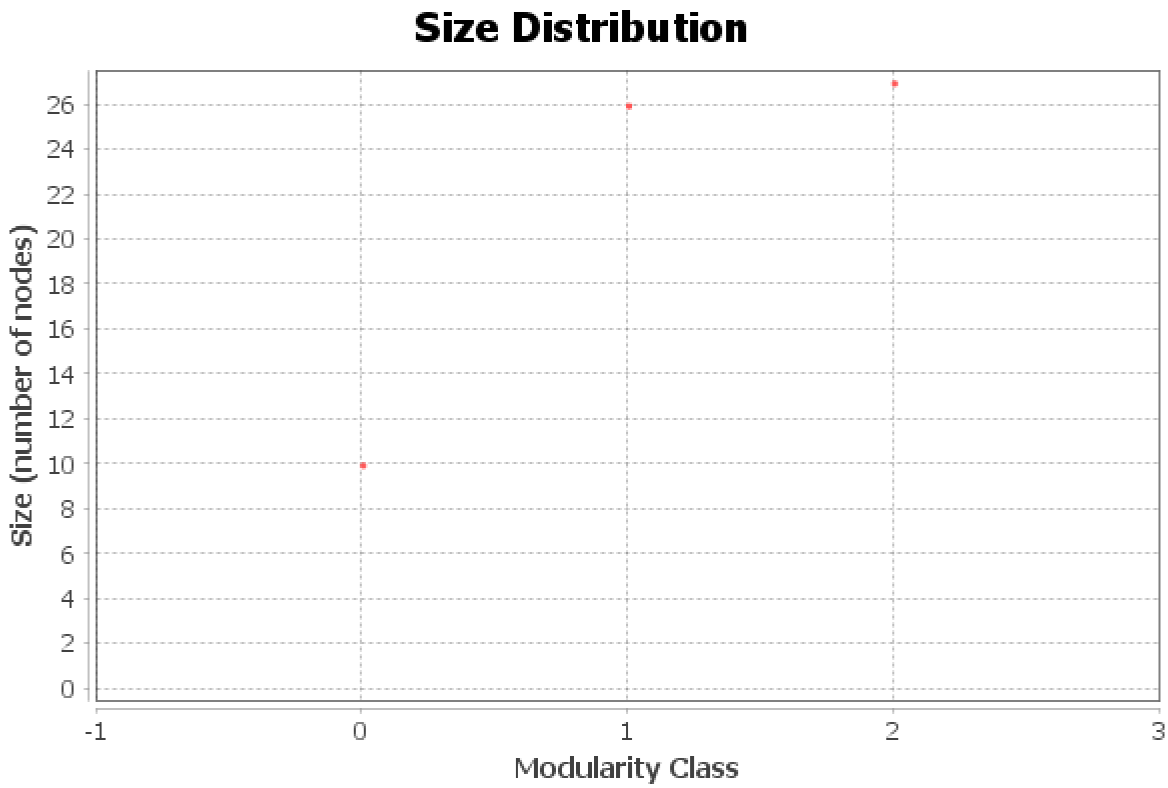


Figure 5. 10 L1 processes network modularity class size distribution

As shown in figure (5.9), the first cluster with the lowest number of Level 1 process on the upper left hand includes the Monitor and Control Plant Chemistry Process which turned out to be most influential node in this network according to its Betweenness Centrality. This finding is no surprise since the majority of focus in the operational readiness program is typically directed towards getting all organizational capabilities up to the level required to satisfy all Regulatory Requirements to commence the safe Fuel Load, Initial Criticality and most importantly maintain safe and reliable operations through controlling Plant Chemistry by qualified operators for the lifecycle of the Nuclear Power Plant. Each of the three clusters seems to be contributing to the success of the Nuclear Power Plant Operational Readiness from a unique perspective and timeframe. The ‘Orange’ cluster seems to be those processes required to ensure the initial commencement of operations like Operating and Monitoring Structures, Systems and Components, Perform Planning, Perform Scheduling & Perform Preventive Maintenance as per the Work Management process. The ‘Purple” cluster seems to be the support process enabling the initial startup. Those processes include Strategic Sourcing Process, Finance process, Providing Legal Services, Provide Information Technology Services, and Licensing and Permits process. The ‘Green’ cluster provides a unique perspective towards those processes pertaining to Managing Outages, Contamination, and Perform Decommissioning. This clustering provides a different perspective on the relationships and Interactions between L1 processes which can ultimately change our perspective on how to manage certain processes to maintain the seamless and robust structure of this network. However, the identified structural properties of clustering in the L1 interactions strongly correlates with the network's robustness to failure. It turned out that the first major hubs are concentrated around specific L1 processes. This structural configuration might pose some risk of hindering the robustness and resilience of the interactions between L1 processes.

5.4.4 Network centrality measures

Centrality statistics are essential measures of the information flows and efficiency of interaction between L1 processes. The Closeness Centrality is the inverse of the mean shortest path between a node and all other nodes in the network that is reachable from it. This metric reflects the ability of a L1 Process to access and transmit information within the network of L1 Processes quickly. It also indicates how close each L1 Process is from every other process in this interaction. Betweenness centrality measures the degree L1 Processes offer the most direct path/Bridges between otherwise disconnected Clusters. A higher betweenness centrality score for L1 Processes will provide a perspective on how critical that process to maintain the structure of the network. into the influence that process has on the network. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. Figure 5.11 highlights the betweenness centrality distribution and the closeness centrality distribution in the interactions amongst L1 processes.

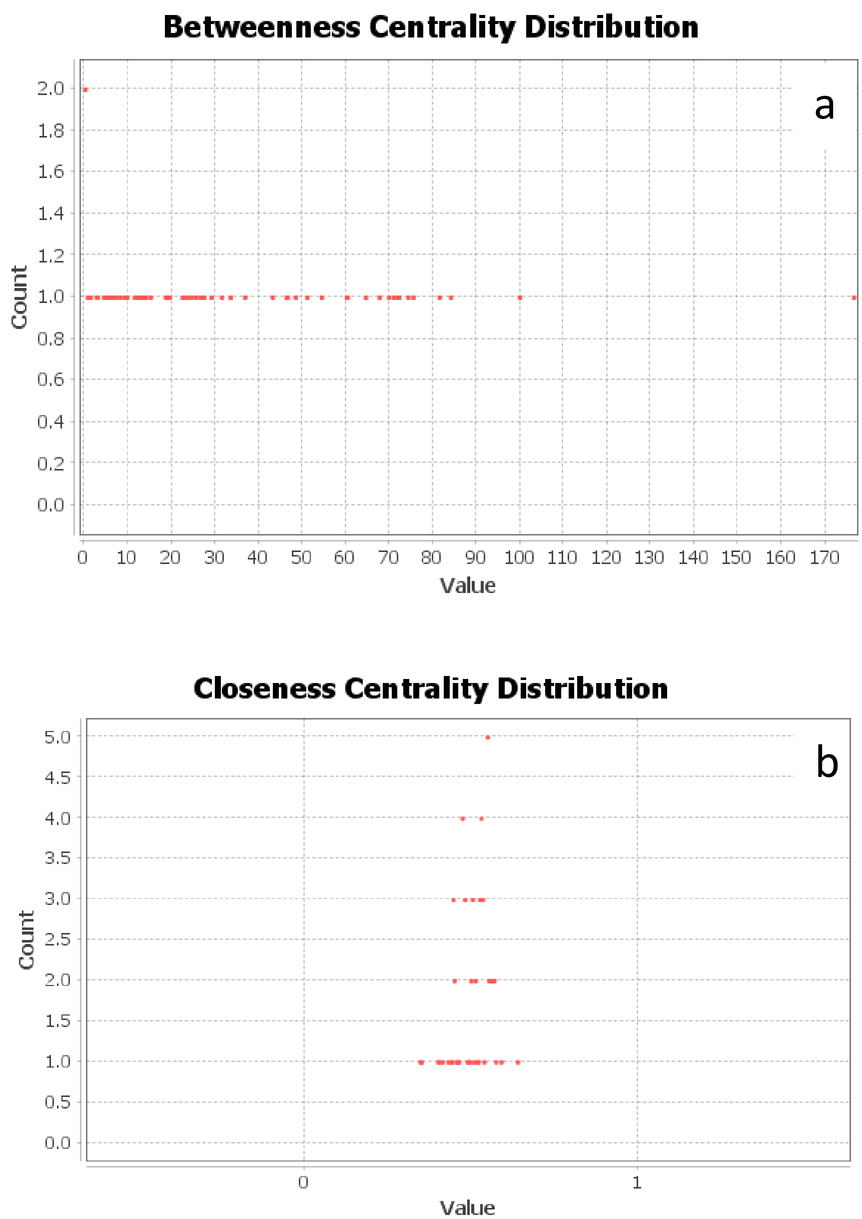


Figure 5. 11 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions amongst L1 processes

Looking at the graph (5.11), it is clearly shown that the distributions of L1 processes based on their Closeness Centrality appear to follow the normal distribution pattern. L1 process in the Nuclear Power Plant Operational Readiness Program is centered around the 0.5 for the closeness centrality and distributed in count on arranging from 1-5 nodes. This observation indicates that most of L1 processes have almost the same influence according to this network statistic. However, Betweenness Centrality gives another perspective. The table (5.14) below highlights L0 processes with the highest Betweenness Centrality. Nodes with the highest Betweenness Centrality like Plant Chemistry Monitoring and Control (Betweenness Centrality = 176.44), Strategic Sourcing Management (Betweenness Centrality = 99.75), Finance Process (Betweenness Centrality=83.93), and Legal Process (Betweenness Centrality= 81.39) are essential to maintain the efficient and effective interaction between L1 processes. Therefore, these processes should be managed with attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining the health of the Management System.

Table 5. 14 L1 processes with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality	modularity class
78	OP003	0.639175	176.445406	0
69	MS001	0.590476	99.757487	2
86	SS002	0.534483	83.930516	2
87	SS003	0.516667	81.395428	2
90	SS006	0.525424	75.378316	2
65	LP007	0.574074	74.201618	2
61	LP003	0.568807	72.081234	2
49	CM003	0.563636	71.656931	1
94	SS011	0.558559	70.783487	2
84	PI006	0.553571	69.717737	2

75	NF003	0.563636	67.608865	1
89	SS005	0.548673	64.385563	0
76	OP001	0.53913	60.268806	1
68	MO003	0.568807	60.062313	2
100	WM002	0.558559	54.306695	1
47	CM001	0.529915	50.913786	1
101	WM003	0.548673	48.367476	1
108	WM011	0.525424	46.461447	0
85	SS001	0.553571	46.314289	2
81	PI003	0.548673	43.00016	1

The main focus of this work is to understand the interaction between L1 processes. Therefore, it is important to investigate in detail the nature of influence the 'Plant Chemistry monitoring and control' has in this network. To do so, the ego network technique will be used. An Ego Network consists of a focal node (also called the "ego") and all the nodes that have some relationship to it. This relationship can be direct, meaning that the nodes are adjacent, or it can be established as a second level relationship (friend of a friend). Using Ego Network Analyses help to model and study the influence of central modes by applying network statistics on that focused snapshot of the bigger network. The below graph (5.12) was produced by Gephi using the Plant Chemistry monitoring and control Ego Network.

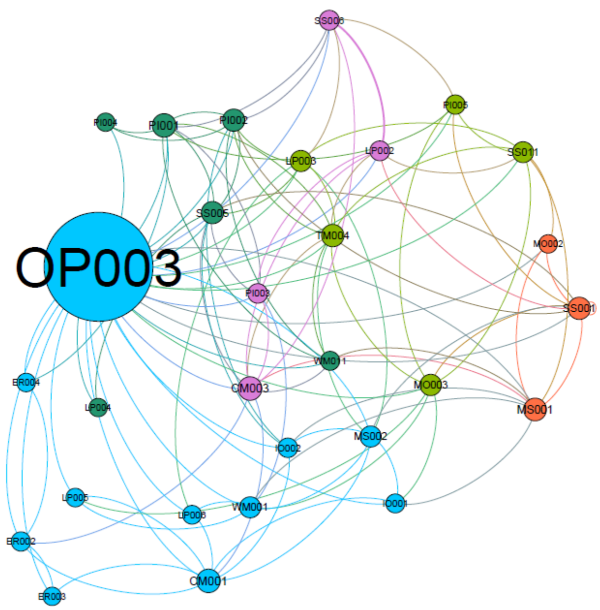


Figure 5. 12 Ego network of plant chemistry monitoring and control process

The structural characteristics of the Plant Chemistry monitoring and control Ego Network are shown in Table (5.15).

Table 5. 15 Characteristic of plant chemistry monitoring and control Ego network

Characteristic	Value	% Visible
Total number nodes	29	46.03%
Total number of Edges	108	30.34%

As shown in figure (5.12), the interaction between Plant Chemistry monitoring and control process with other L1 processes seems to be inefficient and forming a low level of interactions as indicated by the below network statistical measures. The Ego Network density is considerably smaller than the value for a complete graph. This means that of all the connections that may exist in this network including direct links with Plant Chemistry monitoring and control process a very small fraction of them is present. The maximum path length between in this ego network is 1.73 as indicated by the average path length for a graph, we can conclude that the graph is inefficient from a communication standpoint since the maximum path length is almost the same as the network diameter. Key statistics for the Plant Chemistry monitoring and control Ego Network are highlighted in table 5.16.

Table 5. 16 Statistics of plant chemistry monitoring and control Ego network

Network statistic	Value
Graph density	0.266
Network diameter	2
Average Path length	1.73
Average Clustering Coefficient	0.521

5.5. Interactions between level 0 processes and stakeholders in the nuclear power plant operational readiness program

This Network looks at interactions between level 0 Processes and Stakeholders. It depicts the main processes in the Management System structure and People dependencies associated with them. This mapping also shows all Stakeholders (tagged as **positions or organizational Unit**) whose being involved in the implementation of each L0 Process covering a mixture of functions, organizational units and positions. The list of L0 process covered all Management Systems processes and each L0 process was given a code and a node label as per table (5.2). Similarly, all Stakeholders have been identified and given a code and a node label as per Table (5.17).

Table 5. 17 List of stakeholders identified for this study

Stakeholder (positions or organizational Unit)	Node ID	Node Label
Work Management and Outage Planning (Site Oversight)	370	PPL1
Plant Management	371	PPL2
Work Management	372	PPL3
Engineering	373	PPL4
Maintenance	374	PPL5
Operations	375	PPL6
Radiation Protection	376	PPL7
Chemistry	377	PPL8
Procurement Supply Chain	378	PPL9
Quality Assurance	379	PPL10
Security	380	PPL11
Emergency Preparedness	381	PPL12
Work Management and Outage Planning (Site Oversight).	382	PPL13
Maintenance	383	PPL14
Outage Management	384	PPL15
Licensing and Regulatory Affairs	385	PPL16
Enterprise Risk Management	386	PPL17
Corporate Finance	387	PPL18
Reactor Engineering (Site and Site Support)	388	PPL19
Nuclear Fuel Management	389	PPL20
Radiological Protection	390	PPL21
Training	391	PPL22
Safeguards	392	PPL23
Fuel Cycle Management	393	PPL24
Radiation Protection Organization	394	PPL25
Plant Manager	395	PPL26
Environment Depart	396	PPL27
ALARA Committee	397	PPL28
QA Audit department	398	PPL29
Quality Surveillance department	399	PPL30
Comms Director	400	PPL31
selected suppliers	401	PPL32
Employee Concerns Program	402	PPL33
Enterprise Risk Management team	403	PPL34
Corporate Development section	404	PPL35
Program Management Office and Program Delivery sections	405	PPL36
Radiological Waste Management	406	PPL37
PGTC	407	PPL38
Site Projects	408	PPL39
Reactor Engineering	409	PPL40

Fire Protection	410	PPL41
Health and Safety	411	PPL42
Plant Operations	412	PPL43
Corporate (Site) Operations	413	PPL44
all Functions within the Power block	414	PPL45
all Functions within the Power block	415	PPL46
Nuclear Risk Management Department	416	PPL47
Probabilistic Risk Assessment	417	PPL48
Accident Management	418	PPL49
Severe Accident Analysis	419	PPL50
Project Management	420	PPL51
Human Performance Group	421	PPL52
All other departments across	422	PPL53
Operating Experience Group	423	PPL54
Nuclear Safety Culture	424	PPL55
Nuclear Oversight	425	PPL56
VP Licensing & Regulatory Affairs.	426	PPL57
Legal-Holding	427	PPL58
Environmental Management	428	PPL59
Human Capability	429	PPL60
Procurement & Supply Chain	430	PPL61
Information and Communication Technology	431	PPL62
Communications	432	PPL63
Export Control	433	PPL64
Physical and Cyber Security	434	PPL65
VP Construction Interface	435	PPL66
Nuclear Risk Management	436	PPL67
Radiological Protection (RP)	437	PPL68
Quality Assurance (QA)	438	PPL69
Finance	439	PPL70
LRA & Export Controls	440	PPL71
Legal department	441	PPL72
Legal Department-Compliance Manager	442	PPL73
Audit, Risk & Compliance Committee	443	PPL74
CEO	444	PPL75
Internal Audit	445	PPL76
Board	446	PPL77
Legal Compliance	447	PPL78
VP (Vice-President) Information and Communications Technology	448	PPL79
Human Capital Management department	449	PPL80
Capacity Building & Training Department	450	PPL81
ENEC Chief Program Office	451	PPL82

VP - Construction Interface	452	PPL83
VP, Construction Interface	453	PPL84
Plant Fire Protection organization, who report to the plant manager.	454	PPL85
Finance department.	455	PPL86
Finance & Accounting-Holding	456	PPL87
Facilities Management department	457	PPL88
Prime Contractor	458	PPL89
Environment and Sustainability department	459	PPL90
VP, Operational Support.	460	PPL91
Site Engineering	461	PPL92
Plant Engineering	462	PPL93
Simulator group	463	PPL94
Licensing	464	PPL95
Contractors/IC	465	PPL96
Corporate Communications department	466	PPL97
Emergency Response Organization (ERO)	467	PPL98
MS Director	468	PPL99
Procedure Management Group (PMG)	469	PPL100
Information and Communications Technology (ICT)	470	PPL101
Responsible Department Heads	471	PPL102
Function Administrators (Function Admin)	472	PPL103
DCRM Head	473	PPL104
Chief Operations Office	474	PPL105
Commissioning Oversight department.	475	PPL106

Data for this network was imported using the above-mentioned structure into Gephi, Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced Figure (5.13)

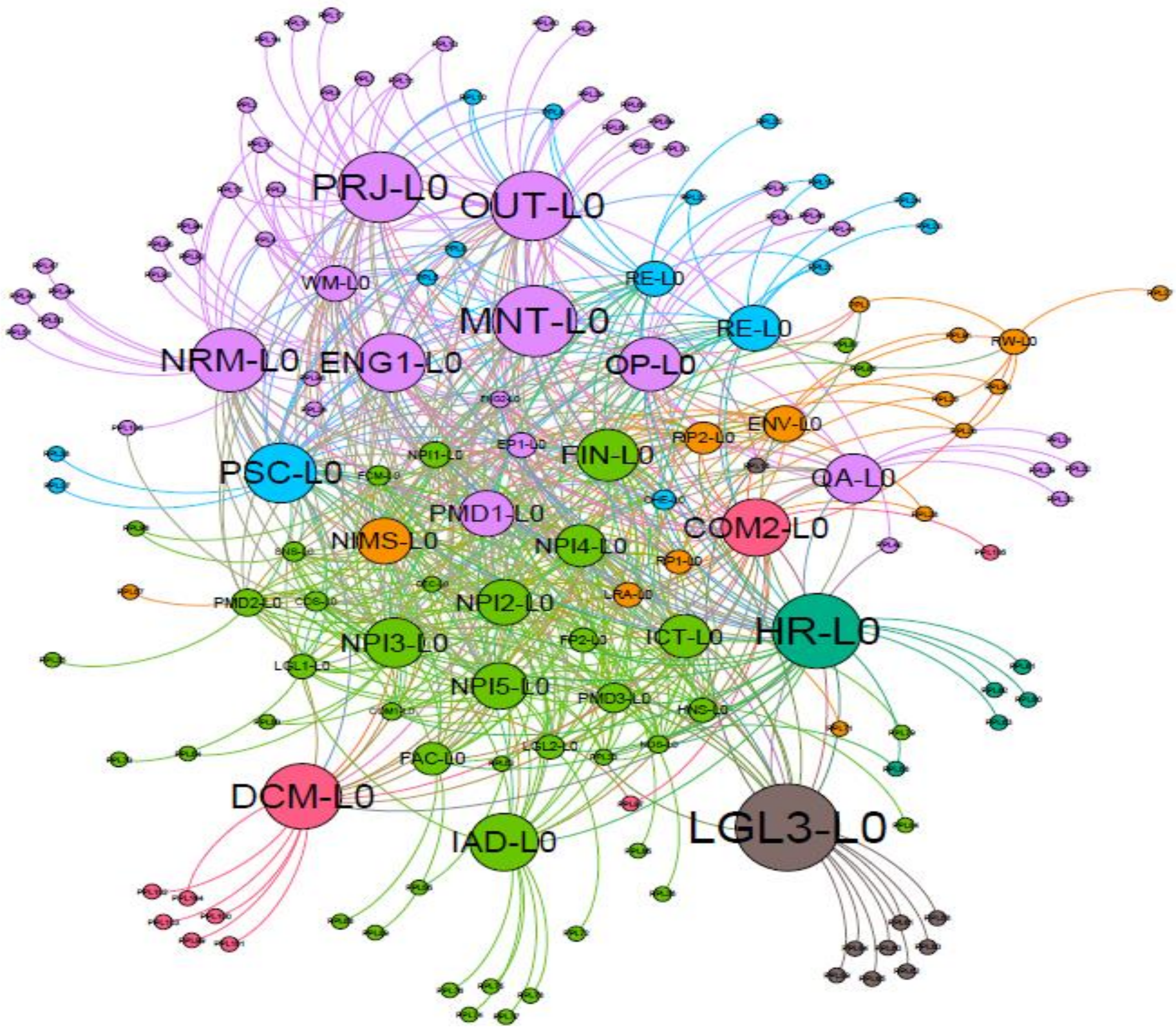


Figure 5. 13 Level 0 processes and stakeholders network

5.5.1 General characteristics

The structural characteristics of the L0 and Stakeholders network are shown in Table (5.18).

Table 5. 18 Structural characteristics of the L0 to stakeholders intersections

Characteristic	Value
Total number of L0 and Stakeholders nodes	152
Total number of undirected interactions (Edges)	644

As shown in graph (5.13), the initial observation is that the interaction between L0 process and Stakeholders looks relatively low dense and nodes are distributed across seven distinct communities. The maximum number of connections required to traverse the interaction between L0 to stakeholders is 5 nodes as indicated by the Network Diameter. Combining this observation with the fact that the maximum path length between L0 to stakeholders is 2.8 as indicated by the average path length for a graph, we can conclude that the graph is efficient from a communication standpoint since the maximum path length between L0 to stakeholders is less than the network diameter.

5.5.2 Network density

Graph density is calculated to measure how tightly interconnected the interaction between L0 processes and stakeholders is by examining the proportion of existing connections relative to the possible total number of edges. A high degree of interaction across the network will have higher density levels while weak interactions results in low Network Density. In this network, density measures the linkage between L0 Processes and Nuclear power plant Operational Readiness Stakeholders. The value of network density ranges from 0 to 1. A density close to 1 indicates that all L0 Processes are strongly linked to Stakeholders within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interaction between

L0 Processes and Stakeholders. A value close to 0 will indicate the existence of weak interaction between L0 Processes and Nuclear power plant Operational Readiness Stakeholders. Furthermore, the density of the interaction in this network can be used to measure the cohesiveness and robustness of the interaction between L0 Processes and Nuclear power plant Operational Readiness Stakeholders, as well as, the coverage of interfaces with Nuclear power plant Operational Readiness Stakeholders as part of the BAU design within the nuclear power plant. The density of interaction between L1 Processes and Stakeholders is 0.056 which suggests that there is a low level of interaction among L0 processes and Nuclear power plant Operational Readiness Stakeholders.

5.5.3 Network clustering coefficient and modularity analysis

This network statistic will help in grouping L0 processes and Nuclear power plant Operational Readiness Stakeholders based on the strength of their relationships into distinct clusters. Clustering coefficient provides the ability to measure the level at which L0 processes and Nuclear power plant Operational Readiness Stakeholders are grouped together, as opposed to being equally or randomly connected across the network. High Clustering coefficient scores are highly anticipated from tightly knit hubs and distinctive communities, whereas dispersed and scattered networks usually produce lower scores. The average Clustering Coefficient for this network is 0.259 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis showed that L0 Processes and stakeholders are distributed across seven distinct communities. The size distribution of the seven clusters is shown in figure 5.14.

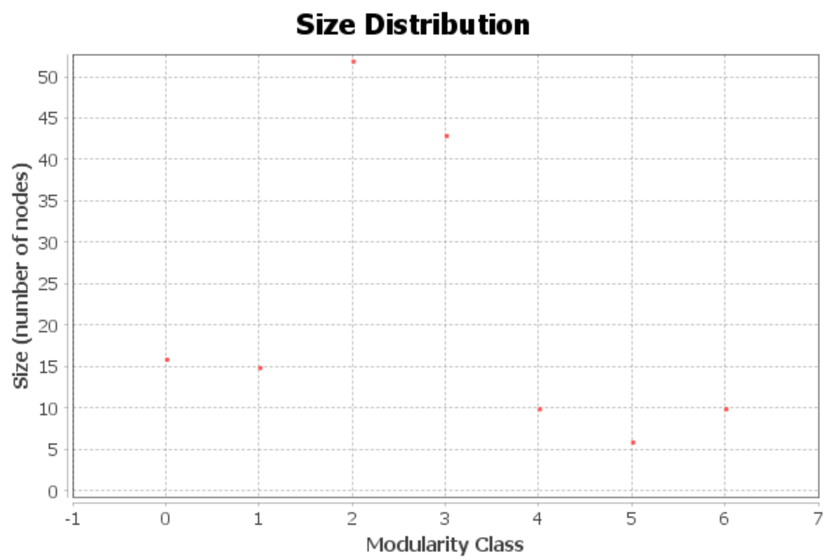


Figure 5. 14 Clusters size distribution in the interactions between L0 processes and stakeholders

Referring to figure (5.13), the green and the purple clusters are the most prominent among the seven communities within the network structure. This observation suggests that certain stakeholder and/or stakeholders' groups within the Nuclear Power Plant Operational Readiness Program are linked to specific Level 0 processes and they do not usually interact with other processes even if the original L0 process they are linked to is interacting with another L0. Furthermore, the hub and spoke model is also prominent in this network where certain processes Like LGL3-L0, IAD-L0, DCM-L0 have a unique group of stakeholders linked into them who do not interact with any other Process in the network. Similarly, OUT-L0, MNT-L0, PRJ-L0, and NRM-L0 showed the same phenomena. This observation supports some findings from the analysis of the first network on the behavior of the Process-based Management System structure of the Nuclear Power Plant Operational Readiness. The Network clustering provides a different perspective on the relationships and Interactions between L0 processes and Stakeholders in terms of segregating those communities as Core cluster, Support cluster, and Oversight cluster, which can ultimately change our perspective on how to manage such interaction.

The clustering and modularity characteristics of interactions between L0 processes and Nuclear power plant Operational Readiness Stakeholders are strongly correlating with the network's robustness to failure. It turned out that the 7 major hubs are concentrated around specific L0 processes which are linked to a unique group stakeholder. To some degree, this structural configuration allows for a fault-tolerant behavior and fosters resilience in the interaction between L0 Processes and L0 processes and Nuclear power plant Operational Readiness Stakeholders.

5.5.4 Network centrality measures

Centrality measures help to demystify certain characteristics in the interactions between L0 processes and Nuclear power plant Operational Readiness Stakeholders. Centrality measures help in identifying which components of the Interactions between Level 0 Processes and Stakeholders in the Nuclear Power Plant Operational Readiness Program have more influence over other components. Furthermore, Centrality is an essential measure of the information flows between L0 processes and Nuclear power plant Operational Readiness Stakeholders when assessed jointly with other statistics to form a comprehensive and accurate understanding of information flow and efficiency of interaction. The Closeness Centrality is the inverse of the mean shortest path between a node and all other nodes in the network that is reachable from it. This metric reflects the ability of L0 Processes and stakeholders to access and transmit information through the network quickly. It also indicates how close a L0 process or a specific stakeholder is from every other node in this network. Betweenness centrality measures the degree L0 Processes and Nuclear power plant Operational Readiness Stakeholders on the other hand offer the most direct bridges between otherwise disconnected Clusters. A higher betweenness centrality score for a node will provide a perspective on how critical that node to maintain the structure of the network. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. Figure 5.15 presents the results of the analysis of betweenness and closeness centrality in interactions between L0 processes and stakeholders.

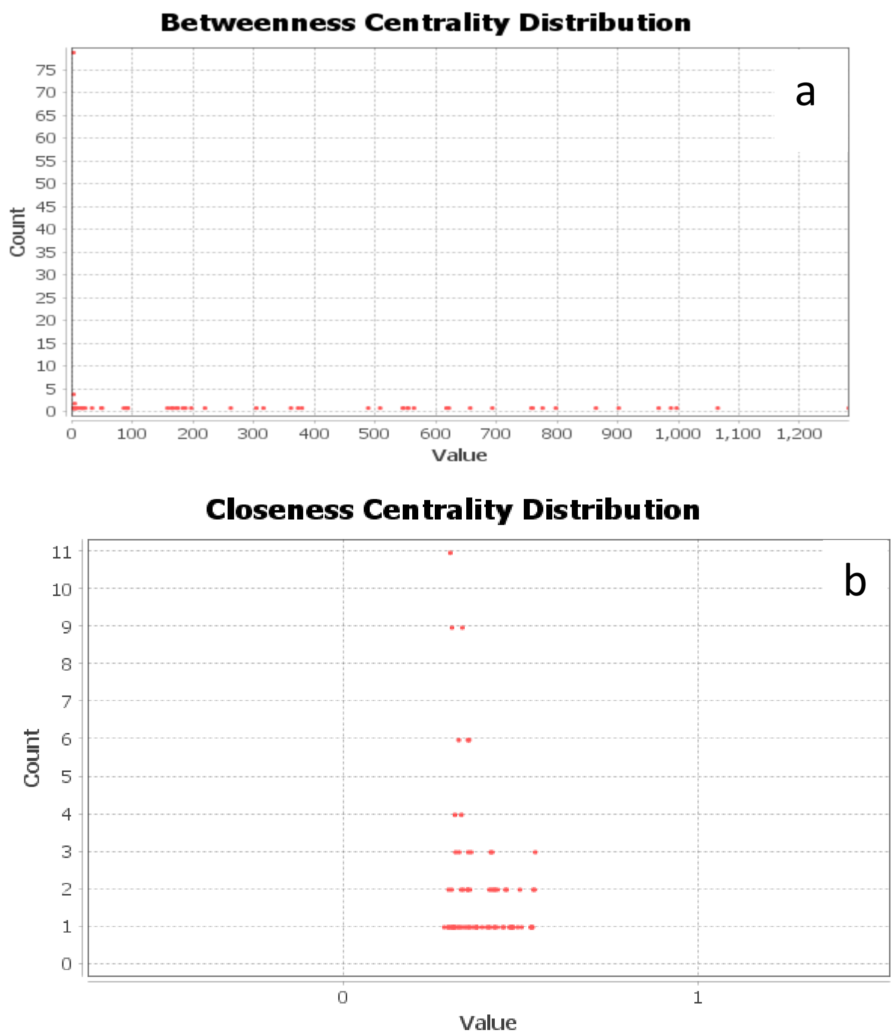


Figure 5. 15 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and stakeholders

As shown in figure 5.15/b, the distributions of L0 processes and the stakeholders based on their Betweenness Centrality is a bit skewed to the right. As one can see, the majority of the L0 processes and the stakeholder's nodes have the same closeness (around 0.5) with a portion pulling the curve towards the higher end. Still, from this angle, we can conclude that majority of L0 processes and stakeholders' nodes have the same influence over this network's structural integrity and flow of information. and integrity. Betweenness centrality provides a different perspective. The table (5.20) below highlights components with the highest Betweenness Centrality. Nodes with the highest Betweenness Centrality like LGL3-L0 (Betweenness Centrality = 1278), HR-L0 (Betweenness Centrality = 1062), MNT-L0 (Betweenness Centrality=994), PRJ-L0 (Betweenness Centrality=985), and OUT-L0 (Betweenness Centrality= 965) are essential to maintain the efficient and effective interaction between L0 processes and Stakeholders. Therefore, these processes should be managed with attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence on fostering effective and efficient communications and sharing of data. Table 5.19 lists L0 Processes with the highest Betweenness Centrality.

Table 5. 19 L0 processes with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality	modularity class
15	LGL3-L0	0.428977	1278.764	4
40	HR-L0	0.535461	1062.612	5
42	MNT-L0	0.491857	994.7999	2
45	PRJ-L0	0.471875	985.4051	2
46	OUT-L0	0.496711	965.3037	2
35	DCM-L0	0.419444	899.4057	6
12	NRM-L0	0.468944	861.807	2
17	PSC-L0	0.527972	795.705	0
1	ENG1-L0	0.491857	773.7457	2
5	IAD-L0	0.419444	757.328	3
38	COM2-L0	0.522491	755.3425	6
21	OP-L0	0.485531	690.9472	2
31	FIN-L0	0.526132	654.5881	3
26	NPI3-L0	0.535461	619.0927	3
4	QA-L0	0.446746	615.3291	2

The main focus of this work is to understand the interaction between L0 processes and Stakeholders in the Nuclear Power Plant Operational Readiness Program. Therefore, it is important to investigate in detail the nature of influence the ‘Statutory and Regulatory Requirements Management Process’ has in this network. To do so, the ego network technique will be used. The below graph (5.16) was produced by Gephi using the Statutory and Regulatory Requirements Management Process Ego Network.

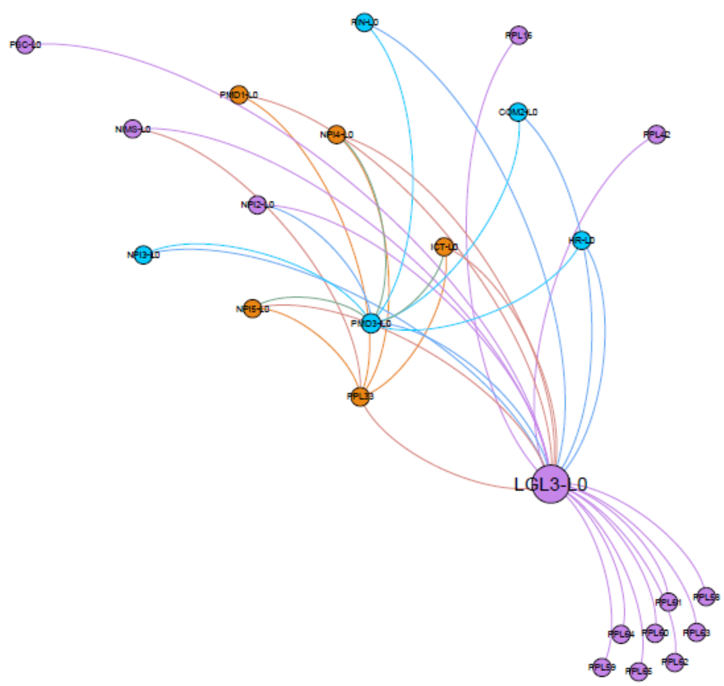


Figure 5. 16 Ego network of the process of managing statutory and regulatory requirements

The structural characteristics of the statutory and regulatory requirements management process Ego network are shown in table 5.20.

Table 5. 20 Characteristic of 'statutory and regulatory requirements process' ego network

Characteristic	Value	% Visible
Total number nodes	24	15.79%
Total number of Edges	36	5.59%

As shown in figure (5.16), the interaction between the process of managing Statutory and Regulatory Requirements and other processes and Stakeholders appears to be dispersed and forming low level of interactions as indicated by the below network statistical measures. However, the Ego Network density is considerably higher than the value for a complete graph. This means that of all the connections that may exist in this network including direct links with the Statutory and Regulatory Requirements Management Process, a very good portion of them are already established. The maximum path length between in this ego network is 1.86 as indicated by the average path length for a graph, we can conclude that the graph is relatively efficient in terms of transferring information across different modes since the maximum path length is less than the network diameter. Table 5.21 summarizes key network statistics for 'Statutory and Regulatory Requirements Management Process' Ego Network

Table 5. 21 Statistics of 'statutory and regulatory requirements management process' ego network

Network statistic	Value
Graph density	0.13
Network diameter	2
Average Path length	1.86
Average Clustering Coefficient	0.739

Despite the fact that the Hub and spoke pattern usually fosters more resilience and failure-proof characteristics, it also poses some considerable risks especially if linked to an influential node like in this case Statutory and Regulatory Requirements Management Process. Critical areas like Export Control, Physical and Cyber Security, and Information and Communication Technology might be affected.

5.6. Interactions between level 1 processes and stakeholders in the nuclear power plant operational readiness program

This analysis provides one level deeper into depicting all interactions between L1 Processes and Stakeholders. It visualizes all Level 1 process in the Management System structure and People dependencies associated with each one of them. This mapping also shows all Stakeholders (tagged as **positions or organizational Unit**) whose being involved in the implementation of each L1 Process covering a mixture of functions, organizational units and positions. The list of L1 processes covered all Management Systems processes and each L1 process was given a code and a node label as per table (5.13). Similarly, all Stakeholders have been identified and given a code and a node label as per Table (5.18).

Data for this network was imported using into Gephi, Force atlas algorithm was applied and the final network graph was produced (Figure 5.17)

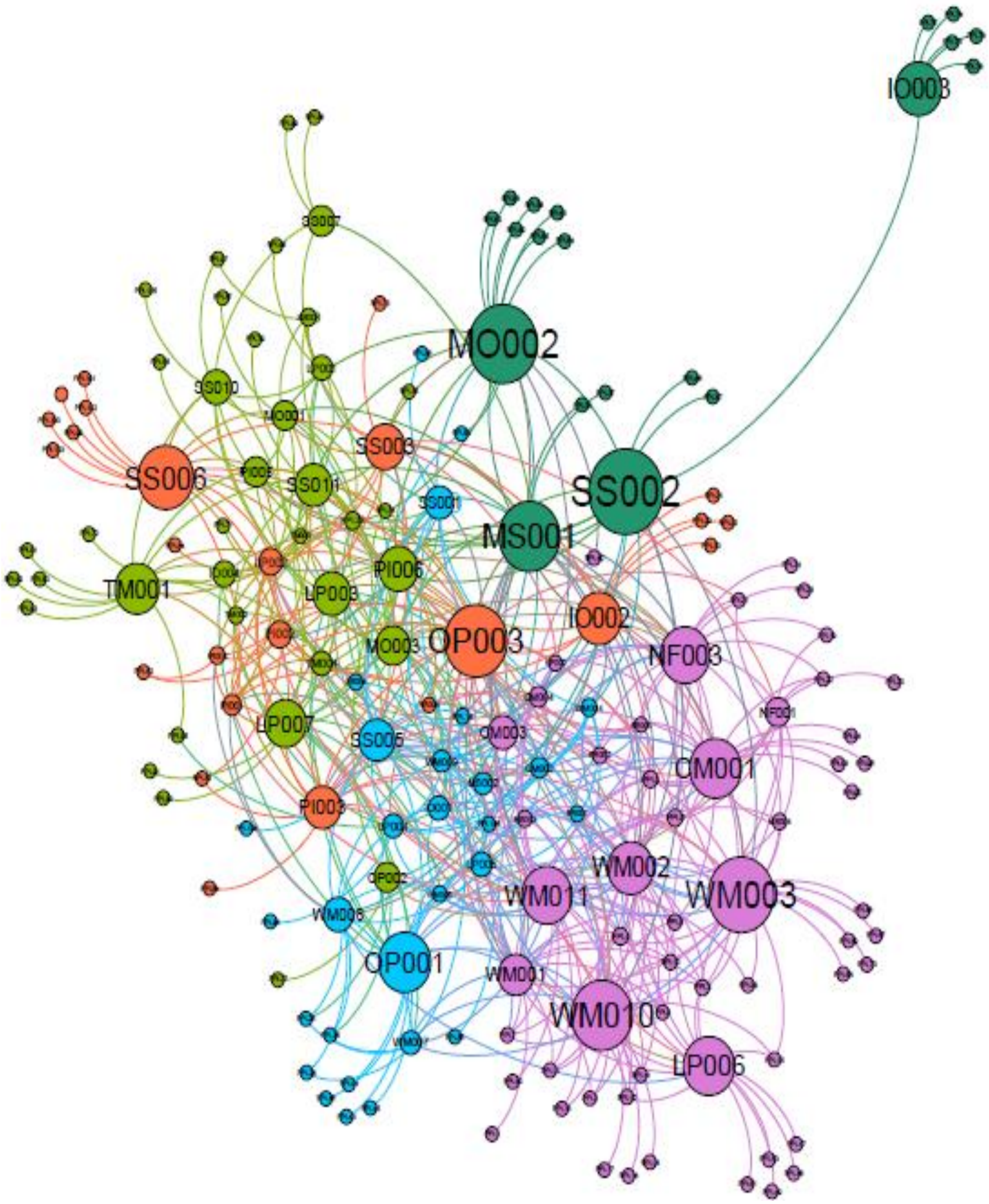


Figure 5. 17 Level 1 processes and stakeholders network

PG1	Core Monitoring program	288
PG2	Other affecting SSCs	289
PG3	MNT-PGD-0003, Maintenance Program Description	290
PG4	ENG-PGD-MR-0001, Maintenance Rule Program Description	291
PG5	MNT-PRC-0070, Preventive Maintenance Program	292
PG6	NIMS-REF-0001, Program Catalog	293
PG7	ENG-PGD-SHE-0001, System Health Program Description	294
PG0	None	295
PG8	Accident Management	296
PG9	Ageing Management	297
PG10	Air Operated Valves (AOVs)	298
PG11	Boric Acid Corrosion (BAC) Control	299
PG12	Chemistry	300
PG13	Containment Leak Rate Testing	301
PG14	Control Room Envelope Habitability	302
PG15	Core Monitoring	303
PG16	Corrective Action	304
PG17	Counterfeit, Fraudulent, Suspect Items	305
PG18	Cyclic and Transient Monitoring	306
PG19	Diesel Fuel Oil Testing	307
PG20	Document Control and Records Management	308

PG21	Emergency Preparedness	309
PG22	Employee Concerns	310
PG23	Equipment Qualification	311
PG24	Erosion and Corrosion Monitoring	312
PG25	Export Control	313
PG26	Fire Protection	314
PG27	Foreign Material Exclusion	315
PG28	Fuel Integrity	316
PG29	Health & Safety	317
PG30	In-Service Inspection	318
PG31	In-Service Testing	319
PG32	Maintenance	320
PG33	Maintenance Rule	321
PG34	Measuring and Test Equipment (M&TE)	322
PG35	Meteorological Monitoring	323
PG36	Motor Operated Valves (MOVs)	324
PG37	Off Site Dose Calculation Program	325
PG38	Operational Radiation Protection	326
PG39	Performance Improvement	327
PG40	Primary Coolant Outside of Containment	328
PG41	Probabilistic Risk Assessment	329
PG42	Process control	330
PG43	Quality Assurance	331
PG44	Radioactive Waste Management	332

PG45	Reactor Coolant Pressure Boundary Material Surveillance	333
PG46	Safeguards	334
PG47	Site Security	335
PG48	Steam Generator Management	336
PG49	Surveillance	337
PG50	System Health Evaluation	338
PG51	Training and Personnel Qualification	339
PG52	Site Security Program,	340
PG53	Emergency Preparedness Program.	341
PG54	Export Control Program	342
PG55	Meteorological Monitoring Program (ENV-PGD-0001, Meteorological Monitoring Program Description)	343
PG56	Offsite Dose Calculation Manual (ODCM) Program (ENV-PGD-0002, Offsite Dose Calculation Manual (ODCM) Program Description)	344
PG57	QA-PGD-0002, Quality Assurance Program Description	345
PG58	HNS-PGD-0001, Health and Safety Program Description	346
PG59	CNT-PGD-0001, Training and Personnel Qualification Program Description	347
PG60	NPI-PGD-0001, Performance Improvement Program Description	348
PG61	NPI-PGD-0002, Corrective Action Program Description	349
PG62	QA-PGD-0001, Counterfeit, Fraudulent and Suspect Items (CFSI) Program Description	350

PG63	CHE-PGD-0002, Diesel Fuel Oil Testing Program Description	351
PG64	EXP-PGD-0001, Export Control Program Description	352
PG65	ENG-PGD-EQP-0001, Equipment Qualification Program Description	353
PG66	MNT-PGD-0004, Measuring and Test Equipment (M&TE) Program Description	354
PG67	DCM-PGD-0001, Document Control and Records Management Program Description	355
PG68	Primary Coolant Outside Containment	356
PG69	RW-PGD-0001, Process Control Program Description	357
PG70	RW-PGD-0002, Radioactive Waste Management Program Description	358
PG71	RP-PGD-0001, Radiation Protection Program	359
PG72	ENV-PGD-0002, Offsite Dose Calculation Program	360
PG73	Quality Assurance	361
PG74	Training and Personnel Qualifications	362
PG75	Performance Improvement Program	363
PG76	All programs	364
PG77	Emergency Preparedness	365
PG78	Training and Personnel Qualification Program	366
PG79	Employee Concerns Program	367
PG80	Radiation Protection	368
PG81	RP-PGD-0001, Radiation Protection	369

5.6.1 General characteristics

The structural characteristics of the L0 to Regulatory Requirements network are shown in table 5.22.

Table 5. 22 Structural characteristics of the L1 processes interactions with stakeholders

Characteristic	Value
Total number of L1 Processes and Stakeholders nodes	178
Total number of undirected interactions (Edges)	550

As shown in figure (5.17), the structural characteristics of the L1 Processes interactions with Nuclear power plant Operational Readiness Stakeholders network stakeholders look similar to the characteristics of Interactions between L0 processes and Nuclear power plant Operational Readiness Stakeholders. The interaction between L1 process and Nuclear power plant Operational Readiness Stakeholders network stakeholders seems to be efficient and the flow of information seems to be smooth as indicated a relatively low dense network. The maximum number of connections required to traverse the interaction between L1 and Nuclear power plant Operational Readiness Stakeholders network stakeholders or in other words the number of steps taken between the two most distant nodes in this interaction to reach one another is 6 nodes as indicated by the Network Diameter. Combining this observation with the fact that the maximum path length in the interactions between L1 and Nuclear power plant Operational Readiness Stakeholders network stakeholders is 3.03 as indicated by the average path length for a graph, we can conclude that this interaction is streamlined and efficient from a communication and information flow standpoint since the maximum path length in the interactions between L1 and Nuclear power plant Operational Readiness Stakeholders network stakeholders is less than the network diameter.

5.6.2 Network density

Network density is a graph statistical measure that is calculated by examining the proportion of existing connections between L1 processes in the Nuclear Power plant Management System and the Nuclear power plant Operational Readiness Stakeholders network stakeholders relative to the possible total number of connections to assess how tightly interconnected is this interaction. A high degree of interaction between L1 processes in the Nuclear Power plant Management System and the Nuclear power plant Operational Readiness Stakeholders will have higher density levels while weak interactions result in low Network Density. In this network, the value of network density ranges from 0 to 1. A density close to 1 indicates that L1 Processes are strongly linked to Stakeholders within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interaction between L1 Processes and Nuclear power plant Operational Readiness Stakeholders. A value close to 0 will indicate the existence of weak interaction between L1 Processes and Stakeholders. The density of interaction between L1 Processes and Nuclear power plant Operational Readiness Stakeholders is 0.039 which suggests that there is a low level of interaction among L1 processes and Stakeholders in the Nuclear power plant Operational Readiness Program.

5.6.3 Network clustering coefficient and modularity analysis

This network statistic will help in grouping L1 Processes and associated Nuclear power plant Operational Readiness Stakeholders based on the strength of their relationships into distinct clusters. Clustering coefficient provides the ability to measure the level at which L1 processes and

Nuclear power plant Operational Readiness Stakeholders are grouped together, as opposed to being equally or randomly connected across the network. As mentioned earlier, clustering coefficient Scores have an inverse correlation with other statistics, including several of the centrality measures, mainly when we are analyzing at the global level (the entire network). Clustering coefficient calculation is based on measuring the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available in the interactions of L1 processes and Nuclear power plant Operational Readiness Stakeholders. Essentially, the Network clustering coefficient measures the degree to which the second layer of L1 processes or Nuclear power plant Operational Readiness Stakeholders are connected to one another (Friends of friends). High Clustering coefficient scores are highly anticipated from tightly interweaved clusters and distinctive communities, whereas dispersed and fragmented networks might be expected to produce lower scores. The average Clustering Coefficient for this network is 0.224 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis showed that L1 Processes and stakeholder's nodes are distributed across 5 distinct communities. The size distribution of the 5 clusters is shown in figure 5.18.

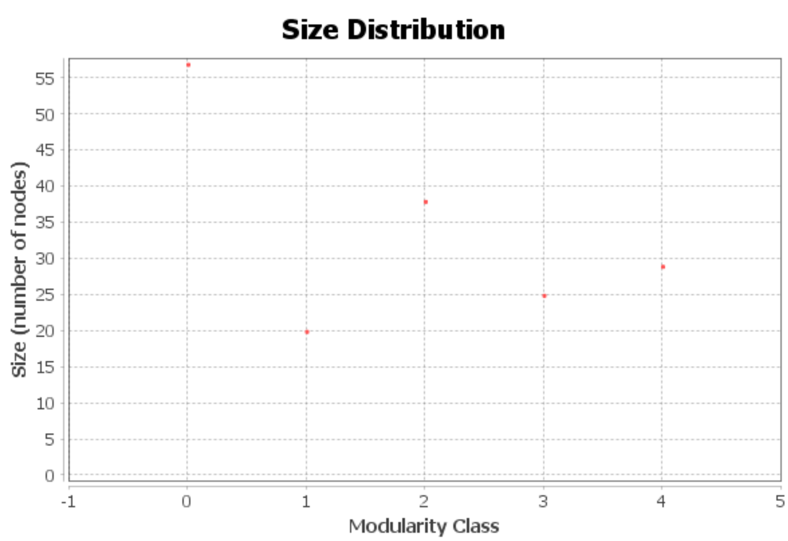


Figure 5. 18 Clusters size distribution in the interactions between L1 processes and stakeholders

This property strongly correlates with the network's robustness to failure. The purple being the biggest cluster and the dark green being the smallest community. Similar to the interaction between L0 Processes and stakeholders, observations from this graph suggests that certain stakeholder and/or stakeholders' groups within the Nuclear Power Plant Operational Readiness Program are linked to specific Level 1 processes and they do not usually interact with another process even if the original L1 process they are linked to is interacting with another L1. Furthermore, the hub and spoke model was also prominent in this network where most L1 processes i.e. SS006, TM001, IO003 have a unique group of stakeholders linked into them who do not interact with any other Process in the network. This observation supports some findings from the analysis of the first and the fourth network on the behavior of the Process-based Management System structure of the Nuclear Power Plant Operational Readiness. The Network clustering provides a different perspective on the relationships and Interactions between L1 processes and Stakeholders in terms of segregating those communities as Core cluster, Support cluster, and Oversight cluster, which can ultimately change our perspective on how to manage such interaction.

5.6.4 Network centrality measures

Some key characteristics in the interactions between L1 processes and Nuclear power plant Operational Readiness Stakeholders can be better understood using Network centrality measures. There are many ways to measure centrality and each of these approaches helps in understanding a specific type of centrality, as opposed to offering competing versions of the same measurement. Centrality measures help in identifying which L1 Processes or Stakeholders have more influence over other components in terms of maintaining the integrity of interaction due to their structural influence. Along the same line, Centrality is an essential measure of the information flows between L1 processes and Nuclear power plant Operational Readiness Stakeholders when analyzed with other network statistics. The Closeness Centrality is the inverse of the mean shortest path between a node and all other nodes in the network that is reachable from it. This metric reflects the ability of L1 Processes and different stakeholders to access and transmit information through the network quickly. It also indicates how close a L1 Processes or a specific stakeholder is from every other node in this network. Betweenness centrality measures the degree L1 Processes and/or Nuclear power plant Operational Readiness Stakeholders offer the most direct path/bridges between otherwise disconnected Clusters in this interaction. A higher betweenness centrality score for a process or a stakeholder provides a perspective on how critical that process or a stakeholder to maintain the structure of the interaction and information flow. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. figure (5.19) presents the results of the analysis of betweenness and closeness centrality in interactions between L1 processes and the Stakeholders in the Nuclear Power Plant Operational Readiness Program.

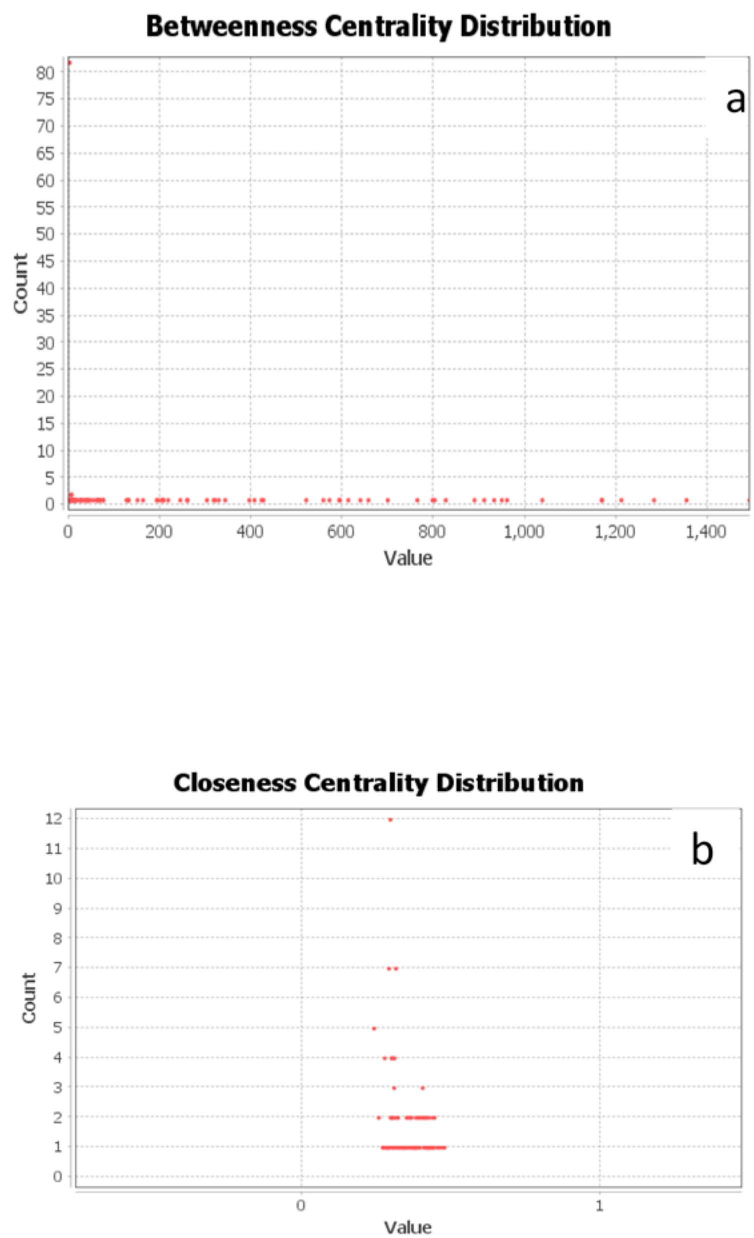


Figure 5. 19 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L1 processes and stakeholders

Similar to what has been observed in L0 processes interaction with Stockholders and as shown in Figure (5.19/b), the distributions of L1 processes and the stakeholders based on their Betweenness Centrality is a bit skewed to the right. As one can see, the majority of the L1 processes and the stakeholder's nodes have the same closeness (around 0.5) with a portion pulling the curve towards the higher end. Still, from this angle, we can conclude that majority of L1 processes and stakeholders' nodes have the same influence over this network's structural integrity and flow of information. and integrity. Betweenness centrality provides a different perspective. Interestingly, the smallest cluster seems to be the most influential. It includes four nodes with the highest Betweenness Centrality in the network. Namely; Finance (Betweenness Centrality = 1490), Manage Statutory and Regulatory Requirements (Betweenness Centrality = 1352), Perform Preventive Maintenance (Betweenness Centrality = 1281 and Monitor and Control Plant Chemistry (Betweenness Centrality = 1209). Table 5. 23 lists L1 Processes with highest Betweenness Centrality.

Table 5. 23 L1 Processes with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality	modularity class
86	SS002	0.438642	1490.988	1
67	MO002	0.411765	1352.747	1
101	WM003	0.450402	1281.551	0
78	OP003	0.474576	1209.983	3
107	WM010	0.440945	1167.978	0
69	MS001	0.465374	1166.406	1
90	SS006	0.402878	1036.504	3
76	OP001	0.421053	959.0981	4
47	CM001	0.422111	947.8265	0
64	LP006	0.411765	930.9935	0
108	WM011	0.418953	909.1241	0
75	NF003	0.4375	887.8157	0
57	IO003	0.311111	825	1
100	WM002	0.455285	800.8303	0

The main focus of this work is to understand the interaction between L1 processes and Stakeholders in the Nuclear Power Plant Operational Readiness Program. Therefore, it is important to investigate in detail the nature of influence the finance process has in this network being the node with the highest Betweenness Centrality. To do so, the ego network technique will be used. The below Finance Process Ego graph (5.20) was produced by Gephi.

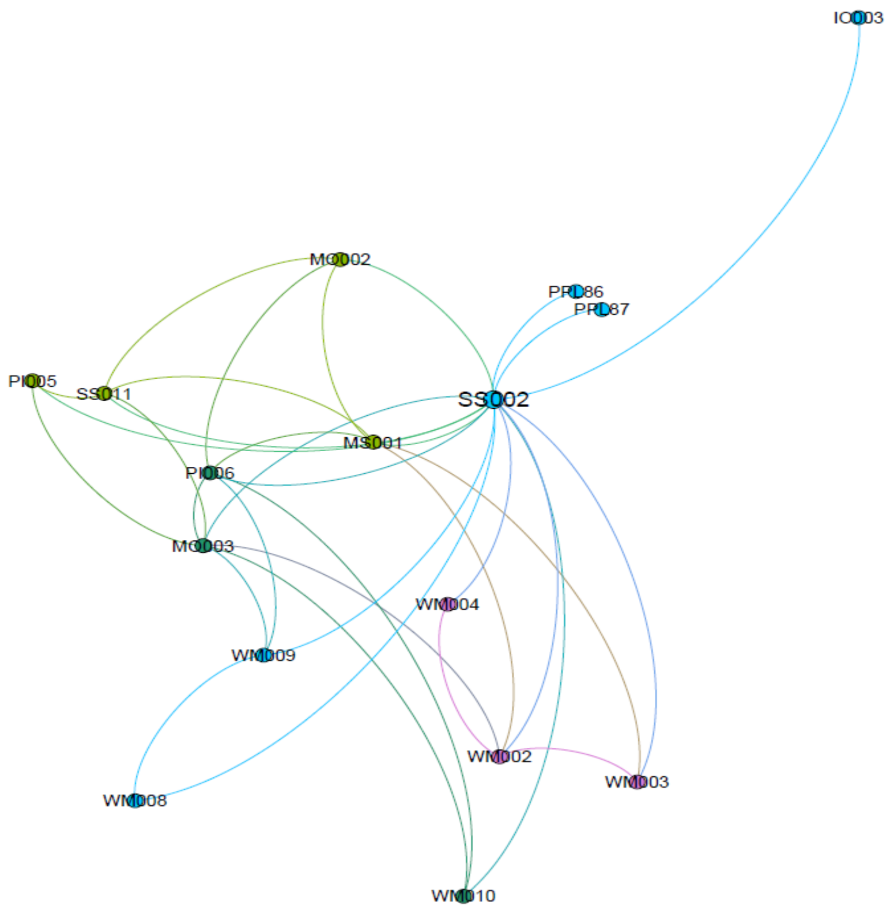


Figure 5. 20 Ego network of finance process

The structural characteristics of the Finance Process Ego Network are shown in table 5.24.

Table 5. 24 Characteristic of finance process Ego network

Characteristic	Value	% Visible
Total number nodes	16	9.47%
Total number of Edges	34	6.18%

As shown in figure (5.20), the interaction between the Finance Process and other L1 processes and Stakeholders appears to be relatively denser and forming a higher level of interactions when compared with the overall L1 process and Stakeholders Network. The Ego Network density is considerably higher than the value for a complete graph which indicates that of all possible connections that may exist in this interaction including direct links with the Finance Process, a very good portion of them is already established. The maximum path length between in this ego network is 1.7 as indicated by the average path length for a graph, we can conclude that the graph is relatively efficient in terms of transferring information across different modes since the maximum path length is less than the network diameter. Table 5. 25 summarizes the key Statistics of Finance Process Ego Network

Table 5. 25 Statistics of finance process Ego network

Network statistic	Value
Graph density	0.283
Network diameter	2
Average Path length	1.7
Average Clustering Coefficient	0.714

As shown in figure (5.20), we can define two groups of nodes in the Finance process Ego Network, Core, and peripheral. It appears that the Finance Process has multiple core connections in some maximal sense with other influential nodes that can be characterized as being “Assurance Processes” like Manage Statutory and Regulatory Requirements and Manage Enterprise Risk. Whereas the Internal audit process is loosely connected to the cohesive ego and lacks maximal cohesion with the core connections.

5.7. Interactions between level 0 processes and nuclear power plant systems

Systems referred to in this study covers Plant Systems, Structures, and Components (SSC). These include, but are not limited to software applications, supporting hardware, safety-related equipment, and buildings. This Network depicts all interactions between Level 0 Processes and Plant Systems. The list of L0 process covered all Management Systems processes and each L0 process was given a code and a node label (Table 5.1). On the other hand, each Plant System associated with the Nuclear Power Plant Operational Readiness was identified and given a code and a node label as per the below table (5.26)

Table 5. 26 List of plant systems, structures and components

Plant System	Node ID	Node Label
Engineering Change Status Information System	476	SYS.1
Life cycle Document Management	477	SYS.2
Electronic Corrective Action Program	478	SYS.3
Active Risk Management	479	SYS.4
SPVMS, Single Point Vulnerability Management System	480	SYS.5
e-CAP, Electronic Corrective Action Program- Holding	481	SYS.6
EWS, Engineering Workstation System	482	SYS.7
e-MR, Maintenance Rule Program	483	SYS.8
SHES, System Health Evaluation System	484	SYS.9
OEIS, Operating Experience Information System	485	SYS.10
Functional Readiness Assessment Tool	486	SYS.11
Controlled Document Management System	487	SYS.12
Operational Management System	488	SYS.13

Active Risk Manager- holding	489	SYS.14
Audit Management System - Internal Audit's MS.	490	SYS.15
Enterprise Content Management System	491	SYS.16
Plant Access Control System	493	SYS.18
Electronic Corrective Action Program	494	SYS.19
Life-Cycle Data Management	495	SYS.20
Regulatory Commitment Tracking System Software	496	SYS.21
Emergency Operations Facility	497	SYS.22
Technical Support Centers	498	SYS.23
Operational Support Centers	499	SYS.24
Alternate Technical Support Center	500	SYS.25
Plant equipment as detailed in Onsite Emergency Plan and Emergency Plan Implementing Procedures	501	SYS.26
Electronic Content Management System (ECMS)- Operating	502	SYS.27
ENET (corporate intranet)	503	SYS.28
Operating Experience Information System	504	SYS.29
Condition Reporting System-update 2020	505	SYS.30
OMS modules (e.g., SAP)	506	SYS.31
Fire Detection and Alarm System	507	SYS.32
Fire Suppression System	508	SYS.33
Initial Fire Response Team Equipment	509	SYS.34
On-site Fire Brigade Equipment and Vehicles	510	SYS.35
Fire Protection Management	511	SYS.36
Physical Protection Management	512	SYS.37
Waste Water Treatment Plant	513	SYS.38
Sewage Water Treatment Plant	514	SYS.39
Permanent Wharf	515	SYS.40
Plant Intake and Discharge Channels	516	SYS.41
Plant Intake Structures	517	SYS.42
Meteorological Monitoring System	518	SYS.43
Offsite Dose Calculation Manual	519	SYS.44
ARIS Business Architect	520	SYS.45
Requirements Management System	521	SYS.46
SAP Materials Management	522	SYS.47
Core Operating Limit Supervisory System	523	SYS.48
Core Protection Calculator System	524	SYS.49
Excore Neutron Flux Monitoring System	525	SYS.50
In-Core Instrumentation System	526	SYS.51
Information Processing System	527	SYS.52
Inverse Count Rate Ratio Calculator (Scaler Timer)	528	SYS.53
Reactivity Computer	529	SYS.54
Control Rods and Neutron Sources	530	SYS.55
Core Analysis Server with relevant codes	531	SYS.56
Fuel Handling & Transfer System	532	SYS.57

Fuel Inspection Stand	533	SYS.58
New Fuel Storage Rack/Spent Fuel Pool Racks	534	SYS.59
Nuclear Material Accounting and Control software	535	SYS.60
OMS PP module	536	SYS.61
Chemical/Safety Equipment	537	SYS.62
Clearance Implementation Equipment	538	SYS.63
Contaminated Area Equipment	539	SYS.64
Electrical Safety Equipment	540	SYS.65
Electronic Shift Operations Management System	541	SYS.66
Fall Protection Equipment	542	SYS.67
Fire Protection Management System	543	SYS.68
Operation Parameter Management System	544	SYS.69
Operator Personal Protective Equipment	545	SYS.70
Other miscellaneous equipment/items for Operations	546	SYS.71
SAP-Plant Maintenance	547	SYS.72
Plant or equipment for level 1 items that support the “Plant”	548	SYS.73
SAP-Production Planning	549	SYS.74
Risk Monitoring System	550	SYS.75
Radiation/ Environment Management	551	SYS.76
Radioactive Material Transportation Management System	552	SYS.77
Steam Generator	553	SYS.78
Primary and Secondary Sampling System	554	SYS.79
Chemistry Laboratory	555	SYS.80
Plant Information	556	SYS.81
Water Quality Management Program	557	SYS.82
Chemical Material Management System	558	SYS.83
Nuclear Plant Construction Management System	559	SYS.84
Steam Generator Management Program	560	SYS.85
Plant Maintenance	561	SYS.86
Self-Assessment	562	SYS.87
SAP (for work control)	563	SYS.88
An electronic OE database	564	SYS.89
Operational Management Systems (OMS) modules	565	SYS.90
Oracle Business Intelligence	566	SYS.91
Oracle Financials	567	SYS.92
Oracle Talent management	568	SYS.93
Primavera P6	569	SYS.94
Settlement System	570	SYS.95
Oracle Payroll System	571	SYS.96
SAP FI/CO	572	SYS.97
Startup Information Management System	573	SYS.98
Progress and Performance Management System	574	SYS.99
Procedure Change Request System	575	SYS.100
Content Management System- 2020 update	576	SYS.101

Content and Documents Management System- 2020 update	577	SYS.102
Adobe Master Suite	578	SYS.103
Infrastructure (Datacenter, Servers, Network and Communication equipment)	579	SYS.104
Oracle	580	SYS.105
TAQA Learning	581	SYS.106
ECMS- Holding	582	SYS.107
ENET- Holding	583	SYS.108
SAP Human capital module	584	SYS.109
SAP HR Work/Hour Tracking	585	SYS.110
Full Scope Simulator	586	SYS.111
Training Facilities and Mock-Ups	587	SYS.112
Classrooms and Supporting Areas	588	SYS.113
Primavera P6 or equivalent project management software	589	SYS.114
Equipment Decontamination Facilities	590	SYS.115
Personal Decontamination Facilities	591	SYS.116
Personnel Monitoring Instrumentation and Equipment	592	SYS.117
Portable Air Sampling Instrumentation	593	SYS.118
Portable Radiation Detection Instrumentation	594	SYS.119
Radiation Area Access Control System	595	SYS.120
Radioisotope Management System	596	SYS.121
RP Laboratory Instrumentation	597	SYS.122
Special Tools and Equipment	598	SYS.123
Radiation and Radioactivity Measurement System	599	SYS.124
project cost management software	600	SYS.125

Data for this network was imported using the above-mentioned structure into Gephi, Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced as presented in figure 5.21.

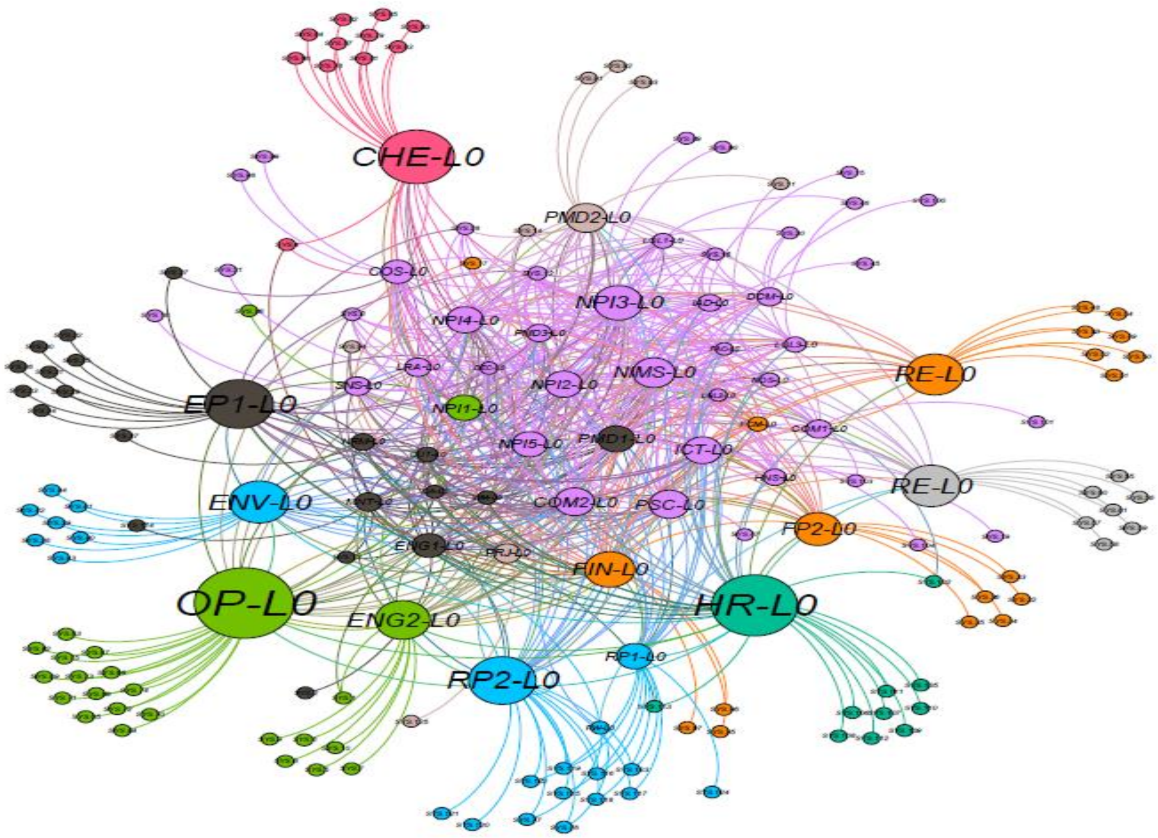


Figure 5. 21 L0 and nuclear power plant systems network

5.7.1 General characteristics

The structural characteristics of L0 Processes and Nuclear Power Plant Systems network are shown in table 5.27.

Table 5. 27 Structural characteristics of the L0 to nuclear power plant systems intersections

Characteristic	Value
Total number of L0 and Nuclear Power Plant Systems nodes	170
Total number of undirected interactions (Edges)	668

Overall and as shown in figure (5.21), the interaction between L0 process and Nuclear Power Plant Systems appears to be relatively low dense. The maximum number of connections required to traverse the interaction between L0 Processes and Nuclear Power Plant Systems (number of steps taken between the two most distant L0 processes and/or Nuclear Power Plant Systems) is 4 as indicated by the Network Diameter. Therefore, the interaction between L0 processes seems to be efficient and the flow of information appears to be flowing smoothly. In addition to being a low dense network, the maximum path length between L0 Processes and Nuclear Power Plant Systems is 2.8 as indicated by the average path length. Thus, we can conclude that the interaction between L0 processes and Nuclear Power Plant Systems within the Nuclear Power Plant Operational Readiness is efficient from a communication and information sharing standpoint since the maximum path length is less than the network diameter.

5.7.2 Network density

Similar to other interactions explained earlier in this study, Graph density assesses how strongly interconnected the network is. In this case, it examines the percentage of established interactions relative to the possible total number of connections between L0 Processes and Nuclear Power Plant Systems. A high degree of interaction between L0 Processes and Nuclear Power Plant Systems will have higher density levels while weak interactions result in low Network Density. Two networks with identical numbers of L0 Processes and Nuclear Power Plant Systems from different Nuclear programs might have very different density levels; even the same interaction between L0 Processes and Nuclear Power Plant Systems measured at different time intervals is likely to have differing density measures as links are formed or broken over time. The value of network density ranges from 0 to 1. A density close to 1 indicates that all L0 Processes are strongly linked to Nuclear Power Plant Systems within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interaction between L0 Processes and Nuclear Power Plant Systems. A value close to 0 will indicate the existence of weak interaction between L0 Processes and Plant Systems, Structures, and Components. Additionally, the density of the interaction in this network can be used to measure the cohesiveness and robustness of the interaction between L0 Processes and Regulatory Requirements, as well as, the inclusiveness and coverage of all regulatory requirements as part of the BAU design within the nuclear power plant is 0.046 which suggests that there is a low level of interaction between L0 processes and Plant Systems, Structures, and Components. The density of the interaction in this network can be used as a measure to assess the cohesiveness and robustness of the Nuclear Power Plant Integrated Management System. Building robust and integrated interfaces between L0 processes as the building blocks for the Nuclear Power Plant Integrated Management System and the Plant Systems, Structures and Components is very critical to realize the overall objective of designing and implementing the Integrated Management System (IMS). The density of interaction between L0 Processes and Plant Systems, Structures and Components is a determining factor in assessing how inclusive is the coverage of IMS to fulfill all regulatory requirements as part of the BAU design within the nuclear power plant in a systematic and structured manner.

5.7.3 Network clustering coefficient and modularity analysis

Network clustering coefficient help in grouping L0 Processes, Plant Systems, Structures and Components based on the strength of their relationships into distinct clusters. Clustering coefficient provides the ability to measure the level at which L0 Processes, Plant Systems, Structures, and Components are grouped, as opposed to being equally or randomly connected across the network. Clustering coefficient calculation is based on measuring the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available in the interactions between L0 Processes, Plant Systems, Structures, and Components. It measures the degree to which second layer/tier L0 Processes, Plant Systems, Structures, and Components are connected to one another. High Clustering coefficient scores are highly anticipated from tightly interweaved clusters and distinctive communities, whereas dispersed interactions usually produce lower Clustering coefficient scores. The average Clustering Coefficient for this network is 0.251 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis showed that L0 Processes, Plant Systems, Structures, and Components are distributed across 9 distinct communities. Figure 5.22 shows the 9 clusters size distribution in the interactions between L0 processes and Plant Systems, Structures, and Components.

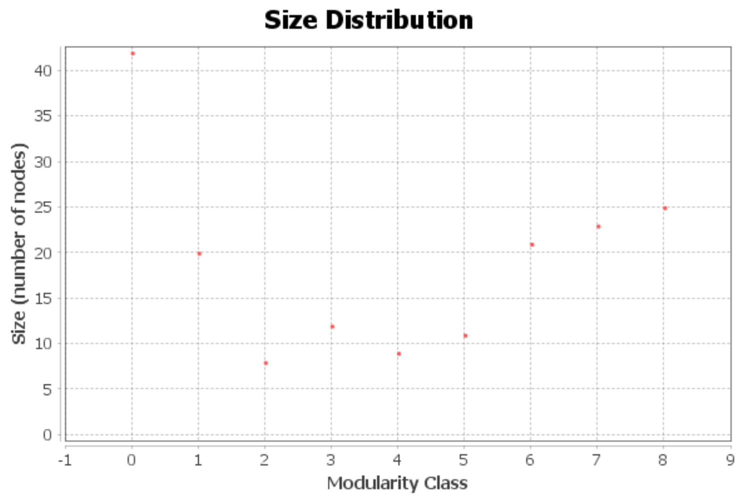


Figure 5. 22 Clusters size distribution in the interactions between L0 processes and plant systems, structures and components

As shown in figure (5.21), most of these communities are centered around specific L0 processes like OP-L0, ENV-L0, EP1-L0, RP2-L0 and CHE-L0 except for the biggest cluster 'The purple' where most of the Support Processes and their interactions with plant systems are grouped together. This observation might suggest a very important notion which is that Core Processes and their associated Plant Systems need to be treated as a standalone entity to ensure bringing all capabilities to the required level by the nuclear regulator while other Support Processes which apparently share similar characteristics can be managed as a one entity serving the core business. This fining might change the way we manage our processes within the Nuclear Operational Readiness settings. The hub and spoke pattern is quite evident across this network where L0 Processes seem to be interacting with a unique set of Plant systems with no overlap with other Systems linked to other Processes. This pattern needs to be studied further to assess the integrity of the Nuclear Power Plant Operational Readiness Management Systems and the level of integration and harmonization between relevant Systems. Similar to other interactions in this study, the property of multiple hubs strongly correlates with the network's robustness to failure. This structural configuration of having 9 major hubs that are concentrated around specific L0 processes which are linked to a unique set of Plant Systems, Structures, and Components might provision a fault-tolerant behavior and fosters resilience in the interaction between L0 Processes and Plant Systems, Structures, and Components.

5.7.4 Network centrality measures

Certain characteristics of the interactions between L0 processes Plant Systems, Structures, and Components can be demystified using Network Centrality Measures. Centrality measures help in identifying which L0 processes Plant Systems, Structures or Components in the nuclear power plant operational readiness have more influence over other components in terms of protecting the integrity of the interaction due to certain structural characteristics of those influential players. Furthermore, Centrality is an essential measure of the information flows between processes L0 processes Plant Systems, Structures, and Components especially when assessed jointly with other statistics like graph density, network diameter, and average path length. On one hand, the Closeness Centrality represents the inverse of the mean shortest path between a L0 process or a plant system and all other nodes in the network that are reachable from it. This metric reflects the ability of L0 Processes and Plant systems to access and transmit information through the network quickly. It also indicates how close a L0 process or a Plant System is to every other node in this network. On the other hand, Betweenness centrality measures to what degree L0 processes Plant Systems, Structures, and/or Components offer the most direct path between otherwise disconnected Clusters in this interaction. A higher betweenness centrality score for L0 process or Plant System will provide a perspective on how critical that process or System to maintain the structure of the network. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. Figure (5.23) presents the results of the analysis of betweenness and closeness centrality in interactions between L0 processes and Plant Systems, Structures, or Components.

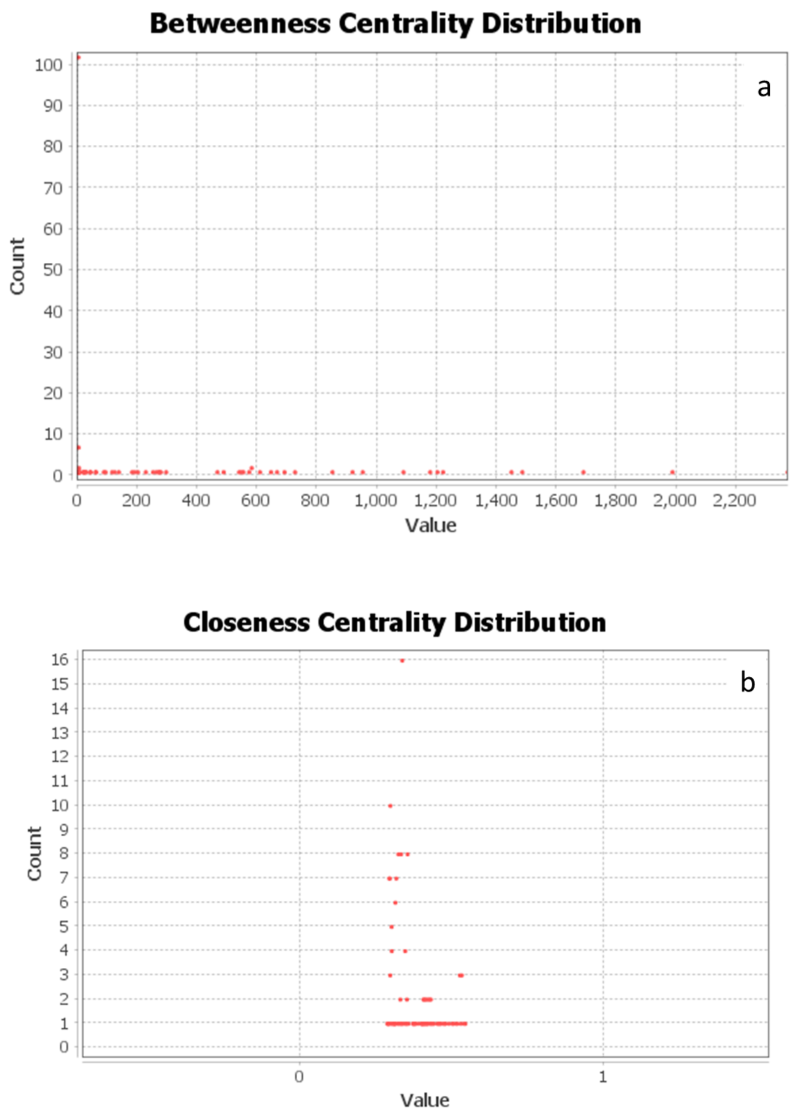


Figure 5. 23 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and plant systems, structures or components.

As shown in figure (5.23), the distributions of L0 processes and the Plant Systems based on their Betweenness Centrality and Closeness Centrality do not follow the normal distribution. As one can see, the majority of the L0 processes and the plant systems have the same closeness (around 0.5), meaning that they're seen from this angle as having the same influence over this network. It is also clear that most of the L0 processes and Plant Systems have low betweenness centrality while a few of them tend to have a high betweenness value. Looking at some interesting insights coming from this interaction, Subject Matter Experts and Management systems Professionals might need to further recognize the essential role some L0 Processes and/or Plant Systems play to keep the efficient flow of information and maintain the structural integrity of this interaction. Those are mainly nodes with the highest Betweenness Centrality. The process of Operating and Monitoring Structures, Systems, and Components appears to be the most influential node in this network (Betweenness Centrality = 2370) followed by HR-L0, CHE-L0, EP1-L0, and RP2-L0 with Betweenness Centrality 1985, 1687, 1483, and 1446 respectively. Table 5.28 below highlights L0 processes with the highest Betweenness Centrality.

Table 5. 28 L0 Processes with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality
21	OP-L0	0.502959	2369.952
40	HR-L0	0.543131	1984.938
23	CHE-L0	0.419753	1687.655
10	EP1-L0	0.47486	1483.325
43	RP2-L0	0.488506	1446.769
13	ENV-L0	0.459459	1218.532
20	RE-L0	0.415648	1199.435
18	RE-L0	0.412621	1175.425
2	ENG2-L0	0.453333	1086.092
31	FIN-L0	0.524691	949.9359
26	NPI3-L0	0.537975	916.106
11	FP2-L0	0.428212	849.0882

14	NIMS-L0	0.53125	723.6232
29	PMD2-L0	0.429293	688.5867
17	PSC-L0	0.524691	663.6372
38	COM2-L0	0.512048	643.6073
39	ICT-L0	0.516717	606.5292

In order to understand the interaction between L0 processes and plant systems in the Nuclear Power Plant Operational Readiness Program, it is important to drill down and analyze the typology and nature of linkage associated with the process of Operating and Monitoring Structures, Systems, and Components since it turned out to be the most influential node based on its high Betweenness Centrality. To do so, the ego network technique will be used. The below Ego graph of the Structures, Systems and Components Operations and Monitoring process (5.24) was produced by Gephi.

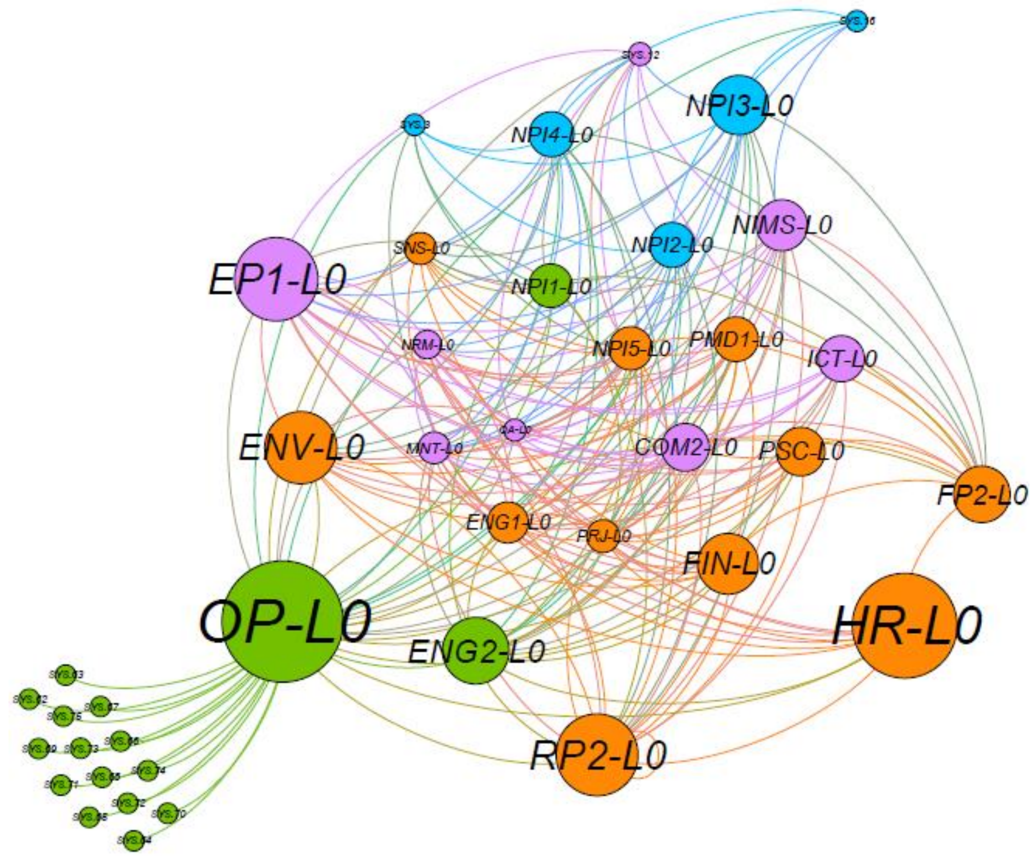


Figure 5. 24 Ego network of structures, systems and components operations and monitoring process

The structural characteristics of the Structures, Systems and Components Operations and Monitoring process Ego Network are shown in table (5.29).

Table 5. 29 Characteristic of finance process Ego network

Characteristic	Value	% Visible
Total number nodes	41	23.98%
Total number of Edges	208	31.14%

As shown in figure (5.24), the interaction between the Structures, Systems and Components Operations and Monitoring process and other nodes appear to be relatively denser and forming a higher level of interactions when compared with the overall L0 processes and plant systems

Network which has a density of 0.046 The Ego Network density is considerably higher than the value for a complete graph which indicates that of all possible connections that may exist in this interaction including direct links with Structures, Systems and Components Operations and Monitoring process, a very good portion of them have already established. The maximum path length between in this ego network is 1.7 as indicated by the average path length for a graph, we can conclude that the graph is relatively efficient in terms of transferring information across different modes since the maximum path length is less than the network diameter. Table 5. 30 summarizes key network Statistics of Structures, Systems, and Components Operations and Monitoring process Ego Network

Table 5. 30 Statistics of structures, systems and components process Ego network

Network statistic	Value
Graph density	0.254
Network diameter	2
Average Path length	1.74
Average Clustering Coefficient	0.444

Looking at the clustering of distinctive communities within the Structures, Systems and Components Operations and Monitoring process Ego Network in figure (5.24), we can observe the importance of Equipment Reliability and Performance Management Process (ENG2-L0) and Corrective Actions Management process (NPI1-L0) to maintain the integrity of L0- Plants system interactions being the only L0 process included with the Structures, Systems, and Components Operations and Monitoring process in the same cluster. Hub and spoke association is noticed between the Structures, Systems and Components Operations and Monitoring process and plant systems with the majority of nodes are grouped near to the Core and few like P2-L0 and HR-L0 seen as peripheral.

5.8. Interactions between level 0 processes and implementing procedures

This mapping will depict all interactions between Level 0 Processes and Implementing Procedures. This network covers all procedures developed to meet safety and quality requirements. those support the implementation of Programs and Processes and specify or describe how an activity is to be performed. The term procedure in this study will also include instructions and drawings including the following key areas:

a. Calibration and Test Procedures
b. Chemical and Radiochemical Control Procedures
c. Emergency Operating Procedures
d. Emergency Plan Implementing Procedures
e. Fire Protection Procedures
f. Fuel Handling Procedures
g. Maintenance Procedures
h. Power Operation and Load Changing Procedures
i. Process Monitoring Procedures
j. Radiation Control Procedures
k. Shutdown Procedures
l. Start-up Procedures
m. System Procedures
n. Temporary Procedures

The list of L0 process covered all Management Systems processes and each L0 process was given a code and a node label as per table (5.1). On the other hand, each Implementing Procedures included in this study have been identified and given a code and a node label as per table 5.31.

Table 5. 31 List of implementing procedures

Implementing Procedure	Node ID	Node Label
1N2-CHE-MAN-0001, Chemical Material Management	954	PRC1
1N2-CHE-PRC-GEN-0001, Chemistry Program	955	PRC2
1N2-CHE-PRC-OPS-0013, SG Hide Out Return Test	956	PRC3
1N2-CHE-PRC-SAM-0001, Primary System Sampling	957	PRC4
1N2-CHE-PRC-SAM-0003, Secondary Process Sample Continuous Monitor	958	PRC5
CHE-PRC-ANA-0002, Chemical Analysis Quality Control	959	PRC6
1N2-CHE-PRC-SAM-0005, Secondary System Sampling	960	PRC7
CHE-PRC-CCS-0002, Primary Laboratory Instrument Management	961	PRC8
CHE-PRC-CCS-0003, Secondary Water Chemistry	962	PRC9
CHE-PRC-CCS-0005, Primary Water Chemistry	963	PRC10
CHE-PRC-CCS-0006, Chemical Material Control	964	PRC11
CHE-PRC-GEN-0001, Secondary Laboratory Instrument Management	965	PRC12
CHE-PRC-GEN-0010, Chemical Laboratory Safety Management	966	PRC13
COM-REF-0001, Brand Guidelines	967	PRC14
COM-PRC-0005, Services Delivery Process	968	PRC15
CO-PRC-000-01, Commissioning Oversight Procedure	969	PRC16
DCM-PRC-0032, Approval of Vendor Prepared Documents	970	PRC17
DCM-PRC-0030, Document Controller Training and Qualification Procedure	971	PRC18
DCM-PRC-0033, Function Administrator Qualification Procedure	972	PRC19
DCM-PRC-0002, Governance Document Numbering	973	PRC20
DCM-PRC-0003, Procedure Generation and Changes	974	PRC21
DCM-PRC-0016, Technical Procedure Writers Guide	975	PRC22
DCM-PRC-0018, Administrative Procedure Writers Guide	976	PRC23
OP-PRC-0077, Procedure Use and Adherence	977	PRC24
DCM-PRC-0004, Controlled Documents Management Procedure	978	PRC25
DCM-PRC-0005, Management of Records	979	PRC26
DCM-PRC-0013, Records Retention Schedule and Disposition	980	PRC27
DCM-PRC-0015, Correspondence Control Procedure	981	PRC28
COM-PRC-0011, Internal Communications Procedure	982	PRC29
COM-PRC-0012, External Communications Procedure	983	PRC30
COM-PRC-0013, Creative Production Procedure	984	PRC31
COM-PRC-0014, Crisis Communications Procedure	985	PRC32
COM-PRC-0015, Social Media Procedure	986	PRC33
COM-PRC-0016, Stakeholders Management Procedure	987	PRC34

COM-PRC-0017, External Campaigns Procedure	988	PRC35
COM-PRC-0018, Events Management Procedure	989	PRC36
COM-PRC-0020, Media Relations Procedure	990	PRC37
COM-PRC-0024, Service Delivery Procedure	991	PRC38
COM-PRC-0025, Digital Communications Procedure	992	PRC39
COM-PRC-0026, Emergency Communications Procedure	993	PRC40
1N2-ENG-PRC-0006, MMIS Design Change Governing Procedure	994	PRC41
ENG-PRC-0021, Engineers' Task Performance Guidelines for Engineering Change	995	PRC42
ENG-PRC-0031, Design Change Proposal and Deliberation Management	996	PRC43
ENG-PRC-0032, Miscellaneous Design Document Change Management	997	PRC44
ENG-PRC-0033, Design Change Package Preparation and Revision Management	998	PRC45
ENG-PRC-0034, Design Change Implementation Completion Management	999	PRC46
ENG-PRC-0044, Engineering, Programmatic and MMIS Software Configuration Management	1000	PRC47
ENG-PRC-0050, Design Change Committee Operation Management	1001	PRC48
ENG-PRC-0052, Start-Up Field Change Requests from Fuel Load to SCD	1002	PRC49
ENG-PRC-0053, Temporary Modification Change from Fuel Load to SCD	1003	PRC50
ENG-PRC-0054, Engineering Evaluations	1004	PRC51
ENG-PRC-CMP-0001, Temporary Modification Control	1005	PRC52
ENG-PRC-CMP-0002, Nuclear Power Plant Configuration Management	1006	PRC53
ENG-PRC-CMP-0003, Design Change Control Management	1007	PRC54
MNT-PRC-0002, Post Maintenance Verification and Testing	1008	PRC55
OP-PRC-0010, System Status Control	1009	PRC56
PRJ-PRC-0001, Project Initiation and Approval Procedure	1010	PRC57
ENG-PGD-SHE-0001, System Health and Evaluation	1011	PRC58
ENG-PGD-MR-0001, Maintenance Rule Description	1012	PRC59
ENG-PRC-0011, Scoping of Maintenance Rule	1013	PRC60
ENG-PRC-0012, Safety Significance Determination	1014	PRC61
ENG-PRC-0016, Establishment of Performance Criteria	1015	PRC62
ENG-PRC-0019, MR Performance Monitoring	1016	PRC63
ENG-PRC-0020, SPV Component Management	1017	PRC64
ENG-PRC-0022, Equipment Reliability Index Management	1018	PRC65
ENG-PRC-0023, System Notebook Development and Management Guidelines	1019	PRC66
ENG-PRC-0024, System Walkdown Guidelines	1020	PRC67
ENG-PRC-0025, Functional Importance Determination Guideline	1021	PRC68
ENG-PRC-0027, Operation of Plant Health Committee	1022	PRC69
ENG-PRC-0028, System Monitoring Guidelines	1023	PRC70
ENG-PRC-0029, System Health Evaluation and Application	1024	PRC71
ENG-PRC-ER-0002, Mid-Long-Term Plant Equipment Investment Plan Management	1025	PRC72
ENG-PRC-ER-0003, Equipment Reliability Oversight Committee (EROC)	1026	PRC73
NPI-PRC-0200, Condition Report Initiation	1027	PRC74
NPI-PRC-0220, Condition Report Evaluation	1028	PRC75
NPI-PRC-0250, Condition Report Trending and Program Performance	1029	PRC76

MNT-PRC-0069, Predictive Maintenance Program	1030	PRC77
MNT-PRC-0070, Preventive Maintenance Program	1031	PRC78
MNT-PRC-0083, Component Health Monitoring	1032	PRC79
MNT-PRC-0084, Maintenance Rework Reduction	1033	PRC80
MNT-PRC-0089, Maintenance History Record	1034	PRC81
WM-PRC-0200, Integrated Risk Management	1035	PRC82
1N2-ENV-PRC-WW-0001, Operation of Wastewater Treatment Facility	1036	PRC83
1N2-RP-PRC-0003, Reactor Containment Building Gaseous Radioactive Effluent Release Management	1037	PRC84
1N2-RP-PRC-0004, Radiation Monitoring Instrument Management	1038	PRC85
1N2-RP-PRC-0005, Liquid Radioactive Waste Release Management	1039	PRC86
1N2-RP-PRC-0006, Operation of Scaling Factor and Periodic Qualification	1040	PRC87
1N2-RP-PRC-PR-0001, Site Radiation Monitoring System Operation	1041	PRC88
1N2-RP-PRC-RDP-0001, Onsite Radiation Monitoring System Channel and Source Surveillance Inspection	1042	PRC89
1N2-RP-PRC-RDP-0002, On-Site Sampling and Request for Analysis	1043	PRC90
1N2-RP-PRC-RDP-0004, Evaluation of total Atmospheric Steam Dump or Steam Generator	1044	PRC91
1N2-RP-PT-WV-0001, Radioactive Liquid and Gas Effluent Periodic Inspection	1045	PRC92
ENV-MAN-0001, Environmental Management System Plan	1046	PRC93
ENV-PRC-0001, Marine Environment Workboat Operations	1047	PRC94
ENV-PRC-0002, Water Intake Continuity (WIC)	1048	PRC95
ENV-PRC-0006, Transparency, Color, Odor & Floating Particle Analysis	1049	PRC96
ENV-PRC-0007, Waste Management Control Plan	1050	PRC97
ENV-PRC-0009, Sanitary Waste Water Plant Operations	1051	PRC98
ENV-PRC-0011, Multi-Parameter Operation	1052	PRC99
ENV-PRC-0012, Free and Total Residual Chlorine Analysis (Colorimetric Method)	1053	PRC100
ENV-PRC-LB-0001, ERL Chemical Safety Program	1054	PRC101
ENV-PRC-LB-0002, Sampling Plan	1055	PRC102
ENV-PRC-LB-0003, Sample Identification and Labeling	1056	PRC103
ENV-PRC-LB-0004, Laboratory Balances	1057	PRC104
ENV-PRC-LB-0005, Sample Collection	1058	PRC105
ENV-PRC-LB-0006, Sample Screening, Receipt, and Chain of Custody	1059	PRC106
ENV-PRC-LB-0007, Determination of Radioiodine in Milk and Water Samples	1060	PRC107
ENV-PRC-LB-0008, Dosimetry Program for Environmental and Personnel Monitoring	1061	PRC108
ENV-PRC-LB-0009, Sample Dissolution	1062	PRC109
ENV-PRC-LB-0010, Separation Chemistry - Tritium	1063	PRC110
ENV-PRC-LB-0011, Environmental Radiochemistry Laboratory Quality Control Plan	1064	PRC111
ENV-PRC-LB-0012, Operation of Gamma Spectrometry Systems	1065	PRC112
ENV-PRC-LB-0013, Operation of Liquid Scintillation Systems	1066	PRC113
ENV-PRC-LB-0014, Environmental Radiochemistry Laboratory Waste Plan	1067	PRC114
ENV-PRC-LB-0015, Analysis for Radioiodine in Iodine Collection Cartridges	1068	PRC115

ENV-PRC-LB-0018, Conduct of Environmental Radiochemistry Laboratory Operations	1069	PRC116
ENV-PRC-LB-0019, Environmental Radiochemistry Laboratory Reagent Preparation Instructions	1070	PRC117
ENV-PRC-LB-0020, Separation Chemistry - Americium	1071	PRC118
ENV-PRC-LB-0021, Separation Chemistry - Iron	1072	PRC119
ENV-PRC-LB-0022, Separation Chemistry - Technetium	1073	PRC120
ENV-PRC-LB-0023, Glass Cleaning	1074	PRC121
ENV-PRC-LB-0024, Separation Chemistry - Thorium	1075	PRC122
ENV-PRC-LB-0025, Separation Chemistry - Plutonium	1076	PRC123
ENV-PRC-LB-0026, Separation Chemistry - Strontium	1077	PRC124
ENV-PRC-LB-0027, Land Use Census	1078	PRC125
ENV-PRC-LB-0028, Environmental Radiation Monitoring System (ERMS) Real Time Gamma Detection System	1079	PRC126
ENV-PRC-LB-0029, Separation Chemistry - Nickel	1080	PRC127
ENV-PRC-LB-0030, ERL Personnel OJT Training and Qualification	1081	PRC128
ENV-PRC-LB-0032, Separation Chemistry - Uranium	1082	PRC129
ENV-PRC-LB-0036, Air Sampler Calibration	1083	PRC130
ENV-PRC-LB-0037, Separation Chemistry - Gross Alpha - Gross Beta	1084	PRC131
NIMS-POL-0002, Nuclear Safety Policy	1085	PRC132
RP-PRC-0025, Radioactive Effluent Management Plan	1086	PRC133
RW-PRC-0002, Disposal of Radioactive Waste Below Disposal Limit	1087	PRC134
ENV-PRC-0004, Environnemental Incident Management	1088	PRC135
ENV-PRC-0014, Environmental Inspection Procedure	1089	PRC136
ENV-PRC-0003, Environmental Sampling and Reports	1090	PRC137
ENV-PRC-0005, Impingement and Entrainment Monitoring Procedure	1091	PRC138
ENV-PRC_0016, Meteorological Monitoring Program Implementation Procedure	1092	PRC139
ENV-PRC-0013, Operation of Composite Sampler	1093	PRC140
1N2-EP-EPIP-AE-0001, Core Damage Assessment	1094	PRC141
1N2-EP-EPIP-AE-0003, Dose Projection Using RASCAL/BARAM	1095	PRC142
1N2-EP-EPIP-AE-0004, Meteorological and Plant Status Data Acquisition	1096	PRC143
1N2-EP-EPIP-GEN-0001, Maintenance of Emergency Plan/Procedures	1097	PRC144
1N2-EP-EPIP-GEN-0002, Communication Methods and Equipment	1098	PRC145
1N2-EP-EPIP-GEN-0004, Emergency Support and Logistics	1099	PRC146
1N2-EP-EPIP-GEN-0005, Emergency Preparedness Training	1100	PRC147
1N2-EP-EPIP-GEN-0006, Emergency Equipment Inspection and Inventory	1101	PRC148
1N2-EP-EPIP-GEN-0007, Record Keeping	1102	PRC149
1N2-EP-EPIP-GEN-0008, Emergency Preparedness Drills and Exercises	1103	PRC150
1N2-EP-EPIP-GEN-0010, Maintenance of Emergency Response Organization	1104	PRC151
1N2-EP-EPIP-ORG-0001, Initial Emergency Response Organization	1105	PRC152
1N2-EP-EPIP-ORG-0002, TSC Organization and Operation	1106	PRC153
1N2-EP-EPIP-ORG-0003, OSC Organization and Operation	1107	PRC154
1N2-EP-EPIP-ORG-0004, EOF Organization and Operation	1108	PRC155
1N2-EP-EPIP-ORG-0006, Offsite Stakeholders	1109	PRC156

1N2-EP-EPIP-PA-0001, Emergency Classification	1110	PRC157
1N2-EP-EPIP-PA-0002, Offsite Protective Action Recommendations	1111	PRC158
1N2-EP-EPIP-PA-0003, Onsite Protective Measures	1112	PRC159
1N2-EP-EPIP-PA-0004, Offsite Notification	1113	PRC160
1N2-EP-EPIP-PA-0005, Emergency Medical Service Actuation and Transport	1114	PRC161
1N2-EP-EPIP-PA-0006, Emergency Exposure Limits	1115	PRC162
1N2-EP-EPIP-PA-0009, Site Evacuation	1116	PRC163
1N2-EP-EPIP-REC-0001, Emergency Termination and Recovery Planning	1117	PRC164
1N2-EP-EPIP-REC-0002, Re-entry	1118	PRC165
1N2-EP-EPIP-SS-0001, Response to Security Related Threats	1119	PRC166
1N2-EP-MAN-0001, Barakah NPP Unit 1&2 Onsite Emergency Plan	1120	PRC167
1N2-EP-MAN-0002, Barakah NPP Emergency Classification Manual	1121	PRC168
1N2-EP-MAN-0003, Evacuation Time Estimate	1122	PRC169
None Listed	1123	PRC170
FCM-PRC-101-01 - Nuclear Fuel Procurement Procedure	1124	PRC171
FCM-PRC-101-02 - Engineering Calculations Procedure	1125	PRC172
FCM-PRC-101-03 - Computer Codes installation Maintenance and Control Procedure	1126	PRC173
FCM-PRC-101-04 - EUP Suppliers Screening Procedure	1127	PRC174
FCM-PRC-101-05 - EUP Suppliers Evaluation Procedure	1128	PRC175
FCM-PRC-101-06 - Spot Nuclear Fuel Procurement Procedure	1129	PRC176
FIN-PRC-0004, Treasury Procedure	1130	PRC177
FIN-PRC-0016, Accrual Guidelines	1131	PRC178
Accounts Payable Procedure	1132	PRC179
Asset Management Procedure	1133	PRC180
Finance Budgeting Forecasting and Reporting Procedure	1134	PRC181
Insurance Procedure	1135	PRC182
Petty Cash Procedure	1136	PRC183
Receivable Procedure	1137	PRC184
FP-PRC-GEN-0001, Fire Protection Plan	1138	PRC185
FP-PRC-0001, Fire Protection Management	1139	PRC186
FP-PRC-0002, Fire Response	1140	PRC187
FP-PRC-0003, Fire Protection Education Training	1141	PRC188
FP-PRC-0004, Fire Door Control	1142	PRC189
FP-PT-FP-0001, Initial Fire Response Team Protection Apparatus Check	1143	PRC190
1N2-FP-PT-FP-0001, Outdoor Fire Hydrant Visual Inspection	1144	PRC191
1N2-FP-PT-FP-0002, Indoor Fire Hydrant Visual Inspection	1145	PRC192
000-FP-PT-FP-0001, Outdoor Fire Hydrant Check and Test	1146	PRC193
1N2-MNT-EM-FP-0001, Fire Detection System Alarm Circuit Check	1147	PRC194
1N2-MNT-EM-FP-0002, CO2 and Clean Agent Fire Suppression System Check	1148	PRC195
1N2-MNT-EPT-FP-0001, 12V Battery Inspection for Diesel Engine-Driven Fire Pump Startup	1149	PRC196
1N2-MNT-EPT-FP-0002, Fire Detector Circuit Check	1150	PRC197

1N2-MNT-MPT-FP-0002, Spray/Sprinkler Visual & Check Air Flow Test	1151	PRC198
1N2-MNT-MPT-FP-0003, Fire protection system firefighting water supply line flushing	1152	PRC199
1N2-MNT-MPT-FP-0006, Fire Pump Diesel Engine Check	1153	PRC200
1N2-MNT-MPT-XX-0001, HVAC Fire Damper Performance Check	1154	PRC201
000-MNT-PRC-0005, Disassembly and Assembly of Fire Pump	1155	PRC202
1N2-OP-AOP-FP-0001, Operation of Power Plant in the Event of Fire	1156	PRC203
1N2-OP-AOP-FP-0002, Abnormal Spray of Fire Fighting Water	1157	PRC204
1N2-OP-ARP-FP-0001, Fire Protection System Alarm	1158	PRC205
1N2-OP-NOP-FP-0001, Fire Protection System	1159	PRC206
1N2-OP-PT-FP-0001, Portable Extinguisher Integrity Check	1160	PRC207
1N2-OP-PT-FP-0002, Seismic Category I Fire Protection System Valve Operability Test	1161	PRC208
1N2-OP-PT-FP-0003, Auxiliary Building Smoke Removal Fan Functional Test	1162	PRC209
1N2-OP-PT-FP-0004, Seismic Category I Fire Protection System Pump & Valve Lineup Check)	1163	PRC210
1N2-OP-PT-FP-0005, Visual Inspection of Fire Protection related Facilities	1164	PRC211
1N2-OP-PT-FP-0006, Visual Inspection of Co2 and Inergen Extinguish for Fire Protection System	1165	PRC212
1N2-OP-PT-FP-0007, Indoor Hydrant Discharge & Hose Hydrostatic Test	1166	PRC213
1N2-OP-PT-FP-0008, Fire Hydrant Flow and Pressure Deviation Measurement	1167	PRC214
1N2-OP-PT-FP-0009, Fire Door Status Check	1168	PRC215
1N2-OP-PT-FP-0010, Aux. Boiler Building Foam Extinguishing System Check	1169	PRC216
1N2-OP-PT-FP-0011, Spray & Sprinkler System Isolation Valve Functional Test	1170	PRC217
1N2-OP-PT-FP-0012, Fire Protection System Valve Functional Test	1171	PRC218
1N2-OP-PT-FP-0013, Fire Protection System Valve Lineup Check	1172	PRC219
1N2-OP-PT-FP-0014, Fire Pump Check & Valve Alignment Check	1173	PRC220
1N2-OP-PT-FP-0015, Seismic Category 1 Hydrant Flow & Pressure Measurement	1174	PRC221
1N2-OP-PT-FP-0016, Spray/Sprinkler Exterior Integrity & Functional Check	1175	PRC222
HNS-POL-0001, H&S Safety Policy	1176	PRC223
HNS-MAN-0001, H&S Manual	1177	PRC224
HNS-PRC-0120, H&S Roles, Responsibilities, and Self-Regulation	1178	PRC225
HNS-PRC-0122, H&S Risk Management & Control	1179	PRC226
HNS-PRC-0115, Contractor H&S Management	1180	PRC227
HNS-PRC-0107, H&S Communication & Awareness	1181	PRC228
HNS-PRC-0103, H&S Training and Competency	1182	PRC229
HNS-PRC-0109, H&S Emergency Management	1183	PRC230
HNS-PRC-0108, H&S Performance Management (KPIs)	1184	PRC231
HNS-PRC-0112, H&S Inspection and Assessment	1185	PRC232
HNS-PRC-0101, H&S Compliance and Management Review	1186	PRC233
HRD-PRC-000-05, Off boarding Procedure	1187	PRC234
HRD-PRC-000-06, Onboarding Procedure	1188	PRC235
HRD-PRC-000-08, Workforce Planning Procedure	1189	PRC236
HRD-PRC-000-10, Management Succession Planning procedure	1190	PRC237

HRD-PRC-111-10, Reward and Recognition Procedure	1191	PRC238
HR-PRC-0003, Employee Development and Succession Planning Procedure	1192	PRC239
HR-PRC-0004, Job Description Procedure	1193	PRC240
HR-PRC-0005, Talent Acquisition Procedure	1194	PRC241
HR-PRC-0006, Workforce Planning Procedure	1195	PRC242
HR-PRC-0007, Assessment Procedure for Hires, Transfers and Promotions	1196	PRC243
HR-PRC-0008, Discipline Policy Including Disciplinary Rules	1197	PRC244
HR-PRC-0009, Discipline Procedure	1198	PRC245
HR-PRC-0011, Employee Outplacement Procedure	1199	PRC246
HR-PRC-0012, Employee Retention Procedure	1200	PRC247
HR-PRC-0013, Employee Return-to-Work Procedure	1201	PRC248
HR-PRC-0014, Grievance Procedure	1202	PRC249
HR-PRC-0015, Leadership Development Procedure	1203	PRC250
HR-PRC-0016, New Employee Probation Procedure	1204	PRC251
HR-PRC-0017, Off boarding Procedure	1205	PRC252
HR-PRC-0018, Organizational Design Procedure	1206	PRC253
HR-PRC-0019, Performance Appraisal Procedure	1207	PRC254
HR-PRC-0020, Talent Management Stratégie Document	1208	PRC255
HR-PRC-0021, Talent Review Procedure	1209	PRC256
HR-PRC-0023, Employee Retention	1210	PRC257
HR-PRC-0024, Leadership Development	1211	PRC258
HR-PRC-0025, Performance Management	1212	PRC259
HR-PRC-0026, Workforce Planning and Organization Design	1213	PRC260
NOS-PRC-0003, Employee Concerns Procedure	1214	PRC261
CBT-PRC-112-12, Instructor Qualification Procedure.	1215	PRC262
CBT-PRC-112-02, ENEC Conduct of Training Procedure.	1216	PRC263
CBT-PRC-002-07, Nuclear Power Plant Training Academic Review Board Procedure.	1217	PRC264
CBT-PRC-112-14, On the Job Training and Task Performance Evaluation Procedure.	1218	PRC265
CBT-PRC-112-01, Training Examination Security and Administration Procedure.	1219	PRC266
CBT-PRC-112-04, NPP Training and Qualification Oversight Process	1220	PRC267
IAD-PRC-101-01 Anti-Fraud and Misconduct Reporting	1221	PRC268
Information and Communication Technology - Incident Management Procedure	1222	PRC269
Information and Communication Technology - Change Management Procedure	1223	PRC270
Information and Communication Technology - Problem Management Procedure	1224	PRC271
Information and Communication Technology - Release Management Procedure	1225	PRC272
Information and Communication Technology - Capacity Management Procedure	1226	PRC273
None	1227	PRC274
LGL-REF-000-08, Excellence in Governance Manual	1228	PRC275
LRA-PRC-0001, Manage FANR Regulatory Requirements	1229	PRC276
LRA-PRC-0006, Regulatory Correspondence Procedure	1230	PRC277
LRA-PRC-0007, Management of FANR Inspections	1231	PRC278
LRA-PRC-0002, Review of Draft FANR Regulations and Regulatory Guides	1232	PRC279

LRA-PRC-0009, FANR Reporting Procedure	1233	PRC280
LRA-PRC-0010, Safety Screening and Evaluation Procedure	1234	PRC281
LRA-PRC-0008, FSAR/Tech. Spec. Update Procedure	1235	PRC282
LRA-PRC-0003, Applications to FANR and Request for Additional Information (RAI) Procedure	1236	PRC283
LRA-PRC-0005, Regulatory Commitment Management Procedure	1237	PRC284
ECS-PRC-000-01, Import of Nuclear Related Items under the construction licenses reporting procedure	1238	PRC285
ECS-PRC-000-04, Import and Export Control Procedure	1239	PRC286
ECS-PRC-000-07, Export Control Reporting Procedure	1240	PRC287
ECS-PRC-000-08, Export Control Inspection Procedure	1241	PRC288
ECS-PRC-000-09, Export Control Information Procedure	1242	PRC289
MNT-PRC-0001, Conduct of Maintenance	1243	PRC290
MNT-PRC-0003, Maintenance Work Task Management	1244	PRC291
MNT-PRC-0012, Supplemental Workers Oversight	1245	PRC292
MNT-PRC-0069, Predictive Maintenance	1246	PRC293
MNT-PRC-0070, Preventive Maintenance	1247	PRC294
LRA-PRC-0001 - Manage FANR Regulatory Requirements	1248	PRC295
LGL- REF- XXXX, Compliance Framework	1249	PRC296
NIMS-PRC-0003, Function Governance	1250	PRC297
NIMS-PRC-0004, Integrated Management System Review	1251	PRC298
NIMS-PRC-0006, Manage IMS Architecture	1252	PRC299
PMD-PRC-0006, Program Review Board (NPRB) Charter	1253	PRC300
NOS-PRC-0001, Comprehensive Readiness Assessment Procedure	1254	PRC301
NOS-PRC-0004, Conduct of Challenge Boards	1255	PRC302
NOS-PRC-0005, Nuclear Oversight Performance Assessment Procedure	1256	PRC303
NOS-PRC-0007, WANO Peer Reviews Preparation, Evaluation, and Response	1257	PRC304
NOS-PRC-0008, if RAT Use and Control	1258	PRC305
NOS-REF-0001, Nuclear Safety Review Board (NSRB) Charter	1259	PRC306
NPI-PRC-0012, Construction Experience Procedure	1260	PRC307
NPI-PRC-0013, Operating Experience Procedure	1261	PRC308
NPI-PRC-0016, Knowledge Management Procedure	1262	PRC309
NPI-PRC-0030, SOER Procedure	1263	PRC310
NPI-PRC-0007, Human Performance Training and Qualification	1264	PRC311
NPI-PRC-0008, Observation and Coaching Program Training and Qualification	1265	PRC312
NPI-PRC-0011, Observation and Coaching Program Procedure	1266	PRC313
NPI-PRC-0021, Human Performance Clock Reset Program	1267	PRC314
NPI-PRC-0300, Pre-Job Briefs and Post-Job Debriefs	1268	PRC315
NPI-REF-0001, Guide to Human Performance and Human Performance Tools	1269	PRC316
NPI-PRC-0026, Procedure Use and Adherence	1270	PRC317
NPI-PRC-0003, Self-Assessment Procedure	1271	PRC318
NPI-PRC-0001, Benchmarking Procedure	1272	PRC319
NPI-PRC-0022, Nuclear Safety Culture Performance Monitoring	1273	PRC320

NPI-PRC-0023, Nuclear Safety Culture Analysis Identification and Planning of Solutions	1274	PRC321
NPI-PRC-0024, Nuclear Safety Culture Implementation and Review of Solutions	1275	PRC322
NPI-PRC-0025, Nuclear Safety Culture Steering Committee Charter	1276	PRC323
NPI-PRC-0210, Condition Report Screening	1277	PRC324
NPI-PRC-0230, Condition Report Action Closure	1278	PRC325
NPI-PRC-0240, Condition Report Administration and Management Controls	1279	PRC326
NRM-PRC-PRA-0001, PRA Model Maintenance and Management Procedure	1280	PRC327
NRM-PRC-PRA-0002, PRA Data Management Procedure	1281	PRC328
NRM-PRC-PRA-0003, Initiating Event Analysis Procedure	1282	PRC329
NRM-PRC-PRA-0004, Accident Sequence Analysis Procedure	1283	PRC330
NRM-PRC-PRA-0005, System Failure Analysis Procedure	1284	PRC331
NRM-PRC-PRA-0006, Human Reliability Analysis Procedure	1285	PRC332
NRM-PRC-PRA-0007, Reliability Data Development Procedure	1286	PRC333
NRM-PRC-PRA-0008, Success Criteria Analysis Procedure	1287	PRC334
NRM-PRC-PRA-0009, Level 1 and 2 PRA Quantification Procedure	1288	PRC335
NRM-PRC-PRA-0010, Flooding Event Analysis Procedure	1289	PRC336
NRM-PRC-PRA-0011, Fire Event Analysis Procedure	1290	PRC337
NRM-PRC-PRA-0012, Seismic Event Analysis Procedure	1291	PRC338
NRM-PRC-PRA-0013, Plant Damage State Analysis Procedure	1292	PRC339
NRM-PRC-PRA-0014, Severe Accident Progression Analysis Procedure	1293	PRC340
NRM-PRC-PRA-0015, Containment Ultimate Pressure Capacity Analysis Procedure	1294	PRC341
NRM-PRC-PRA-0016, Containment Event Tree Analysis Procedure	1295	PRC342
NRM-PRC-PRA-0017, Source Term Analysis Procedure	1296	PRC343
NRM-PRC-PRA-0021, PRA Applications Procedure for Design, Construction and Operation	1297	PRC344
NRM-PRC-PRA-0022, RIMS Operation Procedure	1298	PRC345
NRM-PRC-PRA-0023, Risk Monitoring System (RIMS) Model Development and Management Procedure	1299	PRC346
NRM-PRC-PRA-0024, ORION Operation Procedure	1300	PRC347
NRM-PRC-PRA-0025, ORION Model Development and Management Procedure	1301	PRC348
1N2-NRM-PRC-AM-0001, Barakah NPP Units 1 and 2 Accident Management Program Verification	1302	PRC349
1N2-NRM-PRC-AM-0002, Barakah NPP Units 1 and 2 Accident Management Program Documentation Maintenance	1303	PRC350
1N2-NRM-PRC-AM-0003, Extensive Damage Mitigation Guidelines Writer's Guide	1304	PRC351
1N2-NRM-PRC-AM-0004, Extensive Damage Mitigation Guidelines User's Guide	1305	PRC352
1N2-NRM-PRC-AM-0006, Barakah NPP Units 1 and 2 Accident Management Program Validation Procedure	1306	PRC353
NRM-PRC-AM-0001, Use of Severe Accident Management Guidelines	1307	PRC354
NRM-PRC-SAA-0001, Severe Accident Analysis Procedure	1308	PRC355
NRM-PRC-SAA-0002, Severe Accident Analysis Maintenance & Update Procedure	1309	PRC356
NRM-PRC-SAA-0003, Severe Accident Analysis Software Control Procedure	1310	PRC357

OP-PRC-0002, Conduct of Operations	1311	PRC358
OP-PRC-0005, Decision Making Process	1312	PRC359
OP-PRC-0006, Operator Shift Change and Operation Record Control	1313	PRC360
OP-PRC-0011, Equipment Clearance Safety Procedure	1314	PRC361
OP-PRC-0012, Verification Program	1315	PRC362
OP-PRC-0013, MCR-TRANSCO LDC operations Coordination Procedure	1316	PRC363
OP-PRC-0014, Reactivity Management Program	1317	PRC364
OP-PRC-0049, Guideline on Safety Function Decision	1318	PRC365
OP-PRC-0053, Key Management	1319	PRC366
OP-PRC-0056, Plant Housekeeping and Material Condition Monitoring	1320	PRC367
OP-PRC-0057, Limiting Condition for Operation (LCO) Tracking	1321	PRC368
OP-PRC-0061, Management of Special Test	1322	PRC369
OP-PRC-0071, Operator Work Around Program	1323	PRC370
OP-PRC-0072, Component Labeling	1324	PRC371
OP-PRC-0073, Operability Determination Assessment	1325	PRC372
OUT-PRC-0014, Shutdown Safety	1326	PRC373
1N2-OP-PT-XX-0003, Containment Cleanliness Inspection	1327	PRC374
1N2-OP-ST-PC-0002, Reactor Building Penetration Check	1328	PRC375
OUT-MAN-0001, Outage Management Manual	1329	PRC376
OUT-PRC-0001, Outage Management Procedure	1330	PRC377
OUT-PRC-0002, Outage Schedule Control	1331	PRC378
OUT-PRC-0003, High Risk Evolution	1332	PRC379
OUT-PRC-0005, Forced Outage Management	1333	PRC380
OUT-PRC-0008, Long-Range Outage Planning	1334	PRC381
OUT-PRC-0009, Outage Milestone Procedure	1335	PRC382
OUT-PRC-0012, Planned Outage Scope Control Procedure	1336	PRC383
WM-PRC-0002, Training and Qualification of Work Management and Outage Planning Personnel	1337	PRC384
WM-PRC-0013, Work Management Department (WM&OP) Activity Oversight	1338	PRC385
OUT-PRC-0007, Outage Control Center (OCC) Guidelines	1339	PRC386
OUT-PRC-0015, Outage Execution Procedure	1340	PRC387
PMD-PRC-CDV-0007, Strategic Management Procedure	1341	PRC388
PMD-PRC-0002, Business Planning Procedure	1342	PRC389
PMD-PRC-CDV-0006, Enterprise Performance Management Procedure	1343	PRC390
CNO-HB-18-0001, ORCC Handbook	1344	PRC391
PMD-PRC-ERM-0002, Enterprise Risk Procedure	1345	PRC392
PMD-PRC-0012, Change Management Procedure	1346	PRC393
PMD-PRC-PMO-0020, Management of Projects	1347	PRC394
PMD-PRC-PMO-0021, Project Initiation	1348	PRC395
PMD-PRC-PMO-0022, Project Planning	1349	PRC396

PMD-PRC-PMO-0023, Project Execution	1350	PRC397
PMD-PRC-PMO-0024, Project Monitoring and Controlling	1351	PRC398
PMD-PRC-PMO-0025, Project Change Control	1352	PRC399
PMD-PRC-PMO-0026, Project Reporting	1353	PRC400
PMD-PRC-PMO-0027, Project Closing	1354	PRC401
PSC-PRC-0014, Tender Committee (NTC) Charter	1355	PRC402
PSC-PRC-0100, Contract Management Procedure	1356	PRC403
PSC-PRC-0200, Procurement Procedure	1357	PRC404
PSC-PRC-0300, Warehouse Operations	1358	PRC405
PSC-PRC-0400, Procurement Engineering Support Activities	1359	PRC406
PSC-PRC-0401, Procurement Engineering Standards	1360	PRC407
QA-PRC-0010, Receiving Inspection	1361	PRC408
QA-PRC-0011, Control of Non-Conformance	1362	PRC409
QA-PRC-0012, Quality Surveillance	1363	PRC410
QA-PRC-0015, Surveillance at Suppliers Facility	1364	PRC411
QA-PRC-0017, Review of Supplier Inspection and Test Plan	1365	PRC412
QA-PRC-0018, Qualification of Surveillance Personnel	1366	PRC413
QA-PRC-0019, Review of Supplier Quality Verification Document	1367	PRC414
QA-PRC-0021, Quality Inspection of Maintenance Activities	1368	PRC415
QA-PRC-0005, Quality Assurance Audit	1369	PRC416
QA-PRC-0004, Qualification of Audit Personnel	1370	PRC417
QA-PRC-0007, Supplier QA Manual Review	1371	PRC418
QA-PRC-0014, Evaluation of Supplier	1372	PRC419
FCM-MEMO-16-0025, Reload Core Design Management Procedure	1373	PRC420
FCM-PRC-101-02, Engineering Calculations Procedure	1374	PRC421
FCM–PRC–101–03, Computer Codes Installation Maintenance and Control Procedure	1375	PRC422
RE–CRM–0001, Core Performance Parameters Check in Operation	1376	PRC423
RE-CRM-0002, Low Power Physics Test	1377	PRC424
RE-CRM-0003, Initial Criticality	1378	PRC425
1N2-RE-CRM-0007, Base Power Level Determination of Low Power Physics Test	1379	PRC426
RE-CRM-0005, CEA Worth Measurement Test	1380	PRC427
1N2-RE-CRM-0001, Estimated Critical Boron Concentration Measurement Test	1381	PRC428
1N2–RE–CRM–0002, Isothermal Temperature Coefficient (ITC) Measurement Test	1382	PRC429
RE-CRM-0008, Power Ascension Test	1383	PRC430
RE–CRM–0009, Reactivity Computer Set–up & Check–up	1384	PRC431
1N2-RE-CRM-0003, Daily Burnup Calculation	1385	PRC432
RE-CRM-0012, Secondary Thermal Power Verification	1386	PRC433
1N2-RE-CRM-0004, CPC/COLSS Internal Input Comparison	1387	PRC434
RE–CRM–0014, CPCS DNBR/LPD Check and Verification	1388	PRC435
RE–CRM–0015, Excore Neutron Flux Monitoring System Calibration	1389	PRC436
1N2-RE-CRM-0005, CPCS Operation	1390	PRC437
RE-CRM-0017, CPCS Constant Change	1391	PRC438
RE-CRM-0018, COLSS Constant Change	1392	PRC439

RE-CRM-0019, COLSS Integrity Test	1393	PRC440
RE-CRM-0020, CPCS Temperature Shadowing Factor Check & Verification	1394	PRC441
RE-CRM-0021, In-Core Instrumentation Operation and Performance Check	1395	PRC442
RE-CRM-0022, Low Power Physics Test Data Change and Check	1396	PRC443
RE-CRM-0023, Core Analysis Code (CECOR) Operation	1397	PRC444
RE-CRM-0024, Power Ascension Test Analysis Program Management	1398	PRC445
1N2-RE-CRM-0006, Core Application Program Management	1399	PRC446
RE-NFP-0008, Monitoring and Evaluation of Nuclear Integrity during Operation	1400	PRC447
RE-NFP-0009, Nuclear Fuel Integrity Evaluation Code Operation	1401	PRC448
RE-PRC-0009, Failed Fuel Action Plan	1402	PRC449
RE-PT-RC-0001, In-Core Instrumentation Channel Inspection	1403	PRC450
RE-ST-RC-0001, Core Reactivity Equilibrium Verification	1404	PRC451
RE–ST–RC–0002, Reactor Coolant System (RCS) Flow Rate Measurement Test	1405	PRC452
RE-ST-RC-0003, Moderator Temperature Coefficient (MTC) Measurement Test in Operation	1406	PRC453
RE-ST-RC-0004, Power Calibration	1407	PRC454
RE-ST-RC-0005, COLSS Margin Alarm Verification	1408	PRC455
RE-ST-RC-0006, Core Operating Limit Check during COLSS out of Service	1409	PRC456
RE-ST-RC-0007, Power Distribution and Peaking Factor Measurement	1410	PRC457
1N2-MNT-MM-FH-0003, Refueling	1411	PRC458
1N2-MNT-MM-FH-0007, New Fuel Receiving and Storage	1412	PRC459
1N2-RE-PT-FH-0001, Fuel Handling Area Crane Interlock Operation Test	1413	PRC460
ECS-PRC-000-02, Safeguards Design Information Procedure	1414	PRC461
ECS-PRC-000-03, Safeguards Records and Reporting Procedure	1415	PRC462
ECS-PRC-000-06, Safeguards Additional Protocol Procedure	1416	PRC463
ECS-REF-000-02, Barakah NPP Unit 1-4 Facility Safeguards Plan	1417	PRC464
ESP-PRC-000-05, Regulatory Safeguards Inspection and Visit Procedure	1418	PRC465
RE-NFP-0001, Precautions and Limitations for Fuel Handling	1419	PRC466
RE-NFP-0002, New Fuel Receipt and Inspection	1420	PRC467
RE-NFP-0003, Spent Fuel Withdrawal and Refueling	1421	PRC468
RE-NFP-0004, Spent Fuel Visual Inspection	1422	PRC469
RE-NFP-0005, Ultrasonic Test on Spent Fuel	1423	PRC470
RE-NFP-0007, Nuclear Materials Calculation Code Operation	1424	PRC471
RE-NFP-0011, Spent Fuel High Density Storage Rack Surveillance Capsule Installation and Inspection	1425	PRC472
RE-NFP-0012, Handling of Neutron Source	1426	PRC473
RE-PRC-0024, Management of CEA, ICI and NSA	1427	PRC474
RE-PT-FH-0001, Refueling Machine Load Test	1428	PRC475
RP-PRC-0008, Radiation Surveys	1429	PRC476
RP-PRC-0009, Radiation ALARA Management	1430	PRC477
RP-PRC-0013, Area and Equipment Decontamination	1431	PRC478
RP-PRC-0017, Inspection and Decontamination of Personnel Contamination	1432	PRC479
RP-PRC-0018, Radiation Exposure Dose Management	1433	PRC480
RP-PRC-0021, Fixed Contamination Monitor Operation and Calibration	1434	PRC481

RP-PRC-0022, Respiratory Protective Equipment Use and Management	1435	PRC482
RP-PRC-0023, Management of Entrance and Work in Contaminated Area	1436	PRC483
RP-PRC-0039, Skin Exposure Dose Assessment	1437	PRC484
RP-PRC-RDP-0003, Operation of Access Control System of Radiologically Controlled Area	1438	PRC485
RP-PRC-RDP-0005 Access to the Radiologically Controlled Area	1439	PRC486
RP-PRC-RDP-0009 Use of Portable Radiation/Contamination Detection Equipment	1440	PRC487
RP-PRC-0001, Radiation Work Permit and Application	1441	PRC488
RP-PRC-0002, Measurement and Assessment of Internal Exposure Dose	1442	PRC489
RP-PRC-0005, Control of Protective Supplies in Radiation Controlled Area	1443	PRC490
RP-PRC-0008, Radiation Measurement	1444	PRC491
RP-PRC-0012, Dose Assessment Procedure for a Person Damaging or Losing a Dosimeter	1445	PRC492
RP-PRC-0013, Region and Equipment Decontamination	1446	PRC493
RP-PRC-0014, Radiological Protection Activity During Radiological Abnormal Conditions	1447	PRC494
RP-PRC-0016, Temporary Radiation Controlled Area Operation	1448	PRC495
RP-PRC-0017, Personnel Contamination Survey and Decontamination	1449	PRC496
RP-PRC-0024, Personal Dosimeter Use	1450	PRC497
RP-PRC-0043, TLD Reading System Management Procedure	1451	PRC498
RP-PRC-0033, Low Level? and? Counter Operation and Calibration	1452	PRC499
RP-PRC-0040, Carrying Material in and Out of RCA and On-site Transport of Radioactive Material	1453	PRC500
RP-PRC-RDP-0003, Operation of Access Control System of Radiation Controlled Area	1454	PRC501
RP-PRC-RDP-0005, Access to the Radiologically Controlled Area	1455	PRC502
RP-PRC-RDP-0009, Use of Portable Radiation-Contamination Detection Equipment	1456	PRC503
000-RW-PRC-0001, Explosive Gas and Storage Tank Radioactivity Monitoring Program	1457	PRC504
1N2-RP-PRC-0005, Liquid Radioactive Effluent Release Management	1458	PRC505
1N2-RP-PT-WV-0001, Radioactive Liquid and Gaseous Sampling and Analysis	1459	PRC506
1N2-RP-RDP-0004, Radioactivity Assessment at Atmospheric Steam Dump from Steam Generators	1460	PRC507
RP-PRC-0020, Operation and Calibration	1461	PRC508
RP-PRC-0025, Radioactive Effluent Control Plan	1462	PRC509
RP-PRC-0028, Liquid Scintillation Counter Operation and Calibration	1463	PRC510
RP-PRC-0029, Solid Radioactive Waste Management in RCA	1464	PRC511
RP-PRC-0030, Non-Radioactive System Inspection and Measurement	1465	PRC512
RP-PRC-0031, Transfer and Storage of Radwaste Drum	1466	PRC513
RP-PRC-0033, Low Level / Counter Operation and Calibration	1467	PRC514
RP-PRC-0034, Control of Hazardous Substance in Radiologically Controlled Area	1468	PRC515
RP-PRC-0035, Operation of Radioactive Waste Management Committee	1469	PRC516
RP-PRC-0040, Operation of Concentrate Treatment System	1470	PRC517

RP-PRC-RDP-0040, Carrying Material in and Out of RCA and On-site Transport of Radioactive Material	1471	PRC518
RW-PRC-0001, Receipt, Packing and Transport of Radioactive Material	1472	PRC519
RW-PRC-RDP-0001, Management for Low and Medium Radioactive Waste Interim Building	1473	PRC520
RW-RP-0001, Waste Drumming Facilities Operation	1474	PRC521
SNS-PRC-000-02 – ENEC Corporate Facilities Visitor Management Procedure	1475	PRC522
SNS-PRC-111-02 – Identification Badge Issue Procedure	1476	PRC523
SNS-PRC-111-13 - Classification of Information Protection Program	1477	PRC524
SNS-PRC-111-14 - Physical Access and Monitoring of ENEC Corporate Facilities Procedure	1478	PRC525
SNS-PRC-111-17 - Business Information Protection Program	1479	PRC526
SNS-PRC-111-18 - CCTV Operating Procedure	1480	PRC527
SNS-PRC-111-19 Use of Camera Within ENEC Facilities procedure	1481	PRC528
SNS-PRC-111-21- Physical Access Management and Monitoring of Accommodations Facility	1482	PRC529
SNS-PRC-111-22 – Barakah NPP Target Set Development and Review	1483	PRC530
SNS-PRC-111-23 - Security Incident Reporting Procedure	1484	PRC531
SNS-PRC-111-24 - Attending to Items Important to Safety Procedure	1485	PRC532
SNS-PRC-111-25 - Contraband Material Storage, Retention, and Removal Procedure	1486	PRC533
SNS-PRC-111-27 – Safety Security Interface Implementing Procedure	1487	PRC534
SNS-PRC-111-28 – Testing Maintenance and Calibration Procedure for Security Equipment	1488	PRC535
SNS-PRC-111-29 – Barakah NPP Security Communications Procedure	1489	PRC536
SNS-PRC-111-30 – Cyber Security Assessment Procedure	1490	PRC537
SNS-PRC-111-31 – CICPA land Pass Procedure	1491	PRC538
SNS-PRC-200-02 – Drug and Alcohol Testing Procedure	1492	PRC539
SNS-PRC-200-03 – Behavior Observation Program (BOP) Procedure	1493	PRC540
SNS-PRC-200-04 – Medical Review Officer Procedure	1494	PRC541
SNS-PRC-400-02 - ISMS Risk Management Procedure	1495	PRC542
SNS-PRC-400-03 - Information Security Control Management Procedure	1496	PRC543
SNS-PRC-400-06 - Information Security Incident Response Procedure	1497	PRC544
SNS-PRC-400-07 - Procedure for Fortification of Critical Digital Systems	1498	PRC545
SNS-PRC-400-08 - Identification of Critical Digital Systems that Perform Security Functions	1499	PRC546
SNS-PRC-400-09 - Security Event Reporting Procedure	1500	PRC547
SNS-PRC-400-10 - Identification of CDS that Perform Emergency Preparedness Functions	1501	PRC548
SNS-PRC-400-13 - Critical Digital Assets Identification Procedure	1502	PRC549

Data for this network was imported using the above-mentioned structure into Gephi, Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced in figure (5.25).

PG1	Core Monitoring program	288
PG2	Other affecting SSCs	289
PG3	MNT-PGD-0003, Maintenance Program Description	290
PG4	ENG-PGD-MR-0001, Maintenance Rule Program Description	291
PG5	MNT-PRC-0070, Preventive Maintenance Program	292
PG6	NIMS-REF-0001, Program Catalog	293
PG7	ENG-PGD-SHE-0001, System Health Program Description	294
PG0	None	295
PG8	Accident Management	296
PG9	Ageing Management	297
PG10	Air Operated Valves (AOVs)	298
PG11	Boric Acid Corrosion (BAC) Control	299
PG12	Chemistry	300
PG13	Containment Leak Rate Testing	301
PG14	Control Room Envelope Habitability	302
PG15	Core Monitoring	303
PG16	Corrective Action	304
PG17	Counterfeit, Fraudulent, Suspect Items	305

PG18	Cyclic and Transient Monitoring	306
PG19	Diesel Fuel Oil Testing	307
PG20	Document Control and Records Management	308
PG21	Emergency Preparedness	309
PG22	Employee Concerns	310
PG23	Equipment Qualification	311
PG24	Erosion and Corrosion Monitoring	312
PG25	Export Control	313
PG26	Fire Protection	314
PG27	Foreign Material Exclusion	315
PG28	Fuel Integrity	316
PG29	Health & Safety	317
PG30	In-Service Inspection	318
PG31	In-Service Testing	319
PG32	Maintenance	320
PG33	Maintenance Rule	321
PG34	Measuring and Test Equipment (M&TE)	322
PG35	Meteorological Monitoring	323
PG36	Motor Operated Valves (MOVs)	324
PG37	Off Site Dose Calculation Program	325
PG38	Operational Radiation Protection	326
PG39	Performance Improvement	327
PG40	Primary Coolant Outside of Containment	328
PG41	Probabilistic Risk Assessment	329

PG42	Process control	330
PG43	Quality Assurance	331
PG44	Radioactive Waste Management	332
PG45	Reactor Coolant Pressure Boundary Material Surveillance	333
PG46	Safeguards	334
PG47	Site Security	335
PG48	Steam Generator Management	336
PG49	Surveillance	337
PG50	System Health Evaluation	338
PG51	Training and Personnel Qualification	339
PG52	Site Security Program,	340
PG53	Emergency Preparedness Program.	341
PG54	Export Control Program	342
PG55	Meteorological Monitoring Program (ENV-PGD-0001, Meteorological Monitoring Program Description)	343
PG56	Offsite Dose Calculation Manual (ODCM) Program (ENV-PGD-0002, Offsite Dose Calculation Manual (ODCM) Program Description)	344
PG57	QA-PGD-0002, Quality Assurance Program Description	345
PG58	HNS-PGD-0001, Health and Safety Program Description	346
PG59	CNT-PGD-0001, Training and Personnel Qualification Program Description	347
PG60	NPI-PGD-0001, Performance Improvement Program Description	348

PG61	NPI-PGD-0002, Corrective Action Program Description	349
PG62	QA-PGD-0001, Counterfeit, Fraudulent and Suspect Items (CFSI) Program Description	350
PG63	CHE-PGD-0002, Diesel Fuel Oil Testing Program Description	351
PG64	EXP-PGD-0001, Export Control Program Description	352
PG65	ENG-PGD-EQP-0001, Equipment Qualification Program Description	353
PG66	MNT-PGD-0004, Measuring and Test Equipment (M&TE) Program Description	354
PG67	DCM-PGD-0001, Document Control and Records Management Program Description	355
PG68	Primary Coolant Outside Containment	356
PG69	RW-PGD-0001, Process Control Program Description	357
PG70	RW-PGD-0002, Radioactive Waste Management Program Description	358
PG71	RP-PGD-0001, Radiation Protection Program	359
PG72	ENV-PGD-0002, Offsite Dose Calculation Program	360
PG73	Quality Assurance	361
PG74	Training and Personnel Qualifications	362
PG75	Performance Improvement Program	363
PG76	All programs	364
PG77	Emergency Preparedness	365
PG78	Training and Personnel Qualification Program	366
PG79	Employee Concerns Program	367

PG80	Radiation Protection	368
PG81	RP-PGD-0001, Radiation Protection	369

Figure 5. 25 L0 Processes and implementing procedures network

5.8.1 General characteristics

The structural characteristics of L0 Processes and Implementing Procedures network are shown in Table (5.32).

Table 5. 32 Structural characteristics of L0 processes and implementing procedures intersections

Characteristic	Value
Total number of L0 Processes and Implementing Procedures nodes	559
Total number of undirected interactions (Edges)	1028

As shown in figure (5.25), the initial observation is that the interaction between L0 process and Implementing Procedures looks low dense and nodes are distributed across 17 distinct communities. The maximum number of connections required to traverse the interaction between L0 Processes and Implementing Procedures (the number of steps taken between the two most distant L0 Processes or Procedure in this interaction to reach one another) is 5 nodes as indicated by the Network Diameter. The maximum path length between L0 Processes and Implementing Procedures is 3.37 as indicated by the average path length for this network. Therefore, it is quite evident that interactions between L0 Processes and Implementing Procedures in the Nuclear Power Plant Operational Readiness Program foster seamless communication and flow of information as indicated by a maximum path length between L0 Processes and Implementing Procedures less than the network diameter.

5.8.2 Network density

The density of interactions between L0 Processes and Implementing Procedures is calculated to by examining the proportion of established connections between L0 Processes and Implementing Procedures relative to the possible total number of connections (Edges). The graph density measures how strongly and comprehensively interconnected the interaction between L0 Processes and Implementing Procedures. Similar to other networks, A high degree of interaction will have higher density levels while weak interactions result in low Network Density. In this network, density measures the linkage between L0 Processes and Implementing Procedures. A density close to 1 indicates that L0 Processes are strongly linked to Implementing Procedures within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interaction between L0 Processes and Implementing Procedures. A value close to 0 will indicate the existence of weak interaction between L0 Processes and Implementing Procedures. The density of interaction L0 Processes and Implementing Procedures is 0.006 which suggests that there is a very low level of interaction L0 Processes and Implementing Procedures in the Nuclear power plant Operational Readiness program compared to what it might turn out to be. Using the density of the interaction in this network as a measure of cohesiveness and robustness of the interaction between L0 Processes and Implementing Procedures might indicate the presence of fragility risks to the integrity of this interaction. The Parent-child relationship between L0 processes and Implementing Procedures is a fundamental underlying principle to maintain a robust and fully integrated Management System in any nuclear facility. Therefore, this finding needs to be assessed further within the context of the organization to identify gaps and formulate corrective actions accordingly.

5.8.3 Network clustering coefficient and modularity analysis

The Network clustering coefficient and Modularity class will help in grouping L0 Processes and Implementing Procedures based on the strength of their relationships into distinct clusters. Clustering coefficient and Modularity analysis provide measure the level at which L0 Processes and Implementing Procedures are grouped together, as opposed to being equally or randomly connected across the network. As mentioned earlier, Clustering coefficient Scores have an inverse correlation with other statistics, including several of the centrality measures, mainly when we are analyzing at the global level (the entire network). Clustering coefficient calculation calculates the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available in the interactions between L0 Processes and Implementing Procedures and the degree to which second connections of L0 Processes and Implementing Procedures are connected to one another. Tightly connected clusters usually procedure high Clustering coefficient scores while discrete and spread communities usually produce lower scores. The average Clustering Coefficient for this network is 0.276 which indicates that some well-defined clusters can be identified in the interaction between L0 Processes and Implementing Procedures. Figure 5.26 shows modularity class size distribution in the interactions between L0 Processes and Implementing Procedures. Modularity class analysis showed that L0 Processes and Implementing Procedures Nodes in this network are grouped based on the strength of their relationships into 17 distinct clusters.

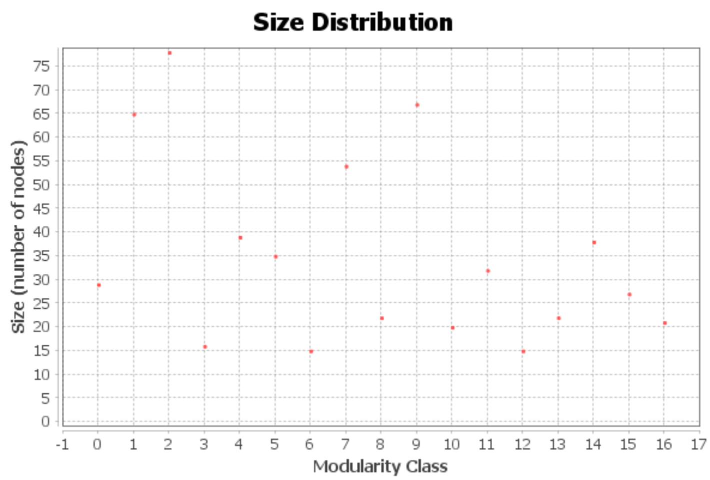
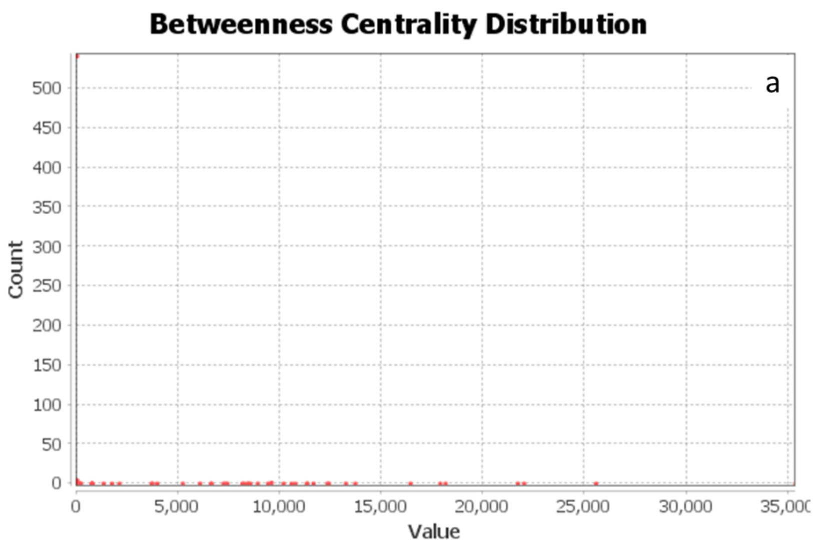


Figure 5. 26 Modularity class size distribution in the interactions between L0 processes and implementing procedures

As shown in figure (5.25), most of the clusters follow the pattern of Hub and Spoke where in most cases L0 Process is linked to a unique set of Implementing Procedure. Few numbers of Implementing Procedures are linked to multiple Processes. This observation revealed some interesting facts about the interaction between Management Systems L0 Process and Implementing Procedures in the Nuclear Power Plant Operational Readiness especially if compared to the nature of the interaction between L0 processes themselves. While L0 to L0 interaction is pretty much following a divergent pattern where most of L0 processes are linked to more than one L0 process, the corresponding Implementing Procedures tends to follow a convergent pattern where they interact solely with one L0 Process only. This pattern should be further studied by Subject Matter Experts in Nuclear Power Plants to better understand and assess to what extent this structure might pose a risk on the effective and efficient execution of coordinated and integrated efforts across different domains within the Nuclear Power Plant Operational Readiness Program. The clustering and modularity characteristics of interactions between L0 Processes and Implementing Procedures correlate with the network's robustness to failure. The fact that the 17 major hubs are concentrated around specific L0 processes which is linked to a unique group of Implementing Procedures allows for a fault tolerant behavior and fosters resilience in the interaction between L0 Processes and Implementing Procedures in the Nuclear power plant Operational Readiness Program.

5.8.4 Network centrality measures

Centrality measures help demystifying certain characteristics in the interactions between L0 Processes and Implementing Procedures. Centrality measures help in identifying which components of the Interactions between L0 Processes and Implementing Procedures in the Nuclear Power Plant Operational Readiness Program have more influence over other components. Furthermore, Centrality is an essential measure of the information flows between L0 Processes and Implementing Procedures when assessed jointly with other statistics to form a comprehensive and accurate understanding of information flow and efficiency of interaction. As explained earlier in this study, the Closeness Centrality is the inverse of the mean shortest path between a node and all other nodes in the network that is reachable from it. This metric reflects the ability of L0 Processes and implementing procedures to access and transmit information through the network quickly. It also indicates how close a L0 process or an implementing procedure is from every other node in this network. Betweenness centrality looks at the influence of L0 processes and implementing procedure from a different angle. Betweenness centrality measures the degree L0 Processes and Implementing Procedures offer the most direct bridges between otherwise disconnected Clusters. Figure 5.27 presents the results of the analysis of betweenness and closeness centrality in interactions between L0 processes and implementing procedures in the Nuclear Power plant Operational Readiness Program.



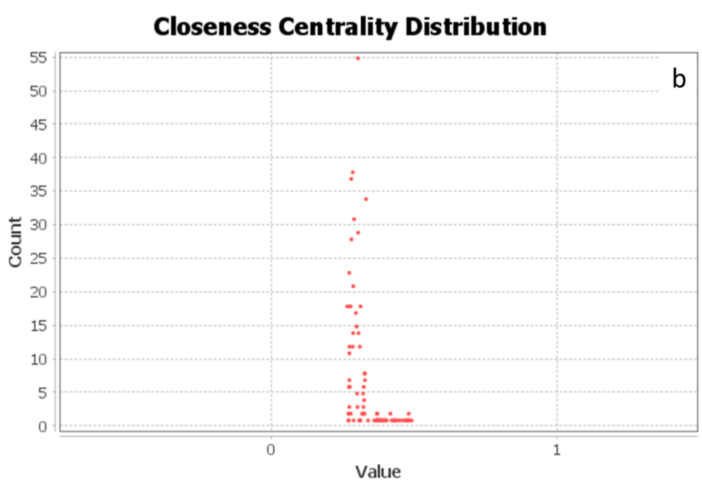


Figure 5. 27 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes and implementing procedures

It is also clear that most of L0 processes and the Implementing Procedures has low betweenness centrality while a few of them tend to have a high betweenness value. As shown in figure (5.27), Closeness Centrality Distribution seems to be skewed to the right with the majority of the L0 processes and the implementing Procedures falling within the same range (0.26 – 0.49) and only a few nodes (21 Node) above 0.40, meaning that they're seen from this angle as having low influence over this network. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. A higher betweenness centrality score for a node will provide a perspective on how critical that node to maintain the structure of the network. Table (5.33) highlights components with the highest Betweenness Centrality.

Table 5. 33 L0 Processes with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality	modularity class
13	ENV-L0	0.427954	35318.32	2
40	HR-L0	0.486486	25522.1	5
11	FP2-L0	0.391821	21982.74	4
18	RE-L0	0.381503	21675.42	14
12	NRM-L0	0.40027	18120.43	11
10	EP1-L0	0.428571	17859.14	7
7	SNS-L0	0.382239	16395.33	0
2	ENG2-L0	0.395473	13686.15	1
21	OP-L0	0.446617	13217.31	1
38	COM2-L0	0.457627	12385.36	7
20	RE-L0	0.376426	12318.02	15
31	FIN-L0	0.477108	11625.53	3
27	NPI4-L0	0.479032	11326.04	8
43	RP2-L0	0.417135	11302.8	16
22	RW-L0	0.356115	10731.17	2
1	ENG1-L0	0.431373	10550.95	1
17	PSC-L0	0.469565	10159.26	15

The main focus of this work is to understand the interaction between L0 processes and implementing procedures in the Nuclear Power Plant Operational Readiness Program. Therefore, it is important to investigate in detail the nature of influence the Environmental Services process has in this network being the node with the highest Betweenness Centrality. To do so, the ego network technique will be used. The below Provide Environmental Services Process Ego graph (5.28) was produced by Gephi.

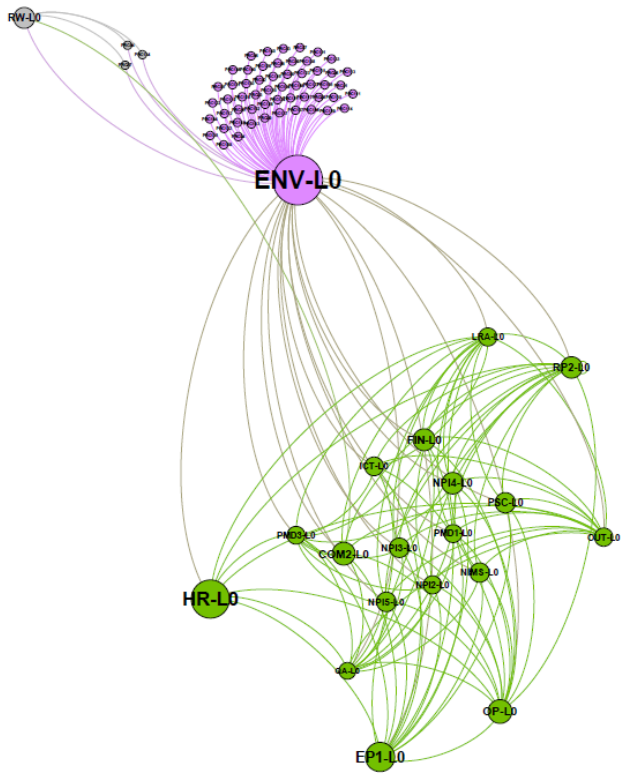


Figure 5. 28 Ego network of environmental services process

The structural characteristics of the Environmental Services Process Ego Network are shown in table (5.34).

Table 5. 34 Characteristic of environmental services process Ego network

Characteristic	Value	% Visible
Total number nodes	78	13.11%
Total number of Edges	165	16.05%

As shown in figure (5.28), the interaction between the Environmental Services Process and implementing procedures appear to be consistent with the density of the complete graph which indicates that of all possible connections that may exist in this interaction including direct links with Environmental Services Process, a very good portion of them is still can be established. The maximum path length in this ego network is 1.94 as indicated by the average path length for a graph, we can conclude that the graph is relatively inefficient in terms of transferring information across different modes since the maximum path length is almost the same as the network diameter. Table 5.35 summarizes key network statistics for the Environmental Services Process Ego Network

Table 5. 35 Statistics of environmental services process Ego network

Network statistic	Value
Graph density	0.283
Network diameter	2
Average Path length	1.94
Average Clustering Coefficient	0.571

According to the network graph in figure (5.28), we can define three groups of nodes in the Environmental Services Process Ego Network. One cluster includes all L0 processes except RW-L0 which form the center of the second cluster and a third cluster with the Environmental Services Process and its associated procedures. Those clusters can be also categorized as Core and peripheral. It appears that the L0 Process cluster has multiple core connections close to each others. Whereas both the Environmental Services Process and RW-L0 process is loosely connected to the cohesive ego and lack maximal cohesion with the L0 processes core connections.

5.9. Interactions between level 0 processes in the nuclear power plant operational readiness

This network analysis depicts and studies all interactions amongst Level 0 Processes in the Nuclear Power Plant Operational Readiness. L0 Processes aim to support the safe and reliable operations of any Nuclear Power plant and they form the backbone of the Nuclear Operational Readiness Management System. this network covers all L0 processes under the following categories:

1. Management Processes are used to provide oversight, review performance, and provide opportunities to improve Core and Support Processes. These Processes are Management Oversight, Independent Oversight, and Performance Improvement.
2. Core Processes that are used to deliver key products and services, by taking input and transforming it into a value-adding output. They are Operate Plant, Work Management, Configuration Management, Equipment Reliability, and Materials, and Services.
3. Support Processes that are used to provide support for our Core Processes. They are: Loss Prevention, Nuclear Fuel, Talent Management, and Support Services.

This network aimed to identify and depict all interactions amongst all L0 processes (Main Processes) forming the structure of the Integrated Management System for the Nuclear Power Plant Operational Readiness Program. The list of L0 process covered all Management Systems processes and each L0 process was given a code and a node label as per table (5.1).

Data for this network was imported into Gephi, Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced as shown in figure (5.29).

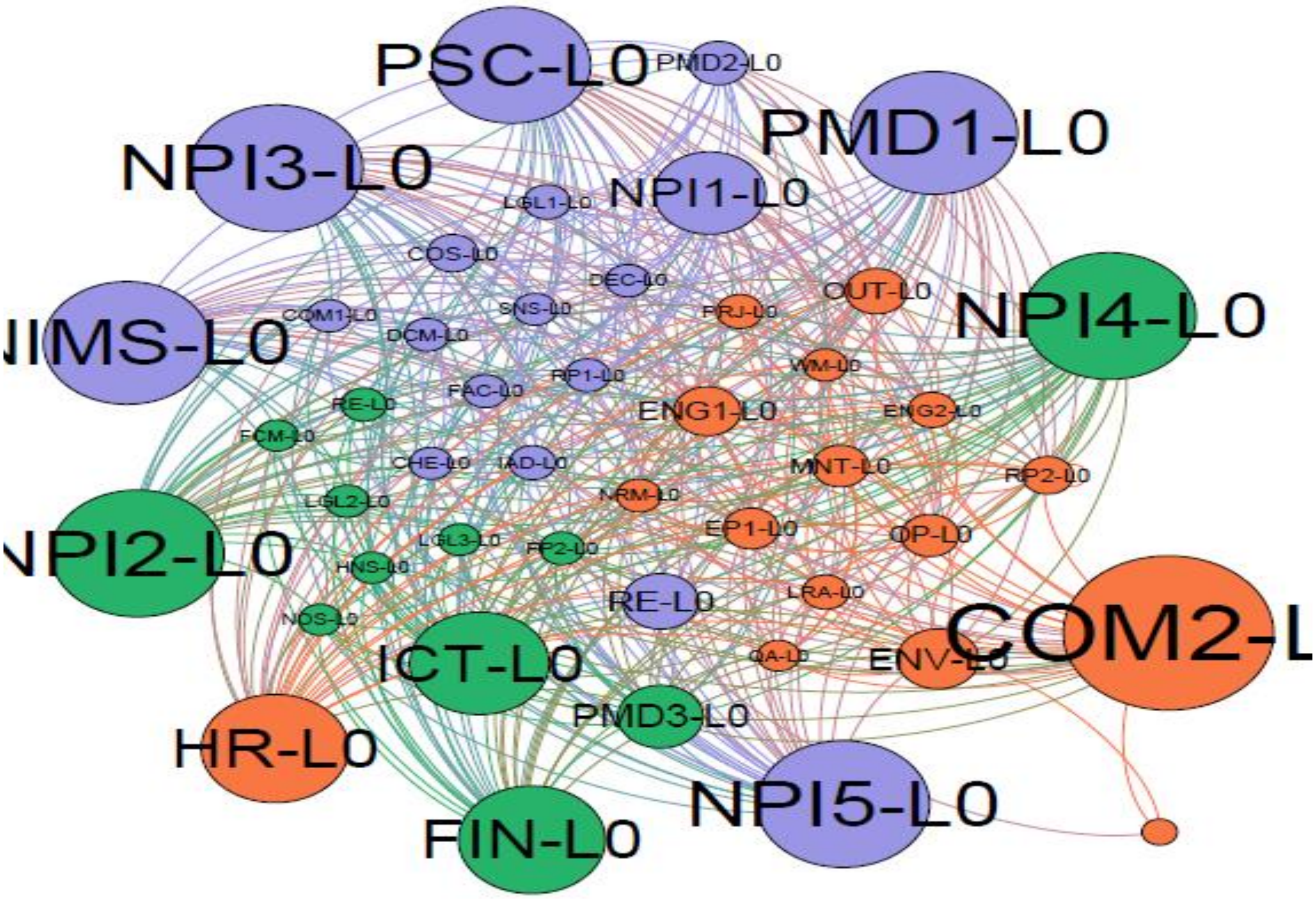


Figure 5. 29 Level 0 processes network

5.9.1 General characteristics

The structural characteristics of the L0 Processes network are shown in table (5.36).

Table 5. 36 Structural characteristics of the L0 processes network

Characteristic	Value
Total number of L0 Processes nodes	46
Total number of undirected interactions (Edges)	461

As shown in figure (5.29), the interaction amongst L0 processes in the Nuclear Power Plant Operational Readiness Program seems to be moderately efficient as indicated by a relatively medium dense network. The number of steps taken between the two most distant L0 processes in this interaction to reach one another (The maximum number of connections required to traverse L0 Processes interaction) is 3 nodes as indicated by the Network Diameter. Also, the maximum path length between L0 processes in this interaction is 1.56 as indicated by the average path length for a graph. Therefore, we can conclude that the graph is moderately efficient from a communication standpoint since the maximum path length between L0 Processes is almost half the network diameter.

5.9.2 Network density

To measure how tightly interconnected L0 processes to each other's, Graph density is used to examine the proportion of existing connections between L0 processes relative to the possible total number of connections. A high degree of interaction between L0 Processes will have higher density levels while weak interactions result in low Network Density. Similar to other networks, two networks of L0 processes with identical numbers of main processes might have very different density levels; even the same network measured at different time intervals is likely to have differing density measures as links are formed or broken over time between L0 processes due to evolving nature of Nuclear Power plant Management Systems structure during the Operational Readiness Phase . as explained earlier, the value of network density ranges from 0 to 1. A density close to 1 indicates a strong linkage amongst L0 processes. While a density of 0.5 suggests the presence of medium interaction amongst L0 Processes. A value close to 0 will indicate the existence of weak interaction between L0 Processes. Om additional insight that can be drawn out of this measurement is the extent to which this network is Cohesive, Robust, and resilient to disruptive events. The density of interaction between L0 Processes is 0.445 which suggests that there is a medium level of interaction among L0 processes.

5.9.3 Network clustering coefficient and modularity analysis

The Network clustering coefficient and Modularity analysis will help in grouping L0 processes based on the strength of their relationships into unique communicates or clusters. The Network clustering coefficient and Modularity analysis provide the ability to measure the level at which L0 processes are grouped together, as opposed to being equally or randomly connected across the network. As explained earlier, Clustering coefficient calculation is based on measuring the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available amongst L0 processes and therefore measures the degree to which second layer L0 processes are connected to one another (Friends of friends). High Clustering coefficient scores are highly anticipated from tightly knit hubs and distinctive communities, whereas dispersed and remotely scattered networks might be expected to produce lower scores. The average Clustering Coefficient for L0 processes interactions is 0.312 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis showed that L0 Processes are distributed across three distinct communities. Modularity class size distribution in these three distinct clusters in the interactions amongst L0 processes is shown in figure 5.30.

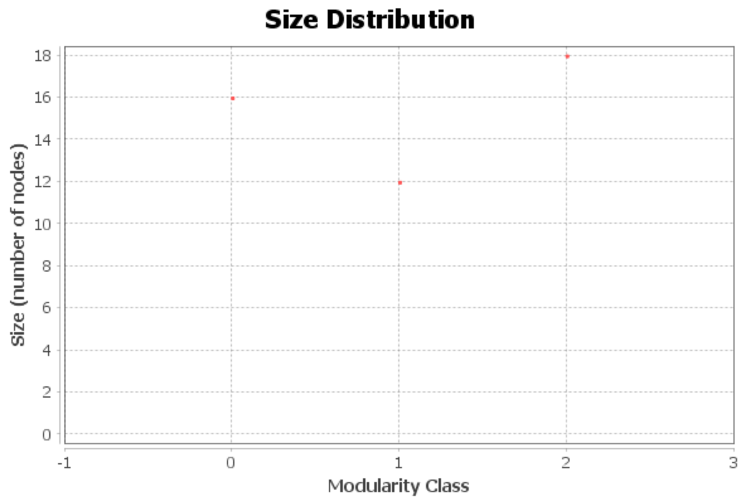
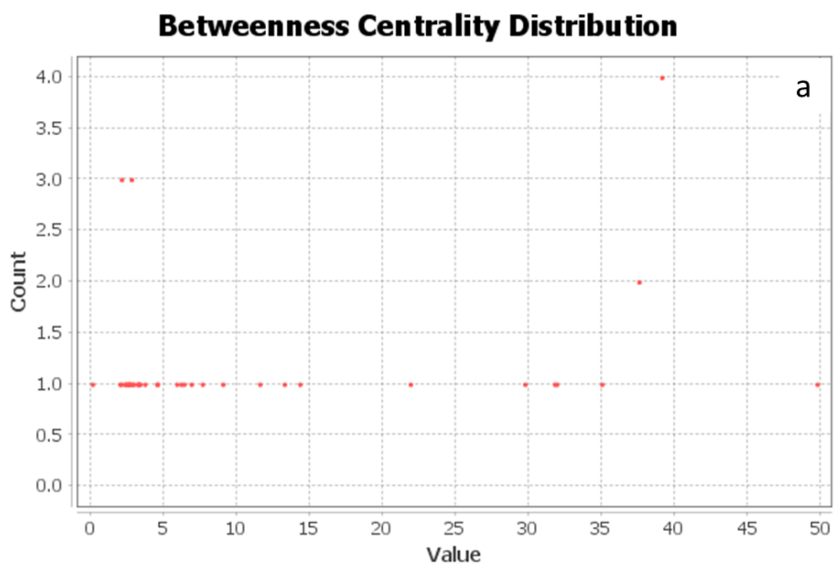


Figure 5. 30 Modularity class size distribution in the interactions amongst L0 processes

Understanding those clusters will help characterizing the behavior of this interaction by using modularity value as a predictor of cluster and network future response to certain parameters like the speed of information flow.

5.9.4 Network centrality measures

Centrality measures help demystifying certain characteristics in the interactions between L0 processes. Centrality measures help in identifying which L0 processes of the nuclear power plant operational readiness have more influence over other Processes in terms of achieving the strategic targets of the program (Safety, reliability, cost, schedule etc.) due to their structural importance. Furthermore, Centrality is an essential measure of the information flows between L0 processes when assessed jointly with other network statistics. Betweenness centrality measures the degree L0 Processes offer the most direct path between otherwise disconnected Processes or Clusters. A higher betweenness centrality score for an L0 Process will provide a perspective on how critical that Process to maintain the structure of this interaction. The Closeness Centrality is the inverse of the mean shortest path between a node and all other nodes in the network that are reachable from it. This metric reflects the ability of L0 Processes to access and transmit information through the network quickly. It also indicates how close a specific L0 process is from every other L0 processes in this network. Figure 5.31 presents the results of the analysis of betweenness and closeness centrality in interactions between L0 processes.



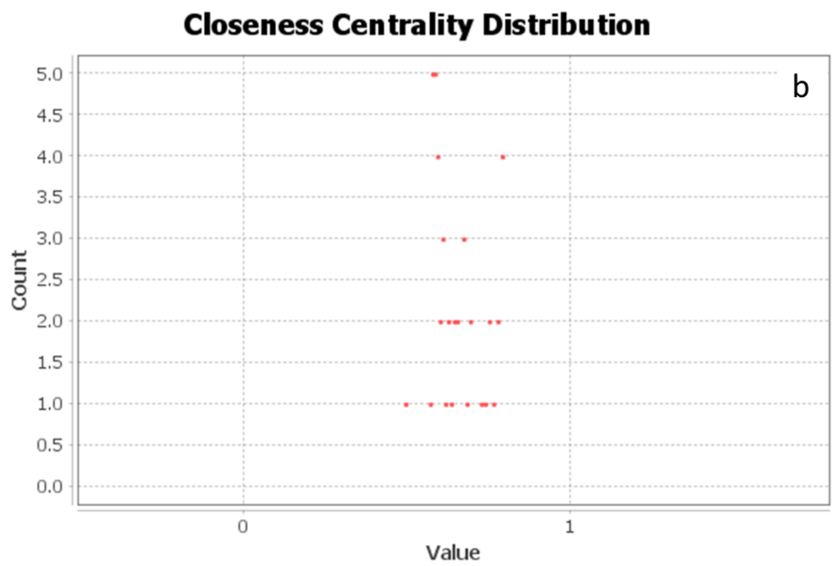


Figure 5. 31 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between L0 processes

As shown in figure (5.31), more than 70% of L0 processes have low betweenness centrality (Less than 20) while a few of them tend to have a high betweenness value and only one node has a betweenness centrality above 40. As shown in the above figure, Closeness Centrality Distribution seems to be following a normal distribution with the majority of the L0 processes falling within the same range (0.49– 0.78) and centered around the mean of 0.64. Therefore, we can conclude that they're seen from this angle as having low influence over this network. Betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. The table (5.37) below highlights L0 processes with the highest Betweenness Centrality. Those processes are critical to maintaining the interaction between L0 processes intact. Those L0 Processes seem to serve as bridges between other L0 processes to satisfy the majority of regulatory requirements. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction amongst L0 process.

Table 5. 37 L0 Processes with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality	modularity class
38	COM2-L0	0.725806	49.73221	0
25	NPI2-L0	0.789474	39.0882	1
26	NPI3-L0	0.789474	39.0882	2
27	NPI4-L0	0.789474	39.0882	1
28	NPI5-L0	0.789474	39.0882	2
14	NIMS-L0	0.775862	37.52134	2
16	PMD1-L0	0.775862	37.52134	2
17	PSC-L0	0.762712	34.97747	2
40	HR-L0	0.75	31.8965	0
31	FIN-L0	0.75	31.73785	1
39	ICT-L0	0.737705	29.71555	1
24	NPI1-L0	0.692308	21.87069	2

In order to understand the interaction between L0 processes in the Nuclear Power Plant Operational Readiness Program, it is important to drill down and analyze the typology and nature of linkage associated with the Communication being the one with the highest Betweenness Centrality. To do so, the ego network technique will be used. The below Ego graph of the Communication process (5.32) was produced by Gephi.

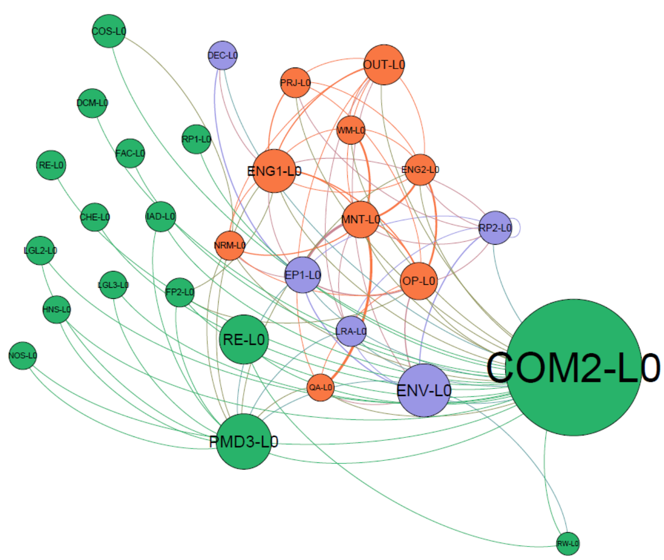


Figure 5. 32 Ego network of communication process

The structural characteristics of the Communication process Ego Network are shown in table (5.38).

Table 5. 38 Characteristic of communication process Ego network

Characteristic	Value	% Visible
Total number nodes	30	65.22%
Total number of Edges	93	20.17%

The interaction between the Communication process and L0 processes appear to be relatively dispersed and forming a low level of interactions when compared with the overall L0 processes Network which has a density of 0.5. The Ego Network density is almost half of the complete graph density which indicates that of a significant number of connections in this interaction including direct links with the Communication process can be established. The maximum path length in this ego network is 1.78 as indicated by the average path length for a graph. Looking at both network statistics together, we can conclude that the communication ego network can be made more efficient from a data/information transmission perspective. Table 5. 39 highlights main network statistics of Communication process Ego Network.

Table 5. 39 Statistics of communication process Ego network

Network statistic	Value
Graph density	0.214
Network diameter	2
Average Path length	1.78
Average Clustering Coefficient	0.732

Looking at the figure (5.32), in particular on the clustering of distinctive communities within the Communication process Ego Network, it is noticeable that the RW-L0 process is loosely connected to the cohesive ego and lack maximal cohesion with the L0 processes core connections clusters while the majority of other L0 processes can be seen as core connected and closely tied to each others. The same behavior of the RW-L0 process has been observed in other networks as well.

5.10. Interactions between strategic programs and regulatory requirements in the nuclear power plant operational readiness program

This Network depicts all interactions between Programs established to deliver certain agreed benefits in the Nuclear Power Plant Operational Readiness and the Regulatory Requirements. As mentioned earlier, those Programs are planned, coordinated group of strategic activities, processes, and/or procedures, developed for a specific purpose to accomplish a clear safety objective that extends for a relatively long period of time (3-5 years) and aims to establish certain organizational capability and/or fulfill certain Regulatory Requirement. Programs are characterized by the following criteria:

1. Programs require specific technical expertise.
2. Programs are required by reference documents (e.g. FANR regulations, Technical Specifications, FSAR, standard nuclear industry practice, or expert judgment)
3. Program data collection activities are repeated at regular intervals.
4. There is a continuity of data where the output and inputs of each data collection cycle are compared to each other. The list of regulatory Requirements was given a code and a node label as per table (5.2). On the other hand, each Program associated with the Nuclear Power Plant Operational Readiness was identified and given a code and a node label as per table (5.7). Data for

this network was imported into Gephi, Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced as per figure (5.33)

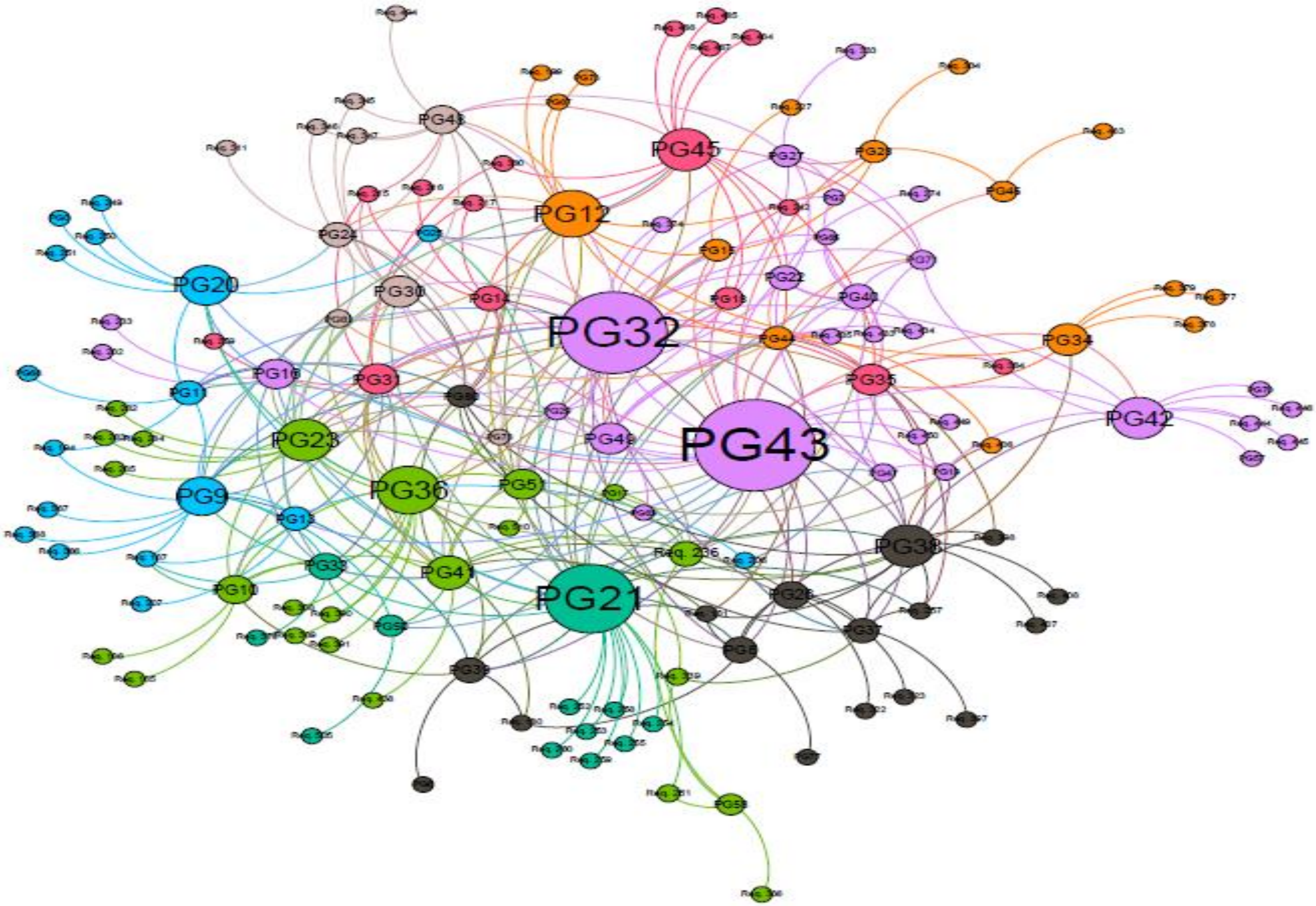


Figure 5. 33 Strategic programs and regulatory requirements network

5.10.1 General characteristics

The structural characteristics of the Strategic Programs and Regulatory Requirements network are shown in table (5.40).

Table 5. 40 Structural characteristics of strategic programs and regulatory requirements interactions

Characteristic	Value
Total number of Strategic Programs and Regulatory Requirements nodes	141
Total number of undirected interactions (Edges)	338

As shown in figure (5.33), The interaction between Strategic Programs and Regulatory requirements seems to be efficient as indicated by a relatively low dense network. The maximum number of connections required to traverse the interaction between Strategic Programs and Regulatory Requirements (the number of steps taken between the two most distant Programs or Regulatory Requirement in this interaction to reach one another) is 6 nodes as indicated by the Network Diameter. The maximum path length in the interactions between Strategic Programs and Regulatory Requirements is 3.04 as indicated by the average path length for a graph. Combining those network statistics, we can conclude that the graph exhibit medium efficiency from a communication and information sharing perspective since the maximum path length between Strategic Programs and Regulatory Requirements is almost half of the network diameter.

5.10.2 Network density

Graph density in this network measures how tightly interconnected the strategic Programs to the Regulatory requirement by examining the percentage of established connections Strategic

Programs and Regulatory Requirements relative to the possible total number of connections. A high degree of interaction between Strategic Programs and Regulatory Requirements will have higher density levels while weak interactions between them result in low Network Density. In this network, a density close to 1 indicates that Strategic Programs are strongly linked to Regulatory Requirements within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interaction between Strategic Programs and Regulatory requirements. A value close to 0 will indicate the existence of weak interaction between Strategic Programs and Regulatory Requirements. Additionally, the density of the interaction in this network can be used to measure the cohesiveness and robustness of the interaction between Strategic Programs and Regulatory Requirements, as well as, the inclusiveness and coverage of all regulatory requirements as part of the long-term Strategic Planning and execution process within the nuclear power plant. The density of interaction between Strategic Programs and the Regulatory Requirements is 0.034 which suggests that there is a very low level of interaction among Strategic Programs and corresponding regulatory requirements. This finding should be analyzed in line with the density of interactions between L0 processes and Regulatory Requirements since both the processes design and strategic programs are used to instill the Regulatory Requirements in the design of the Nuclear Power Plant Management System structure.

5.10.3 Network clustering coefficient and modularity analysis

Clustering coefficient and Modularity analysis provide the ability to measure the level at which strategic Programs and Regulatory requirements are grouped together, as opposed to being equally or randomly connected by grouping Programs and Requirements based on the strength of their relationships into distinct clusters. Clustering coefficient calculation is based on measuring the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available in the interactions between Strategic Programs and Regulatory requirements by measuring the degree to which second-tier Strategic Programs or a regulatory requirement are connected to one another. High Clustering coefficient scores usually represent tightly connected hubs and distinctive communities, whereas low Clustering coefficient scores are usually associated with dispersed and scattered interactions. The average Clustering Coefficient for this network is 0.184 which indicates that some clusters can be identified in this network. Modularity class analysis showed that Strategic Programs and Regulatory Requirements are distributed across 8 distinct communities. L0 Processes and Regulatory Requirements are distributed across 10 distinct communities. Figure 5. 34 shows the 8 clusters' size distribution in the interactions between L0 Processes and Regulatory Requirements.

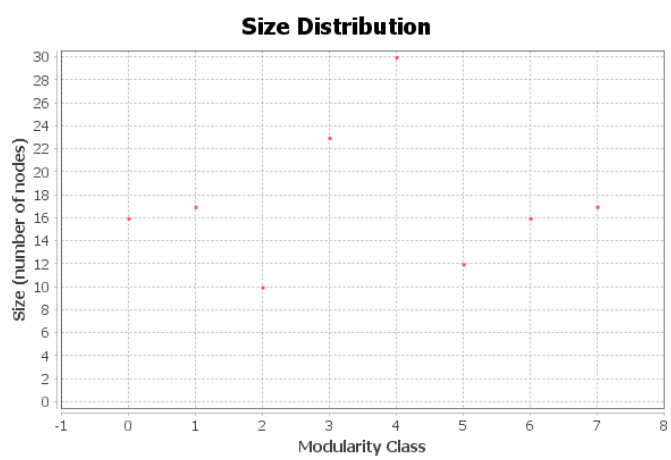
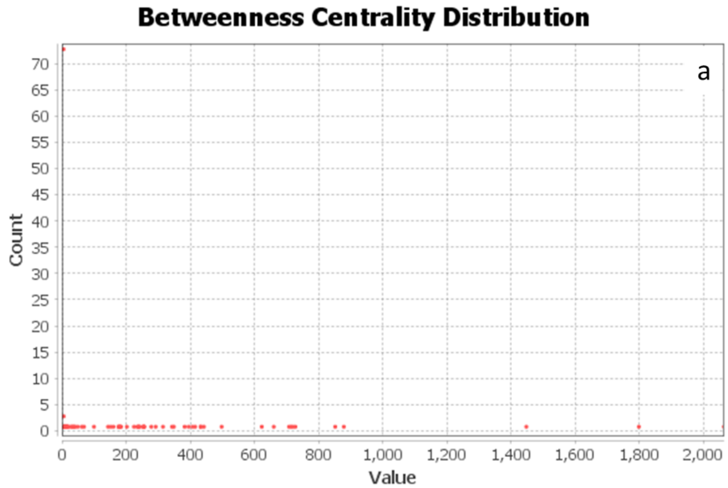


Figure 5. 34 Clusters size distribution in the interactions between L0 processes and regulatory requirements

As clearly shown in figure (5.33), most of the clusters follow the pattern of Hub and Spoke where in most cases Programs are linked specific requirements. This is typical in Nuclear setting where strategic programs are design and executed to fulfil specific regulatory requirements and thereafter, they ideally transform into Business as Usual (BAU) Processes. This property correlates with the robustness to failure. The 8 major hubs are concentrated around specific Strategic Programs which are linked to a unique group of regulatory requirements. This structural configuration allows for a fault-tolerant behavior and fosters resilience in the interaction between Strategic Programs and Regulatory Requirements.

5.10.4 Network centrality measures

Centrality measures help to demystify certain characteristics in the interactions Strategic Programs and the Regulatory Requirements including the identification of influential Strategic Programs in this interaction over other components in terms of achieving the essential role in protecting the integrity of the network structure and the flow of information between Strategic Programs and regulatory Requirements. The Closeness Centrality calculates the inverse of the mean shortest path between a node and all other nodes in the network that is reachable from it. This network statistic reflects the ability of Strategic Programs and Regulatory Requirements to access and transmit information through the network quickly. It also indicates how close a Strategic Program or a regulatory Requirement is from every other node in this network. Betweenness centrality measures the degree to Strategic Programs and Regulatory Requirements offer the most direct path between otherwise disconnected individual Programs and/or Requirements or groups of programs and/or requirements. Higher betweenness centrality a Strategic Program will provide a perspective on how critical that program maintain the structure of the network. Figure (5.35) presents the results of the analysis of betweenness and closeness centrality in interactions between Strategic Programs and regulatory Requirements.



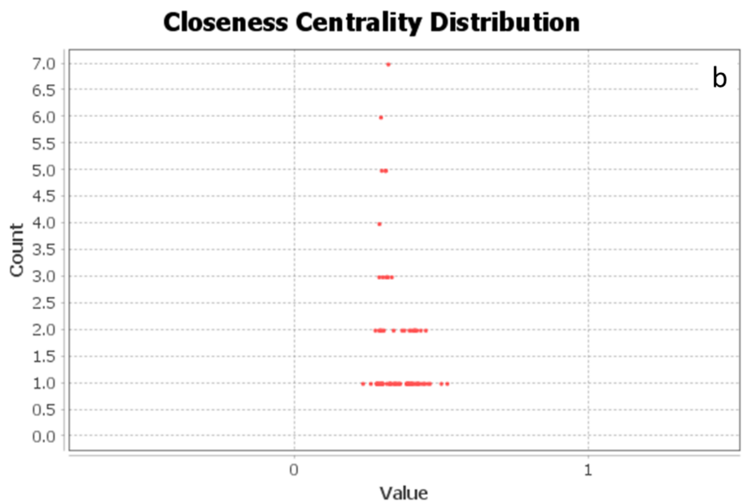


Figure 5. 35 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between strategic programs and the regulatory requirements

As shown in figure (5. 35), centrality Distribution graphs have shown that more than 50% of nodes in this network has zero betweenness centrality. Remaining portion of Strategic Programs and the regulatory Requirements has a betweenness centrality that ranges from 0.4 to 2059. A lot of variabilities are observed. The closeness centrality distribution of Strategic Programs and the regulatory Requirements seems to be following normal distribution and denoting less variability. The majority of Strategic Programs and the regulatory requirements are centered around the mean of 0.34 ranging between 0.23 and 0.50. However, the majority of nodes are seen from this angle as having low to moderate influence over this network. Betweenness centrality provides a different perspective for those poorly connected programs or regulatory requirement nodes (low Degree centrality) that might be essential to the network by being bridges between key other components. The table (5.41) below highlights Strategic Programs with the highest Betweenness Centrality. Programs like PG32, PG43, PG21, PG42, PG36, PG12, PG45, PG23, and PG20 have the highest Betweenness Centrality which might suggest that they are critical to maintaining the interaction between Strategic Programs and Regulatory requirements intact. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction between strategic Programs and Regulatory Requirements.

Table 5. 41 Strategic programs with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality
331	PG43	0.4947	2059.682
320	PG32	0.514706	1794.103
309	PG21	0.456026	1443.299
324	PG36	0.4375	874.1774
300	PG12	0.448718	847.2861
333	PG45	0.394366	723.0133
311	PG23	0.434783	715.414
326	PG38	0.44164	709.7552
330	PG42	0.404624	703.0108
308	PG20	0.410557	655.505
297	PG9	0.416667	618.2993
329	PG41	0.44164	493.0511
322	PG34	0.393258	437.6774
318	PG30	0.426829	428.1383
337	PG49	0.410557	427.3551
323	PG35	0.424242	410.5241
319	PG31	0.424242	402.243

The main focus of this work is to understand the interaction between Strategic Programs and Regulatory Requirements in the Nuclear Power Plant Operational Readiness Program. Therefore, it is important to investigate in detail the nature of influence the Quality Assurance Program has in this network being the node with the highest Betweenness Centrality. To do so, the ego network technique will be used. The below Quality Assurance Program Ego graph (5.36) was produced by Gephi.

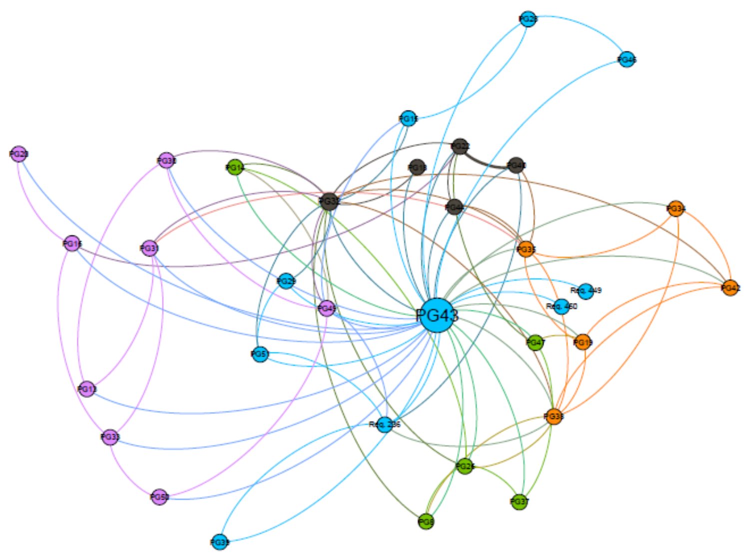


Figure 5. 36 Ego network of quality assurance program

The structural characteristics of the Quality Assurance Program Ego Network are shown in table (5.42).

Table 5. 42 Characteristic of quality assurance program Ego network

Characteristic	Value	% Visible
Total number nodes	33	23.4%
Total number of Edges	86	25.44%

The interaction between the Quality Assurance Program and other nodes (Strategic Programs and Regulatory Requirements) in this ego network appear to be relatively denser and forming a higher level of interactions when compared with the overall Network. The Ego Network density is higher than the value for a complete graph which indicates that a higher portion of the possible connections that may exist in the interaction between Quality Assurance Program and other nodes is already established. The maximum path length between in this ego network is 1.83 as indicated by the average path length for a graph, we can conclude that the graph is relatively efficient and more capable of transferring data on the smaller scale. Table 5.43 summarizes key network Statistics for the quality assurance program ego network.

Table 5. 43 Statistics of quality assurance program Ego network

Network statistic	Value
Graph density	0.163
Network diameter	2
Average Path length	1.83
Average Clustering Coefficient	0.636

We can define four groups of nodes in the Quality Assurance Program Ego Network where most of nodes can be characterized as peripheral. It appears that the Quality Assurance Program forms the center for a few core connections like Req. 236, PG49, PG35, and PG44. The majority of other nodes are loosely connected to the cohesive ego and lack proximity cohesion with the core connection.

5.11. Interactions between strategic programs and roles in the nuclear power plant operational readiness program

This interaction depicts all links and relationships between Programs established to deliver certain agreed benefits in the Nuclear Power Plant Operational Readiness and the Roles. Programs to Roles Interaction mapping is intended to Identify roles and responsibilities for Functions, persons, and/or other entities involved in the Nuclear power plant operational Readiness Program at all levels. Each defined Role in the Nuclear Power plant Operational Readiness Program was given a code and a node label as per table 5.44 below.

Table 5. 44 List of established roles in the nuclear power plant operational readiness program

Role	Node ID	Node Label
Risk Management-Holding	601	RL.1
NRM Director	602	RL.2
Head of Severe Accident Management, Accident Management Team	603	RL.3
Emergency Response Organization	604	RL.4
Training	605	RL.5
Maintenance	606	RL.6
Fire Protection	607	RL.7
Site Engineering Director	608	RL.8
Plant Engineering and Maintenance Director	609	RL.9
Site Manager of Engineering Programs	610	RL.10
Plant Engineering Program Manager	611	RL.11
Site AOV Program Principal Engineer	612	RL.12
Plant AOV Program Engineer	613	RL.13
Plant System Manager	614	RL.14
Plant Design Engineer	615	RL.15
Site Maintenance Rule Engineer	616	RL.16
Probabilistic Risk Assessment (PRA) Engineer	617	RL.17
Plant Maintenance and Engineering Director	618	RL.18
Plant BAC Engineer	619	RL.19
Site Ageing Engineer	620	RL.20

Operations	621	RL.21
System and Component engineers	622	RL.22
Radiation Protection	623	RL.23
Site Support Chemistry Manager	624	RL.24
Plant Chemistry Manager	625	RL.25
Chemistry Heads	626	RL.26
Chemistry Senior Specialist	627	RL.27
Chemistry Engineers and Technicians	628	RL.28
Site Engineering Program Manager	629	RL.29
Site CLR engineer (Ageing Principal Engineer)	630	RL.30
Plant ISI Head	631	RL.31
Plant ILRT and LLRT Coordinator	632	RL.32
Site - Engineering Director	633	RL.33
Plant - Engineering and Maintenance Director	634	RL.34
Site - Manager of Engineering Programs	635	RL.35
Site – Work Management Director	636	RL.36
Site CRH Program Engineer	637	RL.37
Plant System Engineer	638	RL.38
Plant – System Engineering Manager	639	RL.39
Plant – Design Engineer	640	RL.40
Maintenance Engineer	641	RL.41
Reactor Engineering Manager	642	RL.42
Head of Reactor Engineering and Fuel Management	643	RL.43
Safety and Engineering Support Director (Plant)	644	RL.44
Fuel Supplier	645	RL.45
Operations Director and Shift Managers (Plant)	646	RL.46
All Employees	647	RL.47
Management	648	RL.48
Line Managers	649	RL.49
QA Director	650	RL.50
QA Program Manager	651	RL.51
CFSI Program Engineer	652	RL.52
QA Audit Manager	653	RL.53
Quality Surveillance Manager	654	RL.54
Director Procurement & Supply Chain	655	RL.55
Director Engineering	656	RL.56
Contractors	657	RL.57
Director Maintenance	658	RL.58
Program Owner	659	RL.59
QA staff	660	RL.60
Procurement & Supply Chain staff	661	RL.61
Engineering staff	662	RL.62
Maintenance Staff	663	RL.63
Program Engineering Manager (Site)	664	RL.64
Plant Program Engineering Manager (Plant)	665	RL.65
Plant Operation Manager	666	RL.66
Plant Head of Chemistry	667	RL.67

Plant Chemistry Engineers and Technicians	668	RL.68
Plant Operation Team	669	RL.69
responsible department head	670	RL.70
Function Administrator	671	RL.71
Qualified Reviewer	672	RL.72
Emergency Preparedness Director	673	RL.73
Quality Assurance Department	674	RL.74
ERO positions	675	RL.75
Offsite Stakeholders	676	RL.76
Chief Nuclear Officer	677	RL.77
Site Vice President	678	RL.78
personnel who perform investigations of Nuclear Safety or Quality Concerns	679	RL.79
Director, Nuclear Oversight	680	RL.80
ECP Coordinator	681	RL.81
Human Resources	682	RL.82
ECP Manager	683	RL.83
Legal Counsel	684	RL.84
Management and Supervision (Employees and Contractor Workers)	685	RL.85
Nuclear Safety Culture Steering Committee	686	RL.86
Plant Manager	687	RL.87
Plant Operations Director	688	RL.88
Plant Operations Support Manager	689	RL.89
Shift Manager	690	RL.90
Training Director	691	RL.91
Plant Maintenance Manager	692	RL.92
Work Management Director	693	RL.93
All Site Personnel	694	RL.94
Operations Personnel	695	RL.95
Maintenance Personnel	696	RL.96
Clearance and Tagging Working Group	697	RL.97
Plant Supply Chain Director	698	RL.98
Director of Work and Outage Management (Site Engineering)	699	RL.99
Director of Quality Assurance (QA)-H	700	RL.100
Director of Maintenance	701	RL.101
Director of Engineering (Site Engineering)	702	RL.102
Manager of Design Engineering (Site Engineering)	703	RL.103
Manager of Engineering Programs (Site Support)	704	RL.104
Maintenance Engineering Managers: Mechanical, Electrical, I&C (Plant)	705	RL.105
Programs Engineering Manager (Plants)	706	RL.106
Principal Engineer – EQ Program	707	RL.107
Design Engineer (Site Engineering) or Design Agent	708	RL.108
Environmental Qualification Engineer and Seismic Qualification Engineer (Plant)	709	RL.109
Site Engineering – Director	710	RL.110
Engineering Program Manager (Site)	711	RL.111
Design Engineering Manager (Site)	712	RL.112
Principal Engineer –Program (Site)	713	RL.113
Quality Assurance Director	714	RL.114

Maintenance and Engineering Director (Plant)	715	RL.115
Program Engineering Manager (Plant)	716	RL.116
Mechanical Maintenance Engineering Manager (Plant)	717	RL.117
Shift Managers (Plant)	718	RL.118
Radiological Protection Manager (Plant)	719	RL.119
Chemistry Manager (Plant)	720	RL.120
System Engineering Manager (Plant)	721	RL.121
Head of Programs (Plant)	722	RL.122
Engineer (Plant)	723	RL.123
Support Contractor	724	RL.124
Engineering Support Contractor	725	RL.125
Export Control Senior Specialist	726	RL.126
Export Control Specialist	727	RL.127
Export Control Officer	728	RL.128
Export Control Head	729	RL.129
Fire Protection Manager	730	RL.130
Fire Protection program owner	731	RL.131
Safety & Engineering Support Manager	732	RL.132
Fire Safety group	733	RL.133
Safety & Engineering Support Department	734	RL.134
Operations Manager	735	RL.135
Operation Shift Managers	736	RL.136
Fire Controller	737	RL.137
Initial Fire Response Team	738	RL.138
Assistant Fire Controller	739	RL.139
plant employees	740	RL.140
Fire Watch	741	RL.141
head office-Holding	742	RL.142
Stakeholders	743	RL.143
On-site Fire Brigade	744	RL.144
Security Manager	745	RL.145
Off-site Fire Departments	746	RL.146
Site Operation Support Manager	747	RL.147
Radiological Protection Manager	748	RL.148
Emergency Preparedness Manager	749	RL.149
Security and Civil Defense (for Emergency Operation)	750	RL.150
Nuclear Risk Management	751	RL.151
Accident Management	752	RL.152
Maintenance Department	753	RL.153
Organizations Responsible for Works	754	RL.154
All Personnel	755	RL.155
Site Vice President	756	RL.156
Site Maintenance Director	757	RL.157
Plant Maintenance Director	758	RL.158
Engineering Manager or Engineer	759	RL.159
Department Managers	760	RL.160
Operations Managers	761	RL.161

Site FME Program Owner/Site Senior Maintenance Specialist	762	RL.162
Plant FME Coordinators (Responsible Engineer or Person)	763	RL.163
FME Monitor	764	RL.164
Independent FME Monitor	765	RL.165
Head/Supervisor	766	RL.166
Supply Chain Personnel	767	RL.167
Training Department	768	RL.168
Site Ownership of the FME Program (Program Management)	769	RL.169
Workers	770	RL.170
Reactor Engineering Manager (Site Support)	771	RL.171
Head of Reactor Engineering and Fuel Management (Plant)	772	RL.172
Fuel Supplier (Nuclear Fuel and/or ENEC Nuclear Fuel Management)	773	RL.173
Chief Nuclear Officer	774	RL.174
H&S Manager	775	RL.175
Head of Health & Safety Systems	776	RL.176
Head of Corporate Industrial Safety	777	RL.177
All Members of Management Team	778	RL.178
Head of Health	779	RL.179
Site Engineering – Director	780	RL.180
Plant Maintenance and Engineering – Director	781	RL.181
Site Engineering – Manager of Engineering Program	782	RL.182
Site Engineering - Principal Engineer ISI	783	RL.183
Plant Maintenance and Engineering - Head Mechanical	784	RL.184
Site Engineering - Manager of Engineering Program	785	RL.185
Site Engineering - Principal Engineer	786	RL.186
Operations – Director	787	RL.187
Operations Support Head	788	RL.188
Operations Support Specialist	789	RL.189
Mechanical Maintenance Engineering	790	RL.190
Electrical Maintenance Engineering	791	RL.191
Instrumentation & Control (I&C) Maintenance Engineering	792	RL.192
System Engineering	793	RL.193
Director of Engineering (Site)	794	RL.194
Manager of Engineering Program (Site)	795	RL.195
IAMP Principal Engineer (Site)	796	RL.196
Obsolescence Program Engineer (Site)	797	RL.197
System Engineer (Plant)	798	RL.198
Maintenance Support Manager	799	RL.199
Maintenance Program Manager	800	RL.200
Site Program Engineering Manager	801	RL.201
Site Engineering MR Program Engineer	802	RL.202
Plant Program Engineering Manager	803	RL.203
Plant Program Engineering Head of MR	804	RL.204
Plant Program MR Engineer	805	RL.205
Plant System Engineering Manager	806	RL.206
Plant Head of System Engineering	807	RL.207
Plant System Engineers	808	RL.208

Corporate Nuclear Risk Management PRA Manager.	809	RL.209
MR Expert Panel	810	RL.210
Site Maintenance Director (Maintenance Department)	811	RL.211
Maintenance & Engineering Director in the plant	812	RL.212
QA Manager	813	RL.213
Training Department Manager	814	RL.214
Site M&TE Program Owner	815	RL.215
Plant M&TE Engineer	816	RL.216
Department Managers	817	RL.217
Calibration Staff Personnel	818	RL.218
M&TE Users	819	RL.219
Environmental Director	820	RL.220
MMS Contractor	821	RL.221
Environmental Management	822	RL.222
Site MOV Program Principal Engineer	823	RL.223
Plant Engineering Programs Manager	824	RL.224
Plant Site MOV Program Engineer	825	RL.225
Plant System Engineering	826	RL.226
Plant Maintenance	827	RL.227
Environmental Department	828	RL.228
I&C Department	829	RL.229
Radiation Protection staff consists of engineers, supervisors, technicians, and administrative	830	RL.230
Site Support Radiation Manager	831	RL.231
Radiation Protection Manager (RPM)	832	RL.232
Radiation Protection Staff	833	RL.233
Radiation Workers	834	RL.234
Director of Capacity Building and Training	835	RL.235
Manager of Health and Safety	836	RL.236
ALARA Committee	837	RL.237
The NPI Director	838	RL.238
Executives and Senior Managers (Leadership Team)	839	RL.239
Managers and Heads	840	RL.240
Individual Contributors	841	RL.241
Executive Leadership Team	842	RL.242
Operations Support Manager	843	RL.243
Shift Managers and Shift Supervisors	844	RL.244
Shift Local Operators	845	RL.245
Maintenance and Engineering Director	846	RL.246
Maintenance and Engineering	847	RL.247
Maintenance Managers	848	RL.248
Work and Outage Management Director	849	RL.249
All personnel involved in performing surveillances, inspections, and preventive maintenance activities	850	RL.250
Quality Assurance	851	RL.251
Nuclear Risk Management (NRM) Director	852	RL.252
NRM PRA Manager	853	RL.253

Engineering Function Director	854	RL.254
Maintenance Function	855	RL.255
Work Management Function	856	RL.256
Safety and Engineering Support Function	857	RL.257
Department/Function Directors	858	RL.258
Head of Waste Management	859	RL.259
SRS Specialist and RW Specialist	860	RL.260
Operation Team Manager	861	RL.261
Maintenance (Mechanical, Electrical, I&C) Team Manager	862	RL.262
Radiation Protection Manager	863	RL.263
Head of Radiological Protection	864	RL.264
Radioactive Waste Personnel	865	RL.265
Managers of Operations	866	RL.266
Manager of Maintenance Team (Mechanical)	867	RL.267
Managers of Work Teams	868	RL.268
CEO	869	RL.269
Personnel	870	RL.270
Engineering Director (Site)	871	RL.271
Principal Engineer –Program (Site)	872	RL.272
Information security Engineer (Plant)	873	RL.273
Specimen Retrieval and Transportation Contractor	874	RL.274
Program Engineering Manager (Plant)	875	RL.275
Head of Safeguards	876	RL.276
Safeguards Responsible Person (SRP)	877	RL.277
Senior Safeguards Specialist	878	RL.278
Safeguards Specialist	879	RL.279
Safeguards Officer	880	RL.280
Licensing and Regulatory Affairs Deputy Vice President.	881	RL.281
Fuel Management Engineer	882	RL.282
Site Safeguards Implementation Officer	883	RL.283
Federal Authority for Nuclear Regulation (FANR)	884	RL.284
IAEA staff	885	RL.285
Safeguards Department	886	RL.286
Site Security Director	887	RL.287
Information Security and Cyber Security Director	888	RL.288
Personnel Security Manager	889	RL.289
Physical Security Manager	890	RL.290
Site Security Operations Manager	891	RL.291
Security Training Manager	892	RL.292
Cyber Security Manager Description	893	RL.293
Information Security Manager Description	894	RL.294
Site Engineering –Principal Engineer	895	RL.295
Site Support - Chemistry Manager	896	RL.296
Plant - Chemistry SGMP Specialist	897	RL.297
Plant - Chemistry Manager	898	RL.298
Plant Maintenance and Engineering - Head Mechanical	899	RL.299
Plant – Operations	900	RL.300

Operations Director or Designee	901	RL.301
On Duty Shift Manager or Designee	902	RL.302
Test Team Lead or Conductor	903	RL.303
Maintenance, System, and Program Engineers	904	RL.304
All personnel involved in performing surveillances and periodic tests	905	RL.305
Deputy Operations Support Manager	906	RL.306
Operations Head	907	RL.307
System Engineering Manager (Site)	908	RL.308
Plant Manager	909	RL.309
System Engineering Manager (Plant)	910	RL.310
Equipment Reliability Manager (Site)	911	RL.311
Capacity Building & Training Department	912	RL.312
Departments	913	RL.313
staff members	914	RL.314

Following the Data Analysis process for this study, Data for this network was imported into Gephi using the above-mentioned structure, Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced (Figure 5.37)

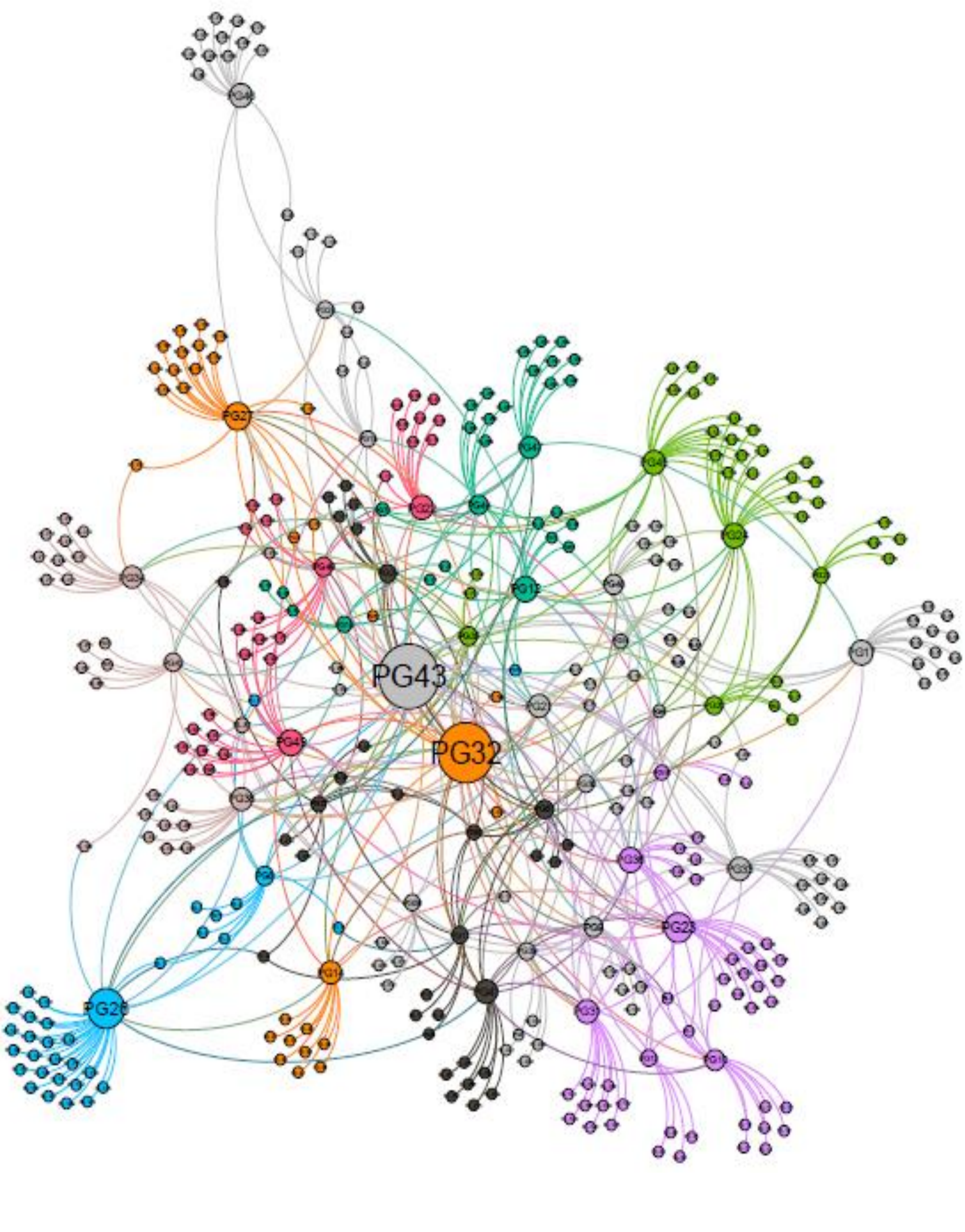


Figure 5. 37 Strategic programs and roles network

5.11.1 General characteristics

The structural characteristics of the Strategic Programs and Roles network are shown in table (5.45).

Table 5. 45 Structural characteristics of strategic programs and roles intersections

Characteristic	Value
Total number of Strategic Programs and Roles nodes	358
Total number of undirected interactions (Edges)	577

From the first look at figure (5.37), the flow of information between Strategic Programs and Roles appears to be seamless and the interaction seems to be efficient as indicated by a very low dense network. The maximum number of connections required to traverse the interaction between Strategic Programs and Roles or in other words the number of steps taken between the two most distant nodes in this interaction to reach one another is 5 nodes as indicated by the Network Diameter. Combining this observation with the fact that the maximum path length between Strategic Programs and Roles is 3.5 as indicated by the average path length for a graph, we can conclude that the graph is efficient from a communication standpoint since the maximum path length between Strategic Programs and Roles is less than the network diameter.

5.11.2 Network density

In this network, density measures the linkage between Strategic Programs and Roles. A density close to 1 indicates that all Strategic Programs are strongly linked to and Roles within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interaction between Strategic Programs and Roles. A value close to 0 will indicate the existence of weak interaction between Strategic Programs and Roles. Additionally, the density of the interaction in this network can be used to measure the cohesiveness and robustness of the interaction between Strategic Programs and Roles. The density of this interaction is 0.009 which suggests that there is a low level of interaction among Strategic Programs and Roles. This observation should be analyzed more in line with the characteristics of interactions between L0 Processes and Strategic Programs. This will provide another critical view of the coverage and integration of strategic Programs within the Nuclear Power Plant Management System.

5.11.3 Network clustering coefficient and modularity analysis

Clustering coefficient and Modularity provides the ability to measure the level at which Strategic Programs and Roles are grouped together, as opposed to being equally or randomly connected across the network. The clustering coefficient measures the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available in the interaction between Strategic Programs and Roles. in essence, this measures the degree to which second-tier Strategic Program or specific Role is connected to one another. Tightly knit clusters and distinctive communities are associated with High Clustering coefficient scores, whereas dispersed interactions produce lower scores. The average Clustering Coefficient for this network is 0.147 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis showed that Strategic Programs and Roles are distributed across 13 distinct communities. Figure (5.38) shows the size distribution of the 13 clusters in the interactions between Programs and Roles

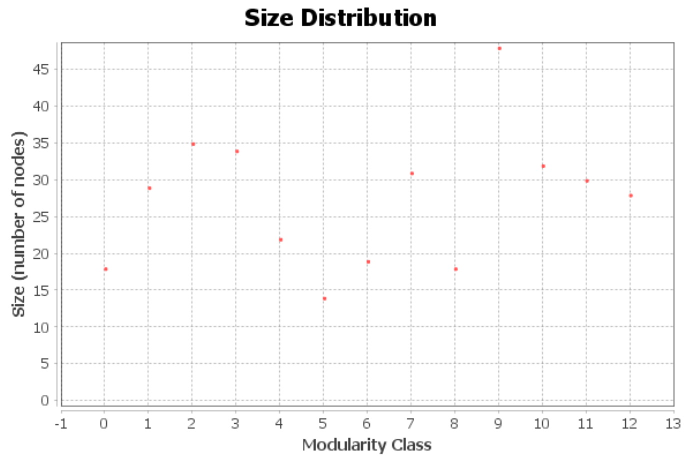
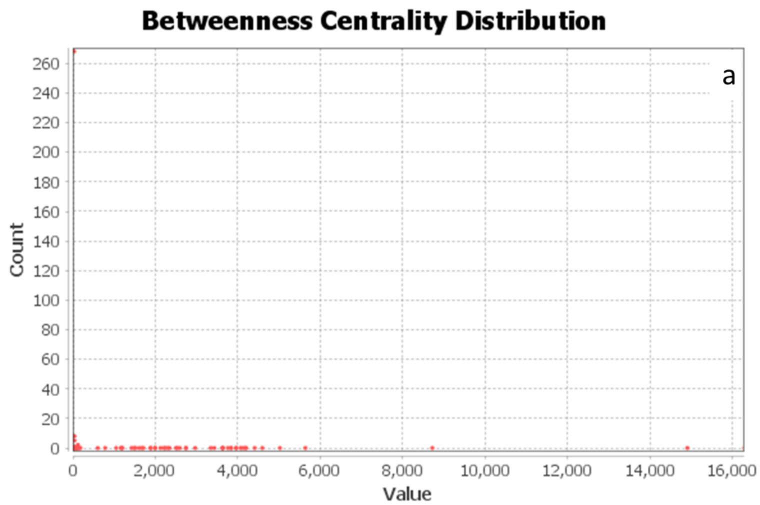


Figure 5. 38 Clusters size distribution in the interactions between programs and roles

As seen in figure (5.37), the interaction between Programs and Defined Roles seems to homogenous and also following in most cases the hub and spoke patterns where most Roles are supporting, interacting, and/or linked to a specific Programs in one-to-one interaction. Furthermore, multiple influential programs can be found in each cluster which further supports the fact that this structural configuration strongly contributes to enhance robustness to failure in interactions between Strategic Programs and Roles.

5.11.4 Network centrality measures

Centrality measures help to understand certain characteristics in the interactions between Strategic Programs and Roles. For example, Centrality measures help in identifying which components in the interaction between Strategic Programs and Roles have more influence over other components. It also helps in assessing the efficiency of information flows Strategic Programs and Roles when assessed jointly with other networks statistics. The Closeness Centrality is the inverse of the mean shortest path between a node and all other nodes in the network that is reachable from it. This metric reflects the ability of Strategic Programs and Roles to access and transmit information through the network quickly. It also indicates how close a Strategic Program or Role node is from every other programs and roles in this network. Figure (5.39) presents the results of analysis of betweenness and closeness centrality the interactions between Strategic Programs and Roles.



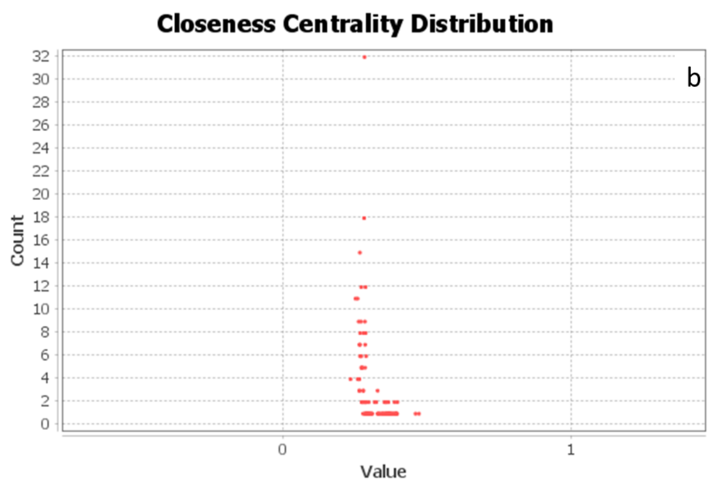


Figure 5. 39 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between strategic programs and roles

Interestingly, Centrality Distribution graphs in figure (5.39) have shown that more than 70% of nodes in this network has zero betweenness centrality. The remaining portion of Strategic Programs and the Roles has a betweenness centrality that ranges from 4.8 to 16255. A lot of variabilities are observed. The closeness centrality distribution of Strategic Programs and the regulatory Requirements seems to be following normal distribution and denoting less variability and a minor positive skewness. The majority of Strategic Programs and the regulatory requirements are centered around the mean of 0.29 ranging between 0.23 and 0.46. However, the majority of nodes are seen from this angle as having low to moderate influence over this network. Betweenness centrality provides a different perspective for those poorly connected programs or Roles nodes (low Degree centrality) that might be essential to the network by being bridges between key other components. Calculating Betweenness centrality can help in measures the degree to which Strategic Programs and Roles offer the most direct ties between otherwise disconnected communities within this interaction. A higher betweenness centrality score for a Strategic Program or a Role will provide a perspective on how critical that Strategic Program or a Role to maintain the structure of the network. Table 5.46 highlights Strategic Programs with the highest Betweenness Centrality.

Table 5. 46 Programs with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality	Hub
331	PG43	0.455939	16255.26	0.306939
320	PG32	0.46789	14871.67	0.356315
314	PG26	0.385113	8686.415	0.15005
311	PG23	0.391877	5608.175	0.207076
315	PG27	0.363544	4990.723	0.095634
337	PG49	0.378981	4563.414	0.156958
300	PG12	0.392739	4377.468	0.177786
324	PG36	0.388889	4168.94	0.200959
305	PG17	0.340324	4144.119	0.067536
312	PG24	0.354871	4085.33	0.10099
310	PG22	0.384284	4030.878	0.116841

Maintenance Program and Quality Assurance Programs are seen as the most influential nodes based on their high Betweenness Centrality. This role is essential to maintain an efficient and effective interaction between Programs and Roles. Therefore, shall be managed carefully to protect the structural integrity and the overall efficiency of interaction and information flow.

To understand the interaction between Strategic Programs and Roles in the Nuclear Power Plant Operational Readiness Program, it is important to drill down and analyze the typology and nature of linkage associated with the Quality Assurance Program (PG43) since it turned out to be the most influential node based on its Betweenness Centrality. To do so, the ego network technique will be used. The below Ego graph of the Quality Assurance Program (figure 5.40) was produced by Gephi.

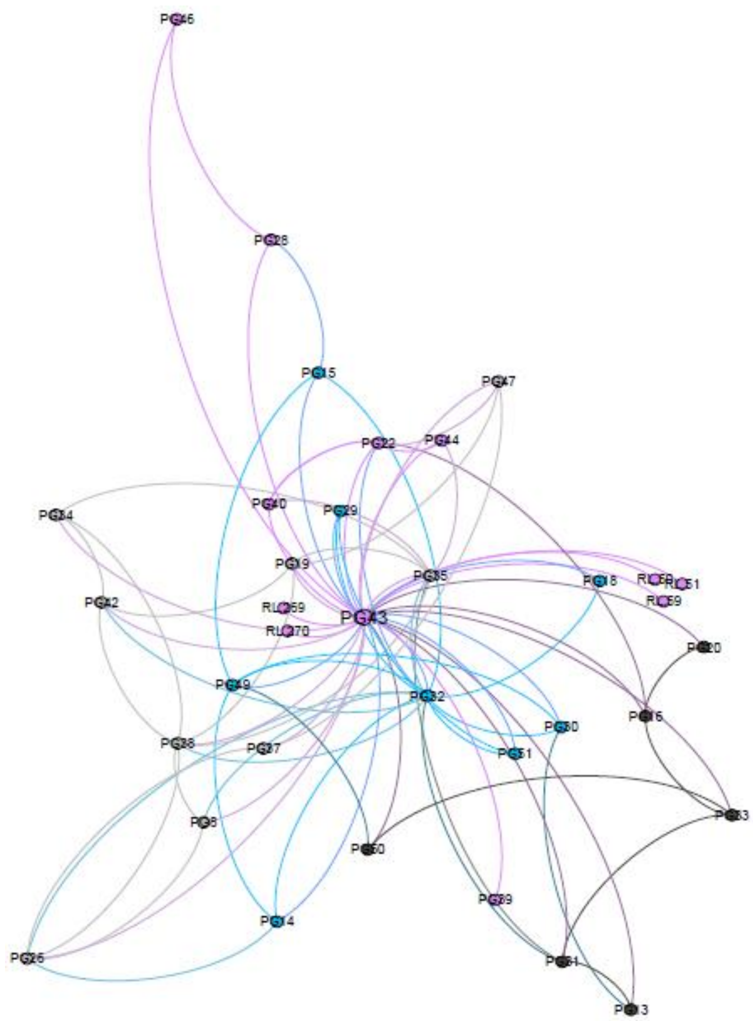


Figure 5. 40 Ego network of quality assurance program (PG43)

The structural characteristics of Quality Assurance Program Ego Network are shown in table (5.47).

Table 5. 47 Characteristic of quality assurance program ego network

Characteristic	Value	% Visible
Total number nodes	35	9.78%
Total number of Edges	83	14.38%

The interaction between the quality assurance program and other nodes (strategic programs and defined roles) in this ego network appear to be relatively denser and forming a higher level of interactions when compared with the overall programs -roles network which has a density of 0.009 the ego network density is considerably higher than the value for a complete graph which indicates that of all possible connections that may exist in this interaction including direct links with quality assurance program, a very good portion of them have already established. The maximum path length between in this ego network is 1.86 as indicated by the average path length for a graph, we can conclude that the graph is relatively efficient in terms of transferring information across different modes since the maximum path length is less than the network diameter. Table 5. 48 highlights key network statistics of quality assurance program ego network

Table 5. 48 Statistics of quality assurance program ego network

Network statistic	Value
Graph density	0.139
Network diameter	2
Average Path length	1.86
Average Clustering Coefficient	0.657

As per the network graph in Figure (5. 41), looking at the clustering of distinctive communities within the Quality Assurance Program Ego Network, we can observe four clusters with majority of nodes falling in the second cluster as show in figure (5.41)

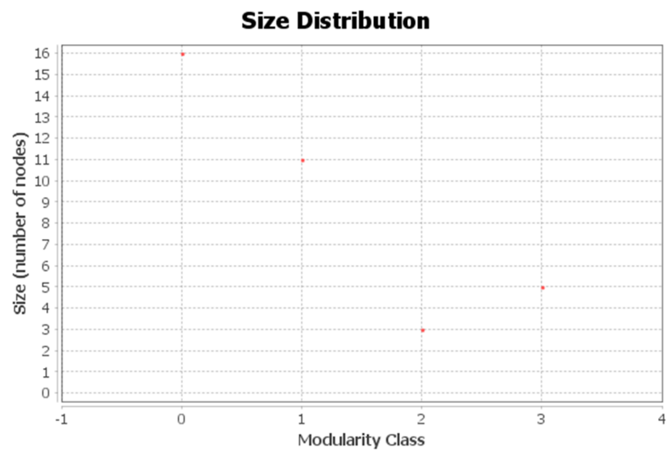


Figure 5. 42 Clusters distribution of the quality assurance program ego network

We can define two groups of nodes in the Quality Assurance Program Ego Network, Core and peripheral. It appears that this Ego network has multiple core connections near to the gravity center being the Quality Assurance Program. Whereas nodes like Safeguards program (PG46) and Fuel Integrity (PG28) are loosely connected to the cohesive ego and lack maximal cohesion with the core connections even though both are part of the first cluster centered by the Quality Assurance Program.

5.12. Interactions between strategic programs in the nuclear power plant operational readiness program

This Network depicts all interactions between all strategic Programs in the Nuclear Power Plant Operational Readiness. Data for this network was imported into Gephi as structured in the table (5.8), Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced (Figure 5.42)

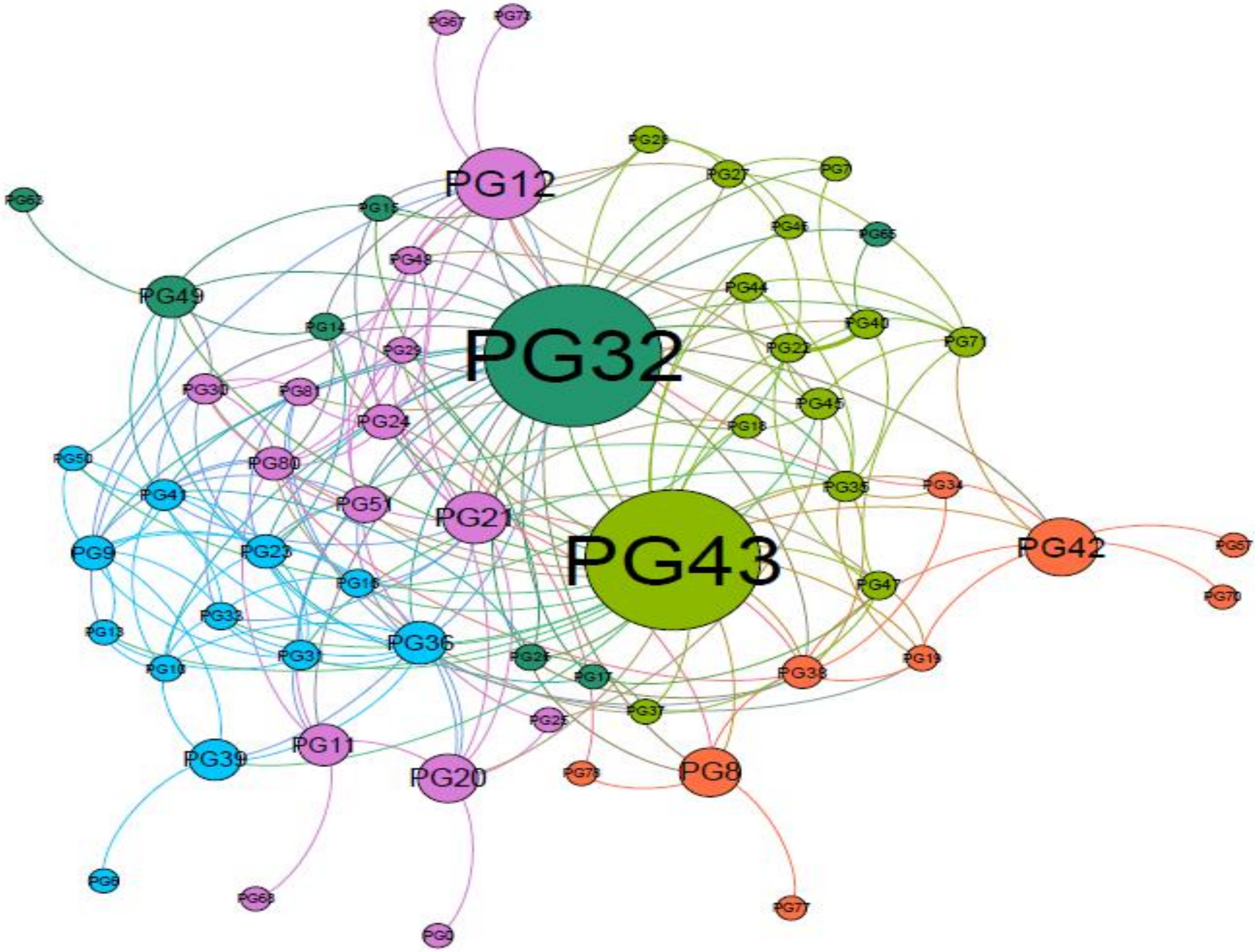


Figure 5. 43 Strategic programs network

5.12.1 General characteristics

The structural characteristics of the strategic programs in the Nuclear Power Plant Operational readiness are shown in table (5.49).

Table 5. 49 Structural characteristics of the strategic programs network

Characteristic	Value
Total number of Strategic Programs	59
Total number of undirected interactions (Edges)	216

The interaction between Strategic Programs seems to be efficient and the flow of information seems to be seamless as indicated a relatively low dense network. The number of steps taken between the two most distant strategic programs in this interaction to reach one another is 5 nodes as indicated by the Network Diameter. Combining this observation with the fact that the maximum path length between strategic programs is 2.7 as indicated by the average path length for a graph, we can conclude that the interaction amongst strategic programs is efficient and the transfer of information is seamless since the maximum path length is less than the network diameter.

5.12.2 Network density

Graph density helps in measuring how tightly interconnected the strategic programs to each others by comparing the proportion of existing connections between strategic programs to the relative to the possible total number of connections. A high degree of interaction across the network will have higher density levels while weak interactions result in low network density. In this network, a density close to 1 indicates that all strategic programs are strongly linked together within the nuclear power plant operational readiness program. While a density of 0.5 suggests the presence of medium interaction between strategic programs. A value close to 0 will indicate the existence of weak interaction between strategic programs. The density of interaction between strategic programs is 0.126 which suggests that there is a low level of interaction strategic programs.

5.12.3. Network clustering coefficient and modularity analysis

Modularity analysis and Clustering coefficient help in measuring the level at which Strategic Programs are grouped, as opposed to being equally or randomly connected across the network. In this network, the clustering coefficient calculation is based on measuring the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available in the interactions amongst Strategic Programs. As explained earlier, this measures the degree to which second-tier Strategic Programs are connected to one another where high Clustering coefficient scores are highly anticipated from tightly connected and distinctive communities, whereas dispersed interactions usually produce lower scores. The average Clustering Coefficient for this network is 0.290 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis also showed that Strategic Programs are distributed across 5 distinct communities. Figure 5.43 shows the size distribution of the 5 clusters in the interactions between Strategic Programs.

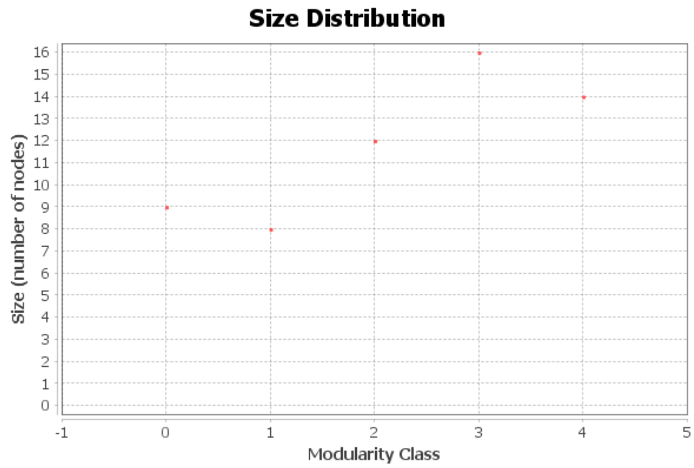


Figure 5. 44 Clusters size distribution in the interactions between strategic programs

Those clusters share commonalities and a label can be tagged to each cluster based on their nature and purpose distinct communities. This property strongly supports the resilience of interactions between strategic programs knowing the high probability of delays, cost overrun, the quality issue associated with programs execution. The 5 major hubs are concentrated around specific strategic programs (mainly with high betweenness centrality). This structural configuration allows for a fault-tolerant behavior in the interaction between strategic programs. Hence, if any program within one of those 5 clusters experiences issues with schedule, cost, or quality, the distal impact most probably would be contained within the cluster with a minimal negative impact on other clusters. Therefore, the probability of realizing strategic benefits out of those programs increases.

5.12.4 Network centrality measures

Certain characteristics in the interactions between Strategic Programs cab be better understood using centrality measures. Centrality is an essential measure of the information flows strategic programs when assessed jointly with other network statistics. As explained earlier, Closeness

Centrality measures the mean shortest path between a node and all other nodes in the network that is reachable from it. This network statistics reflects the ability of a Strategic Program to access and transmit information through the network quickly. It also indicates how close a Strategic Program is from every other Program in this network. Figure (5.44) presents the results of the analysis of betweenness and closeness centrality in this network.

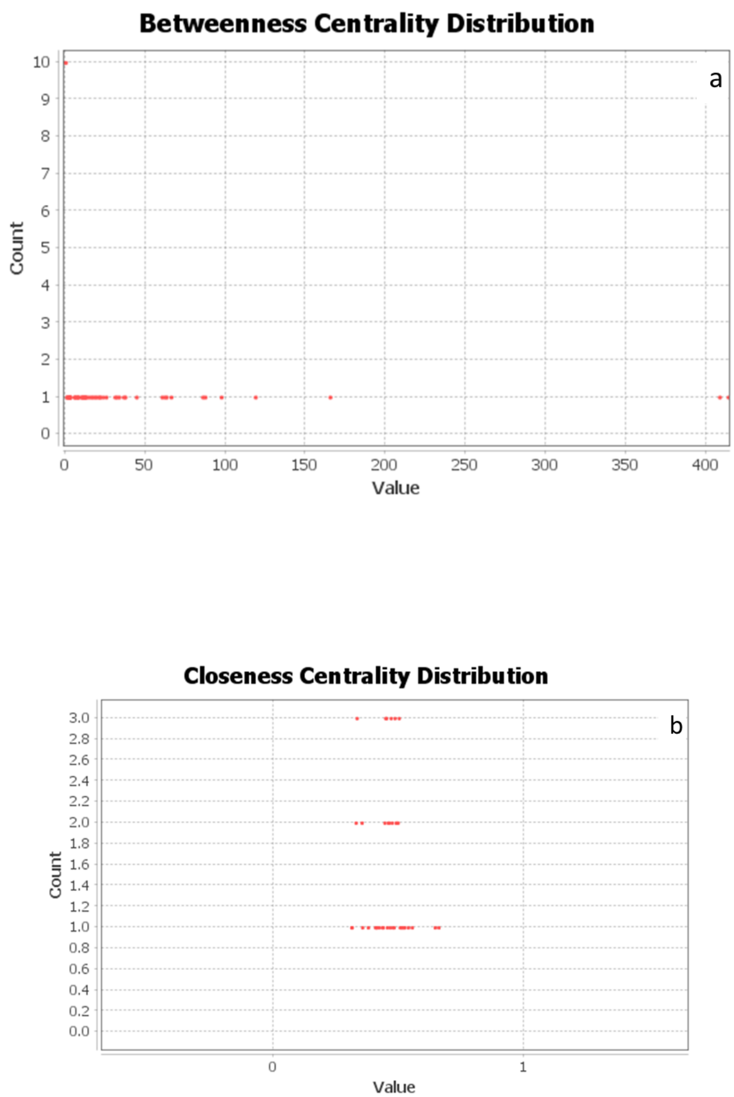


Figure 5. 45 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between strategic programs

Centrality Distribution graphs have shown that around 17% of strategic programs in this network has zero betweenness centrality. The remaining portion of Strategic Programs has a betweenness centrality that ranges from 0.7 and 413. A lot of variabilities are observed and two strategic Programs only have a betweenness centrality above 400. The closeness centrality distribution of Strategic Programs seems to be following normal distribution and denoting less variability and a minor positive skewness. The majority of Strategic Programs are centered around the mean of 0.45 ranging between 0.3 and 0.65. However, the majority of nodes are seen from this angle as having low to moderate influence over this network. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. In this network, Betweenness centrality measures the degree to which Strategic Programs offer the most direct path between otherwise disconnected Clusters. Higher betweenness centrality score for a Strategic Program indicate that this program is critical to maintaining the structure of interactions between strategic programs in the Nuclear Power Plant Operational Readiness. The table (5.50) below highlights Strategic Programs with the highest Betweenness Centrality. Similar to other observations from other networks in this study, Maintenance Program, Quality Assurance Programs, and chemistry program appears to be the most influential Strategic programs in the nuclear power plant operational readiness. They form bridges between different strategic programs in the nuclear power plan due to their structural properties, therefore, they are seen as very critical to maintain the integrity of interactions between strategic programs, foster the effective flow of information between programs and ensure strategic benefits realization.

Table 5. 50 Strategic programs with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality	modularity class
320	PG32	0.659091	413.5781	1
331	PG43	0.644444	408.1704	4
300	PG12	0.537037	165.1106	3
330	PG42	0.491525	118.5405	0
309	PG21	0.552381	97.23231	3
296	PG8	0.483333	87.17917	0
308	PG20	0.483333	85.67028	3
324	PG36	0.522523	65.90223	2
337	PG49	0.491525	63.02476	1
299	PG11	0.446154	61.91026	3
327	PG39	0.449612	60.21477	2

In order to understand the interaction between Strategic Programs in the Nuclear Power Plant Operational Readiness Program, it is important to drill down and analyze the typology and nature of linkage associated with the Maintenance Program being the one with the highest Betweenness Centrality. To do so, the ego network technique will be used. The below Ego graph of the Maintenance Program (5.45) was produced by Gephi.

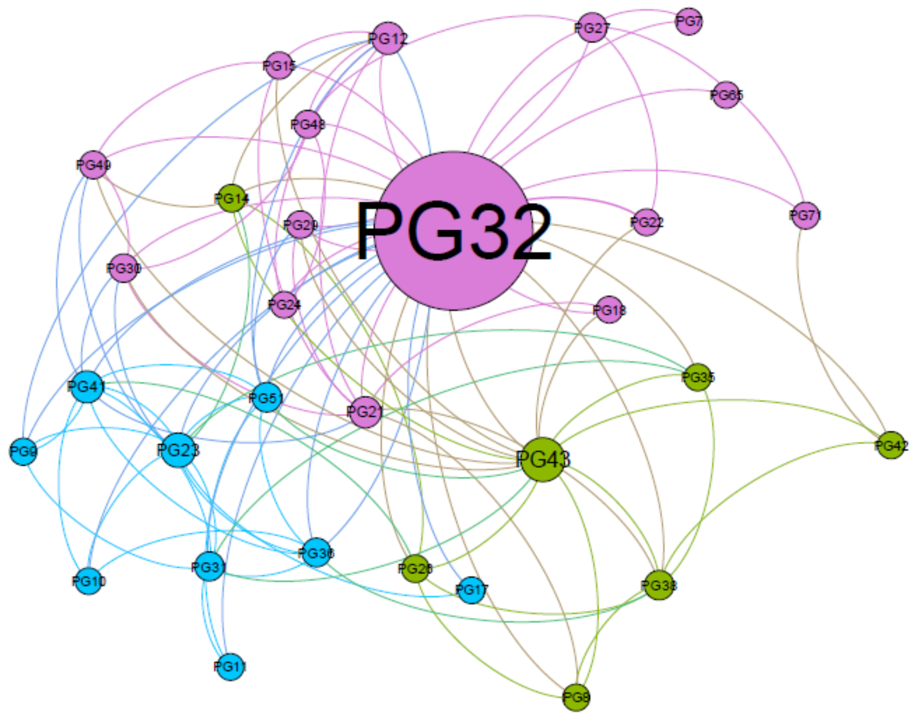


Figure 5. 46 Ego network of maintenance program

The structural characteristics of Maintenance Program Ego Network are shown in Table (5.51).

Table 5. 51 Characteristic of maintenance program Ego network

Characteristic	Value	% Visible
Total number nodes	31	52.54%
Total number of Edges	104	48.15%

As shown in table (5.51), 52.45% of nodes in the complete network are connected to the Maintenance Program in the smaller Ego Network. Maintenance Program Ego Network forms a 48.15% proportion of the complete network interactions. However, the interaction between the Maintenance Program and other Strategic Programs in this Ego Network appear to be significantly dispersed and forming a lower level of interactions when compared with the overall Strategic Programs Network which has a density of 0.5. The Ego Network density is considerably lower than the value for a complete graph which indicates that of all possible connections that may exist in this interaction including direct links with Maintenance Program, a very good portion of them have not been already established. The maximum path length between in this ego network is 1.77 as indicated by the average path length for a graph, we can conclude that the graph is relatively inefficient in terms of establishing a cohesive and tightly interconnected network between Strategic Programs to enable an effective and timely exchange of data and information. Table 5. 52 lists key network statistics for the maintenance program ego network

Table 5. 52 Statistics of maintenance program Ego network

Network statistic	Value
Graph density	0.224
Network diameter	2
Average Path length	1.77
Average Clustering Coefficient	0.583

Looking at the clustering of distinctive communities within the Maintenance Program Ego Network, we can observe three clusters with majority of nodes falling in the first cluster centered by the Maintenance Program itself as show in figure (5.45). It appears that this Ego network has a single core where a majority of nodes are linked to the cohesive ego. Figure (5.46) shows the size distribution of the three clusters in the Maintenance Program Ego Network.

Figure 5. 47 Clusters distribution of the maintenance program Ego network

5.13. Interactions between strategic programs and plant systems in the nuclear power plant operational readiness program

This Network depicts all interactions between Programs in the Nuclear Power Plant Operational Readiness and Plant Systems. Systems referred to in this study covers Plant Systems, Structures, and Components (SSC). These include, but are not limited to software applications, supporting hardware, safety-related equipment, and buildings. Data for this network was imported into Gephi as structured in the table (5.27), Force atlas algorithm was applied, graph statistics were applied and the final network graph was produced (Figure 5.47)

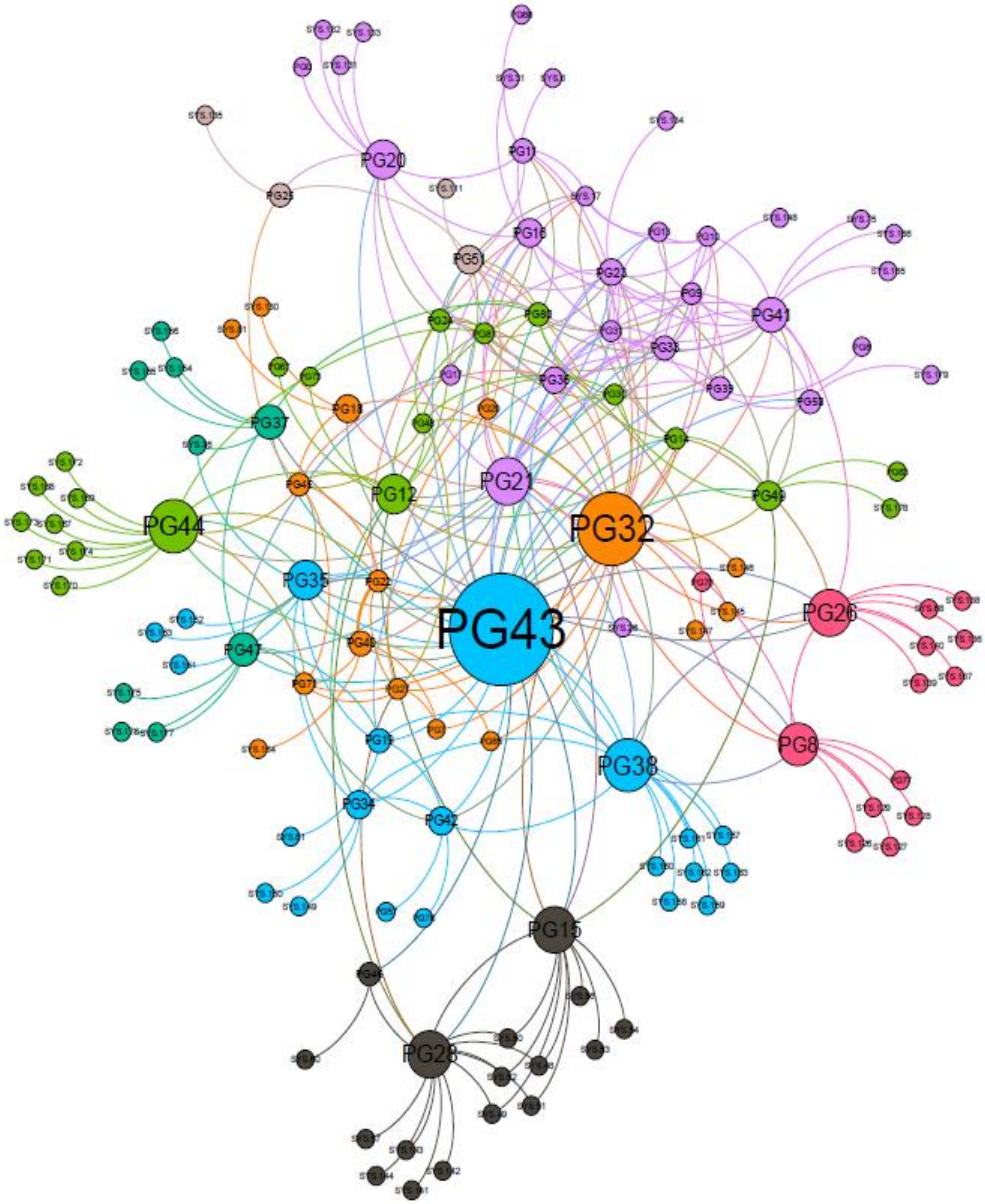


Figure 5. 48 Strategic programs and plant systems network

5.13.1 General characteristics

The structural characteristics of Strategic Programs and Plant Systems network are shown in Table (5.53).

Table 5. 53 Structural characteristics of the strategic programs and plant systems network

Characteristic	Value
Total number of Strategic Programs and Plant Systems nodes	133
Total number of undirected interactions (Edges)	302

The interaction between Strategic Programs and Plant Systems nodes seems to be relatively efficient and the flow of information seems to be seamless as indicated by a low dense network. The maximum number of connections required to traverse the interaction between Strategic Programs and Plant Systems is 5 nodes as indicated by the Network Diameter. The maximum path length between Strategic Programs and Plant Systems is 3.0 as indicated by the average path length for a graph. Therefore, we can conclude that the interaction between Strategic Programs and Plant Systems is efficient from a communication standpoint since the maximum path length is less than the network diameter.

5.13.2 Network density

Similar to other interactions explained earlier in this study, Graph density assesses how strongly interconnected the network is. In this case, it examines the percentage of established interactions relative to the possible total number of connections between Strategic Programs and Plant Systems. A high degree of interaction between Strategic Programs and Plant Systems will have higher density levels while weak interactions result in low Network Density. Two networks with identical numbers of Strategic Programs and Plant Systems from different Nuclear programs might have very different density levels; even the same interaction between Strategic Programs and Plant Systems measured at different time intervals is likely to have differing density measures as links are formed or broken over time. The value of network density ranges from 0 to 1. A density close to 1 indicates that interactions between Strategic Programs and Plant Systems are tight and strongly linked within the Nuclear Power Plant Operational Readiness Program. While a density of 0.5 suggests the presence of medium interaction between Strategic Programs and Plant Systems. A value close to 0 will indicate the existence of weak interaction between Strategic Programs and Plant Systems, Structures, and Components. The density of interaction between L0 Processes and the Additionally, the density of the interaction in this network can be used to measure the cohesiveness and robustness of the interaction between Strategic Programs and Plant Systems, as well as, the inclusiveness and coverage of all regulatory requirements as part of the BAU design within the nuclear power plant is 0.034 which suggests that there is a low level of interaction between Strategic Programs and Plant Systems, Structures, and Components. The density of the interaction in this network can be used as a measure to assess the cohesiveness and robustness of the Nuclear Power Plant Integrated Management System. Building robust and integrated interfaces between Strategic Programs (knowing their strategic importance for achieving the Nuclear Power Plant Integrated Management System objectives) and the Plant Systems, Structures and Components is very critical to realize the overall objective of designing and implementing the Integrated Management System (IMS). The density of interaction between Strategic Programs and Plant Systems, Structures and Components is a determining factor in assessing how inclusive is the coverage of IMS to fulfill all regulatory requirements as part of the BAU design within the nuclear power plant in a systematic and structured manner.

5.13.3 Network clustering coefficient and modularity analysis

Network clustering coefficient help in grouping Strategic Programs, Plant Systems, Structures, and Components based on the strength of their relationships into distinct clusters. Clustering coefficient provides the ability to measure the level at which Strategic Programs, Plant Systems, Structures, and Components are grouped together, as opposed to being equally or randomly connected across the network. Clustering coefficient calculation is based on measuring the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available in the interactions between Strategic Programs, Plant Systems, Structures, and Components. It measures the degree to which second layer/tier Strategic Programs, Plant Systems, Structures, and Components are connected to one another. High Clustering coefficient scores are highly anticipated from tightly interweaved clusters and distinctive communities, whereas dispersed interactions usually produce lower Clustering coefficient scores. The average Clustering Coefficient for this network is 0.258 which indicates that some well-defined clusters can be identified in this network. Modularity class analysis showed that Strategic Programs, Plant Systems, Structures, and Components are distributed across 8 distinctive clusters. The size distribution of the 8 clusters is shown in figure (5.48). Figure 5. 48 shows the modularity class size distribution for the 8 distinctive clusters in the interactions between Strategic Programs, Plant Systems, Structures, and Components.

Figure 5. 49 Modularity class size distribution in the interactions between strategic programs, plant systems, structures and components

Like most of other networks in this study and as shown in figure (5.47), the interaction between Programs and Plant Systems follow the hub and spoke model where programs interact with specific systems in the plant on a one-to-one basis since they have a unique scope that is usually related to particular systems within the plant. Furthermore, most of the clusters in this interaction are dispersed and not centered around a specific strategic program. This pattern needs to be studied further to assess the integrity of the Nuclear Power Plant Operational Readiness Management Systems and the level of integration and harmonization between relevant Systems. Similar to other interactions in this study, the property of multiple hubs strongly correlates with the network's robustness to failure. This structural configuration of having 8 major hubs that are dispersed and not concentrated around specific Strategic Programs might provision a fault-tolerant behavior and fosters resilience in the interaction between strategic Programs and Plant Systems, Structures, and Components.

5.13.4 Network centrality measures

Certain characteristics of the interactions between Strategic Programs Plant Systems, Structures, and Components can be demystified using Network Centrality Measures. Centrality measures help in identifying which Strategic Programs, Plant Systems, Structures or Components in the nuclear power plant operational readiness have more influence over other components in terms of protecting the integrity of the interaction due to certain structural characteristics of those influential players. Furthermore, Centrality is an essential measure of the information flows between processes Strategic Programs, Plant Systems, Structures, and Components especially when assessed jointly with other statistics like graph density, network diameter, and average path length. The Closeness Centrality measures the inverse of the average shortest path between a node and all other nodes in the network. This metric reflects the ability of a Strategic Program, Plant System, Plant Structure or Plant Component to access and transmit information through the network quickly. It also indicates how close a Strategic Program, Plant System, Plant Structure, or Plant Component is from every other Program or Plant System in this network. Betweenness centrality measures to what degree Strategic Programs, Plant Systems, Structures, and/or Components offer the most direct path between otherwise disconnected Clusters in this interaction. A higher betweenness centrality score for Strategic Programs or Plant System will provide a perspective on how critical that Program or System to maintain the structure of the network. Figure (5.49) presents the results of the analysis of Betweenness and closeness centrality in interactions between Strategic Programs, Plant Systems, Structures, and Components.

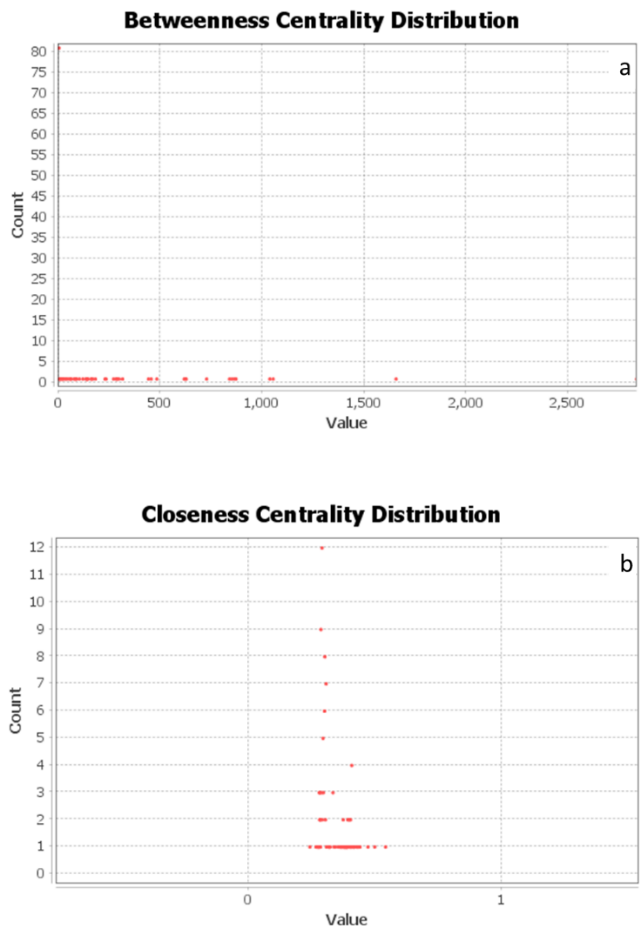


Figure 5. 50 a) Betweenness centrality distribution b) Closeness centrality distribution in the interactions between strategic programs, plant systems, structures and components.

Centrality Distribution graphs have shown that around 60% of strategic programs in this network has zero betweenness centrality. The remaining portion of Strategic Programs has a betweenness centrality that ranges from 2.2 and 2833. A lot of variabilities are observed and four strategic Programs only have a betweenness centrality above 1000. The closeness centrality distribution of Strategic Programs, Plant Systems, Structures, and Components seems to be following normal distribution and denoting less variability and a minor positive skewness. The majority of Strategic Programs, Plant Systems, Structures, and Components are centered around the mean of 0.33 ranging between 0.24 and 0.54. However, the majority of nodes are seen from this angle as having low to moderate influence over this network. Looking at some interesting insights coming from this interaction, Subject Matter Experts and Management systems Professionals might need to further recognize the essential role some Strategic Programs play to keep the efficient flow of information and maintain the structural integrity of this interaction. Those are mainly nodes with the highest Betweenness Centrality as shown in table (5.54) below. Similar to other observations from other networks in this study, Maintenance Program and Quality Assurance Programs appear as the most influential in this network in addition to Operational Radiation Protection and Radioactive Waste Management. Effective management of those Programs appears to be very essential to maintain seamless interactions and provide more influence on the speed of information flow.

Table 5. 54 Programs with the highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality	modularity class
331	PG43	0.540984	2833.141	7
320	PG32	0.498113	1653.564	6
332	PG44	0.407407	1050.27	5
326	PG38	0.44	1034.002	7
309	PG21	0.471429	867.9267	1
316	PG28	0.398792	860.2597	4
314	PG26	0.427184	848.6181	0
303	PG15	0.417722	836.2668	4
296	PG8	0.415094	723.9048	0
323	PG35	0.429967	623.4026	7
300	PG12	0.434211	620.108	5
308	PG20	0.398792	613.8632	1

The main focus of this work is to understand the interaction between Strategic Programs and Plant Systems in the Nuclear Power Plant Operational Readiness Program. Therefore, it is important to investigate in detail the nature of influence the Quality Assurance Program has in this network being the node with the highest Betweenness Centrality. To do so, the ego network technique will be used. The below Quality Assurance Program Ego graph (5.50) was produced by Gephi.

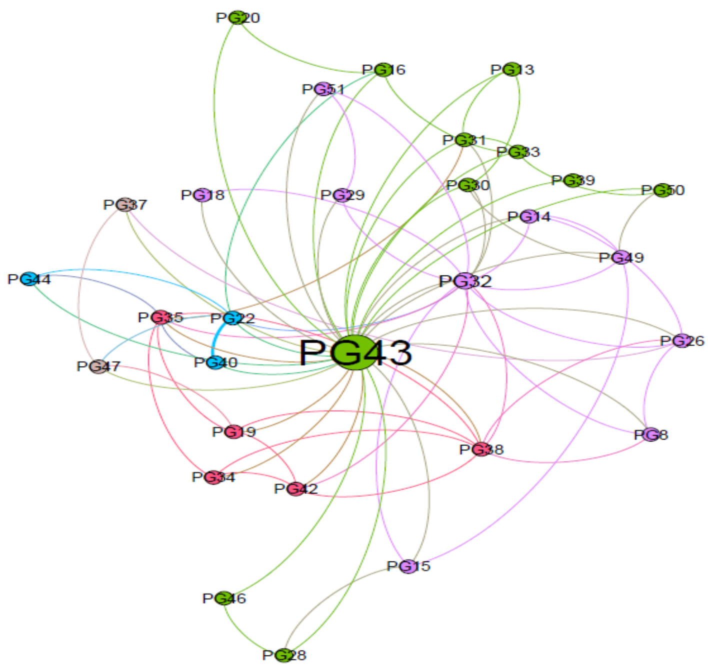


Figure 5. 51 Ego network of quality assurance program

The structural characteristics of the Quality Assurance Program Ego Network are shown in table (5.55).

Table 5. 55 Characteristic of quality assurance program Ego network

Characteristic	Value	% Visible
Total number nodes	30	22.56%
Total number of Edges	78	25.83%

The interaction between the Quality Assurance Program and other nodes (Strategic Programs and Plant Systems) in this ego network appear to be relatively denser and forming a higher level of interactions when compared with the overall Network. The Ego Network density is higher than the value for a complete graph which indicates that a higher portion of the possible connections that may exist in the interaction between Quality Assurance Program and other nodes is already established. The maximum path length between in this ego network is 1.82 as indicated by the average path length for a graph, we can conclude that the graph is relatively efficient and more capable of transferring data on a smaller scale. Table 5. 56 highlights key network statistics for the quality assurance program ego network

Table 5. 56 Statistics of quality assurance program Ego network

Network statistic	Value
Graph density	0.179
Network diameter	2
Average Path length	1.82
Average Clustering Coefficient	0.658

Looking at the clustering of distinctive communities within the Quality Assurance Program Ego Network, we can observe four clusters with majority of nodes falling in the cluster centered by the Quality Assurance Program itself as show in figure (5.51). Despite the fact that that this Ego network has a main core where the majority of nodes are linked to the cohesive ego, most of the connected not including those directly linked to the Quality Assurance Program tend to be loosely connected to the cohesive ego and peripherally located.

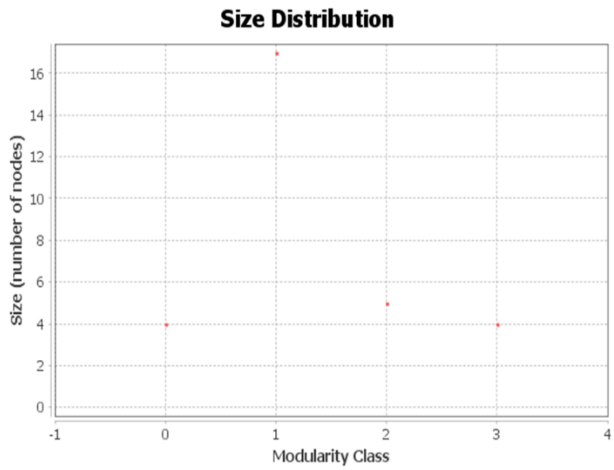


Figure 5. 52 Clusters distribution of the quality assurance program Ego network

5.14. Nuclear power plant operational readiness program full network

This section discusses the results of the analysis of the full network built with the data collected on the Nuclear Power Plant Operational Readiness Program. The analysis is focused on Centrality, Modularity, and Ego Network analysis. The scope of the analysis starts with an overview of the full network and builds on a detailed analysis of the previous 12 networks. An Ego Network of Regulatory Requirements will be studied as being the most important outcomes the Nuclear Power Plant Operational Readiness Program needs to satisfy in order to move from commissioning to commercial operations. Network graph and Statistics metrics are computed with the help of Gephi software.

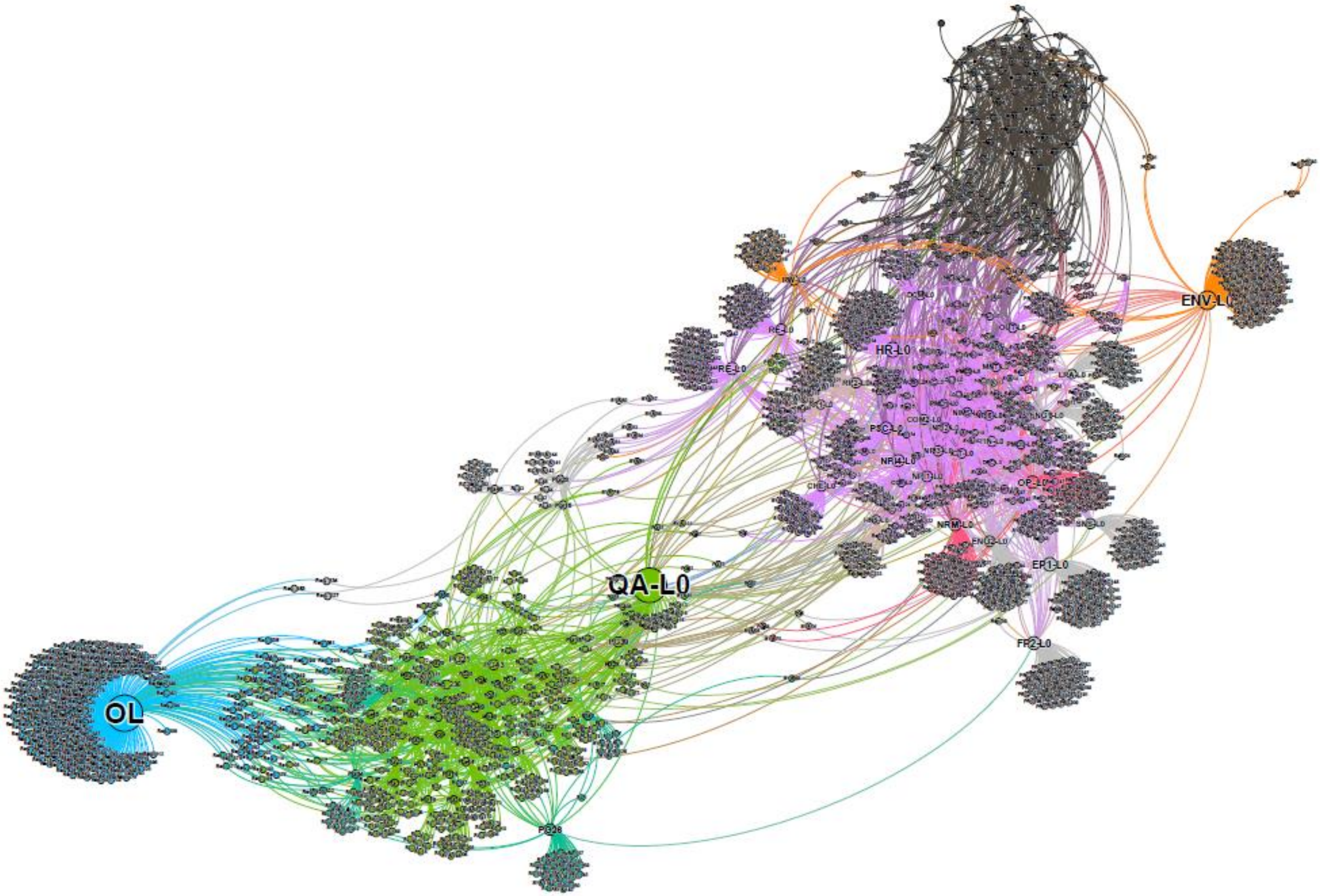


Figure 5. 53 Nuclear power plant operational readiness program full network

5.14.1 Nuclear power plant operational readiness program overview

Figure (5.52) presents the network graph composed of all nodes and relationships of the Nuclear Power Plant Operational Readiness Program. This network aimed to identify and depict all interactions between all components forming the structure of the Nuclear Power Plant Operational Readiness Program as per codes and labels listed in this chapter. The Graph was produced using the Force Atlas layout algorithm with a repulsion strength of 2500, among other visualization parameters. As shown in figure (5.52), some components of the Nuclear Power Plant Operational Readiness Program present a central position in the network, while others are seen as very peripheral and less influential. This will be further studied and explained in the coming subsections. Due to the magnitude of the graph which presents a very high number of nodes and edges, it is difficult to further conclude from visual observation. So, the analysis of the Nuclear Power Plant Operational Readiness Program Network will be complemented by other Ego Networks analysis on the critical success outcomes from the program which is fulfilling regulatory requirements needed to get the Operating License (OL).

From the first look, it is noticeable that the interactions within the Nuclear Power Plant Operational Readiness Program look very dense and heavily interconnected in some areas whereas some other components can be characterized as poorly connected. In many cases, the nature of interactions in Nuclear Power Plant Operational Readiness Program seems to form multiple distinct and large hubs around key components like L0 Processes (Provide Environmental Services (ENV-L0) and Quality Assurance QA-L0), Strategic Programs, and most importantly the regulatory requirements represented by the Operating License (OL) Node. It is also noticeable that the hub and spoke pattern is quite dominant especially in interactions between both Management System Processes and Strategic Programs with other components in the

Nuclear Power Plant Operational Readiness Program. This pattern of interaction support to a great extent the fact that Nuclear Power plants Operational Readiness Programs are designed and structured using process-based models. Furthermore, the hub and spoke pattern prevailed in this interaction explains how key components like each L0 process and Strategic Programs are designed to fulfill specific Regulatory Requirements and ultimately instilling those requirements in the Management Systems Business as Usual (BAU) by design.

5.14.2 General characteristics

The structural characteristics of the Nuclear Power Plant Operational Readiness Program network are shown in table (5.57).

Table 5. 57 Structural characteristics of nuclear power plant operational readiness program network

Characteristic	Value
Total number of nodes	1839
Total number of undirected interactions (Edges)	3619

The interaction between different components in the Nuclear Power Plant Operational Readiness Program seems to be efficient and the flow of information seems to be seamless as indicated by a relatively low dense network. The number of steps taken between the two most distant nodes in the Nuclear Power Plant Operational Readiness Program to reach one another (the maximum number of connections required to traverse the interaction between Nuclear Power Plant Operational Readiness Program nodes) is 8 nodes as indicated by the Network Diameter. Combining this observation with the fact that the maximum path length in this interaction is 0.4 as indicated by the average path length for a graph, we can conclude that Interactions in the

Nuclear Power Plant Operational Readiness Program is efficient from a communication standpoint since the maximum path length is half of the network diameter.

5.14.3 Network density

As highlighted in many places in this study, Network Density measures how tightly interconnected the network is. This Network statistical measure calculates the proportion of existing connections relative to the possible total number of edges. A high degree of interaction across the network will have higher density levels while weak interactions result in low Network Density. In this network, density measures the linkage between different components of the Nuclear Power Plant Operational Readiness Program. The value of network density ranges from 0 to 1. A density close to 1 indicates that Nuclear Power Plant Operational Readiness Program components are strongly linked to each other. While a density of 0.5 suggests the presence of medium interaction between Nuclear Power Plant Operational Readiness Program components. A value close to 0 will indicate the existence of weak interaction between those components. Additionally, the density of the interaction in this network can be used to measure how cohesive and robust is the Nuclear Power Plant Operational Readiness Program as a whole, as well as, the effectiveness of the program to fulfill all regulatory requirements needed to get the Operating License and moved from the commissioning to the Operation phase. The density of interaction in the Nuclear Power Plant Operational Readiness Program is 0.002 which suggests that there is a low level of interaction among Nuclear Power Plant Operational Readiness Program components to what relatively could be established.

5.14.4 Network clustering coefficient and modularity analysis

Network clustering coefficient group nodes based on the strength of their relationships into distinct clusters. This Network Statistic provides the ability to measure the level at which Nuclear Power Plant Operational Readiness Program components are grouped together, as opposed to being equally or randomly connected across the network. Clustering coefficient Scores have an inverse correlation with other network statistics, including several of the centrality measures, mainly when we are analyzing at the global level (the entire Nuclear Power Plant Operational Readiness Program Network). Clustering coefficient calculation is based on measuring the number of closed triangles (triplets) relative to the potential number of triangles (triplets) available in the Nuclear Power Plant Operational Readiness Program. in essence, this measures the degree to which second-tier components are connected to one another (Friends of friends). High Clustering coefficient scores are highly anticipated from tightly knit hubs and distinctive communities, whereas dispersed and remotely scattered networks might be expected to produce lower scores. The average Clustering Coefficient for this network is 0.21 which indicates that some well-defined clusters can be identified in interactions among different components of the Nuclear Power Plant Operational Readiness Program. Modularity class analysis showed that components of the Nuclear Power Plant Operational Readiness Program are distributed across 13 distinct communities. The size distribution of the 13 clusters is shown in figure (5.53). This property strongly correlates with the Nuclear Power Plant Operational Readiness Program robustness to failure. It turned out that the 13 major hubs are concentrated around specific components like L0 or Strategic Programs which are linked to a unique group of regulatory requirements, roles, or plant systems. This structural configuration allows for a fault-tolerant behavior and fosters resilience in the Nuclear Power Plant Operational Readiness Program.

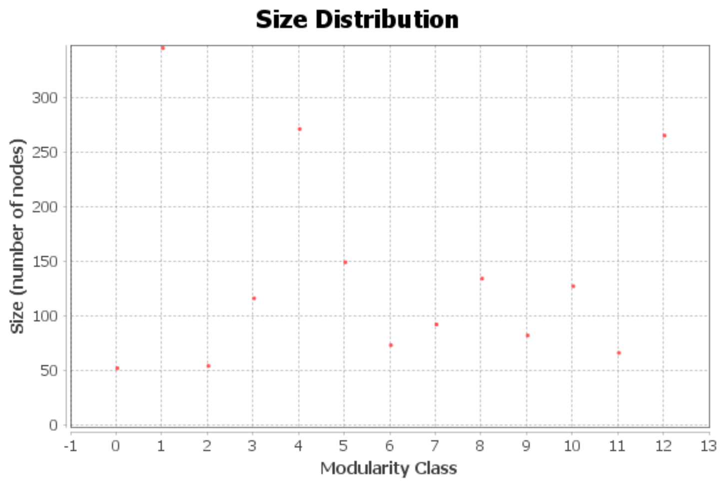


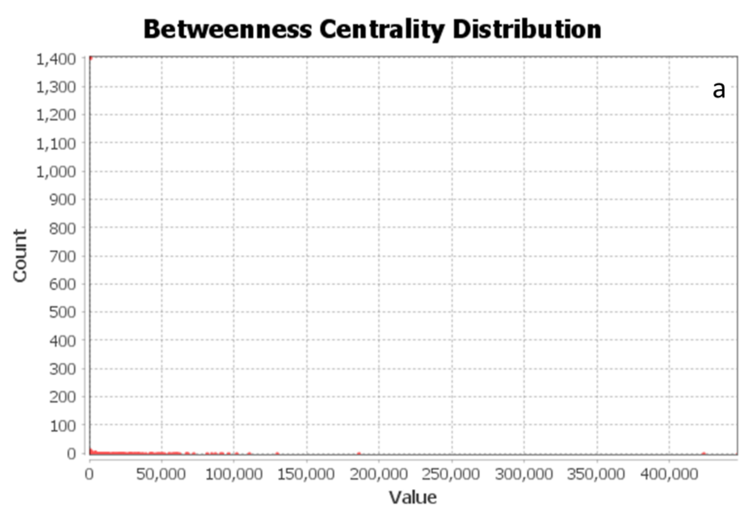
Figure 5. 54 Clusters size distribution in the interactions between different components of the nuclear power plant operational readiness program

As seen in figure (5.52), three key clusters are centered around one component that has a high betweenness Centrality. Two of those distinctive clusters are centered around one of the L0 processes namely; Quality Assurance (QA-L0) and Managing Environmental Services (ENV-L0). Whereas, the third cluster is centered around the most critical success criteria for the Nuclear Power Plant Operational Readiness Program which is getting the Operating License. Ego Network Analysis will be used to Analyze Quality Assurance (QA-L0) and Managing Environmental Services (ENV-L0) structures with a sufficient level of granularity to understand the nature of influence they have on other components and clusters in the Nuclear Power Plant Operational Readiness Program.

The main focus of this work is to model all possible interactions among all components of the Nuclear Power Plant Operational Readiness Program and to analyze the impact on the program success criteria which is fulfilling the Regulatory Requirements needed to get the Operating License. Therefore, it is very important to use Network Analysis to segment and analyze and Regulatory Requirements Nodes. To do so, the ego network tool will be used. An Ego Network consists of a focal node (which is called the "ego") and all the nodes that have some relationship to it. This relationship can be direct, meaning that the nodes are adjacent, or it can be derived in second levels. The use of this technique will allow the model and study of the influence that different components in the Nuclear Power Plant Operational Readiness Program has on each of those Regulatory Requirements and subsequently on the Operating License (OL) Node.

5.14.5 Network centrality measures

Centrality statistics help to demystify certain characteristics in the interactions between different players in the Nuclear Power Plant Operational Readiness Program. As explained earlier, there are many ways to measure centrality and each of these approaches helps in understanding a specific type of centrality, as opposed to offering competing versions of the same measurement. Centrality measures help in identifying which components of the nuclear power plant operational readiness (5Ps) have more influence over other components in terms of achieving the intended benefits represented by fulfilling the Operating License (OL) Regulatory Requirements. Furthermore, Centrality is an essential measure of the information flows between different components of the Nuclear Power Plant Operational Readiness Program when assessed jointly with other statistics to form a comprehensive and accurate understanding of information flow and efficiency of interaction. On one hand, the Closeness Centrality measure the ability of certain component within the Nuclear Power Plant Operational Readiness Program to access and transmit information through the network quickly. It also indicates how close a specific component is from every other component in the Nuclear Power Plant Operational Readiness Program. Components with high closeness centrality have a central position in the network since they're close to other nodes. On the other hand, Betweenness centrality measures the degree nodes within this huge network offer the most direct path/Bridges between otherwise disconnected Clusters. A higher betweenness centrality score for a specific component provides a perspective on how critical that component to maintaining the structure of the Nuclear Power Plant Operational Readiness Program. Unlike other centrality measures, betweenness centrality provides a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. Figure (5.54) presents the results of the analysis of Betweenness and closeness centrality in the Nuclear Power Plant Operational Readiness Program



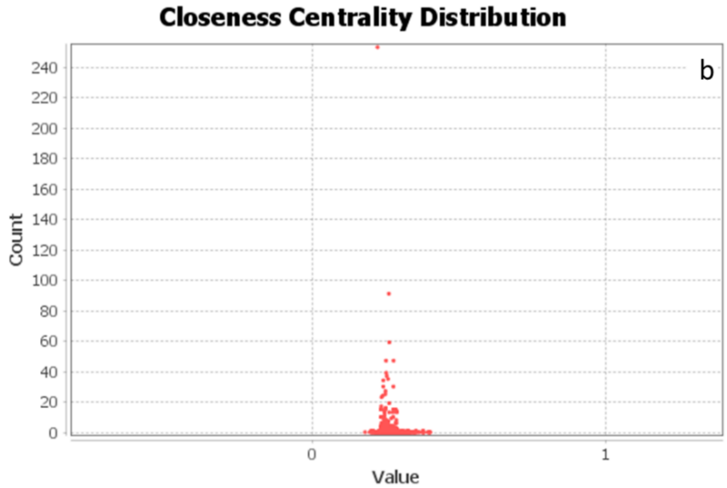


Figure 5. 55 a) Betweenness centrality distribution b) Closeness centrality distribution in the nuclear power plant operational readiness program

Centrality Distribution graphs have shown that more than 75% of Processes, Programs, Procedures, Systems, and Stakeholders in the Nuclear Power Plant Operational Readiness Program this network has zero betweenness centrality. The remaining portion of Strategic Programs has a betweenness centrality that ranges from 3.08 to 446421. Highy variability is observed with six components only have a betweenness centrality above 100000 and only two above 400000. The closeness centrality distribution of the Nuclear Power Plant Operational Readiness Program seems to be following normal distribution and denoting less variability and a minor positive skewness. The majority of Processes, Programs, Procedures, Systems, and Stakeholders are centered around the mean of 0.25 ranging between 0.18 and 0.39. However, the majority of nodes are seen from this angle as having low influence over the Nuclear Power Plant Operational Readiness Program might need to further recognize the essential role some key components to keep the efficient flow of information and maintain the structural integrity of the Nuclear Power Plant Operational Readiness Program. Those are mainly nodes with the highest Betweenness Centrality as shown in table 5.58. Similar to other observations from other networks in this study, Operating License fulfillment, Quality Assurance Process, Environmental Management process, Operate and Monitor Structures, Systems and Components, Emergency Planning and Talent Management appear to be the most influential nodes in the Nuclear Power Plant Operational Readiness Program. Effective management of those processes is very essential to maintain seamless interactions and provide more influence on the speed of information flow.

Table 5. 58 L0 Processes with highest betweenness centrality

Id	Label	Closeness centrality	Betweenness centrality	modularity class
2000	OL	0.280954	446421.8207	12
4	QA-L0	0.390814	422840.5133	4
13	ENV-L0	0.347185	185130.7399	10
40	HR-L0	0.377335	128745.7651	1
10	EP1-L0	0.350162	109562.0989	0
11	FP2-L0	0.329982	100867.0812	9
21	OP-L0	0.375946	95284.69389	7
18	RE-L0	0.331171	90975.34403	11
12	NRM-L0	0.341953	89881.70367	7
27	NPI4-L0	0.398353	86147.09399	1
17	PSC-L0	0.397148	83637.9334	1
314	PG26	0.326581	80512.4576	5
20	RE-L0	0.325944	71257.0367	1
309	PG21	0.3451	67187.38351	5
2	ENG2-L0	0.313973	66507.0637	6
24	NPI1-L0	0.396548	66257.40689	1
331	PG43	0.359546	61344.53354	4

5.14.6 Quality assurance process ego network

The main focus of this work is to understand the interaction between different components in the Nuclear Power Plant Operational Readiness Program and to what extent some of those components play an influential role to maintain the integrity of the structure and the flow of information among different nodes within this massive network. Therefore, it is important to have a deeper look on the nature of influence the Quality Assurance Process, Environmental Services process and Operating License (OL) Regulatory Requirements has in this network. To do so, the ego network technique will be used. An Ego Network consists of a focal node (also called the "ego") and all the nodes that have some relationship to it. This relationship can be direct, meaning that the nodes are adjacent, or it can be established as a second level relationship (friend of a friend). Using Ego Network Analyses help to model and study the influence of central modes by applying network statistics on that focused snapshot of the bigger network. Figure (5.55) "Ego Network of Quality Assurance Process interactions with Strategic Programs" under section 5.3 represents a specific perspective of interactions of Level-0 Quality Assurance with strategic Programs.

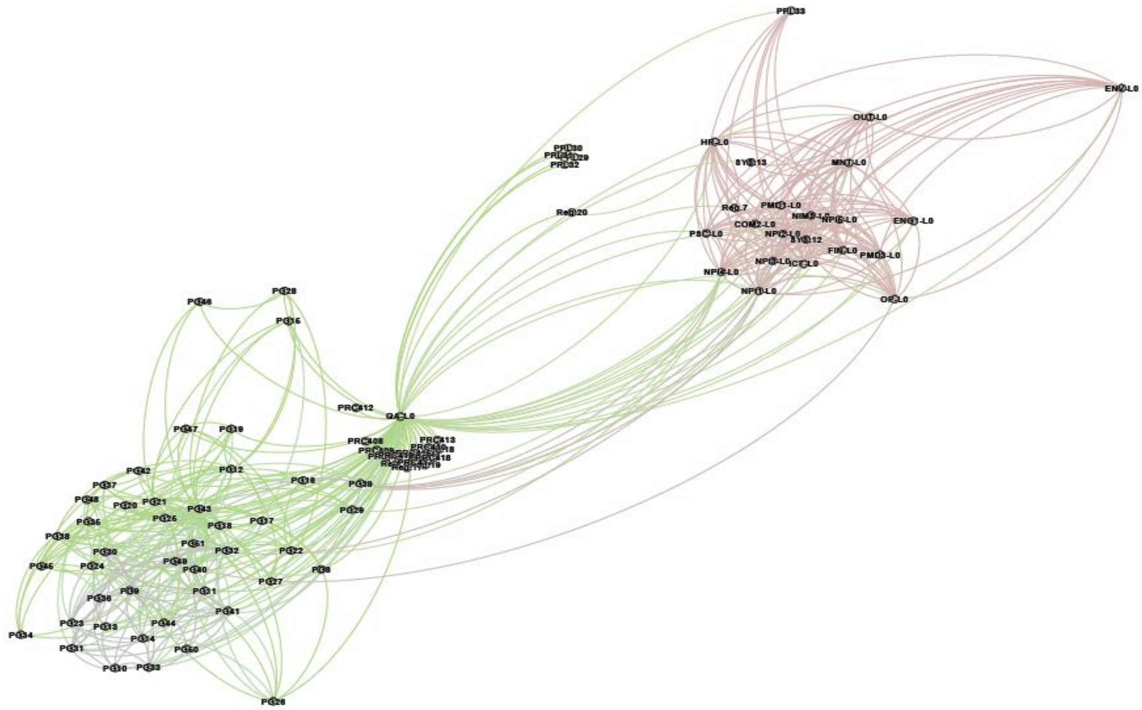


Figure 5. 56 Ego network of quality assurance process

The structural characteristics of the of Quality Assurance Ego Network are shown in table (5.59).

Table 5. 59 Ego network of quality assurance process characteristics

Characteristic	Value	% Visible
Total number nodes	88	4.78%
Total number of Edges	493	13.62%

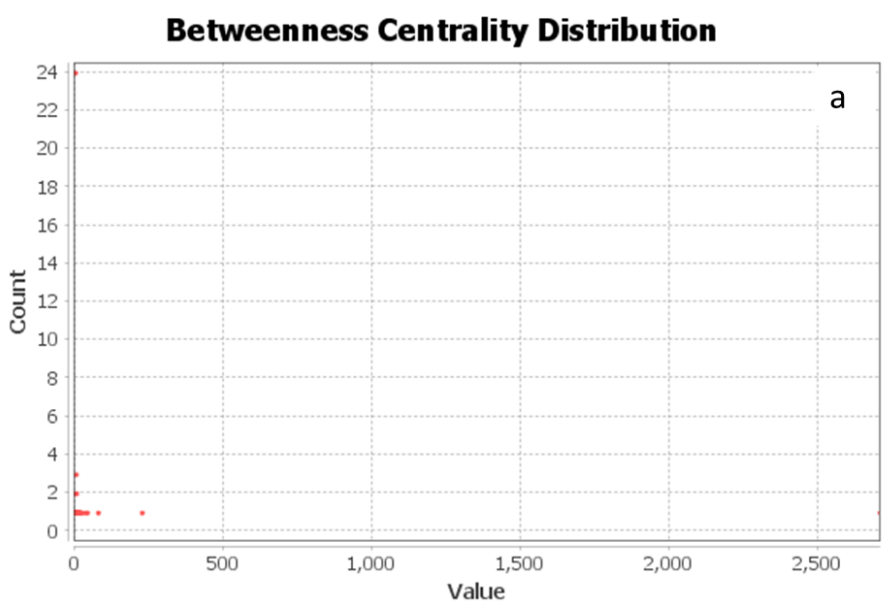
The interaction between Level 0 Quality Assurance and the other 87 components it is connected to in the Nuclear Power Plant Operational Readiness Program seems to be inefficient and forming a low level of interactions as indicated by network statistical measures shown in table 5.60.

Table 5. 60 Ego network of L0 quality assurance process statistics

Network statistic	Value
Graph density	0.002

Network diameter	2
Average Path length	1.9
Average Clustering Coefficient	0.696

The maximum path length between in this ego network is 1.9 as indicated by the average path length for a graph, we can conclude that the Quality Assurance process interaction with other components is inefficient from a communication standpoint since the maximum path length is almost the same as the network diameter. Figure (5.56) presents the results of the analysis of Betweenness and closeness centrality focusing on the Quality Assurance Process Ego Network in the Nuclear Power Plant Operational Readiness Program.



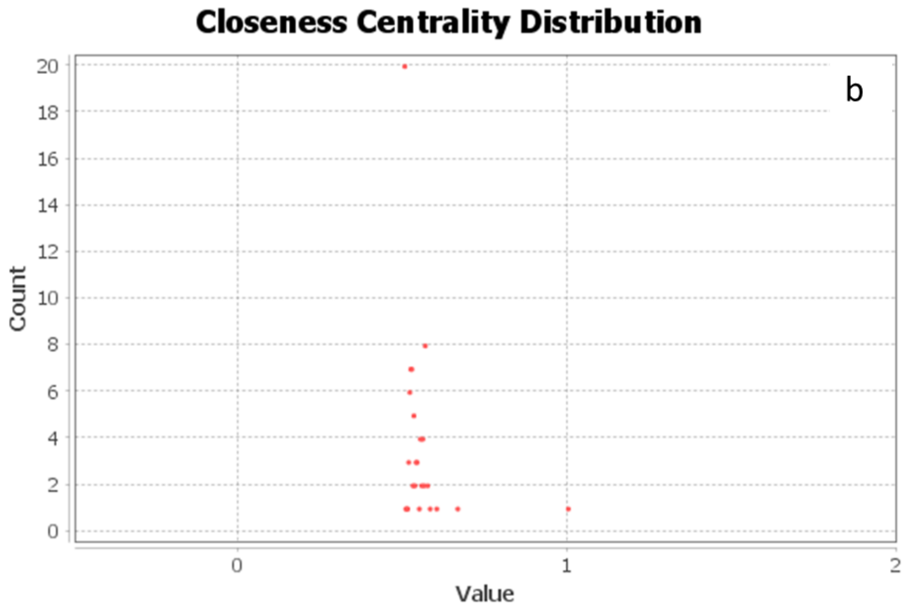


Figure 5. 57 a) Betweenness centrality distribution b) Closeness centrality distribution in the quality assurance Ego network

Centrality Distribution graphs have shown that more than 25% of nodes in this network has zero betweenness centrality. The remaining portion of nodes has a betweenness centrality that ranges from 0.0625 to 224 except for the Quality Assurance Process which has a betweenness centrality of 2706. The closeness centrality distribution of this ego network seems to be positively skewed as a result of the Quality Assurance Process has the highest Closeness centrality (1). The interaction between Level 0 Quality Assurance and the other 87 components is clustered across three distinctive Communities. Figure 5. 57 shows the size distribution of the three clusters identified in the interactions between Quality Assurance Process and other components of the Nuclear Power Plant Operational Readiness Program

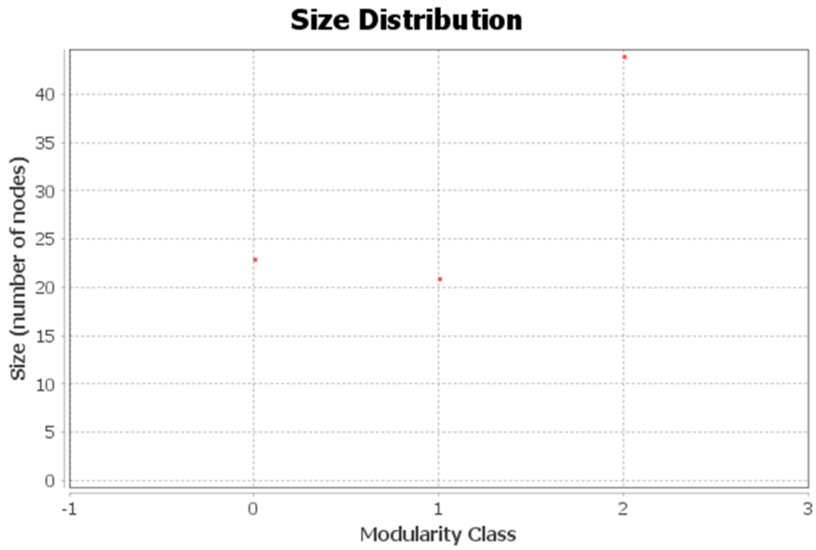


Figure 5. 58 Clusters size distribution in the interactions between quality assurance process and other components of the nuclear power plant operational readiness program

As seen in figure (5.55), the Quality Assurance Process plays a central role and form a hub where certain essential procedures and programs are uniquely connected to it. The other two clusters are dispersed around multiple central nodes.

5.14.7 Environmental services process ego network

This Ego Network will study in-depth the nature of influence the Environmental Services process and interactions with different components in the Nuclear Power Plant Operational Readiness Program. To do so, the ego network technique will be used. The below Environmental Services process Network graph (5.58) was produced by Gephi using the Ego Network. For a different perspective on ENV-L0 specific interactions with regulatory requirements, another Ego Network analysis is represented under section 5.2 in Figure (5.4) Ego Network of ENV-L0.

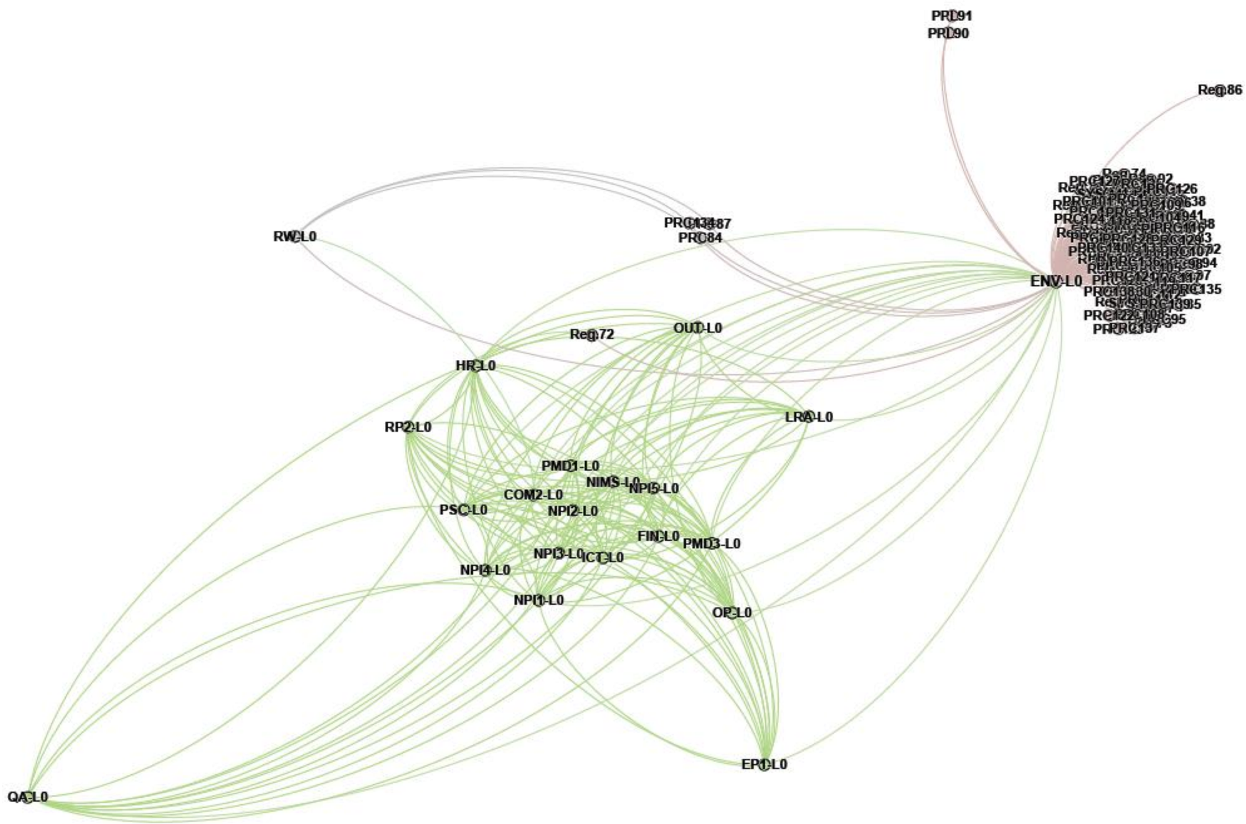


Figure 5. 59 Ego network of environmental services process

The structural characteristics of the of Environmental Services process Ego Network are shown in table (5.61).

Table 5. 61 Ego network of environmental services process characteristics

Characteristic	Value	% Visible
Total number nodes	120	6.53%
Total number of Edges	300	8.29%

The interaction between the Environmental Services process and the other 119 components it is connected to in the Nuclear Power Plant Operational Readiness Program seems to be inefficient and forming a low level of interactions as indicated by network statistical measures shown in table (5.62).

Table 5. 62 Ego network of environmental services process statistics

Network statistic	Value
Graph density	0.002
Network diameter	2
Average Path length	1.9
Average Clustering Coefficient	0.854

Similar to the Quality Assurance Ego Network, the maximum path length between in this ego network is 1.9 as indicated by the average path length for a graph, we can conclude that the Environmental Services process interaction with other components is inefficient from a communication standpoint since the maximum path length is almost the same as the network diameter. Figure (5.59) presents the results of the analysis of Betweenness and closeness centrality focusing on the Environmental Services process Ego Network in the Nuclear Power Plant Operational Readiness Program.

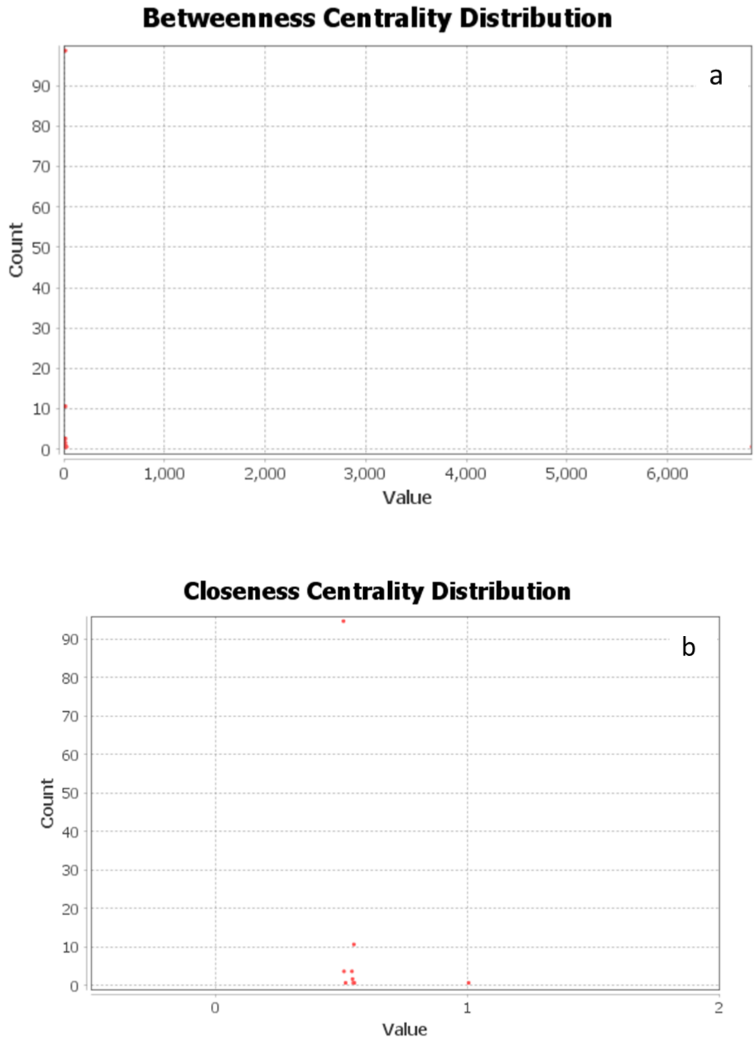


Figure 5. 60 a) Betweenness centrality distribution b) Closeness centrality distribution in the environmental services process Ego betwork

Centrality Distribution graphs have shown that more than 80% of nodes in this ego network has zero betweenness centrality. The remaining portion of nodes has a betweenness centrality that ranges from 0.13 to 9.6 except for the Environmental Services process which has a betweenness centrality of 6825. The closeness centrality distribution of this ego network seems to be positively skewed as a result of the Environmental Services process has the highest Closeness centrality (1). The interaction between the Environmental Services process and the other 119 components is clustered across three distinctive Communities. The size distribution of the ENV-L0 of distinctive clusters is shown in figure (5.60).

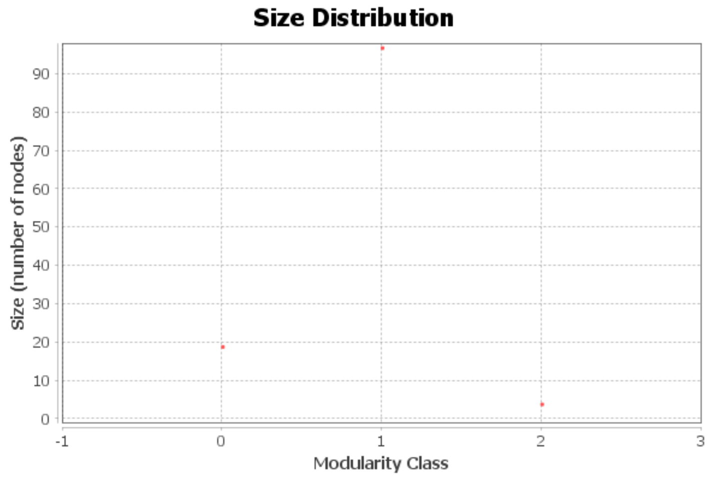


Figure 5. 61 Clusters size distribution in the interactions between environmental services process and other components of the nuclear power plant operational readiness program

As seen in figure (5.58), the Environmental Services process play a central role and form a hub where certain essential procedures and programs are uniquely connected to it. The other two clusters are dispersed around multiple central nodes.

5.14.8 Operating license (OL) requirements ego network

This Ego Network will study in-depth the most important outcome of the Nuclear Power Plant Operational Readiness Program which is fulfilling all regulatory requirements needed to receive the Operating License from the National Nuclear Regulator. This Ego Network will analyze the nature of interactions around the Operating License Hub and the nature of interactions with different components in the Nuclear Power Plant Operational Readiness Program. To do so, the ego network technique will be used. The below Operating License (OL) Requirements graph (5.61) was produced by Gephi using the Ego Network.

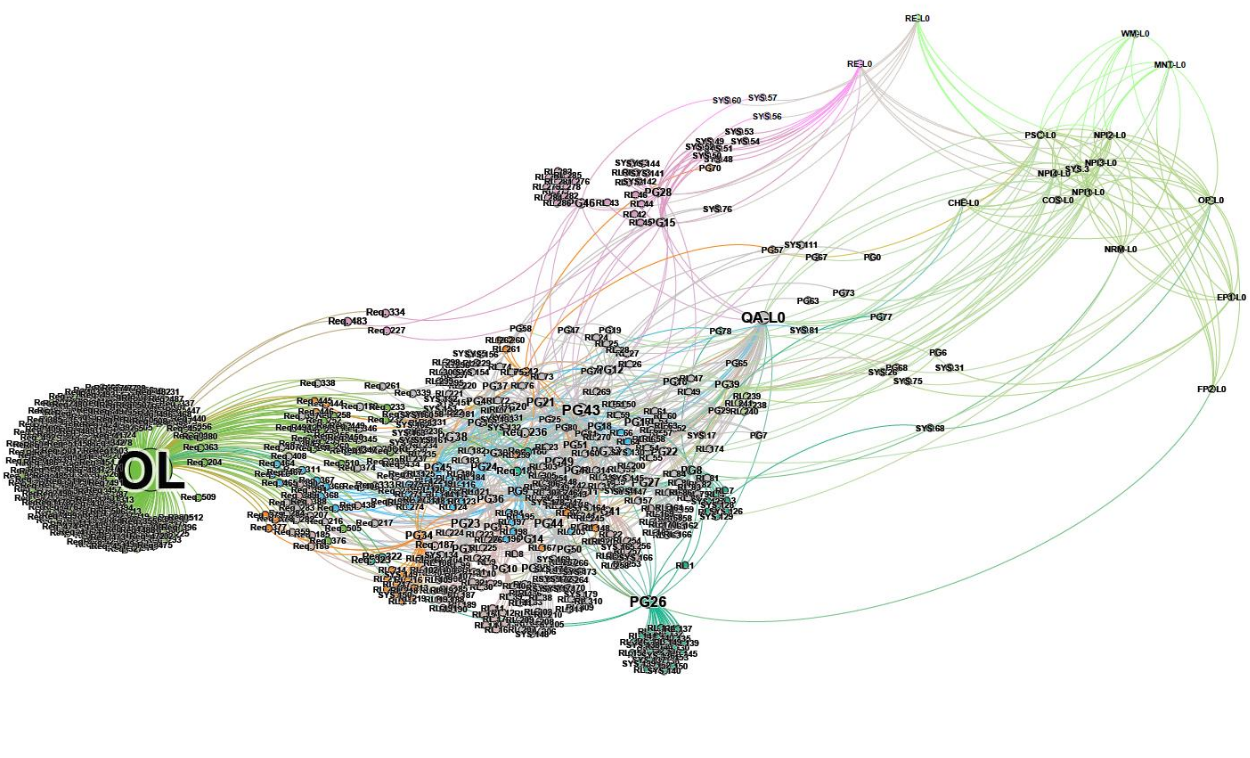


Figure 5. 62 Ego network of operating license (OL) requirements

The structural characteristics of the of Operating License (OL) Requirements Level 3 depth Ego Network are shown in table (5.63).

Table 5. 63 Ego network of operating license (OL) requirements characteristics

Characteristic	Value	% Visible
Total number nodes	760	41.33%
Total number of Edges	1315	36.34%

The interaction between Operating License (OL) Requirements and the other components in the Nuclear Power Plant Operational Readiness Program seems to be relatively efficient. However, forming a low level of interactions as indicated by network statistical measures shown in table (5.64).

Table 5. 64 Ego network of operating license (OL) requirements statistics

Network statistic	Value
Graph density	0.005
Network diameter	4
Average Path length	3.3
Average Clustering Coefficient	0.231

the maximum path length between in this ego network is 3.3 as indicated by the average path length for a graph, we can conclude that the Operating License (OL) Requirements interaction with other components appear to be relatively efficient from a communication standpoint since the maximum path length is less than the network diameter. Figure (5.62) presents the results of the analysis of Betweenness and closeness centrality focusing on the Operating License (OL) Requirements Ego Network in the Nuclear Power Plant Operational Readiness Program.

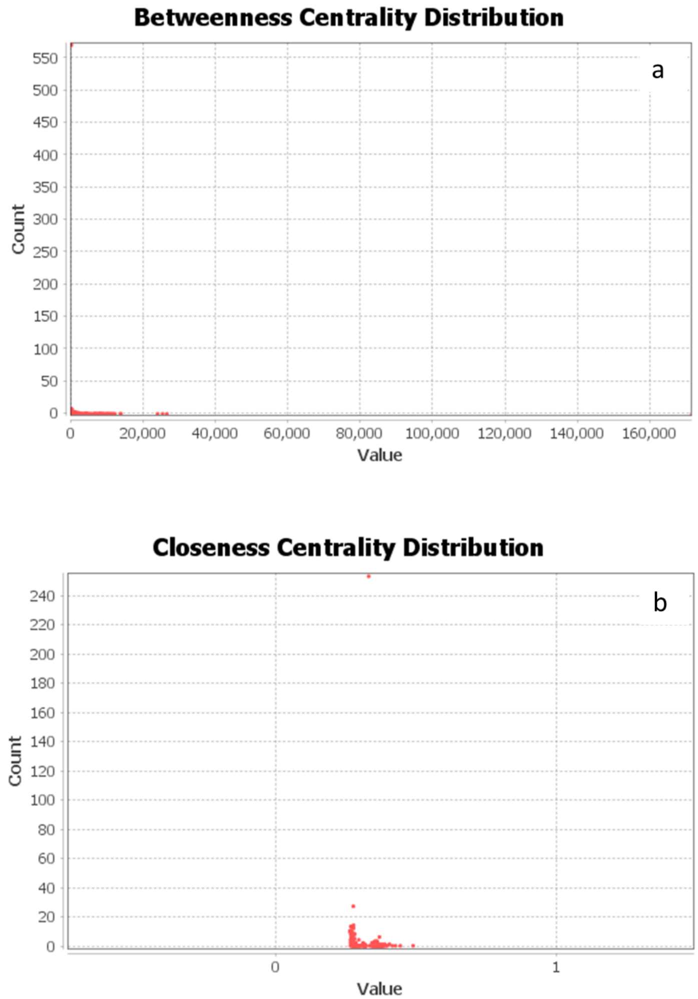


Figure 5. 63 a) Betweenness centrality distribution b) Closeness centrality distribution in the operating license (OL) requirements Ego network

Centrality Distribution graphs have shown that more than 75% of nodes in this ego network has zero betweenness centrality. The remaining portion of nodes has a betweenness centrality that ranges from 2 to 26367 except for the Environmental Services process which has a betweenness centrality of 171301. The closeness centrality distribution of this ego network seems to be positively skewed as a result of the Operating License (OL) Requirements has the highest

Closeness centrality (1). The interaction between Operating License (OL) Requirements and the other components is clustered across 11 distinctive Communities. The size distribution of the Operating License (OL) of distinctive clusters is shown in figure (5.63).

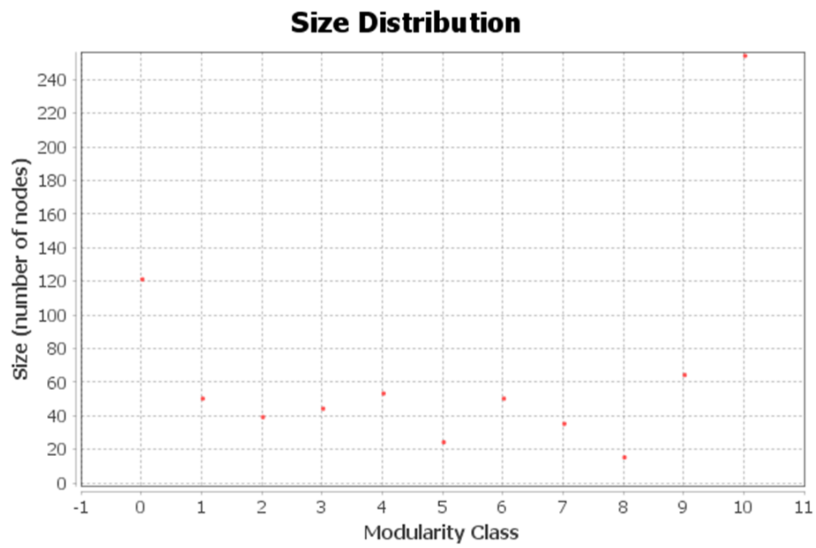


Figure 5. 64 Clusters size distribution in the interactions between operating license (OL) requirements and other components in NPP

As seen in figure (5.61), the Operating License Requirements represented by the (OL) node interacts directly with Strategic Programs and roles as the first layer of the interface. Subsequently, Strategic programs serve as a mediator between regulatory requirements and other components like Process, Plant systems, and procedures. This observation requires specific attention from industry experts and Management systems professionals to assess how the design of strategic programs would help fulfill this critical role.

5.15. Linking findings to research objectives

This research identified and illustrated all established interactions between Programs, Processes, Procedures, Systems, and Stakeholders of Nuclear Power Plants Operational Readiness. All interactions have been mapped using adjacency matrices which subsequently transform into network graphs using Gephi software. Thirteen networks were developed as per the following structure:

1) Level 0 Process to Requirement
2) Level 0 Process to Program
3) Level 1 Process to another level 1 process
4) Level 0 Process to Stakeholders
5) Level 1 Process to Stakeholders
6) Level 0 Process to Plant Systems
7) L0 process to Implementing procedure
8) Level 0 Process to L0 Process
9) Programs to Requirement
10) Programs to Role
11) Program to Program
12) Program to Plant System
13) Complete network graph analysis on the operational readiness program level.

Those 13 network graphs supported the researcher in modeling and demystifying the complexity (interactions and the structure of information flow) of nuclear operational project processes and stakeholders of the UAE nuclear sector. Also, analyzing the 13 networks in terms of their general networks' characteristics and network density, helped in unleashing specific characteristics for each network in terms of the information flow efficiency and degree of connectedness. Which ultimately, supported in achieving the third objective in this research.

This research has analyzed the thirteen networks identified in the Nuclear Power Plants Operational Readiness program systematically to provide complete analysis on network clustering coefficients, modularity analysis, and network centrality measures. those networks' statistical measures were used to study the nature of influence for each node in the 13 networks. In addition, the meaning of each network statistical measure was interpreted and illustrated in relation to the research aim and objectives. Influential nodes have been defined in each network. Furthermore, the nature of influence and interdependencies have been further analyzed through ego network analysis and preliminary interpretation of main observations emerged from the network analysis have been provided. By doing that, the research has achieved the objective of evaluating the interdependencies and the nature of influence within detailed interactions between the components of the nuclear power plant operational readiness program in UAE.

After developing and analyzing the complete network of Nuclear Power plant Operational Readiness as a whole, the network has been analyzed in terms of its general characteristics, networks density, network clustering coefficient, and modularity analysis, network centrality measures in order to achieve the objective of identifying the most influential components on the program level. Furthermore, the ego topology was used, because it focuses on studying a selected node environment and the nodes that interact with the ego node. This research used ego Network analysis on the complete network on the Quality Assurance Process, the Environmental Services process and the Operating License (OL) Requirements. Furthermore, the same methodology was applied to the Plant Chemistry monitoring and control process, Managing Statutory and Regulatory Requirements process, Finance Process, Managing and operating Structures, Systems and Components process, Communication process, Quality Assurance Program and Maintenance Program. This analysis helped the researcher in identifying the key influential components of nuclear operational project processes and readiness in the UAE nuclear sector; hence, the second research objective was achieved. By achieving the first three research objectives and answering corresponding research questions, this study builds on the validation interviews that were assembled to strengthen the validity of findings drawn from network analysis to propose a methodology that can be adopted by the UAE energy sector to manage complexity. This methodology is captured in detail in chapter 4.

This research produced two key tangible outputs; a model that describes the complex network and info. structure that exists between the 5 key components in the world's largest and most advanced Nuclear Power Plant Operational Readiness Program and a practical methodology for addressing the shortcomings of the conventional project management functions of planning and control in examining and modeling megaproject complexity and dynamics. Furthermore, based on the findings of the 13-network analysis, the following key outcomes have been produced:

1. The density of interactions between different components of the Nuclear Power Plant Operational Readiness is low, indicating a limited number of information sharing channels established
2. The Structural configuration of Hub and Spoke is a clear characteristic of the Nuclear Power Plant Operational Readiness, indicating a fault tolerance behavior and possible Information silos.
3. There is several Influential nodes in each interaction, which to great extent affects the communication and interactions' structural integrity.
4. The majority of Interactions in the Nuclear Power Plant Operational Readiness Program are structured around a central core, with multiple sub-group (Clusters/Hubs) composed of different actors with different distributions, indicating communication silos. Not every actor gets information predictably.
5. Information can diffuse throughout the Nuclear Power Plant Operational Readiness efficiently.
6. There are just 3 main processes holding the top ranks in their influential strategic positions in regards to achieving the overall objective of the Nuclear Power Plant Operational Readiness, getting the Operating License.

On one hand, those outcomes support the study contributes to Theoretical knowledge in terms of the original testing of Network Analysis (borrowed from graph and complexity theory) on the Nuclear Power Plants Operational Readiness Programs domain through conducting the first of its kind empirical work to demystify the complexity and info. Structure of a Nuclear Power Plants Operational Readiness Program by applying network analysis on the largest and most advanced nuclear power program worldwide. On the other hand, those outcomes provide insight into how the flow of information might influence achieving operating License requirements and demonstrates the utility of network analysis for demystifying complexity and managing information in Nuclear Power Plant operational readiness.

5.16. Chapter summary

This chapter has investigated and illustrated interactions and information flow structures of the 13 networks included in this study. All networks have been analyzed in terms of general network characteristics, network density, network clustering coefficient and modularity analysis, network centrality measures. In addition, ego networks for influential nodes have been analyzed and investigated. Also, this chapter provided a preliminary interpretation of the main observations that emerged from the network analysis.

Chapter 6: Discussion of results

6.1 Introduction

This chapter aims to presents a discussion of the main findings that resulted from the analysis chapter. Identified themes and results from the analysis chapter are presented in three main sections. The first section presents a discussion of the research findings on the interdependencies and the nature of influence within detailed interactions between the components of the nuclear power plant operational readiness program in UAE; whilst the second section discusses the Identification of key influential components in the nuclear operational readiness, and the third section discusses the results from the complexity modeling of nuclear operational project processes and stakeholders. The output of this chapter is a discussion of the specific findings in relation to the research objectives and the available literature on the Nuclear Power Plant Commissioning and Operational Readiness Program.

6.2 Research objective 1

Evaluate the interdependencies and the nature of influence within detailed interactions between the components of the nuclear power plant operational readiness program in UAE;

6.2.1 Interactions between level 0 processes and regulatory requirements within the nuclear power plant operational readiness program

This study identified 46 Main Process (referred to in this study as L0 processes). These processes form the backbone of the Integrated Management systems of the Nuclear power plant and support safe and reliable operations. All *Management Processes, Core Processes, and Support Processes* aim to meet Nuclear Power Plant Operational Readiness strategic and regulatory objectives have been included in this study. The dependency mapping between L0 Processes and the set of defined Regulatory Requirements has resulted in forming 691 undirected connections. The interactions between Level 0 Processes and Regulatory Requirements within the Nuclear Power Plant Operational Readiness Program is cluttered, concentrated round the center and forming multiple distinct and large hubs around main processes like Provide Environmental Services (ENV-L0), Monitor and Control Contamination (RP1-L0), Perform Emergency Planning (EP1-L0), Provide Handling, Storage and Disposal of Fuel (RE-L0), Manage External Assessments (NOS-L0) and Maintain License and Permits (LRA-L0). However, a low level of interaction among L0 processes and corresponding regulatory requirements was identified as evident by the low Network density.

This result supports Lawry and Pons (2013) view that the way the commissioning process is managed across different industries and sectors is yet seen as ad hoc and lacks full integration between different components and stakeholders. Interactions between L0 Processes and Regulatory Requirements are distributed across 10 distinct communities. The majority of identified hubs are concentrated around specific L0 processes which is linked to a unique group of regulatory requirements. Within the context of the Nuclear Industry, a conclusion can be made that this structural configuration allows for a fault-tolerant behavior and fosters resilience in the interaction between L0 Processes and Regulatory Requirements. Additionally, ENV-L0, RP1-L0, EP1-L0, RE-L0, NOS-L0, and LRA-L0 are the most influential L0-Processes to maintain the interaction between L0 processes and Regulatory requirements intact due to their high Betweenness Centrality.

6.2.2 Interactions between level 0 processes and strategic programs within the nuclear power plant operational readiness program

This interaction looked at the relationship between Nuclear Power Plant L0 Processes and the Strategic Programs established to deliver certain agreed benefits for the Nuclear Power Plant Operational Readiness. A total of 81 Strategic Programs included in this study based on the following criteria:

1 Programs require specific technical expertise.

2 Programs are required by reference documents (e.g. FANR regulations, Technical Specifications, FSAR, standard nuclear industry practice, or expert judgment)

3 Program data collection activities are repeated at regular intervals.

4 There is a continuity of data where the output and inputs of each data collection cycle are compared to each other

The interactions between L0 Processes and Strategic Programs has resulted in forming 570 undirected connection. However, a low level of interaction between L0 processes and Strategic Programs was identified within the Nuclear Power Plant Operational Readiness as evident by Low Network density (0. 070). Similar to the pattern identified in the interaction between L0 processes and the Regulatory Requirements, L0 Processes and strategic Programs interactions are distributed across 6 distinct communities that are concentrated around specific L0 processes and linked to a unique group of Strategic Programs. The Quality Assurance Process acts as a central hub for the majority of the Programs and has the highest Betweenness Centrality. This can be attributed to the key influence the Quality Assurance Process has on the design and execution of Nuclear Power Plant Operational Readiness Programs. This relationship can be understood from two different perspectives. Firstly, the oversight role was delivered by the Quality Assurance on certain Programs during the Nuclear Power Plant Operational Readiness phase to ensure compliance with the ASMI Standard and other Regulatory Requirements. This role will require establishing multiple Interfaces, Validation & Verification points, and surveillance activities with a large number of Programs. Secondly, the establishment of QA-specific Programs needed to establish certain organizational capabilities needed to ensure safe and reliable operations of the Nuclear Power Plant. This finding supports IAEA (2008), IAEA (2016), ONR (2016), and ASN (2013) that Quality Assurance is a key component of the commissioning process in nuclear power plants and very essential to verify that systems and components of the constructed nuclear facility conform to the design and acceptable performance criteria.

Quality Assurance and Procurement Process are critical to maintaining the interaction between L0 processes and Strategic Programs intact and efficient due to their high Betweenness Centrality. Some other nodes like RW-L0 is a bit peripheral to the network structure because the Radioactive Waste management Process at this phase of the development of the Nuclear Power Program is managed as a second priority compared to other processes like Operations, Maintenance, and Capacity building, and work Management. However, interfaces with other L0 processes and Strategic Programs should be considered and established at the commissioning phase to ensure satisfying regulatory requirements by incorporating RW requirements in all relevant processes. Otherwise, some rework and major adjustments might be needed to ensure fulfilling onsite and off-site radiological waste.

6.2.3 Interactions amongst level 1 processes in the nuclear power plant operational readiness program

L1 Processes form the fundamental structural component of the Management System in any Nuclear Power plant. They are sub-processes from L0 and understanding the nature of the interactions between them is very crucial to comprehend the behavior of the whole Management System and its effectiveness in delivering its purpose of supporting the achievements of Strategic Goals and Objectives of the Nuclear Power Plant Operational Readiness. 62 Level 1 processes were included in this analysis and have formed 356 undirected connections. Nevertheless, a low level of interaction among L1 processes was identified as evident by the low Network density (0.02). This finding indicates that interactions between L1 processes in the Nuclear Power Plant Operational Readiness Program might be fragile and to some extent not resilient enough to absorb shocks caused by any future unanticipated disruptive events.

Moreover, Interactions between Level 1 processes are clustered into three distinctive communities. One cluster includes the Monitor and Control Plant Chemistry Process which turned out to be the most influential node in this network according to its Betweenness Centrality. This finding is no surprise since the majority of focus in the operational readiness program is typically directed towards getting all organizational capabilities up to the level required to satisfy all Regulatory Requirements to commence the safe Fuel Load, Initial Criticality and most importantly maintain safe and reliable operations through controlling Plant Chemistry by qualified operators for the lifecycle of the Nuclear Power Plant. Each of the three clusters seems to be contributing to the success of the Nuclear Power Plant Operational Readiness from a unique perspective and timeframe. The second cluster includes processes required to ensure the initial commencement of operations like Operating and Monitoring Structures, Systems and Components, Perform Planning, Perform Scheduling & Perform Preventive Maintenance as per the Work Management process. The third cluster includes support processes enabling the initial startup. Those processes include Strategic Sourcing Process, Finance process, Providing Legal Services, Provide Information Technology Services, and Licensing and Permits process. The First cluster provides a unique perspective towards those processes of Managing Outages, Contamination, and Perform Decommissioning. This clustering provides a different perspective on the relationships and Interactions between L1 processes which can ultimately change our perspective on how to manage certain processes to maintain seamless integration and prevent carrying out unnecessary activities. This result adds to Kirsilä, Hellström, and Wikström (2007) on the need to view commissioning as a comprehensive system to ensure engineers do not carry out unnecessary activities in this critical phase.

6.2.4 Interactions between level 0 processes and stakeholders in the nuclear power plant operational readiness program

This interaction studied relationships between the main processes and People dependencies associated with it. This mapping also shows all Stakeholders (tagged as positions or organizational Unit) whose being involved in the implementation of each L0 Process covering a mixture of functions, organizational units and positions. The 152-node analyzed in this interaction have formed 644 undirected interactions. However, the density of interaction between L1 Processes and Stakeholders was 0.056 which suggests that there is a low level of interaction among L0 processes and Nuclear power plant Operational Readiness Stakeholders. Modularity class analysis showed that L0 Processes and stakeholders are distributed across seven distinct communities. certain stakeholder and/or stakeholders' groups within the Nuclear Power Plant Operational Readiness Program are linked to specific Level 0 processes and they do not usually interact with other processes even if the original L0 process they are linked to is interacting with another L0. Furthermore, the hub and spoke model is also prominent in this network where certain processes Like LGL3-L0, IAD-L0, DCM-L0 have a unique group of stakeholders linked into them who do not interact with any other Process in the network. Similarly, OUT-L0, MNT-L0, PRJ-L0, and NRM-L0 showed the same phenomena. This observation supports some findings from the analysis of the first network on the behavior of the Process-based Management System structure of the Nuclear Power Plant Operational Readiness. The Network clustering provides a different perspective on the relationships and Interactions between L0 processes and Stakeholders in terms of segregating those communities as Core cluster, Support cluster, and Oversight cluster, which can ultimately change our perspective on how to manage such interaction. This finding agrees with IAEA (2008), IAEA (2016), ONR (2016), AERB (1998), and ASN (2013) that commissioning within the nuclear shall include governance and oversight processes designed to verify that systems and components of the constructed nuclear facility meet the required performance criteria.

6.2.5 Interactions between level 1 processes and stakeholders in the nuclear power plant operational readiness program

This analysis provided one level deeper look into interactions between L1 Processes and Stakeholders. It studied all Level 1 processes in the Management System structure and People dependencies associated with each one of them. It covered all Stakeholders (tagged as positions or organizational Unit) whose being involved in the implementation of each L1 Process covering a mixture of functions, organizational units and positions. Interactions between the178 L1 Processes and Stakeholders nodes have formed 550 undirected Edge. The density of interaction between L1 Processes and Nuclear power plant Operational Readiness Stakeholders (0.039) has indicated that only a low level of interaction among L1 processes and Stakeholders exists compared to what could be further established. Similar to the interaction between L0 Processes and stakeholders, certain stakeholder and/or stakeholders' groups within the Nuclear Power Plant Operational Readiness Program are linked to specific Level 1 processes and they do not usually interact with other processes even if the original L1 process they are linked to is interacting with another L1. Furthermore, the hub and spoke model was also prominent in this network where most L1 processes i.e. SS006, TM001, IO003 have a unique group of stakeholders linked into them who do not interact with any other Process in the network. This observation supports some findings from the analysis of the first and the fourth network on the behavior of the Process-based Management System structure of the Nuclear Power Plant Operational Readiness. The Network clustering provides a different perspective on the relationships and Interactions between L1 processes and Stakeholders in terms of segregating those communities as Core cluster, Support cluster, and Oversight/governance cluster. This result agrees with both Lawry and Pons (2013) and IPENZ (2007) that governance and control processes are applied on operational readiness activities to ensure realizing deliverables on time, within budget, and up to the quality standard required.

6.2.6 Interactions between level 0 processes and nuclear power plant systems

This study identified 124 Plant Systems. Systems referred to in this study covers Plant Systems, Structures, and Components (SSC). These include, but are not limited to software applications, supporting hardware, safety-related equipment, and buildings. Interactions between the 124 Plant Systems and the 46 Level 0 Processes have resulted in forming 668 undirected unique edges. However, these connections still forming a low level of interaction between L0 processes and Plant Systems, Structures and Components compared to what could be established. The density of interaction between L0 Processes and Plant Systems, Structures and Components is a determining factor in assessing how inclusive is the coverage of IMS to fulfill all regulatory requirements as part of the BAU design within the nuclear power plant in a systematic and structured manner.

Interactions between L0 Processes and Plant Systems, Structures, and Components are clustered around 9 main distinctive communities. Most of these communities are centered around specific L0 processes like OP-L0, ENV-L0, EP1-L0, RP2-L0, and CHE-L0 except for the biggest cluster where most of the Support Processes and their interactions with plant systems are grouped. This observation might suggest a very important notion which is that Core Processes and their associated Plant Systems need to be treated as a standalone entity to ensure bringing all capabilities to the required level by the nuclear regulator while other Support Processes which share similar characteristics can be managed as a one entity serving the core business. This finding might change the way we manage our processes within the Nuclear Operational Readiness settings. The hub and spoke pattern is quite evident across this network where L0 Processes seem to be interacting with a unique set of Plant systems with no overlap with other

Systems linked to other Processes. This pattern needs to be studied further to assess the integrity of the Nuclear Power Plant Operational Readiness Management Systems and the level of integration and harmonization between relevant Systems. Similar to other interactions in this study, the property of multiple hubs strongly correlates with the network's robustness to failure. In line with Cagno, Caron, and Mancini (2002) view that Plant commissioning is “a transient state phenomenon during which every single sub-system continually varies over time in function of the sequence in which operations are carried out”, this structural configuration of having 9 major hubs that are concentrated around specific L0 processes which are linked to a unique set Plant Systems, Structures and Components might provision a fault-tolerant behavior and fosters resilience in the interaction between L0 Processes and Plant Systems, Structures, and Components.

6.2.7 Interactions between level 0 processes and implementing procedures

This network analysis covered all procedures developed to meet safety and quality requirements. those procedures support the implementation of Programs and Processes and specify or describe how an activity is to be performed. The term procedure in this study also included instructions and drawings including the following key areas:

a. Calibration and Test Procedures

b. Chemical and Radiochemical Control Procedures

c. Emergency Operating Procedures

d. Emergency Plan Implementing Procedures

e. Fire Protection Procedures

f. Fuel Handling Procedures

g. Maintenance Procedures

h. Power Operation and Load Changing Procedures

i. Process Monitoring Procedures

j. Radiation Control Procedures

k. Shutdown Procedures

l. Start-up Procedures

m. System Procedures

n. Temporary Procedures

Interactions between the 559 L0 Processes and Implementing Procedures nodes have formed 1028 undirected edges. However, this number of edges was not sufficient to establish a satisfactory level of interactions L0 Processes and Implementing Procedures in the Nuclear power plant Operational Readiness program as compared to what it might turn out to be according to the network density which is seen as very low (0.006). Interactions between L0 Processes and Implementing Procedures are grouped based on the strength of their relationships into 17 distinct clusters. Most of the clusters follow the pattern of Hub and Spoke where in most cases L0 Process is linked to a unique set of Implementing Procedure. Few numbers of Implementing Procedures are linked to multiple Processes. This observation revealed some interesting facts about the interaction between Management Systems L0 Process and Implementing Procedures in the Nuclear Power Plant Operational Readiness especially if compared to the nature of the interaction between L0 processes themselves. While L0 to L0 interaction is pretty much following a divergent pattern where most of L0 processes are linked to more than one L0 process, the corresponding Implementing Procedures tends to follow a convergent pattern where they interact solely with one L0 Process only. The fact that the 17 major hubs are concentrated around specific L0 processes which are linked to a unique group of Implementing Procedures also allows for a fault-tolerant behavior and fosters resilience in the interaction between L0 Processes and Implementing Procedures in the Nuclear power plant Operational Readiness Program.

6.2.8 Interactions between level 0 processes in the nuclear power plant operational readiness

This thesis studied all interactions amongst Level 0 Processes in the Nuclear Power Plant Operational Readiness. Interactions between the 46 L0 Processes have formed 461 undirected edges. A medium level of interaction among L0 processes was observed as evidenced by the network density of (0.445). Furthermore, L0 Processes are distributed across three distinct communities, and interaction between Level 0 Processes is moderately efficient from a communication standpoint since the maximum path length between L0 Processes is almost half the network diameter.

6.2.9 Interactions between strategic programs and regulatory requirements in the nuclear power plant operational readiness program

This study also analyzed all interactions between Programs established to deliver certain agreed benefits in the Nuclear Power Plant Operational Readiness and the Regulatory Requirements set by the national nuclear regulator. Mapped interactions between the 141 Strategic Programs and Regulatory Requirements formed 338 undirected Edges. Interactions between Strategic Programs and Regulatory Requirements in the Nuclear Power Plant Operational Readiness Program exhibit medium efficiency from a communication and information sharing perspective since the maximum path length between Strategic Programs and Regulatory Requirements is almost half of the network diameter. Moreover, the density of interaction between Strategic Programs and the Regulatory Requirements is 0.034 which suggests that there is a very low level of interaction among Strategic Programs and corresponding regulatory requirements. This finding needs to be further investigated in line with the density of interactions between strategic Programs and Regulatory Requirements since both the process design and strategic programs are the two management approaches used to instill the Regulatory Requirements in the design of the Nuclear Power Plant Management System structure. Strategic programs and Regulatory Requirements interactions have formed 10 distinct communities exhibiting the Hub and Spoke pattern where in most cases Programs are linked to specific requirements. This is typical in a Nuclear setting where strategic programs are designed and executed to fulfill specific regulatory requirements and thereafter, they ideally transform into Business as Usual (BAU) Processes. Findings from this thesis agree with Dvir (2005) that the planning for commissioning activities handover to BAUs has not been receiving proper attention from practitioners and engineer to ensure efficient and effective execution of this critical phase of the project life cycle.

6.2.10 Interactions between strategic programs and roles in the nuclear power plant operational readiness program

This thesis analyzed all links and relationships between Programs established to deliver certain agreed benefits in the Nuclear Power Plant Operational Readiness and the Roles. Programs to Roles Interaction mapping is intended to Identify roles and responsibilities for Functions, persons, and/or other entities involved in the Nuclear power plant operational Readiness Program at all levels. Interactions between the 358 Strategic Programs and Roles produced 577 undirected edges. Interaction between Strategic Programs and Roles enable efficient communication and transition of information as evident by the maximum path length between Strategic Programs and Roles being less than the network diameter. However, the density of this interaction is 0.009 which suggests that there is a low level of interaction among Strategic Programs and Roles relative to the total possible number of connections. This result should be further studied in line with the IAEA Nuclear Energy Series No. NP-T-2.7 (IAEA 2012) lessons learned of Effective management of intercedences, interfaces, and commissioning roles and responsibilities.

Strategic Programs and Defined Roles are distributed across 13 distinct communities. The interaction between Programs and Defined Roles seems to homogenous and also following in most cases the hub and spoke patterns where most Roles are supporting, interacting, and/or linked to a specific Programs in one-to-one interaction. Furthermore, multiple influential programs can be found in each cluster which further supports the fact that this structural configuration strongly contributes to enhance robustness to failure in interactions between Strategic Programs and Roles.

6.2.11 Interactions between strategic programs in the nuclear power plant operational readiness program

This study analyzed the nature of interactions between the 59 Strategic Programs in the Nuclear Power Plant Operational Readiness Program. Interactions between those programs formed 216 undirected Edge. still, a low level of interaction between Strategic Programs was established as evident by the low Network density (0.126). Moreover, Strategic Programs are distributed across

5 distinct clusters. Those clusters share commonalities and a label can be tagged to each cluster based on their nature and purpose of each distinct communities. This property strongly supports the resilience of interactions between strategic programs knowing the high probability of delays, cost overrun, the quality issue associated with programs execution. The 5 major hubs are concentrated around specific strategic programs (mainly with high betweenness centrality). This structural configuration allows for a fault-tolerant behavior in the interaction between strategic programs. Hence, if any program within one of those 5 clusters experiences issues with schedule, cost, or quality, the distal impact most probably would be contained within the cluster with a minimal negative impact on other clusters. Therefore, the probability of realizing strategic benefits out of those programs increases.

6.2.12 Interactions between strategic programs and plant systems in the nuclear power plant operational readiness program

This thesis studied all interactions between Programs in the Nuclear Power Plant Operational Readiness and Plant Systems. Systems referred to in this study covers Plant Systems, Structures, and Components (SSC). These include, but are not limited to software applications, supporting hardware, safety-related equipment, and buildings. Interfaces between the 133 Strategic Programs and Plant Systems formed 302 undirected linkages. This interaction seems to be relatively efficient

and the flow of information seems to be seamless since the maximum path length is less than the network diameter. This observation supports Fiatech's Capital Facilities Information Handover Guide (2006) emphasis on the critical role of information flow for the success of commissioning activities. However, a low level of interaction between Strategic Programs and Plant Systems, Structures and Components exist relative to the proportion of possible connections as evidenced by the 0.034 Network Density. the cohesiveness and robustness of the interaction between Strategic Programs and Plant Systems, as well as, the inclusiveness and coverage of all regulatory requirements as part of the BAU design within the nuclear power plant can be improved. Strategic Programs, Plant Systems, Structures, and Components are distributed across 8 distinctive clusters. Similar to other networks in this study, the interaction between Programs and Plant Systems follows the hub and spoke model where programs interact with specific systems in the plant on a one-to-one basis since they have a unique scope that is usually related to particular systems within the plant. Furthermore, most of the clusters in this interaction are dispersed and not centered around a specific strategic program. This pattern needs to be studied further to assess the integrity of the Nuclear Power Plant Operational Readiness Management Systems and the level of integration and harmonization between relevant Systems. The eight hubs are dispersed and not concentrated around specific Strategic Programs. This might suggest a fault-tolerant behavior and fosters resilience in the interaction between strategic Programs and Plant Systems, Structures, and Components.

Validation of network graphs can be achieved by examining network graphs and statistics with observed data using multiple methods such as interviews, observation, or collection of records. (Schrieber & Carley 2003). Therefore, the 13 network graphs have been validated by conducting a one-to-one interview with process owners and domain experts. The interview structure was assembled using standard network analysis questions to strengthen the validity of findings drawn from network analysis (Cross et al., 2004; Newman, 2003). The selected interview questions were reviewed with Network methods expert from BUiD and the wording of some questions was modified. A total of 46 process owners and 62 subject matter experts were interviewed as part of the validation interviews. These questions were selected using the recognition technique to support respondents in identifying all interactions by providing the initial view developed based on the secondary data review and organized as per the structure derived from the literature and explained in detail in chapter 2. The recognition technique produces a more accurate evaluation of network structure compared to the free recall techniques (Hlebec & Ferligoj, 2002). It was very essential to pay attention to how the network models reflect reality by adopting multiphase iterative review processes that involve relevant stakeholders (Chang & Harrington, 2006). This study has adopted an iterative, collaborative interpretation as shown in figure (4.5) to improve the robustness of this study's findings. This process ensured that results are interpreted in the right context given the structure and operations of the UAE nuclear power plant operational readiness. The use of secondary data coupled with detailed stakeholders review of the network models enhance the reliability of findings derived from network analysis (Scott, 2000). In addition,

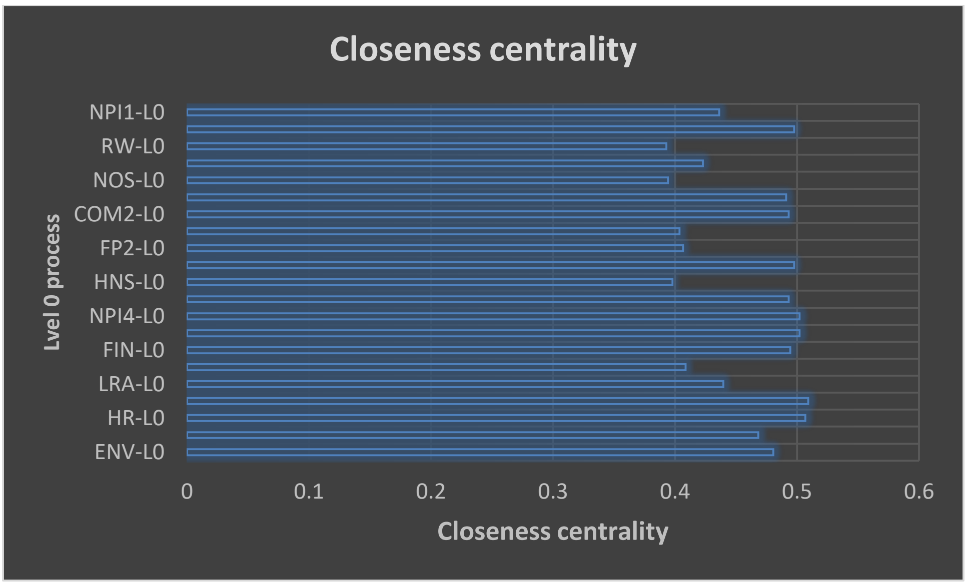
6.3 Research objective 2

Identify the key influential components of nuclear operational project processes and readiness in the UAE nuclear sector;

6.3.1 Interactions between level 0 processes and regulatory requirements within the nuclear power plant operational readiness program

This research identified the top central players in the Level 0 Processes and Regulatory Requirements network to meet the objective of exploring the centrality and effect of each factor.

Centrality was used in this study as an essential measure of the information flow between L0 processes and Regulatory Requirements. In addition, Betweenness Centrality provided a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. The centrality was investigated using both closeness and betweenness. Figure 6.1 presents the statistical comparison of top nodes influencing processes and the regulatory Requirements network.



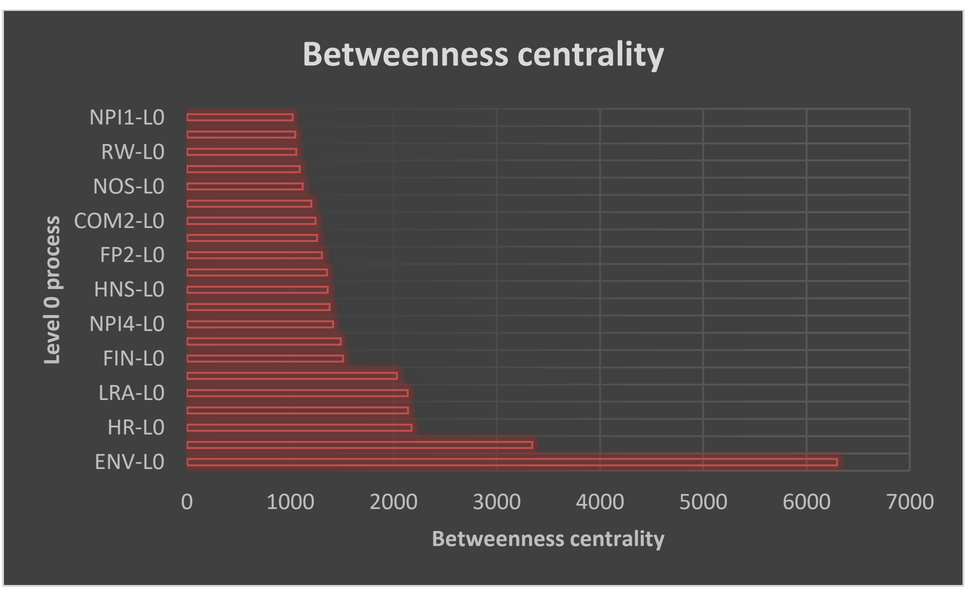


Figure 6. 1 Statistical comparison of top nodes influencing processes and the regulatory requirements network

As shown in figure (6.1), the majority of the L0 processes and the regulatory requirements have the same closeness (around 0.5), meaning that they're seen from this angle as having the same influence over this network, while a few of them tend to have a high closeness value. Whereas, ENV-L0, RP1-L0, EP1-L0, RE-L0, NOS-L0, and LRA-L0 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between L0 processes and Regulatory requirements intact. Those nodes serve as bridges between other L0 processes to satisfy the majority of regulatory requirements. Table 6.1 summarizes the researcher's observations on influential nodes in the Level 0 Processes and Regulatory Requirements network.

Table 6. 1 Researcher's observations on influential nodes in level 0 processes and regulatory requirements network

Network name	L0 processes affecting the interaction between Level 0 Processes and Regulatory Requirements
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the Level 0 Processes and Regulatory Requirements network are: 1. ENV-L0 2. RP1-L0 3. EP1-L0 4. RE-L0 5. NOS-L0 6. LRA-L0
Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis, ENV-L0, RP1-L0, EP1-L0, RE-L0, NOS-L0, and LRA-L0 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between L0 processes and Regulatory requirements intact. Those nodes seem to serve as bridges between other L0 processes to satisfy the majority of regulatory requirements. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction

	between L0 process and Regulatory Requirements
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.2 Interactions between level 0 processes and strategic programs within the nuclear power plant operational readiness program

This research identified the top central players in the Level 0 Processes and Strategic Programs network to meet the objective of exploring the influence and effect of each node. Centrality was used in this study as an essential measure of the information flows between Level 0 Processes and Strategic Programs. In addition, Betweenness Centrality provided a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. The centrality was investigated using both closeness and betweenness. Figure (6.2) presents the statistical comparison of top nodes influencing Level 0 Processes and Strategic Programs network

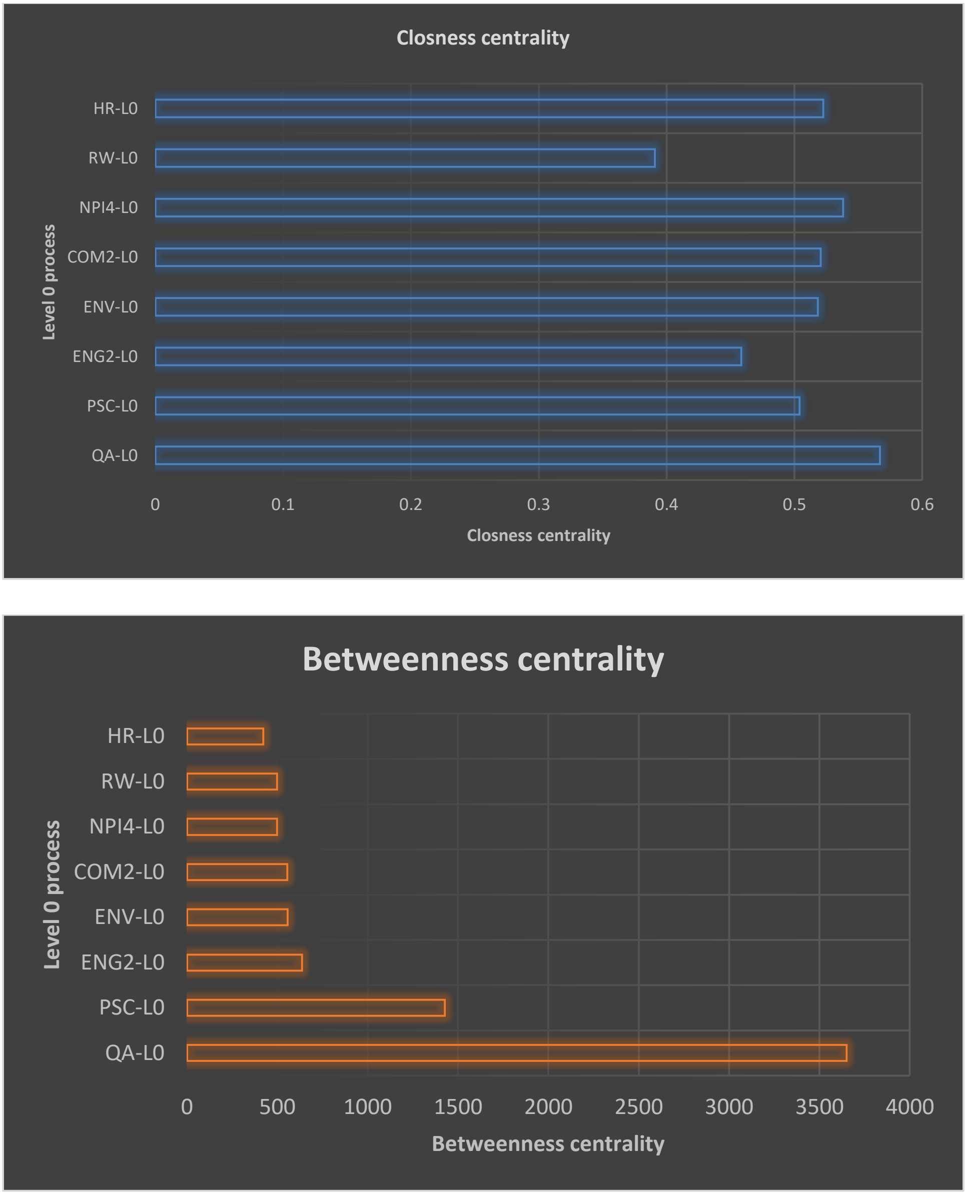


Figure 6. 2 Statistical comparison of top nodes influencing level 0 processes and strategic programs network

As shown in figure (6.2), the quality assurance and procurement process are the two most critical to maintaining the interaction between L0 processes and Strategic Programs intact and efficient due to their high Betweenness Centrality. Some other nodes like RW-L0 is a bit peripheral to the network structure due to the fact that the Radioactive Waste management Process at this phase of the development of the Nuclear Power Program is managed as a second priority compared to other processes like Operations, Maintenance, and Capacity Building, and work Management. However, interfaces with other L0 processes and Strategic Programs should be considered and established at the commissioning phase to ensure satisfying regulatory requirements by incorporating RW requirements in all relevant processes. Otherwise, some rework and major adjustments might be needed to ensure fulfilling onsite and off-site radiological waste. The capacity building process for commissioning professionals is fundamental to address the competency gap in managing complexity among commissioning engineers. This result agrees with ICC (2012), USDVA (2013) and Tribe and Johnson (2008) that commissioning professionals need to fulfill an essential competency requirement in providing relevant experience and qualification in relation to the complexity of the same type of commissioning activities or projects they are managing or planning to manage. Decision-makers and Subject Matter Experts in the Nuclear Power Plant Operational Readiness Program should pay attention to the impactful role Quality Assurance and Procurement processes play in maintaining the robust structure and efficient and effective interaction between L0 processes and strategic Programs. They also might need to rethink the relationship and interfaces of the Radiological Waste Management Process with other operational Readiness Processes and Strategic Programs. Table 6. 2 summarizes the researcher's observations on influential nodes in L0 process and strategic Programs network.

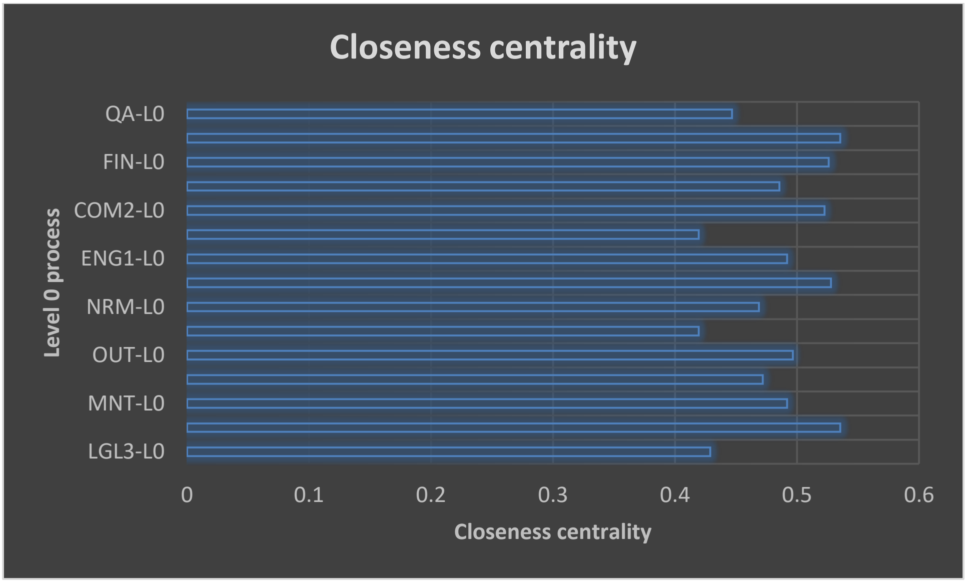
Table 6. 2 Researcher's observations on influential nodes in L0 process and strategic programs network

Network name	L0 processes affecting the interaction between L0 process and strategic Programs
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the L0 process and strategic Programs network are: 1. QA-L0 2. PSC-L0 3. ENG2-L0 4. ENV-L0

	5. COM2-L0 6. NPI4-L0 7. RW-L0 8. HR-L0
Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis, QA-L0, PSC-L0, ENG2-L0, ENV-L0 COM2-L0, NPI4-L0, RW-L0, and HR-L0 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between L0 process and strategic Programs intact. Those nodes seem to serve as bridges between other L0 processes to satisfy the majority of regulatory requirements. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction between L0 process and strategic Programs
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.3 Interactions amongst level 1 processes in the nuclear power plant operational readiness program

This research identified the top central players in the Level 1 Processes network in order to meet the objective of exploring the influence and effect of each node. Centrality was used in this study as an essential measure of the information flows between Level 1 Processes. In addition, Betweenness Centrality provided a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components.



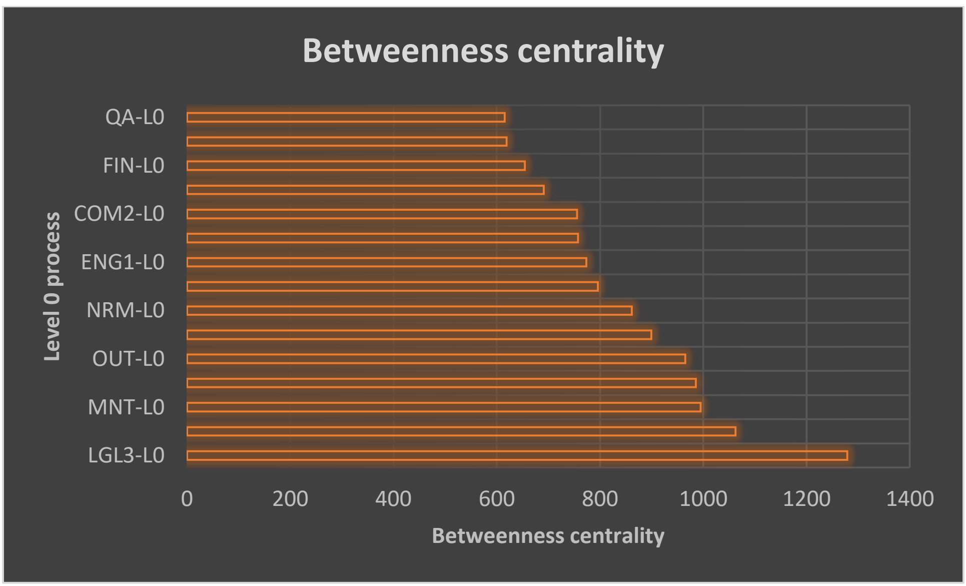


Figure 6. 3 Statistical comparison of top nodes influencing level 1 processes network

As shown in figure (6.3), L1 processes distribution based on Closeness Centrality followed the normal distribution. However, L1 processes in the Nuclear Power Plant Operational Readiness Program are centered around the 0.5 for the closeness centrality. Therefore, most L1 processes have almost the same influence according to this network statistic. However, Betweenness Centrality gives another perspective. Nodes with the highest Betweenness Centrality like Plant

Chemistry Monitoring and Control (Betweenness Centrality = 176.44), Strategic Sourcing Management (Betweenness Centrality = 99.75), Finance Process (Betweenness Centrality=83.93), and Legal Process (Betweenness Centrality= 81.39) are essential to maintain the efficient and effective interaction between L1 processes. Therefore, these processes should be managed with attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining the health of the Management System. Table 6.3 summarizes the researcher's observation on influential nodes in the L1 processes network.

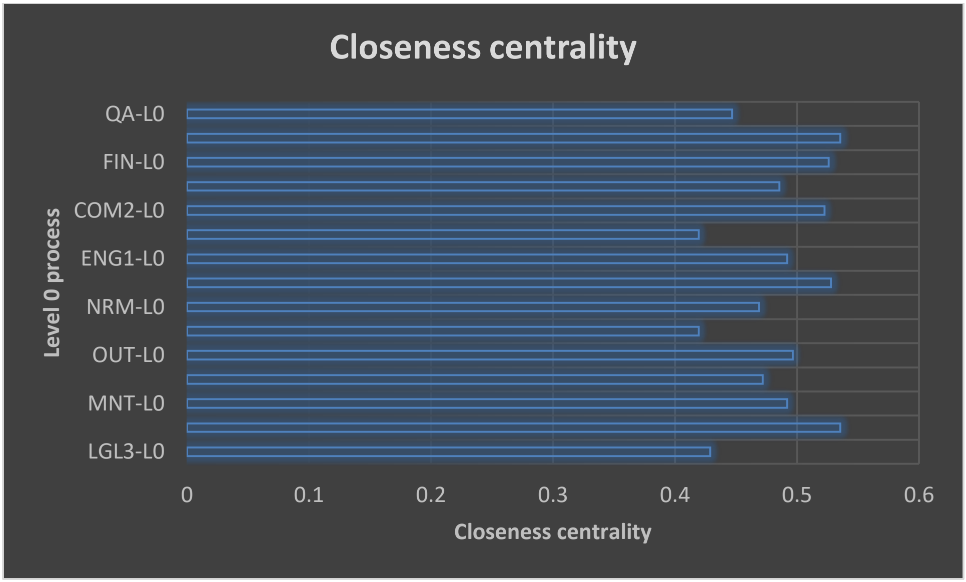
Table 6. 3 Researcher's observations on influential nodes in L1 processes network

Network name	L1 processes affecting the interaction in L1 processes Network
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the L1 process network are: 1. OP003 2. MS001 3. SS002 4. SS003 5. SS006 6. LP007 7. LP003 8. CM003 9. SS011 10. PI006 11. NF003 12. SS005 13. OP001 14. MO003 15. WM002 16. CM001 17. WM003 18. WM011 19. SS001 20. PI003

Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis, OP003, MS001, SS002, SS003, SS006, LP007, LP003, CM003, SS011, PI006 NF003, SS005, OP001, MO003, WM002, CM001, WM003, WM011, SS001and PI003 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between L1 process intact. Those nodes seem to serve as bridges between other L1 processes to satisfy the majority of regulatory requirements. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction between L1 processes.
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.4 Interactions between level 0 processes and stakeholders in the nuclear power plant operational readiness program

This research identified the top central players in Level 0 Processes and Stakeholders network in order to meet the objective of exploring the influence and effect of each node. Centrality was used in this study as an essential measure of the information flow between Level 0 Processes and Stakeholders. In addition, Betweenness Centrality provided a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. Figure (6.4) highlights the statistical comparison between top nodes influencing Level 0 Processes and Stakeholders network.



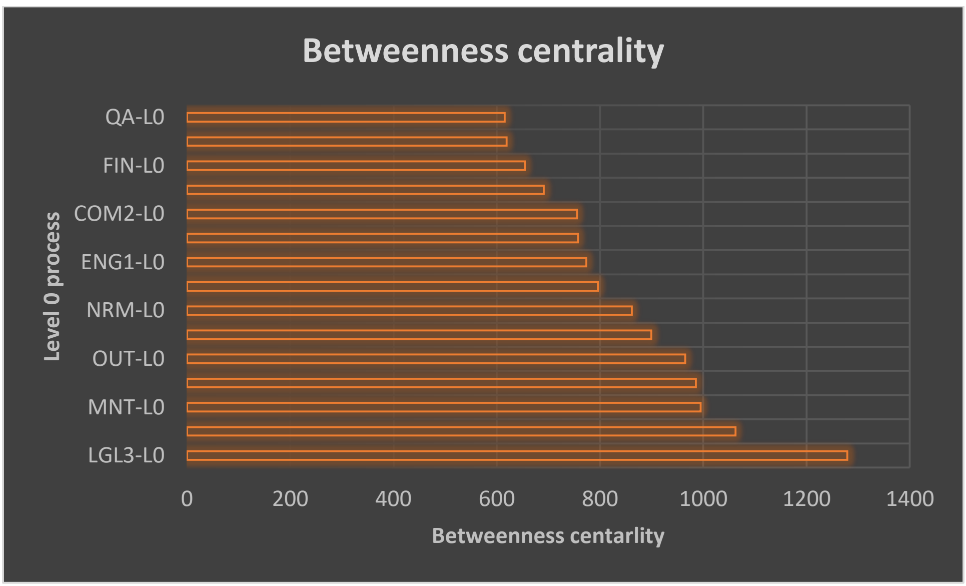


Figure 6. 4 Statistical comparison of top nodes influencing level 0 processes and stakeholders network

As shown in figure (6.4), the majority of the L0 processes and the stakeholder's nodes have the same closeness (around 0.5) with a portion pulling the curve towards the higher end. Still, from this angle, we can conclude that majority of L0 processes and stakeholders' nodes have the same influence over this network's structural integrity and flow of information. and integrity. Whereas, Nodes like LGL3-L0 (Betweenness Centrality = 1278), HR-L0 (Betweenness Centrality = 1062), MNT-L0 (Betweenness Centrality=994), PRJ-L0 (Betweenness Centrality=985), and OUT-L0 (Betweenness Centrality= 965) are seen as influential in their role to maintain the efficient and effective interaction between L1 processes and Stakeholders. Table 6.4 summarizes the researcher's observation on influential nodes in L0 processes and the stakeholder's network.

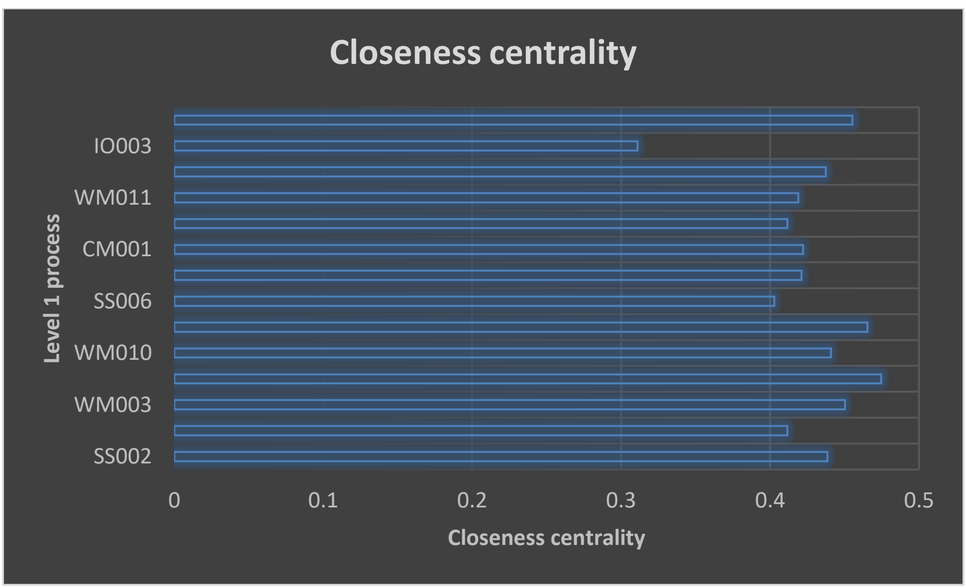
Table 6. 4 Researcher's observations on influential nodes in L0 processes and the stakeholder's network

Network name	L0 processes affecting the interaction in L0 processes and the stakeholder's Network
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the L0 processes and the stakeholder's network are: 1. LGL3-L0 2. HR-L0 3. MNT-L0 4. PRJ-L0 5. OUT-L0 6. DCM-L0 7. NRM-L0 8. PSC-L0 9. ENG1-L0 10. IAD-L0 11. COM2-L0 12. OP-L0 13. FIN-L0 14. NPI3-L0 15. QA-L0
Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis, LGL3-L0, HR-L0, MNT-L0, PRJ-L0 OUT-L0, DCM-L0, NRM-L0, PSC-L0, ENG1-L0, IAD-L0, COM2-L0, OP-L0, FIN-L0, NPI3-L0, and QA-L0 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between L0 processes and the stakeholders intact. Those nodes seem to serve as bridges between L0 processes and the stakeholders to satisfy the majority of regulatory requirements. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction between L0 processes and the stakeholders.
Conclusion	This result supports the claim that factors in this network are interrelated and some factors

	have more Influence than others in this network.

6.3.5 Interactions between level 1 processes and stakeholders in the nuclear power plant operational readiness program

This research identified the top central nodes in the Level 1 Processes and Stakeholders network. Centrality was used in this study as an essential measure of the information flows between Level 1 Processes and Stakeholders. Also, Betweenness Centrality provided a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. Figure (6.5) presents the statistical comparison between top nodes influencing Level 1 Processes and Stakeholders network.



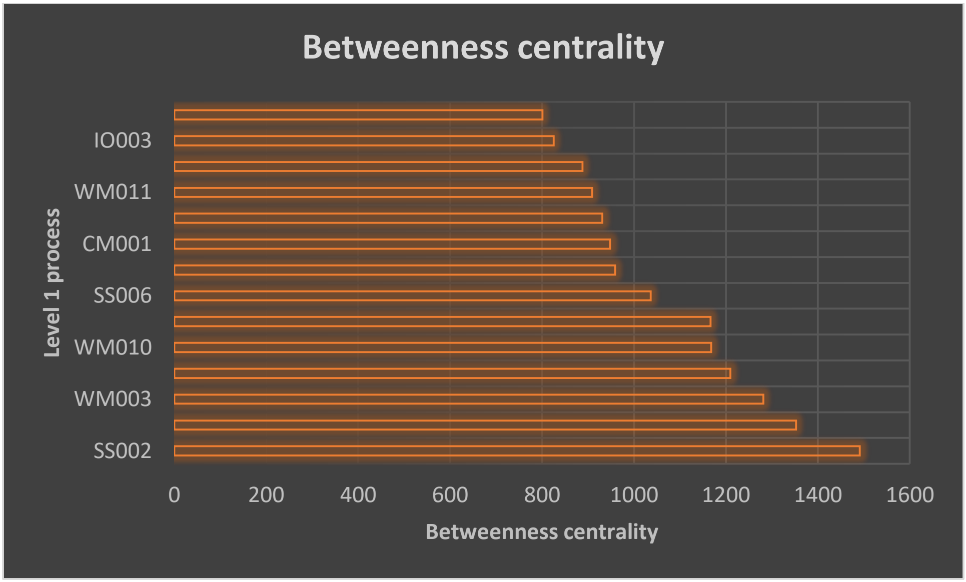


Figure 6. 5 Statistical comparison of top nodes influencing level 1 processes and stakeholders network

Similar to what has been observed in L0 processes interaction with Stockholders and as shown in figure (6.5), the majority of the L1 processes and the stakeholder's nodes have the same closeness (around 0.5) with a portion pulling the curve towards the higher end. Still, from this angle, we can conclude that majority of L1 processes and stakeholders' nodes have the same influence over this network's structural integrity and flow of information. and integrity. However, Betweenness Centrality indicated that the smallest cluster in this interaction is the most influential. It includes four nodes with the highest Betweenness Centrality in the network. Namely; Finance (Betweenness Centrality = 1490), Manage Statutory and Regulatory Requirements (Betweenness Centrality = 1352), Perform Preventive Maintenance (Betweenness Centrality = 1281 and Monitor and Control Plant Chemistry (Betweenness Centrality = 1209). Table 6. 5 summarizes the researcher's observation on influential nodes 1 Processes and Stakeholders network.

Table 6. 5 Researcher's observation on influential nodes 1 processes and stakeholders network

Network name	L1 processes affecting the interaction 1 Processes and Stakeholders Network
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the 1 Processes and Stakeholders network are: 1. SS002 2. MO002 3. WM003 4. OP003 5. WM010 6. MS001 7. SS006 8. OP001 9. CM001 10. LP006 11. WM011 12. NF003 13. IO003 14. WM002
Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis, SS002, MO002, WM003, OP003 WM010, MS001, SS006, OP001, CM001 LP006, WM011, NF003, IO003, and WM002 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between 1 Processes and Stakeholders intact. Those nodes seem to serve as bridges between 1 Processes and Stakeholders.
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.6 Interactions between level 0 processes and nuclear power plant systems

This research identified the top central players in the Level 0 Processes and Plant Systems network in order to meet the objective of exploring the influence and effect of each node. Centrality was used in this study as an essential measure of the information flows between Level 0 Processes and Plant Systems and components. In addition, Betweenness Centrality provided a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. The statistical comparison between top nodes influencing Level 0 Processes and Plant Systems network is presented in figure (6.6).

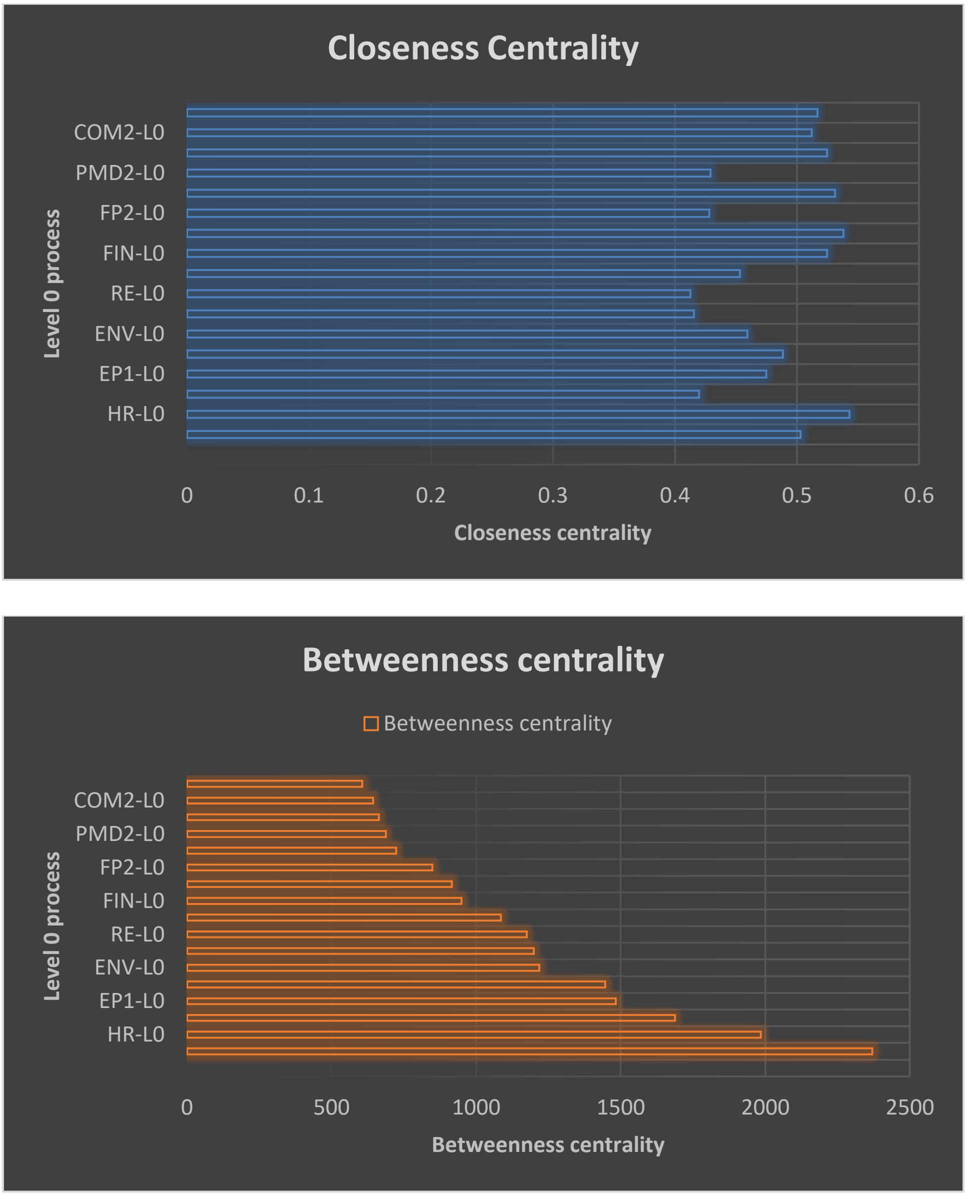


Figure 6. 6 Statistical comparison of top nodes influencing level 0 processes and plant systems network

As shown in figure (6.6), the majority of the L0 processes and the plant systems have almost the same influence over this network based on Closeness Centrality. Subject Matter Experts and

Management systems Professionals might need to further recognize the essential role some L0 Processes and/or Plant Systems play to keep the efficient flow of information and maintain the structural integrity of this interaction. Those are mainly nodes with the highest Betweenness Centrality. The process of Operating and Monitoring Structures, Systems, and Components appears to be the most influential node in this network (Betweenness Centrality = 2370) followed by HR-L0, CHE-L0, EP1-L0 and RP2-L0 with Betweenness Centrality 1985, 1687, 1483 and 1446 respectively. Table 6.6 summarizes the researcher's observations on influential nodes in L0 processes and Plant Systems network.

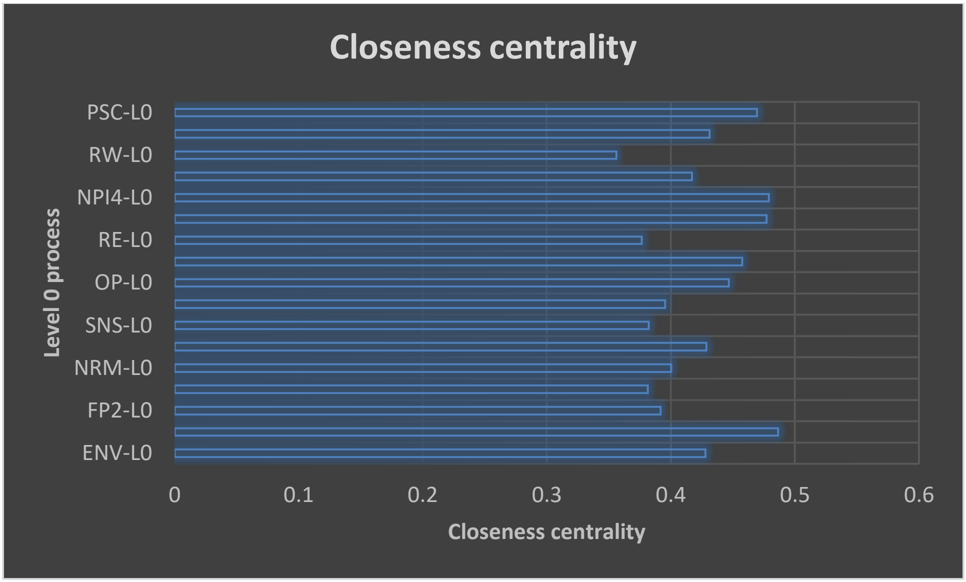
Table 6. 6 Researcher's observations on influential nodes in L0 processes and plant systems network

Network name	L0 processes affecting the interaction in L0 processes and Plants Systems Network
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the L0 processes and Plant Systems network are: 1. OP-L0 2. HR-L0 3. CHE-L0 4. EP1-L0 5. RP2-L0 6. ENV-L0 7. RE-L0 8. RE-L0 9. ENG2-L0 10. FIN-L0 11. NPI3-L0 12. FP2-L0 13. NIMS-L0 14. PMD2-L0 15. PSC-L0 16. COM2-L0 17. ICT-L0

Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis, OP-L0, HR-L0, CHE-L0, EP1-L0 RP2-L0, ENV-L0, RE-L0, RE-L0, ENG2-L0 FIN-L0, NPI3-L0, FP2-L0, NIMS-L0, PMD2-L0, PSC-L0, COM2-L0, and ICT-L0 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between L0 processes and the Plant Systems intact. Those L0 Processes serve as bridges between L0 processes and the plant systems. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction between L0 processes and plant systems.
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.7 Interactions between level 0 processes and implementing procedures

This research has also identified the top central nodes in the Level 0 Processes and Implementing Procedures network in order to meet the objective of exploring the influence and effect of each individual node. Centrality was used in this study as an essential measure of the information flows between Level 0 Processes and Implementing Procedures. In addition, Betweenness Centrality provided a different perspective for those poorly connected nodes that might be critical to the network by being bridges between key other components. Figure (6.7) presents the statistical comparison between top nodes influencing Level 0 Processes and the Implementing Procedures network.



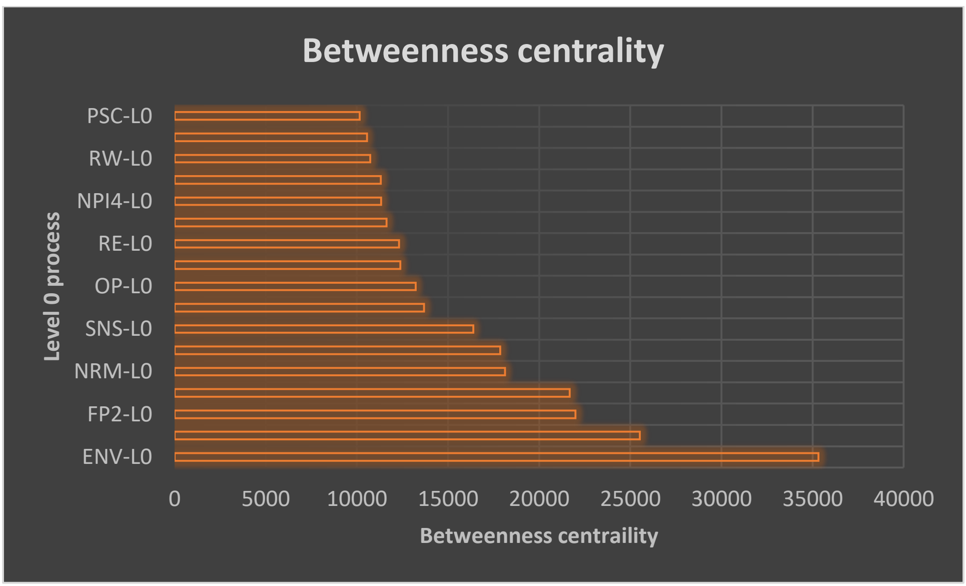


Figure 6. 7 Statistical comparison of top nodes influencing level 0 processes and implementing procedures network

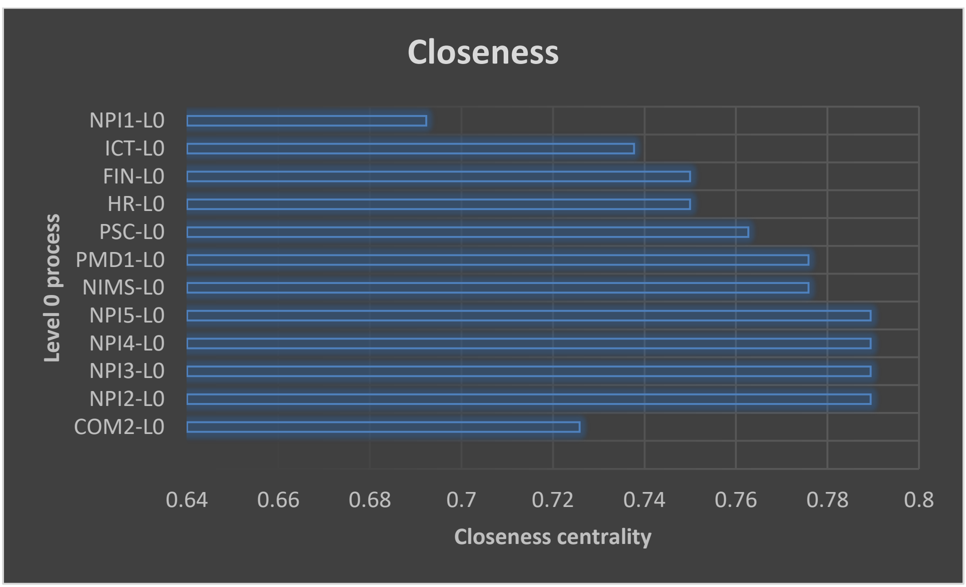
Based on Closeness Centrality in figure (6.7), the majority of the L0 processes and the implementing Procedures falling within the same range (0.26 – 0.49) and only a few nodes (21 Node) above 0.40, meaning that they're seen from this angle as having low influence over this network. However, based on Betweenness Centrality, ENV-L0, HR-L0, FP2-L0, RE-L0, NRM-L0, EP1-L0 are the most influential nodes and most critical nodes to maintain the structure of the network. Table 6.7 summarizes the researcher's observations on influential nodes in L0 processes and the Implementing Procedures network.

Table 6. 7 Researcher's observations on influential nodes in L0 processes and implementing procedures network

Network name	L0 processes affecting the interaction in L0 processes and Implementing Procedures Network
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the L1 process network are: 1. ENV-L0 2. HR-L0 3. FP2-L0 4. RE-L0 5. NRM-L0 6. EP1-L0 7. SNS-L0 8. ENG2-L0 9. OP-L0 10. COM2-L0 11. RE-L0 12. FIN-L0 13. NPI4-L0 14. RP2-L0 15. RW-L0 16. ENG1-L0 17. PSC-L0
Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis, ENV-L0, HR-L0, FP2-L0, RE-L0, NRM-L0 EP1-L0, SNS-L0, ENG2-L0, OP-L0 COM2-L0, RE-L0, FIN-L0, NPI4-L0. RP2-L0 RW-L0, ENG1-L0, and PSC-L0 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between L0 processes and implementing Procedures intact. Those nodes seem to serve as bridges between other L0 processes and Procedures to satisfy the majority of regulatory requirements.
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.8 Interactions between level 0 processes in the nuclear power plant operational readiness

This research identified the top central players in the Level 0 Processes network in order to meet the objective of exploring the centrality and effect of each process. Centrality was used in this study as an essential measure of the information flows between L0 processes. In addition, Betweenness Centrality provided a different perspective on what influential processes are. The centrality was investigated using both closeness and betweenness. Figure (6.8) present the statistical comparison on both centrality measure between top nodes influencing L0 processes network.



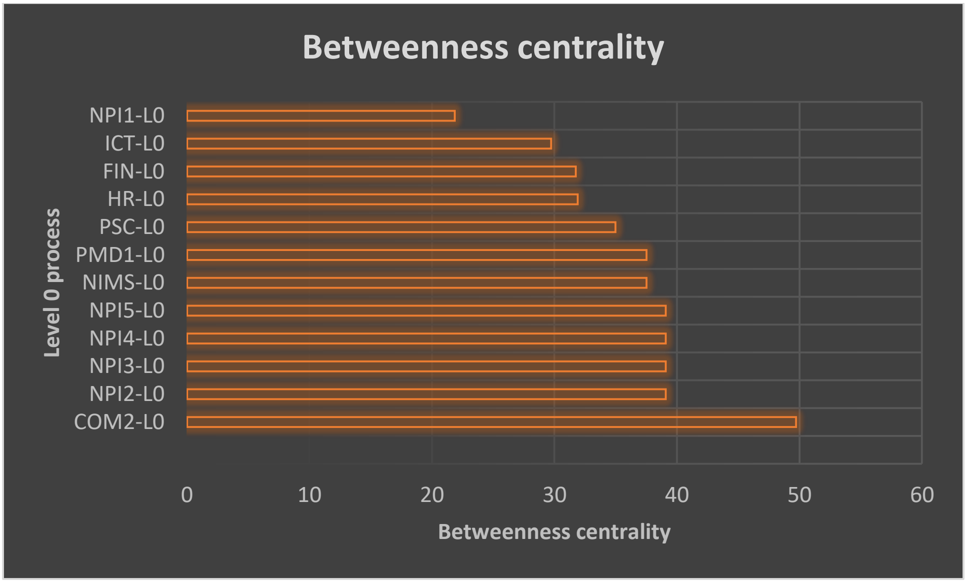


Figure 6. 8 Statistical comparison of top nodes influencing L0 processes network

Looking at the closeness centrality in figure (6.8), NPI2-L0, NPI3-L0, NPI4-L0, NPI5-L0, NIMS-L0, and PMD1-L0 are seen as having more influence over this network. However, betweenness centrality added COM2-L0 on top of the list. This finding agrees with IAEA Safety Standards Series No. SSR-2/2 (Rev. 1) that the operating organization shall ensure that the interfaces and the communication lines between different groups (i.e. groups for design, groups for construction, contractors, groups for commissioning, and groups for operations) shall be clearly specified and controlled. This result also agrees with IAEA (2016) and AERB (1998) that communication and effective use of commissioning data is a key enabler for successful commissioning. In order to understand the interaction between L0 processes in the Nuclear Power Plant Operational Readiness Program, it is important to drill down and analyze the typology and nature of linkage associated with the Communication being the one with the highest Betweenness Centrality.

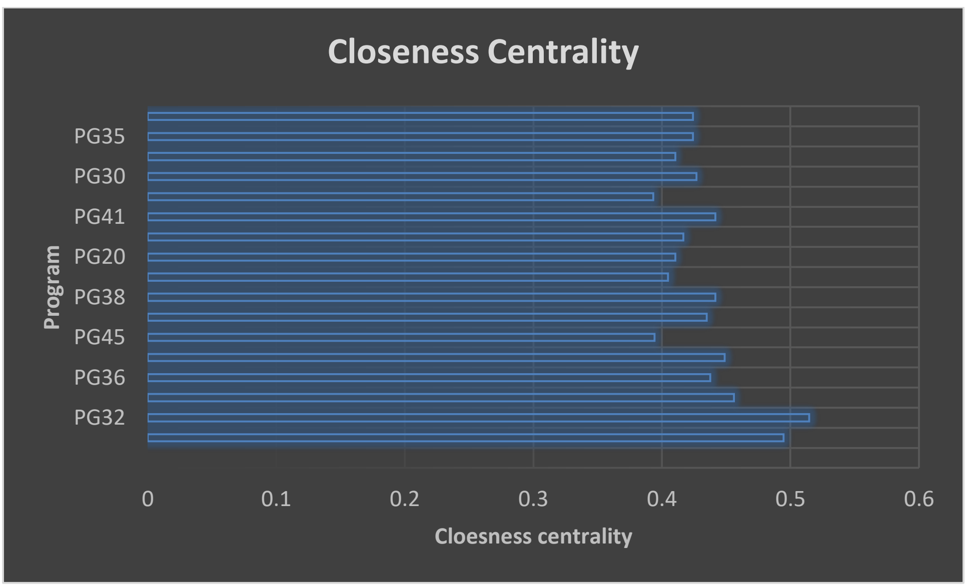
RW-L0 process is loosely connected to the cohesive ego and lacks maximal cohesion with the L0 processes core connections clusters while the majority of other L0 processes can be seen as core connected and closely tied to each others. Same behavior of the RW-L0 process has been observed in other networks as well. Table 6. 8 summarizes the researcher's observations on influential nodes in the Level 0 Processes network.

Table 6. 8 Researcher's observations on influential nodes in Level 0 processes network

Network name	Nodes affecting the interaction between Level 0 Processes
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the Level 0 network are: 1. COM2-L0 2. NPI2-L0 3. NPI3-L0 4. NPI4-L0 5. NPI5-L0 6. NIMS-L0 7. PMD1-L0 8. PSC-L0 9. HR-L0 10. FIN-L0 11. ICT-L0 12. NPI1-L0 13. NPI2-L0
Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis COM2-L0, NPI2-L0, NPI3-L0, NPI4-L0, NPI5-L0, NIMS-L0, PMD1-L0, PSC-L0, HR-L0, FIN-L0, ICT-L0, NPI1-L0and NPI2-L0 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between L0 processes intact. Those nodes seem to serve as bridges between other L0 processes to satisfy the majority of regulatory requirements. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction between L0 processes
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.9 Interactions between strategic programs and regulatory requirements in the nuclear power plant operational readiness program

This study has identified the most influential nodes in the Strategic Programs and Regulatory Requirements network to meet the objective of exploring the centrality and effect of each individual component. Centrality was used in this study as an essential measure of the information flows between Strategic Programs and Regulatory Requirements. Also, Betweenness Centrality provided a different perspective on what influential processes are. The centrality was investigated using both closeness and betweenness. Figure (6.9) presents the statistical comparison using both centrality measures on top nodes influencing Strategic Programs and Regulatory Requirements network.



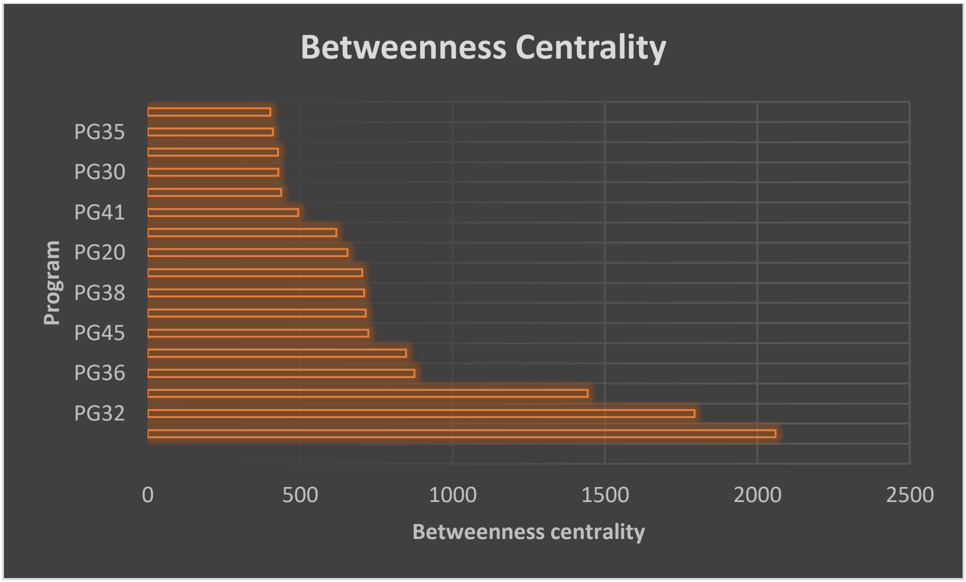


Figure 6. 9 Statistical comparison of top nodes influencing strategic programs and regulatory requirements network

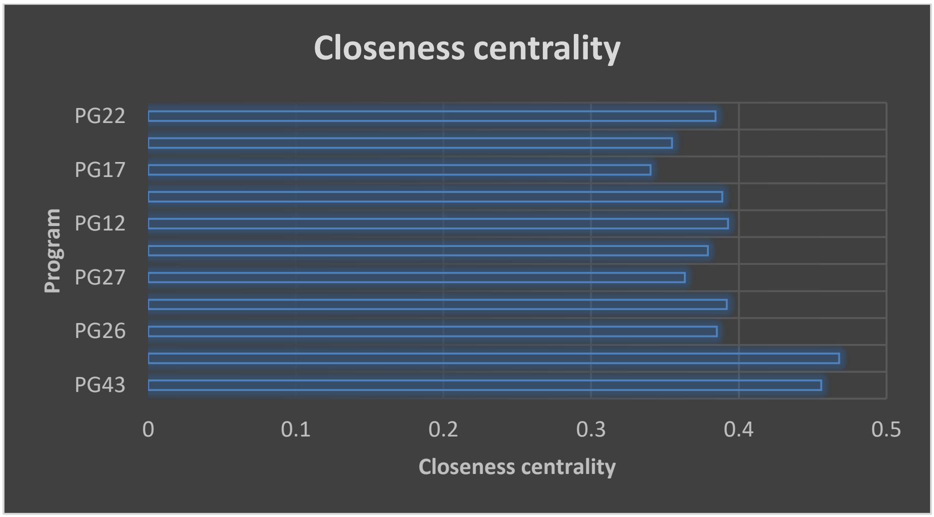
The majority of Strategic Programs and the regulatory requirements are centered around the mean of 0.34 ranging between 0.23 and 0.50. However, the majority of nodes are seen from this angle as having low to moderate influence over this network. Betweenness centrality provides a different perspective for those poorly connected programs or regulatory requirement nodes (low Degree centrality) that might be essential to the network by being bridges between key other components. More than 50% of nodes in this network has zero betweenness centrality. However, Programs like PG32, PG43, PG21, PG42, PG36, PG12, PG45, PG23, and PG20 are the most critical to maintaining the interaction between Strategic Programs and Regulatory requirements intact. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their structural importance and influence in maintaining efficient and effective interaction between strategic Programs and Regulatory Requirements. Table 6.9 summarizes the researcher’s observations on influential nodes in the Programs and Regulatory Requirements network

Table 6. 9 Researcher's observations on influential nodes in programs and regulatory requirements network

Network name	Nodes affecting the interaction between strategic Programs and Regulatory Requirements
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the strategic Programs and Regulatory Requirements network are: 1. PG43 2. PG32 3. PG21 4. PG36 5. PG12 6. PG45 7. PG23 8. PG38 9. PG42 10. PG20 11. PG9 12. PG41 13. PG34 14. PG30 15. PG49 16. PG35 17. PG31
Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis PG43, PG32, PG21, PG36, PG12, PG45, PG23, PG38, PG42, PG20, PG9, PG41 PG34, PG30, PG49, PG35and PG31 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between Programs and Regulatory Requirements intact. Those nodes seem to serve as bridges between other Programs and Regulatory Requirements to satisfy the majority of regulatory requirements.
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.10 Interactions between strategic programs and roles in the nuclear power plant operational readiness program

Most influential nodes in the Strategic Programs and Roles network have been identified in order to meet the objective of exploring the centrality and effect of each individual component. Similar to other networks, centrality was investigated using both closeness and betweenness as an essential measure of influence and structural importance. Figure (6.10) presents the statistical comparison of top nodes influencing Strategic Programs and Roles network using both centrality measures.



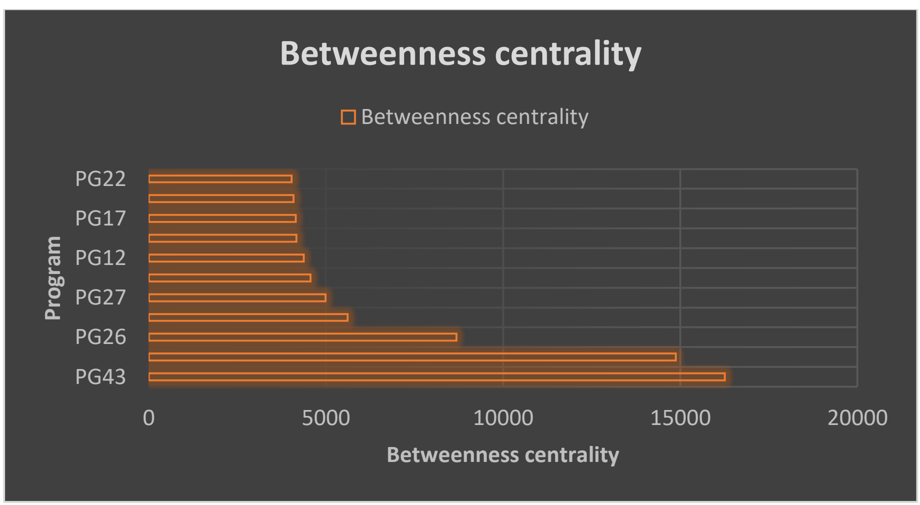


Figure 6. 10 Statistical comparison of top nodes influencing strategic programs and roles network

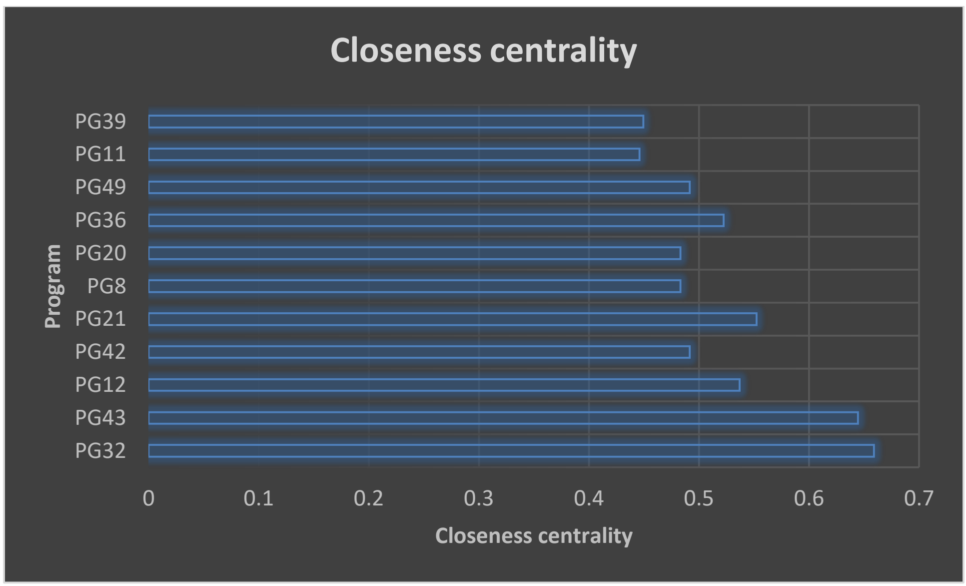
The majority of Strategic Programs and the regulatory requirements are centered around the mean of 0.34 ranging between 0.23 and 0.50. However, the majority of nodes are seen from this angle as having low to moderate influence over this network. More than 50% of nodes in this network has zero betweenness centrality. Betweenness centrality provides a different perspective for those poorly connected programs or regulatory requirement nodes (low Degree centrality) that might be essential to the network by being bridges between key other components. According to figure (6.10), PG32, PG43, PG21, PG42, PG36, PG12, PG45, PG23 and PG20 are the most influential programs in this network. Table 6. 10 summarizes the researcher's observations on influential nodes in Strategic Programs and Roles network

Table 6. 10 Researcher's observations on influential nodes in strategic programs and roles network

Network name	Nodes affecting the interaction between Strategic Programs and Roles
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the Strategic Programs and Roles network are: 1. PG43 2. PG32 3. PG26 4. PG23 5. PG27 6. PG49 7. PG12 8. PG36 9. PG17 10. PG24 11. PG22
Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis PG43, PG32, PG26, PG23, PG27, PG49, PG12, PG36, PG17, PG24, and PG22 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between Strategic Programs and Roles intact. Those nodes seem to serve as bridges between other Strategic Programs and Roles to satisfy the majority of regulatory requirements.
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.11 Interactions between strategic programs in the nuclear power plant operational readiness program

This research identified the top central players in Strategic Programs in the Nuclear Power Plant Operational Readiness Program in order to meet the objective of exploring the centrality and effect of each program. centrality was investigated using both closeness and betweenness as an essential measure of influence and structural importance. The statistical comparison of top nodes influencing Strategic Programs Network using both betweenness and closeness centrality measures is presented in figure (6.11)



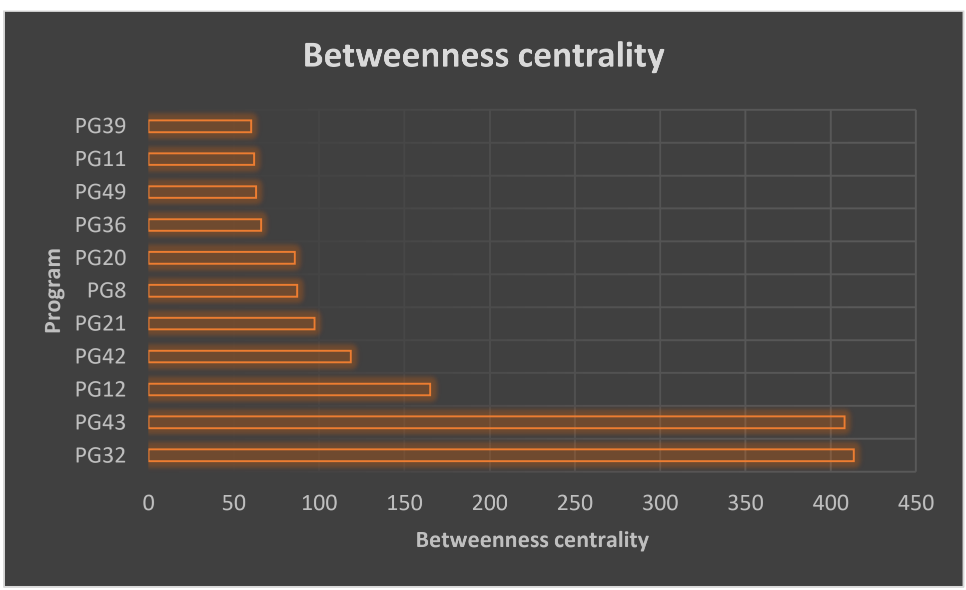


Figure 6. 11 Statistical comparison of top nodes influencing strategic programs network

The majority of Strategic Programs in this network are centered around the mean of 0.45 ranging between 0.3 and 0.65 on Closeness Centrality. However, the majority of nodes are seen from this angle as having low to moderate influence over this network. 17% of strategic programs in this network has zero betweenness centrality. Similar to other observations from other networks in this study and as shown in figure (6.11), Maintenance Program, Quality Assurance Programs, and chemistry program appear to be the most influential Strategic programs in the nuclear power plant operational readiness. They form bridges between different strategic programs in the nuclear power plan due to their structural properties, therefore, they are seen as very critical to maintain the integrity of interactions between strategic programs, foster the effective flow of information between programs, and ensure strategic benefits realization. Table 6.11 summarizes the researcher's observations on influential nodes in Strategic Programs in the Nuclear Power Plant Operational Readiness Program

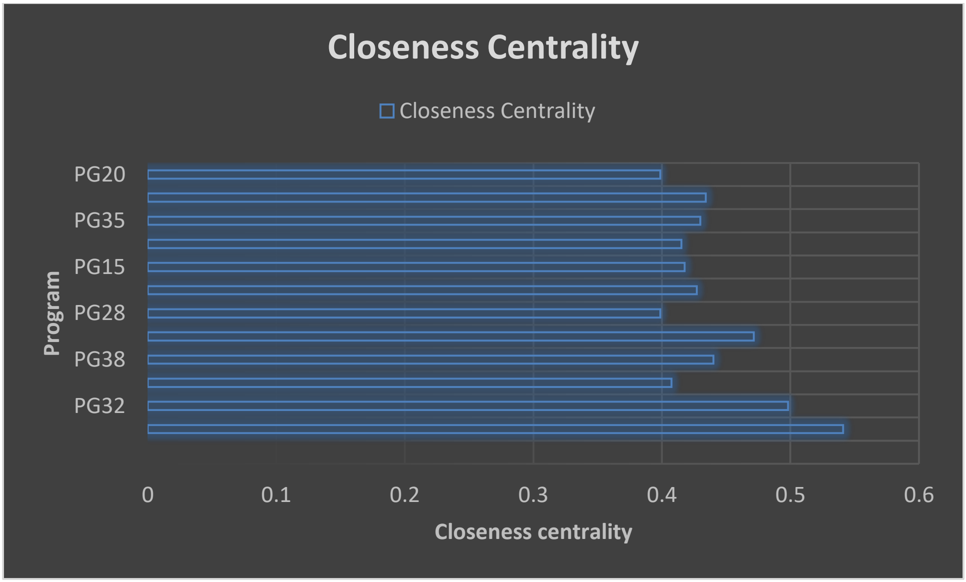
Table 6. 11 Researcher's observations on influential nodes in strategic programs in the nuclear power plant operational readiness program

Network name	Nodes affecting the interaction between Strategic Programs in the Nuclear Power Plant Operational Readiness Program
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the Strategic Programs network are: 1. PG32 2. PG43 3. PG12 4. PG42 5. PG21 6. PG8 7. PG20 8. PG36 9. PG49 10. PG11 11. PG39

Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis, PG32, PG43, PG12, PG42, and PG21 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between Strategic Programs in the Nuclear Power Plant Operational Readiness Program. Those nodes seem to serve as bridges between other L0 processes to satisfy the majority of regulatory requirements. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their importance in offering the most direct path between otherwise disconnected Clusters.
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.3.12 Interactions between strategic programs and plant systems in the nuclear power plant operational readiness program

This research also identified the top central players in Strategic Programs and Plant Systems network to meet the objective of exploring the centrality and effect of each node. centrality was investigated using both closeness and betweenness as an essential measure of influence and structural importance. Figure (6.12) presents the comparison between top nodes influencing Strategic Programs and Plant Systems Network using both centrality measures.



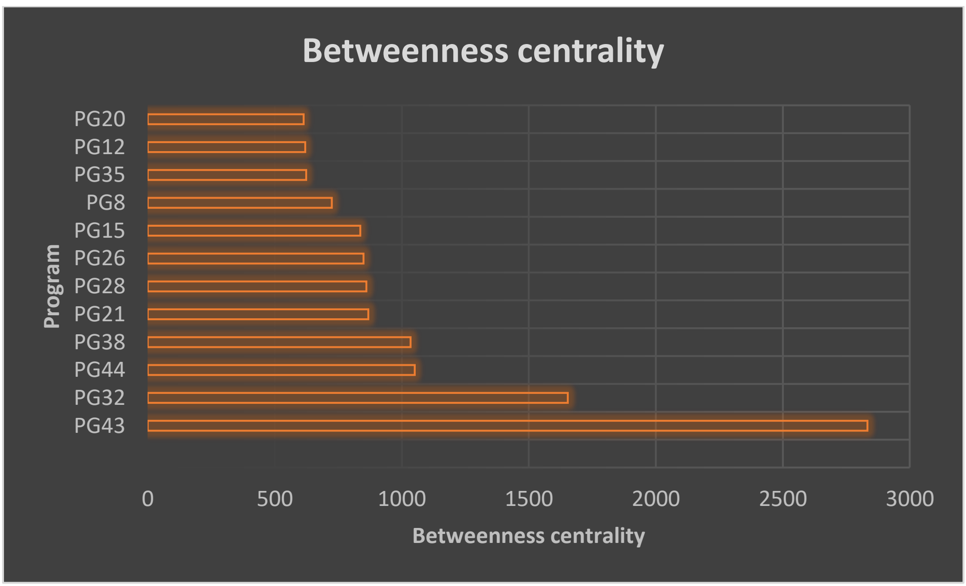


Figure 6. 12 Statistical comparison of top nodes influencing strategic programs and plant systems network

The closeness centrality distribution of Strategic Programs, Plant Systems, Structures, and Components seems to be following normal distribution and denoting less variability and a minor positive skewness. The majority of Strategic Programs, Plant Systems, Structures, and Components are centered around the mean of 0.33 ranging between 0.24 and 0.54. However, the majority of nodes are seen from this angle as having low to moderate influence over this network. 60% of strategic programs in this network has zero betweenness centrality. The remaining portion of Strategic Programs has a betweenness centrality that ranges from 2.2 and 2833. High variability is observed and four strategic Programs only have a betweenness centrality above 1000. As shown in figure (6.12), Maintenance Program and Quality Assurance Programs are the most influential programs in this network in addition to Operational Radiation Protection and Radioactive Waste Management. Table (6.12) summarizes the researcher's observations on influential nodes in Strategic Programs and Plant Systems Network

Table 6. 12 Researcher's observations on influential nodes in strategic programs and plant systems network

Network name	Nodes affecting the interaction between Strategic Programs and Plant Systems
Sub-research question	*Do some components have more centrality than others in this network?*
Results	This research found that the most central nodes in the Strategic Programs and Plant Systems network are: 1. PG43 2. PG32 3. PG44 4. PG38 5. PG21 6. PG28 7. PG26 8. PG15 9. PG8 10. PG35 11. PG12 12. PG20
Researcher's observation	This research has found that, according to the betweenness centrality and Ego Network Analysis, PG43, PG32, PG44, PG38, PG21, PG28, PG26, and PG15 have the highest Betweenness Centrality which might suggest that those nodes are critical to maintaining the interaction between Strategic Programs and Plant Systems. Those nodes seem to serve as bridges between other L0 processes to satisfy the majority of regulatory requirements. Therefore, should be given more importance and attention in the Nuclear Power Plant Operational Readiness Program knowing their importance in offering the most direct path between otherwise disconnected Clusters.
Conclusion	This result supports the claim that factors in this network are interrelated and some factors have more Influence than others in this network.

6.4 Research objective 3

Model the complexity (interactions and the structure of information flow) of nuclear operational project processes and stakeholders of the UAE nuclear sector;

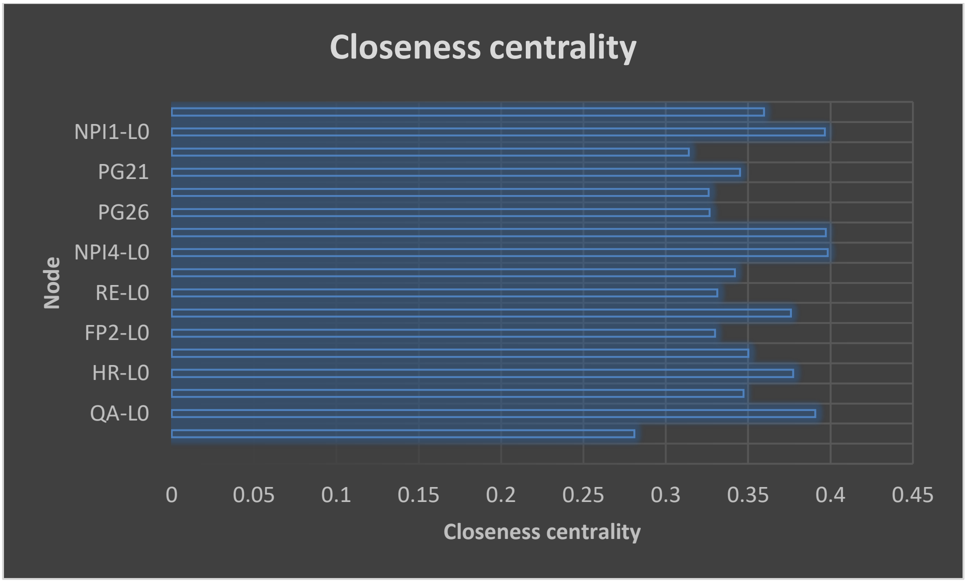
This thesis studied the nature of the interaction between Processes, Programs, Procedures, Systems and Stakeholders in the Nuclear Power Plant Operational Readiness Program. It was clearly noticeable in many cases that distinct and large hubs are established around key components like L0 Processes (Provide Environmental Services (ENV-L0) and Quality Assurance QA-L0), Strategic Programs, and most importantly the regulatory requirements represented by the Operating License (OL) Node. This result clearly supports the IAEA (2018) and AERB (1998) that performing top quality commissioning programs provide all involved stakeholders with assurance on meeting all applicable requirements needed to get the operational license (OL) and move the nuclear plant to the commercial operation phase. Furthermore, the hub and spoke pattern is quite dominant especially in interactions between both Management System Processes and Strategic Programs with other components in the Nuclear Power Plant Operational Readiness Program. This pattern of interaction support to a great extent the fact that Nuclear Power plants Operational Readiness Programs are designed and structured using process-based models. Furthermore, the hub and spoke pattern prevailed in this interaction explains how key components like each L0 process and Strategic Programs are designed to fulfill specific Regulatory Requirements and ultimately instilling those requirements in the Management Systems Business as Usual (BAU) by design. The Nuclear Power Plant Operational Readiness Program network included a total number of 1839 nodes distributed between Processes, Programs, Procedures, Systems, and Stakeholders. Interactions between those nodes established 3619 undirected connections. This finding supports Doty (2007) and Cagno, Caron, and Mancini

(2002) that the complexity of Operational Readiness is a distinguishing feature of the commissioning process and a real challenge for conducting top quality commissioning process. This finding supports Lawry and Pons (2013) view that the lack of proper integration in managing the commissioning process is a challenge across different industries and sectors. This finding also reemphasizes Cagno, Caron, and Mancini (2002) view that complex interfaces between different stakeholders need to be fully understood to prevent errors and delays during the commissioning phase.

Components of the Nuclear Power Plant Operational Readiness Program are distributed across 13 distinct communities. The majority of those 13 major hubs are concentrated around specific components like L0 or Strategic Programs which are linked to a unique group of regulatory requirements, roles, or plant systems. This structural configuration allows for a fault-tolerant behavior and fosters resilience in the Nuclear Power Plant Operational Readiness Program. More importantly, three key clusters are centered around one component that has a high betweenness Centrality. Two of those distinctive clusters are centered around one of the L0 processes namely; Quality Assurance (QA-L0) and Managing Environmental Services (ENV-L0). Whereas, the third cluster is centered around the most critical success criteria for the Nuclear Power Plant Operational Readiness Program which is getting the Operating License. This thesis has modeled all possible interactions among all components of the Nuclear Power Plant Operational Readiness Program and analyzed the impact on the program success criteria which is fulfilling the Regulatory Requirements needed to get the Operating License. Therefore, Ego Network Analysis has been performed to Analyze Quality Assurance (QA-L0) and Managing Environmental Services (ENV-L0) structures with a sufficient level of granularity and will be discussed in section (6.4) to answer the 4th research question. This thesis has also identified that 75% of

Processes, Programs, Procedures, Systems, and Stakeholders in the Nuclear Power Plant Operational Readiness Program this network has zero betweenness centrality. The remaining portion of Strategic Programs has a betweenness centrality that ranges from 3.08 to 446421. High variability is observed with six components only have a betweenness centrality above 100000 and only two above 400000. The closeness centrality distribution of the Nuclear Power Plant Operational Readiness Program seems to be following normal distribution and denoting less variability and a minor positive skewness. The majority of Processes, Programs, Procedures, Systems, and Stakeholders are centered around the mean of 0.25 ranging between 0.18 and 0.39. However, the majority of nodes are seen from this angle as having low influence over the Nuclear Power Plant Operational Readiness Program might need to further recognize the essential role some key components to keep the efficient flow of information and maintain the structural integrity of the Nuclear Power Plant Operational Readiness Program.

Furthermore, this study has identified the most influential nodes in the Nuclear Power Plant Operational Readiness Program network to meet the objective of exploring the centrality and effect of each individual component on the level of the complete network. Centrality was used in this study as an essential measure of the information flows between Programs, Processes, Procedures, systems, and stakeholders. Also, Betweenness Centrality provided a different perspective on what influential processes are. The centrality was investigated using both closeness and betweenness. Figure (6.13) present a comparison between the most influential nodes in the Nuclear Power plant Operational Readiness Program based on both centrality measures.



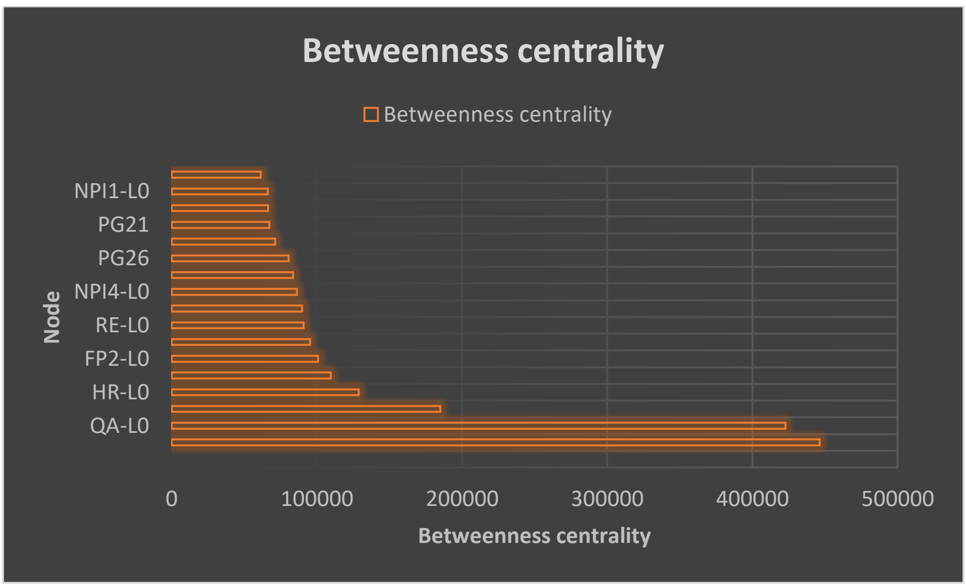


Figure 6. 13 Statistical comparison of most influential nodes in the nuclear power plant operational readiness program

The closeness centrality distribution of the Nuclear Power Plant Operational Readiness Program follows a normal distribution and denoting less variability and a minor positive skewness. The majority of Processes, Programs, Procedures, Systems, and Stakeholders are centered around the mean of 0.25 ranging between 0.18 and 0.39. However, the majority of nodes are seen from this angle as having low influence over the Nuclear Power Plant Operational Readiness Program. As shown in figure (6.13), according to the betweenness centrality, the most influential nodes in the Nuclear Power Plant Operational Readiness Program were Operating License fulfillment, Quality Assurance Process, Environmental Management process, Operate and Monitor Structures, Systems, and Components, Emergency Planning and Talent Management process.

6.5 Research objective 4

6.5.1 Quality assurance process Ego network

The main focus of this thesis is to understand the interaction between different components in the Nuclear Power Plant Operational Readiness Program and to what extent some of those components play an influential role to maintain the integrity of the structure and the flow of information among different nodes within this massive network. Therefore, a deeper look at the nature of the influence of the Quality Assurance Process through the ego network technique has been used. All interactions associated with the Level-0 Quality Assurance process on the complete network level has been produced as shown in Figure (6.14)

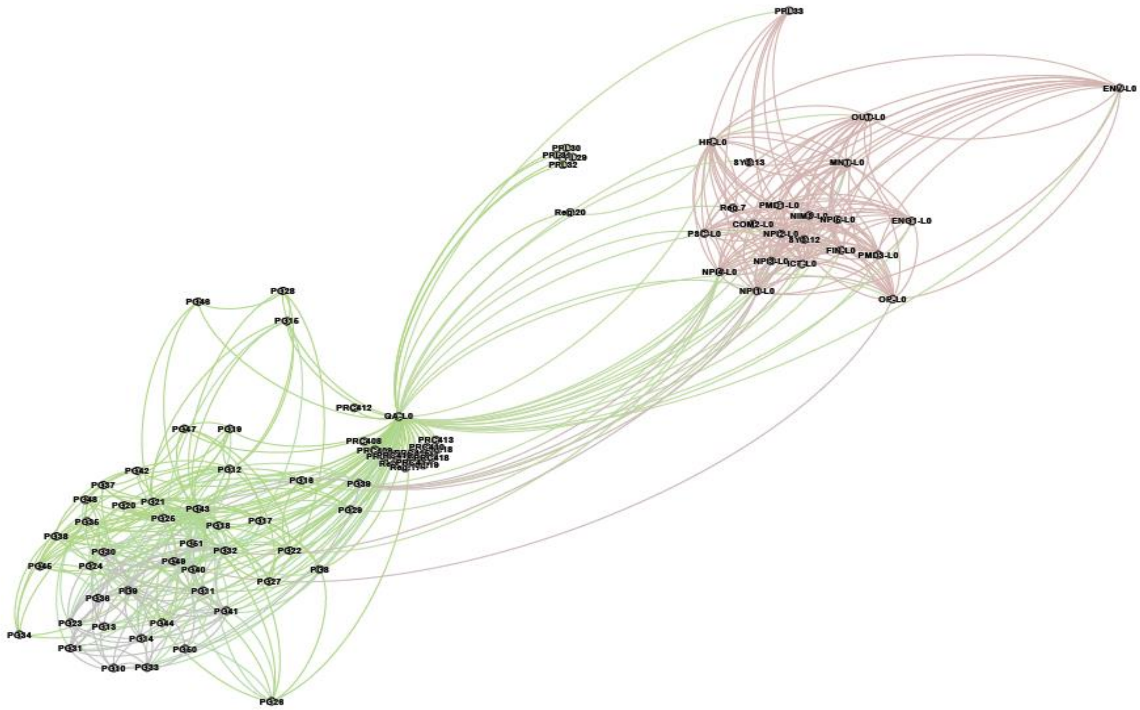


Figure 6. 14 Ego network of quality assurance process

The interaction between Level 0 Quality Assurance and the other 87 components in the Nuclear Power Plant Operational Readiness Program formed 493 connection (More than 13% of the complete network). However, this is still seen as a low level of interactions relative to the total possible interactions that can be established between the Quality Assurance Process and other components as indicated by low network density. This is no difference than the complete Nuclear power plant Operational Readiness Program Network. However, the maximum number of connections required to traverse the interaction between the Quality Assurance Program and other components in the Nuclear power plant Operational Readiness or in other words the number of steps taken between the two most distant nodes in Quality Assurance Ego Network to reach one another is 2 nodes as indicated by the Network Diameter. Combining this observation with the fact that the maximum path length between Quality Assurance Process and other nodes in this Ego Network is 1.9 as indicated by the average path length for a graph, we can conclude that interactions connected with this highly influential process are inefficient from a communication standpoint since the maximum path length between the Quality Assurance Process and other components is almost the same as the network diameter. More than 25% of nodes linked to the Quality Assurance process in its Ego network has zero betweenness centrality. The remaining portion of nodes has a betweenness centrality that ranges from 0.0625 to 224. Level 0 Quality Assurance Process and the other 87 components are clustered across three distinctive clusters. The Quality Assurance Process plays a central role and form a hub where a group of essential procedures and programs are uniquely connected to it.

6.5.2 Environmental services process Ego network

This thesis also analyzed in depth the nature of the Environmental Services process influence and the type of interactions it has with different components in the Nuclear Power Plant Operational Readiness Program. All interactions associated with the Environmental Services process have been identified and depicted using the Ego Network technique as shown in graph (6.15) below.

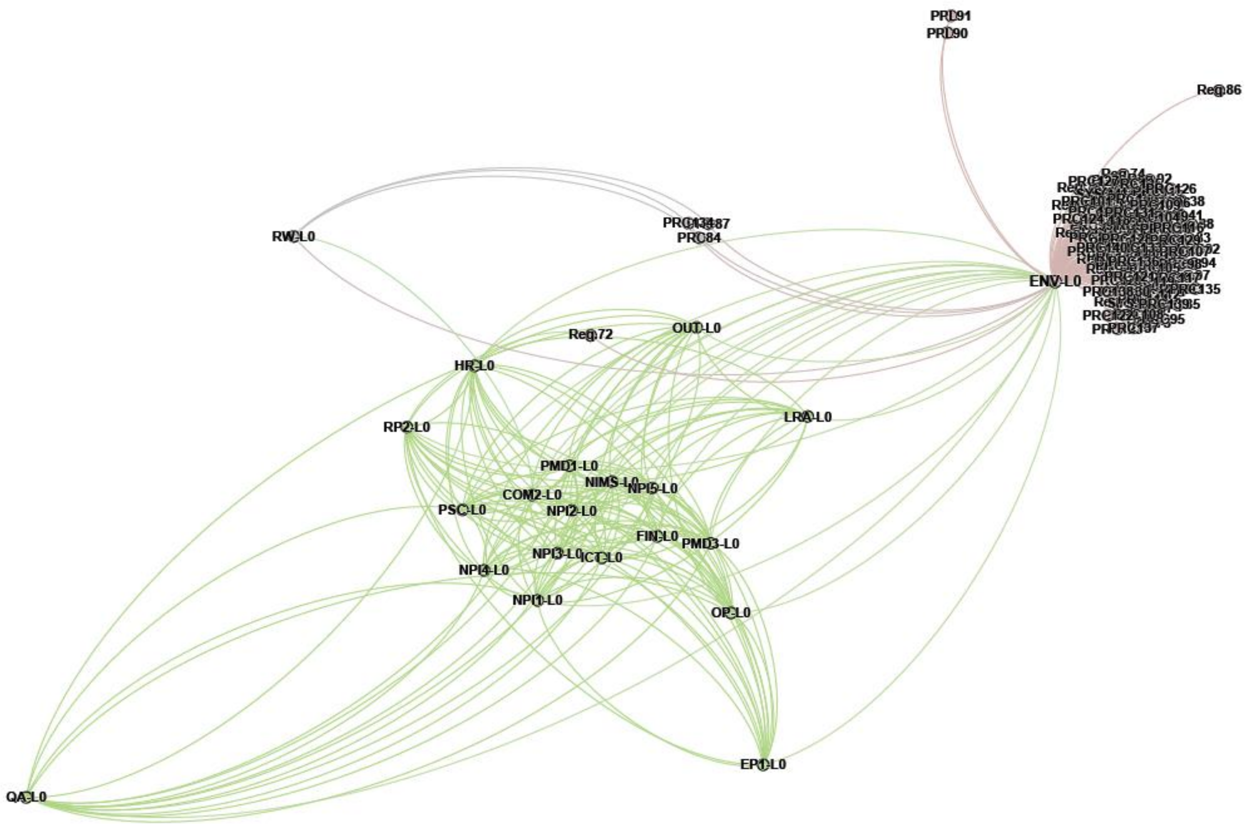


Figure 6. 15: Ego network of environmental services process

The structural characteristics of the the Environmental Services process Ego Network included 120 nodes and formed 300 edges formed 493 connection (around 8% of the complete Nuclear Power Plant Operational Readiness Network). However, the connections between the Environmental Services process and the other 119 components form a low level of interactions as indicated by low Ego network density. This is no different to the complete Nuclear power plant Operational Readiness Program Network. Interactions established with this highly influential process is inefficient from a communication standpoint. This is evident by the fact that the maximum path length between the Environmental Services process and other components is almost the same as the network diameter. 80% of nodes linked to the Environmental Services process in the ego network has zero betweenness centrality and the interaction between

Environmental Services process and the other 119 components are clustered across three distinctive Communities where the Environmental Services process play a central role and form a hub where certain essential procedures and programs are uniquely connected to it. Whereas, other clusters are dispersed around multiple central nodes.

6.5.3 Operating license (OL) requirements Ego network

In this section, this research discusses the results of the main outcome of all interactions within the Nuclear Power Plant Operational Readiness Program which is fulfilling the Operating License requirements and subsequently receiving the Plant Operating License (OL) from the National Nuclear Regulator. Therefore, it was very essential to understand the nature of interactions around the Operating License Hub and its relationship with other components in the Nuclear Power Plant Operational Readiness Program. To do so, the ego network technique was used to analyze in-depth the nature of influence the Operating License node has. All interactions associated with the Operating License node on the complete network level has been produced as shown in Figure (6.16)

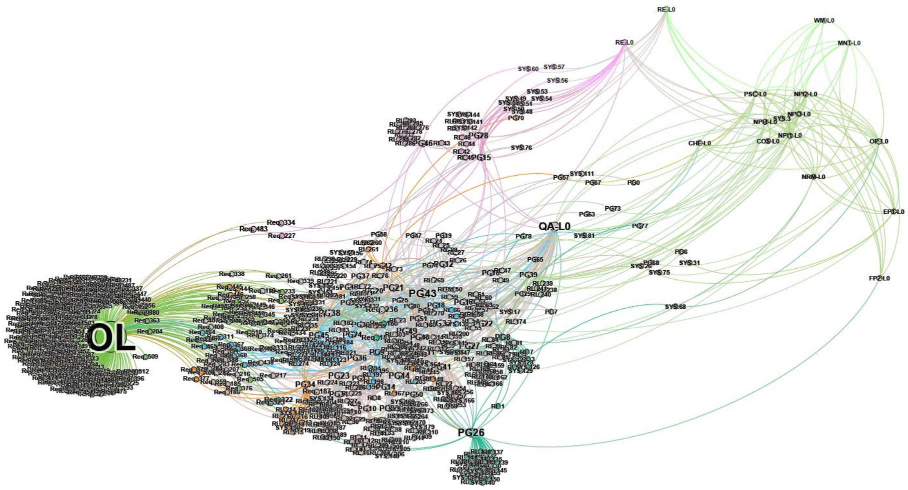


Figure 6. 16 Ego network of operating license (OL) requirements

The structural characteristics of the Operating License (OL) Requirements Level 3 depth Ego Network included 760 nodes (41.33% of the complete network) and produced 1315 edge (36.34% of the complete network). Similar to the complete network, the level of interaction between regulatory requirements and other components in the Nuclear Power Plant Operational Readiness program is relatively low compared to the total possible number of interactions that can be established as indicated by low network density. However, the interaction between OL and other components is still seen as being efficient from data exchange and communication perspective since the maximum path length between the Operating License node and other components is less than the network diameter. The interaction between Operating License (OL) Requirements and the other components is clustered across 11 distinctive Communities.

Strategic programs serve as a mediator between regulatory requirements and other components like Process, Plant systems, and procedures. The Operating License Requirements represented by the (OL) node interact directly with Strategic Programs and roles as the first layer of the interface. This observation requires specific attention from industry experts and Management systems professionals to assess how the design of strategic programs would help fulfil this critical role.

6.6 Chapter summary

This chapter was divided into four sections to discuss the research results. The first section discussed Interactions between different actors involved in the UAE Nuclear power plants Operational Readiness programs (Programs, Processes, Procedures, systems, and stakeholders), dividing those interactions into twelve individual networks. In the second part, the most central components for all networks were discussed. The third part discussed Interdependencies on the Nuclear Power Plant Operational Readiness Program level. The fourth section discussed the most influential components of different Programs, Processes, Procedures, systems, and stakeholders on achieving the Operating License requirements. Additionally, Ego Networks for the Quality Assurance Process, Environmental Services Process, and the Operating License (OL) node have also been discussed. The next chapter will present the research conclusions.

Chapter 7: Conclusions

7.1Introduction

This chapter presents the research conclusions. The first part will review the Research Objectives achieved by this thesis by linking the objectives with the relevant chapters. The second part will discuss research limitations. finally, the third part will present the contribution of this research to the knowledge. The chapter ends with the research recommendations and proposals for further work.

7.2 Accomplishing the research objectives

7.2.1 To Evaluate the interdependencies and the nature of influence within detailed interactions between the components of the nuclear power plant operational readiness program in UAE;

To achieve this objective, in Chapter 5 and in line with the literature reviewed in chapter 2 and the methodology explained in chapter 4, this research identified all known interactions between Programs, Processes, Procedures, Systems, and Stakeholders of Nuclear Power Plants Operational Readiness program using dependency matrices. Subsequently, Gephi software was used to transform all dependency matrices into Network graphs. Thirteen networks were developed and graphs are explained in Chapter 5 as per the following structure:

1) Level 0 Process to Requirement
2) Level 0 Process to Program
3) Level 1 Process to another level 1 process
4) Level 0 Process to Stakeholders
5) Level 1 Process to Stakeholders

6) Level 0 Process to Plant Systems

7) L0 process to Implementing procedure

8) Level 0 Process to L0 Process

9) Programs to Requirement

10) Programs to Role

11) Program to Program

12) Program to Plant System

13) Complete network graph analysis on the operational readiness program level.

This research identified and illustrated all established interactions between Programs, Processes, Procedures, Systems, and Stakeholders of Nuclear Power Plants Operational Readiness. All interactions have been mapped using adjacency matrices which subsequently transform into network graphs and underlying statistical models using Gephi software and force Atlas Algorithm. Key conclusions derived from this analysis were the following:

1. A low density of interactions between different components of the Nuclear Power Plant Operational Readiness exists, which indicates that a limited number of information sharing channels are established between the five key components of the UAE nuclear power plant operational readiness programme
2. Interactions between the five key components in the UAE nuclear power plant operational readiness programme form -in the majority of cases- a Hub and Spoke structural configuration. This structural pattern indicates a fault tolerance behavior and a possible Information silo.

3. The majority of Interactions in the Nuclear Power Plant Operational Readiness Program are structured around a central core, with multiple sub-group (Clusters/Hubs) composed of different actors with different distributions, indicating communication silos. Not every actor gets information predictably.
4. Information can diffuse throughout the Nuclear Power Plant Operational Readiness efficiently.

7.2.2 Understand identify the key influential components of nuclear operational project processes and readiness in the UAE nuclear sector;

To achieve this objective, in Chapter 5 and in line with the literature reviewed in chapter 2 and the methodology explained in chapter 4, this research analyzed the thirteen networks identified in the Nuclear Power Plants Operational Readiness program systematically to provide complete analysis on general networks characteristics, Networks Density, Networks clustering coefficient, and Modularity Analysis and Networks centrality measures to study the interactions and influence of network nodes. In addition, the meaning of each metric was interpreted and illustrated in relation to the research aim and objectives. Results are discussed in Chapter 6 in explaining the influence that occur between the different components. Interdependencies have been defined and the nodes in table 7.1 have been identified as the most influential.

Table 7. 1 Most influential actor in the nuclear power plant operational readiness

No.	Node
1	ENV-L0
2	RP1-L0
3	EP1-L0
4	QA-L0

5	PSC-L0
6	ENG2-L0
7	OP003
8	MS001
9	SS002
10	LGL3-L0
11	HR-L0
12	MNT-L0
13	MO002
14	WM003
15	OP-L0
16	CHE-L0
17	FP2-L0
18	COM2-L0
19	NPI2-L0
20	NPI3-L0
21	PG43
22	PG32
23	PG21
24	PG26
25	PG12
26	PG44

This research concluded that:

1. There is a number of Influential nodes in each interaction which to great extent Communication and interactions structural integrity tends to depend on them
2. There are just 3 main processes holding the top ranks in their influential strategic positions in regards to achieving the overall objective of the Nuclear Power Plant Operational Readiness, getting the Operating License.

7.2.3 To model the complexity (interactions and the structure of information flow) of nuclear operational project processes and stakeholders of the UAE nuclear sector;

After the complete network on the level of Nuclear Power plant, Operational Readiness program was explored and analyzed by this research in chapters 5 and 6, and in order to achieve this objective of identifying the most influential components on the program level, the ego topology was used, because it focuses on studying a selected node environment and the nodes that interact with the ego node (Ortega, 2014). This research used ego Network analysis on the complete network on the Quality Assurance Process, the Environmental Services process and the Operating License (OL) Requirements. Furthermore, the same methodology was applied to the Plant Chemistry monitoring and control process, Managing Statutory and Regulatory Requirements process, Finance Process, Managing and operating Structures, Systems and Components process, Communication process, Quality Assurance Program and Maintenance Program. as can be seen in Chapter 5 and Chapter 6.

7.2.1 Propose a methodology that can be adopted by the UAE energy sector to manage complexity.

To achieve this objective, in Chapter 5 and in line with the methodological gap identified in chapter 2 (Daniel and Daniel 2019, IAEA 2016, IAEA 2012, USDOE 2010, Sireli and Mengers 2009) and the validation exercise explained in the methodology chapter, this research has tested the appropriateness and usefulness of using the network analysis techniques to modeling the complexity of the UAE nuclear power plant operational readiness programme. The analysis and demystification of the complexity of the UAE nuclear power plant operational readiness programme was primarily achieved by:

1. Mapping and illustrating interactions and Information sharing structures
2. Highlighting Interdependencies and the nature of influence between the five key components (5 Ps) of the UAE nuclear power plant operational readiness programme.

This research produced two key tangible outputs; a model that describes the complex network and info. structure that exists between the 5 key components of the UAE nuclear power plant operational readiness programme and a practical methodology for addressing the shortcomings of the conventional project management functions of planning and control in examining and modeling megaproject complexity and dynamics.

7.3 Research limitations

In any scientific research, there are those constraints that might impact or influence the interpretation of the findings, applications to practice, and limitations to generalizability. This research, despite its significant contribution to knowledge, has faced some challenges and is no exception from this fact. key limitations of this research are:

1. The data collected relate to a specific organizational context; the dependency matrices and linkages between different components of the Nuclear Power Plant Operational Readiness Program are formed based on the UAE organizational and ecosystem setup.

This setup might differ from country to country and therefore should be taken into account when interpreting research findings.

2. One of the biggest challenges faced by this research is the amount of work needed to develop Dependency matrices and depict all interactions between the different components of the Nuclear Power Plant Operational Readiness Program. Due to the nature of this research and its objective to answer the research questions, the number of individual components defined was noticeably large, 1839 node. Furthermore, the validation and verification of interactions required a significant amount of time. However, that was necessary to achieve research objectives and answer the research questions
3. The strict Data classification process implemented in the Nuclear Power program limited the ability to access and retrieve additional data that could have been used to detail some interactions and/or establish additional linkages for information flow. The same challenge was faced during the data validation meetings with SMEs and process owners.

7.4 Knowledge contributions

This research aimed to demystify the complexity of interaction that occurs in the Nuclear Power Plant Operational Readiness Programs. It contributes to the methodology through the use of network analysis to explore and investigate the nature of interactions complexity between Processes, Programs, Procedures, Systems, and Stakeholders. The findings of this research will equip professional sand decision-makers with a granular and detailed view that will assist them in making the right decision in order to increase the success of Nuclear Power

Plant Operational Readiness Programs of being on time, on schedule, and fulfilling the expected quality standards.

This study is contributing to theoretical knowledge by:

1. Original testing of Network Analysis (borrowed from graph and complexity theory) on the Nuclear Power Plants Operational Readiness Programs domain. There has been limited use of network methods in the Nuclear Industry. Application has been limited to studies of Safety and Security. Nuclear Power Plants Operational Readiness Programs share the characteristics of Complex Adaptive Systems (CAS). Thus, the use of Network Analysis has been identified as a fundamental need for NPP commissioning programs to better analyze complexity and develop its Information flow structure.
2. Conducting the first of its kind empirical work to demystify the complexity and info. Structure of a Nuclear Power Plants Operational Readiness Program by applying network analysis on the largest and most advanced nuclear power program worldwide.
3. Original testing of how network analysis might address the shortcomings of the Information Processing Theory of not counting for the non-linearity and Interorganizational perspective by applying network analysis in the context of NPP.

In addition, this study contributes significant practical knowledge in both domains; Nuclear Commissioning and Project Management, because it:

1. Produces a model that describes the complex network and info. structure that exists between the 5 key components in the world's largest and most advanced Nuclear Power Plant Operational Readiness Program. This model helps practitioners/engineers and decision-makers to:

a) Simulate and better understand distal impacts of decisions

b) Provide insights into more effective and efficient Organizational Design.

c) Provide another perspective to help resources deployment

2. Provides insight into how the flow of information might influence achieving operating License requirements

3. Demonstrates the utility of network analysis for demystifying complexity and managing information in Nuclear Power Plant operational readiness.

4. Provides a practical methodology for addressing the shortcomings of the conventional project management functions of planning and control in examining and modeling megaproject complexity and dynamics.

Therefore, research findings will be valuable for practitioners and decision-makers in the UAE energy sector, the nuclear industry worldwide, local and international nuclear regulators, and other similar high reliable and complex industries. In light of the above-mentioned practical contribution, this study outlines the following recommendations and suggested guidelines for the UAE government:

a) Utilize the 13 models developed by this research to help to understand the complex interactions and information structures between the 5 key components of the UAE Nuclear Power Plant Operational Readiness Program.

b) Use the validated models along with additional trusted data sources to test and simulate the causality relationship between decisions distal impacts

c) Use the findings of network analysis- both structural and statistical- to rethink the Nuclear power plant organizational design principles. Pay more attention to the influential nodes and clusters.

d) Use the findings of network analysis- both structural and statistical- to provide insights for better deployment of resources. These resources include manpower, information and communication technology resources, financial resources and mission-critical know-how. Special attention to be given to the influential nodes and clusters.

e) Replicate the same research for the other new nuclear builds in the UAE nuclear energy sector to provides reliable insight into how the flow of information might influence achieving operating License requirements

f) Start incorporating Network Analysis techniques as a supporting methodology in project management offices in the UAE energy sector to help in addressing the shortcomings of the conventional project management functions of planning and control in examining and modeling megaproject complexity and dynamics.

In addition, this study recommends that practitioners working in the nuclear energy sector start using network analysis to demystifying the complexity of interactions and information-flow structures in the nuclear energy sector. This research established the utility of network analysis in the nuclear power plant's operational readiness. However, practitioners in different functional areas like operations, maintenance, outage management, engineering, and capital projects can benefit from adopting the same technique to address complexity issues within their specific domains. This research recommends that practitioners focus on the following practical usages of validated network graph within their functional areas:

a) Testing and simulation of design changes and/or modifications to better understand distal impacts of such decisions on strategic priorities and performance targets.

b) Provide insights and new perspectives based on identified structural characteristics to ensure effective and efficient organizational design.

c) Provide insights and new perspectives based on identified structural characteristics to ensure effective deployment and utilization of rescores.

7.5 Recommendations for further research

This research has studied the complexities of the Nuclear Power Plant Operational Readiness Program at the lowest granularity possible. It focused on uncovering the complexity of interactions and interdependence between the different components in the Nuclear Power Plant Operational Readiness Program, which has resulted in a list of contributions to knowledge, as has been stated above. Nevertheless, this research believes that some areas need to be investigated in future research, those are:

1. By using the results of this research, the researcher recommends trying to develop a modeling and simulation tool that depicts all identified interactions and load them with resources. This tool can be used to anticipate future distal impacts of decisions made by commissioning engineers and senior management on the success of the Nuclear Power Plant Operational Readiness Program.

2. Also, this research recommends addressing the same research problem in a different setting, context, location, and culture. This might produce unique insights and findings that emerge from a unique organizational culture, organizational context, or ecosystem and value chain structure. Network patterns do not assess the culture of organizations. The work atmosphere and attitudes of management and staff contribute to trust and safety in organizations and can affect performance as much as patterns of information exchange (Podolny & Baron, 1997).
3. This research demystified complexities between different players in the Nuclear Power Plant Operational Readiness Program, it is recommended that future researches in the same field add data related to cost and schedule performance and apply regression analysis on top of the Network Analysis to provide a different perspective supported by inferential statistical analysis.
4. This research recommends based on the results that have been reached to establish a framework for managing and auditing the Nuclear Power Plants Integrated Management Systems (IMS). This framework includes design principles that focus on addressing complexity and fostering effective integration Management.

References

Amaratunga, D., Baldry, D., Sarshar, M. and Newton, R. 2002. Quantitative and qualitative research in the built environment: application of "mixed" research approach. *Work Study*. **51** (1), pp. 17-31

Arnold, R.D. and Wade, J.P. 2015. A definition of systems thinking: A systems approach. *Procedia Computer Science*. **44** (1), pp. 669-678.

Ashby, R. 1956. *An Introduction to Cybernetics*. [Online]. London: Chapman & Hall LTD. [Accessed 18 February 2020].Available from: http://pespmc1.vub.ac.be/LIBRARY.html

Atomic Energy Regulatory Board. 1998. Safety Guide No. AERB/SG/O-5. *Radiation protection during operation of nuclear power plants: commissioning procedures for pressurized heavy water reactor based nuclear power plants*. Mumbai: AERB.

Atomic Energy Regulatory Board. 1998. Safety Guide No. AERB/SG/O-4. *Radiation protection during operation of nuclear power plants: commissioning procedures for pressurized heavy water reactor based nuclear power plants*. Mumbai: AERB.

Baccarini, D. 1996. The concept of project complexity—a review. *International Journal of Project Management*. **14**(4), pp. 201-204.

Battini, D., Persona, A. and Allesina, S. 2007. Towards a use of network analysis: quantifying the complexity of Supply Chain Networks. *International Journal of Electronic Customer Relationship Management*. **1**(1), pp. 75-90.

Baumgartner, F.R. and Jones, B.D. 2010. *Agendas and instability in American politics*. 2nd ed. Chicago: University of Chicago Press.

Beinhocker, E.D. 1997. Strategy at the edge of chaos. *The McKinsey Quarterly*. **1**(1), pp. 25-39

Bernhardt, R. 1997. Approaches for commissioning time reduction. *Industrial Robot*. **24**(1), pp. 62-7.

Binti Ab Hamid, A.H., Abd Rozan, M.Z., Deris, S. and Ibrahim, R. 2011. Deployment of system dynamics method in systems thinking for Malaysia nuclear plant safety systems. *GSTF Business Review*. **1**(1), pp.1-7

Boote, D.N. and Beile, P. 2005. Scholars before researchers: On the centrality of the dissertation literature review in research preparation. *Educational Researcher*. **34**(6), pp. 3-15.

Borgatti, S.P. and Foster, P.C. 2003. The network paradigm in organizational research: A review and typology. *Journal of Management.* **29**(6), pp. 991-1013.

Brannick, T. and Coghlan, D. 2007. In defense of being “native”: The case for insider academic research. *Organizational Research Methods*. **10**(1), pp. 59-74.

Brown, R.B., Rowe, M.B., Nguyen, H. and Spittler, J.R., 2001. Time-constrained project delivery issues. *American Association of Cost Engineers*. **44**(6), pp. 28-34

Browning, T.R. 2001. Applying the design structure matrix to system decomposition and integration problems: a review and new directions. *IEEE Transactions on Engineering Management*. **48**(3), pp. 292-306.

Cabrera, D. 2006. *Systems Thinking*. Ph.D. Thesis, Cornell University.

Cagno, E., Caron, F. and Mancini, M. 2002. Risk analysis in plant commissioning: The Multilevel Hazop. *Reliability Engineering and System Safety*. **77**(3), pp. 309-323.

California Commissioning Collaborative. 2006. *California Commissioning Guide*. Sacramento, CA: CCC.

Capra, F. 1983. *The turning point: Science, society, and the rising culture*. New York: Bantam.

Capra, F. 1996. *The web of life: A new synthesis of mind and matter*. London: HarperCollins.

Carley, K. and Wallace, A. 2001. Computational organization theory: A new perspective. *Encyclopedia of Operations Research and Management Science*. Kluwer Academic Publishers, Norwell, MA.

Carrascosa, M., Eppinger, S.D. and Whitney, D.E. 1998. Using the design structure matrix to estimate product development time. *In Proceedings of the ASME Design Engineering Technical Conferences; Design Automation Conference.* pp. 1-10.

Chang, M.H and Harrington Jr, J.E. 2006. Agent-based models of organizations. *Handbook of Computational Economics.* **2** (1), pp. 1273-1337.

Charmaz, K. 2006. *Constructing grounded theory: A practical guide through qualitative analysis*. 2nd ed. London: Sage.

Chroust, G and Finlayson, D. 2016. Anticipation and systems thinking: a key to resilient systems. *In Proceedings of the 60th Annual Meeting of the International Society for the Systems Sciences (ISSS), CO, USA*. **1**(1).

Collins, J.C., Collins, J. and Porras, J.I. 2005. *Built to last: Successful habits of visionary companies*. 3rd ed. New York: Harper Business.

Collis, J. and Hussey, R. 2013. *Business research: A practical guide for undergraduate and postgraduate* students. 4th ed. London: Macmillan International Higher Education.

Creswell, J.W. 2014. *Research design: International student edition*. 4th ed. Los Angeles: Sage.

Cross, R., Laseter, T., Parker, A. and Velasquez, G. 2004. Assessing and improving communities of practice with organizational network analysis. *The Network Roundtable at the University of Virginia*. pp.2-22.

Crotty, M. 1998. *The foundations of social research: Meaning and perspective in the research process*. London: Sage.

De, P., Singh, A.E., Wong, T., Yacoub, W. and Jolly, A.M. 2004. Sexual network analysis of a gonorrhoea outbreak. *Sexually Transmitted Infections*. **80**(4), pp. 280-285.

Doty, S. 2007. Simplifying the commissioning process. *Energy Engineering*. **104**(2), pp. 25-45.

Dvir, D. 2005. Transferring projects to their final users: The effect of planning and preparations for commissioning on project success. *International Journal of Project Management*. **23**(4), pp. 257-265.

Eppinger, S.D. and Browning, T.R. 2012. *Design structure matrix methods and applications*. Cambridge: MIT press.

Epstein, J.M. 2006. *Generative social science: Studies in agent-based computational modeling*. Princeton: Princeton University Press.

Forrester, J.W. 1968. Industrial dynamics—after the first decade. *Management Science*. **14**(7), pp. 398-415.

Forrester, J.W. 1970. Urban dynamics. *Industrial Management Review*. **11**(3), pp. 67-77.

Galbraith, J.R. 1973. *Designing complex organizations*. Boston: Addison-Wesley Publishing Co.

Galbraith, J.R. 1974. Organization design: An information processing view. *Interfaces*. **4**(3), pp. 28-36.

Galbraith, J.R. 1977. *Organization design*. Boston: Addison-Wesley Publishing Co.

Gibbs, G.R. 2002. *Qualitative data analysis: Explorations with NVivo*. Buckingham: Open University.

Gikas, P. 2008. Commissioning of the gigantic anaerobic sludge digesters at the wastewater treatment plant of Athens. *Environmental Technology*. **29**(2), pp. 131-139.

Gray, D.E. 2013. *Doing research in the real world*. 3rd ed. London: Sage.

Hanneman, R.A. and Riddle, M. 2005. Introduction to social network methods. [Online]. Riverside: University of California. [Accessed 20 December 2019]. Available from: http://faculty.ucr.edu/~hanneman/

Hlebec, V. and Ferligoj, A. 2002. Reliability of social network measurement instruments. *Field methods*. **14**(3), pp. 288-306.

Horsley, D.M.C. 1998. *Process plant commissioning: a user guide*. 2nd ed. Warwickshire: Institute of Chemical Engineers.

International Atomic Energy Agency 2014. Safety Standards Series No. SSG-28. *Commissioning for nuclear power plants*. Vienna: IAEA. [Accessed 15 July 2019]. Available from: https://www.iaea.org/publications/10425/commissioning-for-nuclear-power-plants

International Atomic Energy Agency. 2004. IAEA-TECDOC-1390. *Construction and commissioning experience of evolutionary water-cooled nuclear power plants*. Vienna: IAEA. [Accessed 16 July December 2019]. Available: https://www.iaea.org/publications/7055/construction-and-commissioning-experience-of-evolutionary-water-cooled-nuclear-power-plants

International Atomic Energy Agency. 2006. Safety Standards Series No. GS-G-3.1. *Application of the management system for facilities and activities*. Vienna: IAEA. [Accessed 15 July 2019]. Available from: https://www.iaea.org/publications/7467/application-of-the-management-system-for-facilities-and-activities

International Atomic Energy Agency. 2009. Safety Standards Series No. GS-G-3.5. *The management system for nuclear installations*. Vienna: IAEA. [Accessed 20 December 2019]. Available from: https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1392_web.pdf

International Atomic Energy Agency. 2012. Nuclear Energy Series No. NP-T-2.7. *Project management in nuclear power plant construction: guidelines and experience*. Vienna: IAEA. [Accessed 17 July 2019]. Available from: https://www.iaea.org/publications/8759/project-management-in-nuclear-power-plant-construction-guidelines-and-experience

International Atomic Energy Agency. 2016. Nuclear Energy Series No. NP-T-3.5. *Ageing management of concrete structures in nuclear power plants*. Vienna: IAEA. [Accessed 20 December 2019]. Available from: https://www.iaea.org/publications/10659/ageing-management-of-concrete-structures-in-nuclear-power-plants

International Atomic Energy Agency. 2016. Safety Standards Series No. SSR-2/2 (Rev. 1). *Safety of nuclear power plants: commissioning and operation*. Vienna: IAEA. [Accessed 20 December 2019]. Available from: https://www.iaea.org/publications/10886/safety-of-nuclear-power-plants-commissioning-and-operation

International Atomic Energy Agency. 2018. Nuclear Energy Series NP-T-2.10. *Commissioning guidelines for nuclear power plants.* Vienna: IAEA. [Accessed 15 August 2019]. Available from: https://www.iaea.org/publications/10975/commissioning-guidelines-for-nuclear-power-plants

International Code Council. 2012. ICC G4-2012. *Guideline for Commissioning*. Washington: ICC. [Accessed 20 December 2019]. Available from: https://www.commissioning.org/commissioningguideline/

International Electrical Testing Association. 2013. ANSI/NETA ATS-2013. *Standard for acceptance testing specifications for electrical power equipment and systems*. Portage: NETA. [Accessed 20 December 2019]. Available from: http://www.iemworldwide.com/pdf/ansi-neta-ats-2009.pdf

International Electrotechnical Commission. 2012. IEC 62382. *Control systems in the process industry: electrical and instrumentation loop check*. Geneva: IEC. [Accessed 20 December 2019.] Available from: https://webstore.iec.ch/publication/6948

IPENZ. 2007. *Practice Note 09: Commissioning Capital Plant*. Wellington: IPENZ. [Accessed 20 December 2019]. Available from: https://d2rjvl4n5h2b61.cloudfront.net/media/documents/Practice_Note_9_Commissioning_Capital_Plant.pdf

Jacomy, M., Venturini, T., Heymann, S. and Bastian, M. 2014. ForceAtlas2, a continuous graph layout algorithm for handy network visualization designed for the Gephi software. *PloS One*. **9**(6), p.p.1-11.

Kirsilä, J., Hellström, M. and Wikström, K. 2007. Integration as a project management concept: a study of the commissioning process in industrial deliveries. *International Journal of Project Management*. **25**(7), pp. 714-721.

Lawry, K. and Pons, D.J. 2013. Integrative approach to the plant commissioning process. *Journal of Industrial Engineering.* **2013**(1), pp. 2-12.

Leveson, N.G. 2011. Applying systems thinking to analyze and learn from events. *Safety Science*. **49**(1), pp. 55-64.

Leveson, N.G. 2016. *Engineering a safer world: Systems thinking applied to safety*. Cambridge: MIT Press.

Marsden, P.V. 2005. Recent developments in network measurement: *Models and methods in social network analysis*. Cambridge: Cambridge University Press.

Midgley G. 2003. *Systems Thinking, Volume II: Systems Theories and Modelling*. London: Sage Publications.

Midgley G. 2003. *Systems Thinking, Volume III: Second Order Cybernetics, Systemic Therapy and Soft Systems Thinking*. London: Sage Publications.

Midgley G. 2003. *Systems Thinking, Volume IV: Critical Systems Thinking and Systemic Perspectives on Ethics, Power and Pluralism*. London: Sage Publications.

Midgley, G. 2003. Science as systemic intervention: Some implications of systems thinking and complexity for the philosophy of science. *Systemic Practice and Action Research*. **16**(2), pp. 77-97.

Mingers, J. and White, L. 2010. A review of the recent contribution of systems thinking to operational research and management science. *European Journal of Operational Research*. **207**(3), pp. 1147-1161.

Monat, J.P. and Gannon, T.F. 2015. What is systems thinking? A review of selected literature plus recommendations. *American Journal of Systems Science*. **4**(1), pp. 11-26.

Monge, P.R., Contractor, N.S., Contractor, P.S., Peter, R. and Noshir, S. 2003. Theories of communication networks. Oxford University Press, USA.

Mote, J.E. 2005. R&D ecology: using 2-mode network analysis to explore complexity in R&D environments. *Journal of Engineering and Technology Management*. **22**(2), pp. 93-111.

Mueller, N., Krauss, M. and Luke, D. 2004. Interorganizational Relationships Within State Tobacco Control Networks: A Social Network Analysis. *Preventing Chronic Disease*. **1**(4). pp. 2-12

National Electrical Contractors Association. 2009. NECA 90-2009. *Recommended practice for commissioning building electrical systems.* Bethesda: NECA.

National Institute of Building Sciences. 2012. Guideline 3-2012. *Building enclosure commissioning process.* Washington: NIBS. [Accessed 15 July 2019.] Available from: https://www.wbdg.org/FFC/NIBS/nibs_gl3.pdf

National Institute of Standards and Technology. 2006. NISTIR 7259. *Capital facilities information handover guide.* Washington: NIST. [Accessed 10 August 2019.] Available from: https://www.nist.gov/publications/capital-facilities-information-handover-guide

Newman, M.E. 2003. The structure and function of complex networks. *SIAM Review*. **45**(2), pp. 167-256.

Nguyen, T. 2014. Software project management towards failure avoidance. In: *The international conference on software engineering and applications*, 29-31 august 2014, Vienna. pp. 560-567.

Office of Nuclear Regulation. 2016. NS-TAST-GD-028. *Control and Instrumentation Aspects of Nuclear Plant Commissioning*. Bootle: ONR.

Ortega, J.L. 2014. Influence of co-authorship networks in the research impact: Ego network analyses from Microsoft Academic Search. *Journal of Infometrics*. **8** (3), pp. 728-737.

Petkova, O. and Petkov, D. 2015. Towards a better understanding of factors affecting software project complexity. In: *The Proceedings of the Conference on Information Systems Applied Research*, 1-4 November 2015, Wilmington. pp. 1508-1525.

Pidgeon, N. 2010. Systems thinking, culture of reliability and safety. *Civil Engineering and Environmental Systems*. **27**(3), pp. 211-217.

Podolny, J.M. and Baron, J.N. 1997. Resources and relationships: Social networks and mobility in the workplace. *American Sociological Review*. **62**(5) pp. 673-693.

Poston, T. and Stewart, I. 1978. Catastrophe theory and its applications; Surveys and reference works in mathematics. *Bulletin of Mathematical Biology*. **41**(1), pp. 615–616.

Pourbohloul, B., Meyers, L.A., Skowronski, D.M., Krajden, M., Patrick, D.M. and Brunham, R.C. 2005. Modeling control strategies of respiratory pathogens. *Emerging Infectious Diseases*. **11**(8), pp. 1249-1255.

Project Management Institute. 2017. A Guide to the Project Management Body of Knowledge. Project Management Institute, Newtown Square, Pa, USA, 6th edition.

Provan, K.G. and Milward, H.B. 2001. Do networks really work? A framework for evaluating public-sector organizational networks. *Public Administration Review*. **61**(4), pp. 414-423.

Richmond, B. 1993. Systems thinking: critical thinking skills for the 1990s and beyond. *System Dynamics Review*. **9**(2), pp. 113-133.

Robson, C. 2002. *Real world research: A resource for social scientists and practitioner-researchers.* Oxford: Blackwell.

Rosenergoatom. 2017. Annual report. [Online]. Russia [Accessed 20 January 2020]. Available from: http://report2017.rosenergoatom.ru/#/en/.

SÄTEILYTURVAKESKUS. 2003. Guide YVL 2.5. *The commissioning of a nuclear power plant*. Helsinki: STUK. [Accessed 20 January 2020] Available from: https://www.iaea.org/publications/10425/commissioning-for-nuclear-power-plants

Saunders, M., Lewis, P. and Thornhill, A. 2009. *Research methods for business students*. 5th ed. London: Pearson Education.

Schlange, L.E. 1995. Linking futures research methodologies: an application of systems thinking and metagame analysis to nuclear energy policy issues. *Futures*. **27**(8), pp. 823-838.

Schreiber, C. and Carley, K. 2003. The impact of databases on knowledge transfer: simulation providing theory. In: *NAACSOS Conference Proceedings*, Pittsburgh. pp.2-12.

Scott, J. 2000. *Social network analysis: A handbook*. 2nd ed. London: Sage publications.

Senge, P.M. 2006. *The fifth discipline: The art and practice of the learning organization*. New York: Crown Business.

Sireli, A.Y. and Mengers, C.A. 2009. Need for change towards systems thinking in the US Nuclear industry. *IEEE Systems Journal*. **3**(2), pp. 239-253.

Starbuck, W.H. 1965. Handbook of organizations. Organizational growth and development. Chicago: Rand McNally.

Strogatz, S.H. 2018. *Nonlinear dynamics and chaos: with applications to physics. Biology, Chemistry and Engineering*. 2nd ed. Florida: CRC press.

Tang, D., Zhang, G. and Dai, S. 2009. Design as integration of axiomatic design and design structure matrix. *Robotics and Computer-Integrated Manufacturing*. **25**(3), pp. 610-619.

Tejeda, J. and Ferreira, S. 2014, January. Applying Systems Thinking to Analyze Wind Energy Sustainability. *Procedia Computer Science*. **28**(1), pp. 213-220.

The United Arab Emirates' Government portal. 2020. *UAE Policy on nuclear energy*. [online]. [Accessed 12 October 2020]. Available from: https://u.ae/en/information-and-services/environment-and-energy/water-and-energy/types-of-energy-sources

Tribe, M.G. and Johnson, R.R. 2008, Effective capital project commissioning. In: *The annual Pulp and Paper Industry Technical Conference.* Seattle, WA, USA. (pp. 106-119).

United States Department of Energy. 2010. DOE-STD-3006-2010. *Planning and Conducting Readiness Reviews*. Washington: USDOE. [Accessed 20 January 2020]. Available from: https://www.standards.doe.gov/standards-documents/3000/3006-astd-2010/@@images/file

United States Department of Veterans Affairs. 2013. *Whole Building Commissioning Process Manual*. Washington: USDVA. [Accessed 20 January 2020]. Available from: http://www.nebb.org/assets/1/7/PST_BSC_2009.pdf

Von Bertalanffy, L. 1969. *General system theory: foundations, development, applications*. New York: George Braziller.

Wajahat, A., Nazir, A., Akhtar, F., Qureshi, S., Razaque, F. and Shakeel, A. 2020. Interactively Visualize and Analyze Social Network Gephi. In: *2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)* (pp. 1-9). IEEE.

Wasserman, S. and Faust, K. 1994. *Social network analysis: Methods and application*. Cambridge: Cambridge university press.

Weber, R.P. 1990. *Basic content analysis*. 2nd ed. London: Sage.

Wertheim, E. G. 2001. *Historical background of organizational behavior*. [online]. [Accessed 15 July 2019]. Available from: http://web.cba.neu.edu/~ewertheim/introd/history.htm

Wheatley, M. 2011. *Leadership and the new science: Discovering order in a chaotic world*. 3rd ed. California: Berrett-Koehler Publishers

Woo, T.H. (2013). *Systems thinking safety analysis: nuclear security assessment of physical protection system in nuclear power plants*. [online]. Science and Technology of Nuclear Installations. [Accessed 10 January 2020]. Available from: https://www.hindawi.com/journals/stni/2013/473687/

Xia, W. and Lee, G. 2005. Complexity of information systems development projects: conceptualization and measurement development. *Journal of Management Information Systems*. **22**(1), pp. 45-83.

Yin, R.K., 2009. *Applied social research methods. Case study research: design and methods*. 4th ed. Los Angeles, CA: Sage.

Yin, R.K., 2012. *Applications of Case Study Research: A (Very) Brief Refresher on the Case Study Method.* [online]. [Accessed 12 October 2020]. Available from: www.uk.sagepub.com/books/.Book235140/toc

Young, W. and Leveson, N. 2013. Systems thinking for safety and security. In: *Proceedings of the 29th Annual Computer Security Applications Conference*. Association for Computing Machinery, New York, United States. December 9-13, 2013, pp. 1-8.