Bournemouth University

SNACH

A NEW FRAMEWORK TO SUPPORT BUSINESS PROCESS IMPROVEMENT

PhD Thesis

Oluwatoyin Fakorede

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ABSTRACT

Business processes are central to any organisation. They coordinate activities, roles, resources, systems and constraints within and across organisational boundaries to achieve predefined business goals. The demand for dynamic business environments, customer satisfaction, global competition, system integration, operational efficiency, innovation and adaptation to market changes necessitates the need for continuous process improvement.

In order to adequately respond to these demands, business processes are designed in two approaches: Business Process Re-engineering (BPR) and Business Process Improvement (BPI). This thesis follows the BPI approach which considers existing infrastructure in an organization to improve operational efficiency and achieve organisational goals. Many methodologies have been developed for conducting BPI projects, but they provide little support for the actual act of systematically improving a business process

We adopted case study as the research strategy to examine a collaborative business process, specifically the UK Higher Education Institutions (HEI) admission process. The design science research methodology was used to answer the research questions and satisfy the research objectives. The Map technique was employed to construct the new BPI artefact based on the Mandatory Elements of Method (MEM) from Method Engineering. The new BPI framework comprises of a number of elements to support analysts and practitioners in process improvement activities.

We present a novel approach to BPI, the SNACH (**S**imulation **N**etwork **A**nalysis **C**ontrol flow complexity and **H**euristics) framework that supports the actual act of process improvement using a combination of process analysis techniques with integrated quantitative measurable concepts to measure and visualize improvement in four dimensions: cost, cycle time, flexibility and complexity. A simulation technique was employed to analyse the process models in terms of time and cost; and Control Flow Complexity was used to calculate the logical complexity of the process model.

A complex network analysis approach was used to provide information about the structural relationship and information exchange between process activities. Using a complex network analysis approach to reduce a process model to a network of nodes and links so that its structural properties are analysed to provide information about the structural complexity and flexibility of the network. To achieve this higher level of abstraction, an algorithm was defined and validated using four disparate process models. The complex network analysis technique is integrated into the SNACH framework and its significance lies in the study of the nature of

the individual nodes and the pattern of connections in the network. These characteristics are assessed using network metrics to quantitatively analyse the structure of the network, thereby providing insight into the interaction and behavioural structure of the business process activities.

To conclude the design science research process phases, the artefact was evaluated in terms of its effectiveness and efficiency to systematically improve a business process by conducting an experiment using another use case.

DEDICATION

I dedicate this thesis to my wife Gbemisola and our children, Bunmi and David. My deepest appreciation goes to them for their unwavering support throughout the number of years the work has taken. Without their love, understanding, patience and encouragement I would not have been able to complete this work. I could not have asked for more, you have added colour and beauty to my life. I love you all.

ACKNOWLEDGEMENTS

"*Being confident of this very thing, that He who has begun a good work in you will carry it on to completion until the day of Christ Jesus*." Philippians 1:6. I am deeply grateful to God for the grace, strength, and wisdom to complete this work. May His name be praised forever more.

My sincere appreciation to my first supervisor Dr. Philip Davies for his methodical approach and guidance, wisdom and encouragement. Thank you for choosing to supervise me when it all looked gloomy, you pointed me in the right direction and helped frame the research. You are truly a destiny helper. Special appreciation to Dr. Paul de Vrieze for his technical guidance and thoroughness. Many thanks to David Newell my third supervisor for his encouragement and guidance.

With gratitude, I thank the faculty of Science and Technology for providing the opportunity and administrative support through all the phases of my research.

Lastly, my deepest appreciation goes to the loveliest family on earth, the members of Breath of Life Church for their love, prayers and encouragement.

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GLOSSARY

AB-BPM	AB-Business Process Methodology
BC	Betweenness Centrality
BPM	Business Process Modelling
BPMN	Business Process Modelling Notation
BPI	Business Process Improvement
BPPAM	Business Process and Practice Alignment Methodology
BPR	Business Process Re-engineering
BPSim	Business Process Simulation
BU	Bournemouth University
CFC	Control Flow Complexity
CSF	Critical Success Factor
CNC	Coefficient of Network Complexity
CP	Coupling metric
DC	Degree Centrality
DFD	Data Flow Diagram
DSR	Design Science Research
EPC	Event-driven Process Chains
EPML	Event-driven Process Chain Mark-up Language
HEI	Higher Education Institution
IC	Interface Complexity
KPI	Key Performance Indicator
LAN	Local Area Network
MEM	Mandatory Elements of a Method
NARIC	National Agency for the Recognition and Comparison of International Qualifications and Skills
NOA	Number of Activities
NOAJS	Number of Activities, Joins and Splits
OMG	Object Management Group

OPM	Object-Process Methodology
PDCA	Plan-Do-Check-Act
RAD	Role Activity Diagram
SEF	Service Engineering Framework
SNACH	Simulation Network Analysis Control flow complexity and Heuristics
SNV	Social Network Visualizer
TAD	Tabular Application Development
TQM	Total Quality Management
UCAS	Universities and Colleges Admission Service
UML AD	Unified Modelling Language Activity Diagram
WAN	Wide Area Network
YAWL	Yet Another Workflow Language

DECLARATION

It is hereby declared that the work contained within this thesis has not been submitted to the requirements for an award at this, or any other, education institution, other than that which this submission is made for. The pronouns ‘we’ and ‘our’ are employed for flow and style purposes.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Business Process Management uses IT to drive and improve business processes, increase productivity and save cost. Research in this field has emanated from work in management science, computer science and information systems, giving rise to many tools, models and methods to support the complete life cycle of business process management (Van der Aalst, Weske and Hofstede, 2003). The term process has several contexts such as manufacturing process, application process, business process, production process etc. However, since the 1990's business process has received a wide acceptance from practitioners and authors attempting to give an improved (Recker and Mendling, 2016).

We define a business process as a collection of logically related activities performed in a coordinated manner involving roles, resources, and constraints to achieve predefined business goals.

From the adopted definition, it can be deduced that there is a logical structure to the activities involved in a business process and information flow between these activities. The sequence of activities is explained in the following illustrative example:

In buying a home in the UK, a buyer speaks to a mortgage advisor who will carry out some checks based on the financial information provided by the buyer

The mortgage advisor then informs them if they can get a mortgage, and how much they can borrow, and in most cases obtains an agreement in principle from a potential mortgage provider. The buyer then finds a property of interest and agrees a price with the seller. A mortgage application is completed with the chosen mortgage provider, who carries out certain checks to validate the information provided by the buyer. The buyer appoints a solicitor to deal with the conveyance aspect of the purchase process while the mortgage provider would have the property valued. If the valuation is satisfactory, an official mortgage offer is made to the buyer. Once all necessary searches and legal obligations have been implemented, contracts are exchanged between the seller and the buyer including the transfer of deposit and funds from the mortgage provider. A moving date is agreed which is also known as the completion date where the buyer collects the keys to the property.

1.2 Business Process Modelling

The above process description can be represented in the form of a model in order to facilitate the understanding of the various activities required to fulfil a specific goal, in this case purchasing a home. These models can be conceptual, mathematical or graphical in form (Liu, Li and ZHAO, 2009). The graphical representation of the activities involved in fulfilling a business process is known as Business Process Modelling (BPM). Business process models are created to capture and visualize the various activities involved in a process, to aid communication amongst stakeholders, for process analysis and to make sound judgement in decision making (Lodhi, Koppen and Saake, 2011). This business process can be either a real-world business process as perceived by a modeller, or a business process conceptualized by a modeller. The getting a mortgage process model is shown in Figure 1 modelled from the buyer's perspective using Business Process Modelling Notation (BPMN).

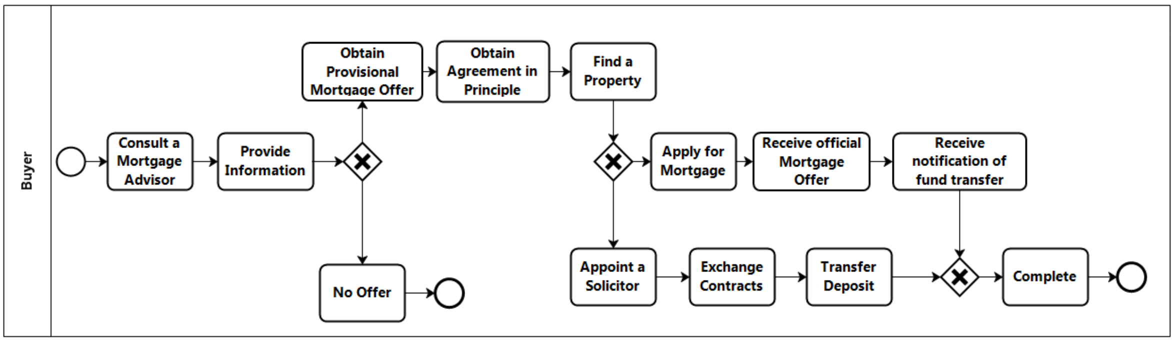


Figure 1*: Getting a Mortgage Process Model*

When business processes span across organisational boundaries involving multiple actors to achieve a common business objective, they are referred to as Collaborative Business Processes. In the mortgage example, we can see multiple organisations such as the Bank, Estate Agent, Solicitors and the Buyer collaborating to fulfil the purchase of a property as illustrated in Figure 2.

The buyer provides information about their finances after consulting a mortgage advisor for guidance about making a successful mortgage application. They provide information about their finances, employment status and relevant information required for a mortgage application.

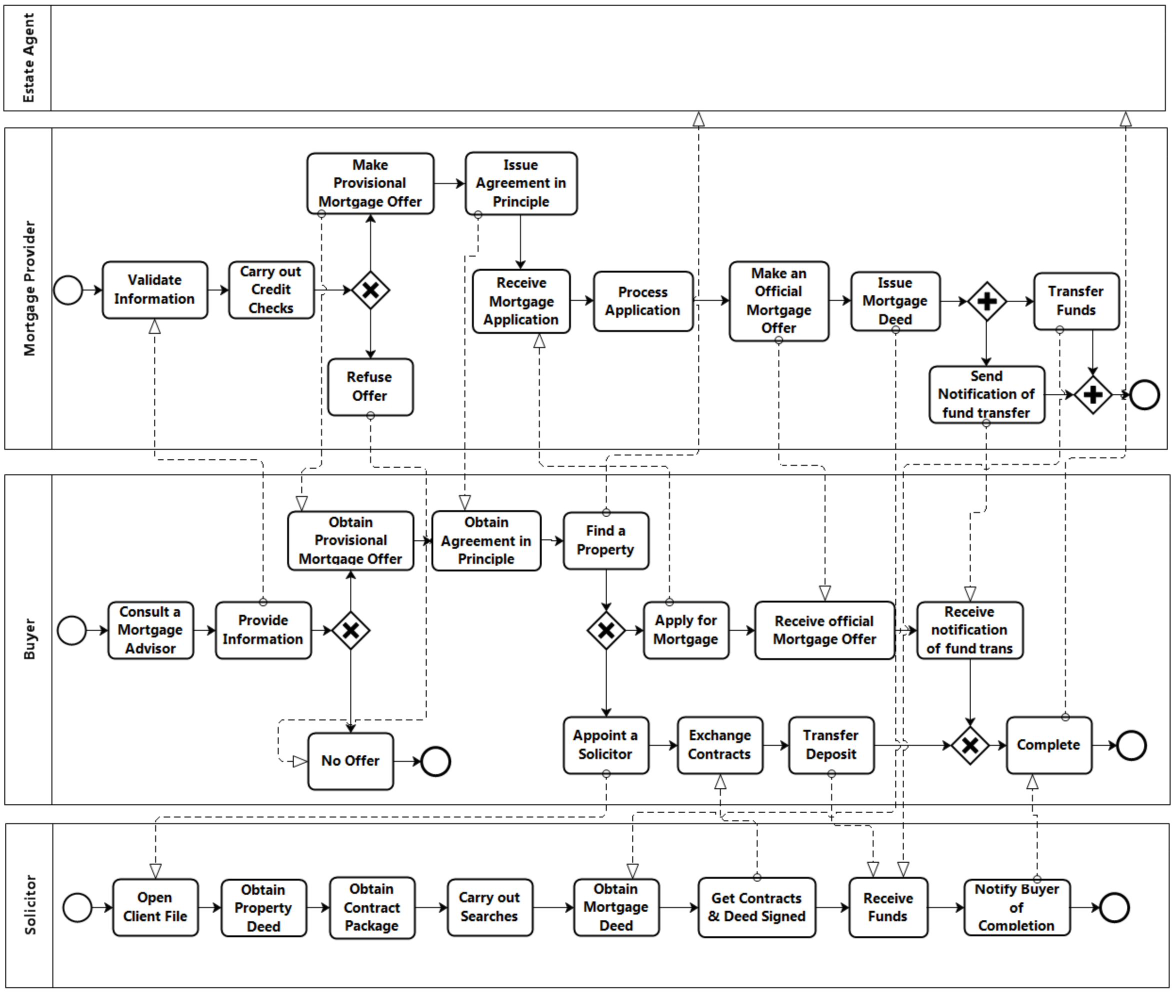


Figure 2: Collaborative Business Process for Getting a Mortgage

The mortgage provider receives such information, validates it, and carries out credit checks. The outcome of the checks will determine if a provisional mortgage offer is made or not. The buyer having obtained an agreement in principle document, commences a property search via Estate Agents. Once a suitable property is found, the buyer makes a formal mortgage application and appoints a solicitor to start the conveyancing process. The Solicitor opens a client file for the buyer, downloads the property deed from the land registry, obtains the contract package from the seller's solicitor, and carries out relevant searches on the property.

Simultaneously, the mortgage provider processes the mortgage application then, all things being equal, an official mortgage offer is sent to the buyer. The solicitor requests and obtains the mortgage deed from the mortgage provider, gets the contracts, mortgage deed and property deed signed by all parties and finally requests funds and then the whole process is completed. In comparison to traditional business process management (BPM), a collaborative BPM has additional stakeholders since more than one organisation is involved. This leads to more complex process models and more sophisticated control flows between the participating organisations (Hermann *et al.*, 2017). It is such complex business process models this research seeks to investigate.

1.3 Business Process Analysis

The need for organisations to maintain good quality service levels, balanced resource utilization, quick response times, adaptation to market changes and customer demands, healthy staff and customer satisfaction, time and cost savings and to continually be at a competitive advantage necessitates the need for continuous process analysis. As illustrated in Figure 2, business processes within a collaborative environment means that the processes must conform to inter and intra-organisational regulatory requirements or constraints and must meet both business and operational requirements of all the partners, potentially increasing the complexity of the business process and making it less flexible.

A business process is analysed both at design time and run time to find design flaws and diagnosis support respectively (van der Aalst, 2013). Process analysis facilitates the identification of issues within the current (as-is) business process and ensures that they do not reoccur in the proposed (to-be) process. It further allows analysts to investigate business process properties, identify bottleneck areas, eliminate unnecessary or non-value adding activities and compare any potential process alternatives (Boekhoudt, Jonkers and Rougoor, 2000; Irani, Hlupic and Giaglis, 2002). Therefore, process analysis is a necessary exercise to examine an as-is business process in order to create a to-be business process (Mendling, 2007). Chapter 2 presents an analysis of process analysis techniques and the suitable choice of technique for this research.

1.4 Motivation and Research Question

This research is motivated by the need to support the improvement of business processes using a structured approach to enhance the identification of weaknesses in collaborative business processes and to systematically create an improved process with measurable concepts to track improvement activities. As the related work in Chapters 2 and 5 indicates, several process improvement approaches provide improvement guidelines but a degree of creativity is required to produce the improved business process model [10][11](Adesola and Baines, 2005). The following sub-sections show the justification for the research questions.

1.4.1 A Systematic Approach to Business Improvement

Business process redesign can be realized via two approaches: Business Process Re-engineering (BPR) and Business Process Improvement (BPI).

The BPR approach was introduced by Michael Hammer (Caeldries, 2011), it entails the creation of the process redesign from scratch without referencing any existing process design and disregarding the traditions of the way business has always been done, rethinking and radically redesigning the business process to achieve dramatic improvements. For example, a quick service restaurant has an ordering process like this: the customer orders food, the order goes to the kitchen, the kitchen prepares the food and the food is delivered to the customer. Applying BPR, the food may be prepared in a separate location and delivered to the restaurant on a daily basis so that when the customer orders, staff collate the orders and deliver them. This is a complete change in the business process.

In contrast, BPI, introduced by James Harrington (Harrington, 1991a), is applicable to situations where incremental changes are made to a process design to meet some new requirements, or to increase the efficiency and effectiveness of the existing business process. For instance, in the above quick service restaurant example, if BPI is applied, technology could be introduced into the ordering process such as an automated food ordering system where food orders are sent directly to the kitchen from a POS (point of sale) terminal instead of a manual or traditional food ordering approach.

While BPR focusses on revolutionary or radical changes to a business process, BPI focusses on continuous improvement and evolutionary changes (Griesberger *et al.*, 2011). In this thesis, attention is given to the BPI approach because we want to focus on continuous improvement and evolutionary changes, and we discuss various BPI methodologies in chapter 2. Many of these methodologies or approaches provide extensive support for process improvement such as planning, benchmarking, mapping processes, and identifying problems, brainstorming etc. However, there is little support for the actual act of systematically moving from the as-is process model to the to-be process model (Griesberger *et al.*, 2011; Zellner, 2011; Falk *et al.*, 2013; Lang *et al.*, 2015). This leads to our first research question:

- How can a systematic approach that supports the act of process improvement be defined or developed?

1.4.2 Process Improvement Measures

Performance measurements enable measurement activities to be used alongside process improvement techniques in order to quantitatively compare measurement information between the as-is and to-be processes. This is quite important in that it is one of the principal sources of information for decision making enabling practitioners and analysts to plan, track improvement efforts and satisfy certain improvement requirements (González *et al.*, 2010).

Improving efficiency in any organization generally necessitate that the processes should become quicker, cheaper to run and performs better.

A well-engineered business process is characterized by the use of measurements to monitor and guide process performance in a desired direction, therefore for an organisation to attain maturity in their processes, measurements should be integrated as a fundamental part of their business improvement objectives (González *et al.*, 2010). Measures can be applied during the design stage of the process development to capture the static properties of the business process such as complexity, density, cohesion etc. On the other hand, measures can be applied at execution stage to quantify the dynamic properties of the business process such as cycle time, cost etc. Measures obtained at design and execution time can be used to compare the result of the as-is and to-be processes in order to ascertain how much improvement has been achieved within a specific time frame. These measures are presented in Figure 3 and Figure 4. In this thesis we consider both design time and execution time measures.

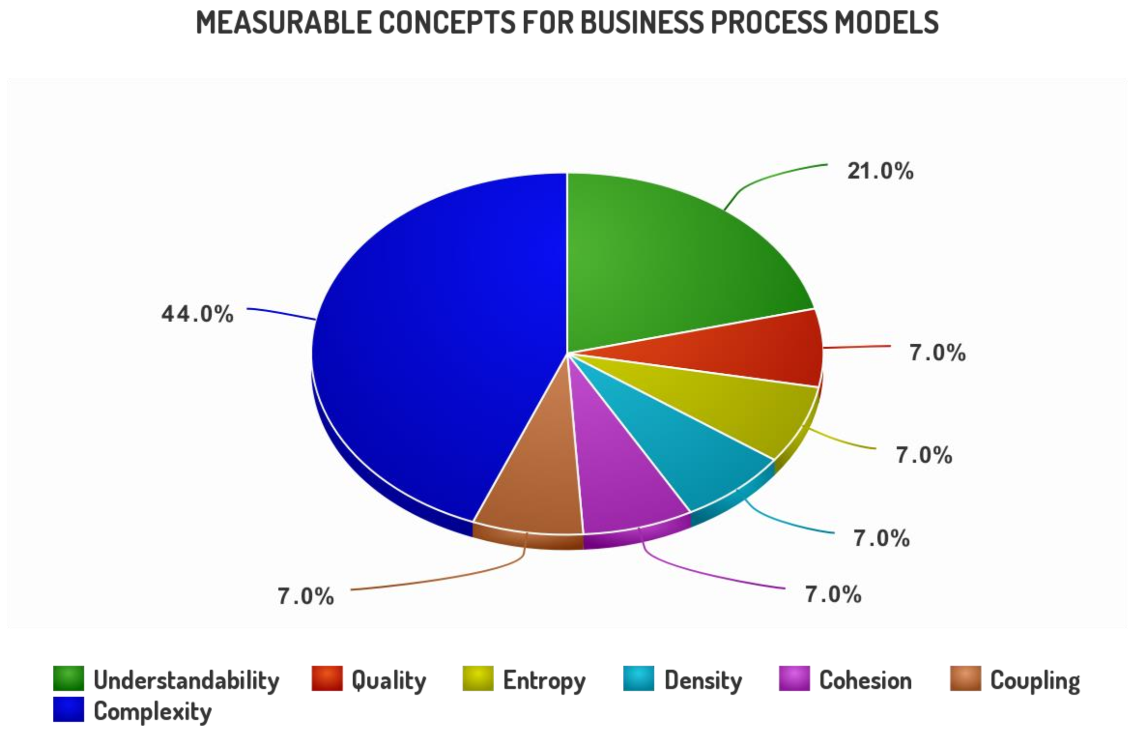


Figure 3: Design Time Measurable Concepts (González *et al.*, 2010)

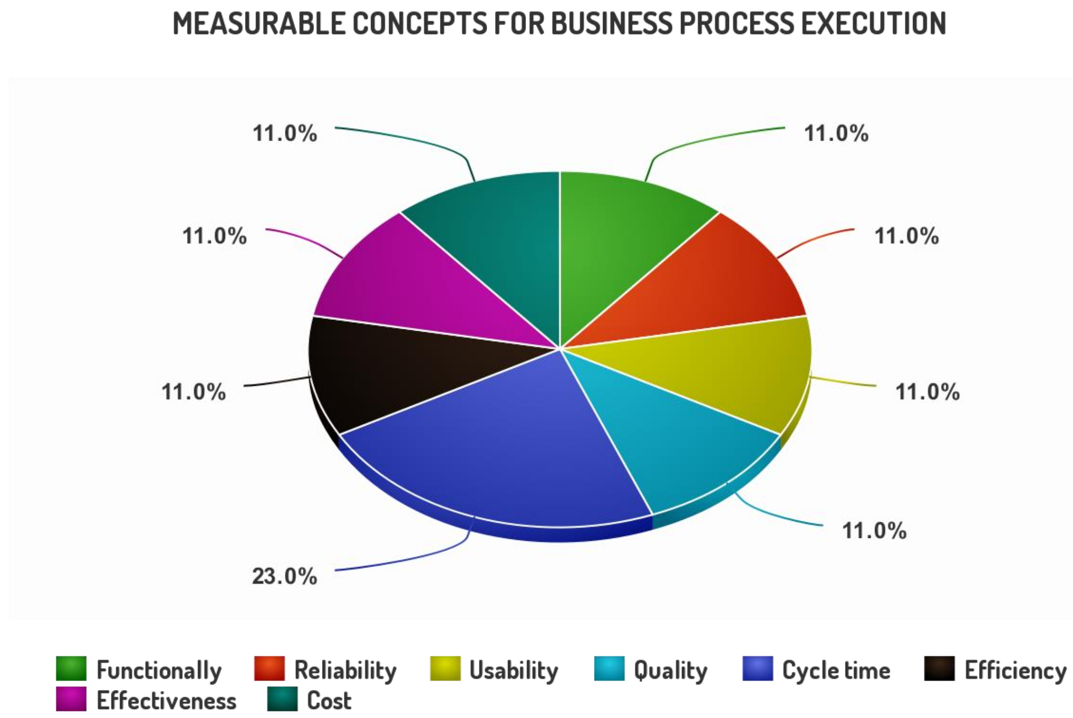


Figure 4: Design Time Measureable Concept (González *et al.*, 2010)

Most of the above mentioned measures are adapted from software engineering due to the parallel relationship that exists between them but many of these measures lack empirical validation, that is the practical utilization of these metrics have not been validated through the use of experiments, surveys or case studies (González *et al.*, 2010)(Sánchez-González *et al.*, 2011). Furthermore, there is no standard set of measurements that can be used as principal metrics to measure improvement. Although, some authors have proposed quality (Khlif *et al.*, 2009), complexity (Laue, no date), the Quadrangle comprising of Time, Cost, Quality and Flexibility (Dumas *et al.*, 2013). It is therefore, evident that there is no formal agreement among researchers and practitioners on appropriate measurable concepts to measure process improvement. This leads to our second research question:

- What metrics or measurable concepts are appropriate for quantitatively measuring process improvement both at design and execution stages?

Measures are directly connected to process analysis in that they provide information about the performance of the process model. The type and nature of the analysis technique used determines the measures that will apply depending on the purpose of the analysis, for instance the Flow Analysis technique can be used to calculate the average cycle time of a whole process if the whole cycle time for each activities is known, Basic Queuing Theory on the other hand helps to estimate waiting times and queue length, and the simulation technique provides performance indicators such as cycle time, average waiting times, cost and average resource utilization. Other process analysis techniques such as Root Cause Analysis, and Value-added Analysis do not provide any quantitative information. While execution time measures such as time and cost can be easily derived, how can efficiency, effectiveness, reliability and usability be derived quantitatively? We are interested in an analysis technique that facilitates quantitative measures; this leads to our third research question:

- Which process analysis technique is most suitable for the quantitative analysis of process models in a collaborative environment?

Additionally, design time metrics tend to provide measures about the structural aspects of models (Sánchez-González *et al.*, 2011), such as internal quality. Quality as a measurable concept is multidimensional and should be quantified using multiple measures. One dimension is internal quality such as density, coupling, complexity which influences external quality measures such as understandability, usability, and modifiability. By external quality we mean quality measures that are perceivable by end users or stakeholders which can be rather subjective and may not be detailed enough to provide a concrete basis for decision making (Dumas *et al.*, 2013).

In this thesis, preference is given to internal quality measures because it can proffer insight into the macroscopic properties of the business process model such as the strength or quality of the relationship between the activities in the model. There is no exclusive and exhaustive method for executing process analysis and it can be difficult to formalize in complete detail due to the fact that it is a very domain specific and knowledge intensive process (Levina and Hillmann, 2012). However, existing traditional business process analysis techniques cannot assess the structural properties of a business process model. We therefore consider the complex network analysis approach to analyse the structural relationship and behavioural structure of the process activities.

1.4.3 Towards a New Approach to Business Process Improvement

Limitations of the present methods of business process improvement indicate there is scope for looking at the problem in a different way. Business processes are commonly modelled as diagrams which at their fundamental level are complex networks. This suggests the question as to whether complex network analysis (CNA) has anything to contribute to business process improvement.

Complex network analysis is not new to Information Systems Research, it has been applied as both a tool and method in identifying service domains and understanding of underlying structures of enterprise architecture, and to show the statistical connection between model errors and metrics (Aier, 2006; Aier and Schönherr, 2007; Mendling, Neumann and Van Der Aalst, 2007; Trier, 2008).

A network is a group of connected points. The points are referred to as nodes and the lines are called links. Complex networks research is multidisciplinary in nature and has been used as an analysis technique to obtain informative quantitative properties of a network. Any system that is made up of individual components that are linked together can become a subject of network analysis. For example, the internet, railway network, connection between people on social media platforms, connection of computers in a LAN or WAN, network of natural gas pipelines in the UK etc. The pattern of connections in a particular system can be illustrated as a network, the components are depicted as nodes and the connections as links.

Evidently, the performance of the network is affected by its structure, for example in road traffic, alternative routes will result in less traffic jams, although the alternative route is not necessary the fastest. Road construction engineers usually conduct traffic impact simulations for road construction projects, policy setting and traffic organisation (Yang, Hao and Luo, 2012). Therefore, the metric 'shortest path' in complex network analysis becomes applicable in finding the shortest alternative route during a construction project.

The properties of a network structure can be modelled and measured to give information about practical issues of concern which could enhance the improvement of the network. In order to apply the complex network analysis approach, business process models are reduced to networks and quantitative measures are obtained about their structure. This leads to the 4th and last research question:

- Can a reduced process model contribute towards improving and measuring business processes?

1.4.4 Research Question Summary

It seems counter intuitive that a reduced process model can have anything to contribute to improvement, since some or even much of the information about the process is lost in the reduction or projection onto the complex network sub-space. This is not therefore a question which has received much attention.

The research questions are re-ordered to emphasize the main contributions:

1. How can a systematic approach that supports the act of process improvement be defined or developed?

2. Can a reduced process model contribute towards improving and measuring business processes?
3. What metrics or measurable concepts are appropriate for quantitatively measuring process improvement both at design and execution stages?
4. Which process analysis technique is most suitable for the quantitative analysis of process models in a collaborative environment?

1.5 Research Objectives

Based on the research questions, the aim of the study is stated as follows;

To develop a framework that supports the act of process improvement with integrated measurable concepts to track process improvement activities in a collaborative environment.

To achieve the desired aim, more specific objectives are stated below;

1) **To determine an appropriate choice of modelling approach and language with explicit constructs that supports the analysis technique.**
   This objective is based on research question 4. The choice of business process modelling language must have adequate constructs to capture: a) the operational activities of business processes; b) the collaborating parties that make up the organisational units; c) the process owners; d) the IT systems that drive the business; e) the logical flow of activities and constraints, and f) compatible with the choice of business process analysis technique.
2) **To determine an appropriate process analysis technique that supports collaborative business process improvement.**
   This objective is also based on research question 4. There are several classifications of business process analysis techniques depending on the purpose of the analysis. In our case, the purpose of the process analysis is to give quantitative insight into the performance of a business process, facilitating the identification of weaknesses in order to create a to-be business process.
3) **To determine an appropriate choice of process improvement measurable concepts to quantitatively measure process improvement both at design and execution stages.**
   This objective is based on research question 3. It involves the selection of measurable concepts that will be used to track and visualize process improvements.
4) **To demonstrate the application of complex network analysis as a technique:**
   a. **That supports the Identification of potential bottle-neck activities in business process models.**

b. **That supports the analysis, improvement and measurement of business processes.**

This objective is based on research question 2. We propose a new idea to explore the use of complex network analysis approach to provide information about the structural relationship and information exchange between process activities with the aim to support the analysis, improvement and measurement of business processes.

5) **Develop an algorithm for reducing a process model to its network structure.**
This objective is also derived from question 2. It will perform an analysis of different types of networks in order to determine the appropriate type of network to be used in our case. In addition, it will determine the amount of detail that will be removed when a business process model is projected into a network.

6) **Evaluate the process improvement framework by conducting an experiment.**
This objective is based on the research aim and research question 1. We propose the Simulation Network Analysis Control flow complexity and Heuristics (SNACH) framework, a novel approach to support business process improvement. The framework will be evaluated by conducting an experiment using a case study.

1.6 Research Contributions to Knowledge

Investigating various business process analysis techniques will lead to identifying the appropriate technique for analysing HEI processes in a collaborative environment. Although, simulation is useful in giving quantitative execution time measures, including cost, cycle time, revealed potential bottleneck areas, visualization of over or under-utilization of resources, these outcomes are dependent on the correctness of the input parameters. This necessitates the use of historic clearing data to generate more accurate results with regards to the clearing process models. The simulation technique can provide quantitative execution time measures but has limited support for obtaining quantitative information about the structural properties of a business process model, this research will demonstrate that the application of complex network analysis can further confirm bottleneck areas and identify potential unnecessary activities in a process model based on its structural properties. This research will make the following contributions:

1) Systematic selection of model-based quantitative measurable concepts to measure process improvement both at design and execution stages.

2) Development of an algorithm to downscale a process model to a network of nodes and links. This contribution is based on the unique approach of applying complex network analysis to provide information about the structural relationship and information exchange between

process activities. This information is obtained by using complex network metrics to quantitatively analyse the structure of the network, thereby providing insight into the interaction and behavioural structure of the business process activities.

3) Determine through investigation the best choice of nodal relationship (directed, undirected and weighted) when projecting a business process model into a complex network.

4) Creation of process improvement guidelines based on the structural properties of the process model.

5) Creation of improvement heuristics selection criteria from a catalogue

6) Development of the **S**imulation **N**etwork **A**nalysis, **C**ontrol Flow Complexity and **H**euristics (SNACH) framework to support the actual act of process improvement. It consists of quantitative analysis techniques, improvement heuristics and metrics to compare the results of both the as-is and to-be process models.

1.7 Thesis Structure

The argument which will be presented in this thesis is that a new approach to business process improvement using SNACH framework has a contribution to make to the field.

In Chapter 2, Business Process Concepts and Related Work, we review the literature on business process modelling language and its components. We compare various modelling languages and the motivation for the choice of language. Furthermore, it presents an analysis of various business process analysis techniques, the requirements that must be satisfied by the appropriate analysis technique and the motivation for the choice of tool. From this review, we specify the requirements that must be satisfied by the appropriate business process modelling language which will be used to capture the operational activities of our business case study.

In Chapter 3, Research Methodology, presents an overview of the methodological aspects of research. We present the choice of methodology for carrying out research in information systems and conclude that the Design Science Research (DSR) approach is the most appropriate. We apply this methodology to create our BPI framework.

In Chapter 4, Complex Network Analysis, we develop a technique of projecting a Business process model onto the sub-space of a complex network and identify the useful Measurable Concepts that can be used in business process improvement. We show three possible projections onto complex networks projective spaces: simple (undirected), directed and weighted. We investigate how each aspect should be measured. We were unable to establish the relationship between weighted projection and business process modelling technique used in our case, therefore weighted projection is not taken into account.

We develop algorithms for the two projections undirected and directed and apply the algorithm to 4 different process models; each process has both as-is and to-be models making 8 models in total. The projection algorithm was applied to all the 8 models using a suitable network analysis tool. In order to determine whether to use directed or undirected network, 16 projections were created – 8 for directed network and another 8 for undirected network. The results were compared in order to choose a more accurate projection.

In addition, we review these 16 projections in the light of measures used in Complex Network Analysis and draw conclusions about the use of such measures within business process modelling.

In Chapter 5, The Proposed SNACH Approach, we discuss existing process improvement methodologies both from industrial and academic settings. An analysis of these methodologies is carried out based on the Mandatory Elements of a Method (MEM), MEM components are capable of supporting a more structured approach to process improvement. We employ the use of the Map technique for method construction to create the various fragments that makeup our BPI method. Finally, the SNACH framework is introduced as an approach that supports the act of process improvement.

In Chapter 6, An Applied Case Study: HEI Admissions, presents the case study conducted in this research. It begins by presenting good practice in UK Higher Education Admissions, and then describes the UCAS admission application process.

The case study comprises of two scenarios: the clearing process and the general admission process. Both processes are modelled from three perspectives – UCAS, University and applicant to demonstrate the properties of a collaborative business process. The clearing process models (both as-is and to-be) were used in chapter 4 to investigate the appropriate network projection and in chapter 7 to evaluate the performance metrics. The general admission process was applied in chapter 7 to evaluate the SNACH framework via an experiment.

In Chapter 7, Evaluation of Approach, the second to the last stage in the DSR methodology is evaluation. The evaluation was carried out, firstly to compare the results of the as-is and to-be clearing process models using the performance metrics/measures defined in chapter 4 and secondly to evaluate the SNACH framework by applying it to the general admission process via an experiment.

Chapter 8, Conclusion and Further Work concludes the thesis. This chapter summarise the work that has been carried out. It introduces the findings of the research and shows how it relates to fulfilling the research objectives and how the work contributes to knowledge. It closes by discussing areas for further work.

Figure 5 presents a visual representation of the thesis structure and where each research objectives were accomplished.

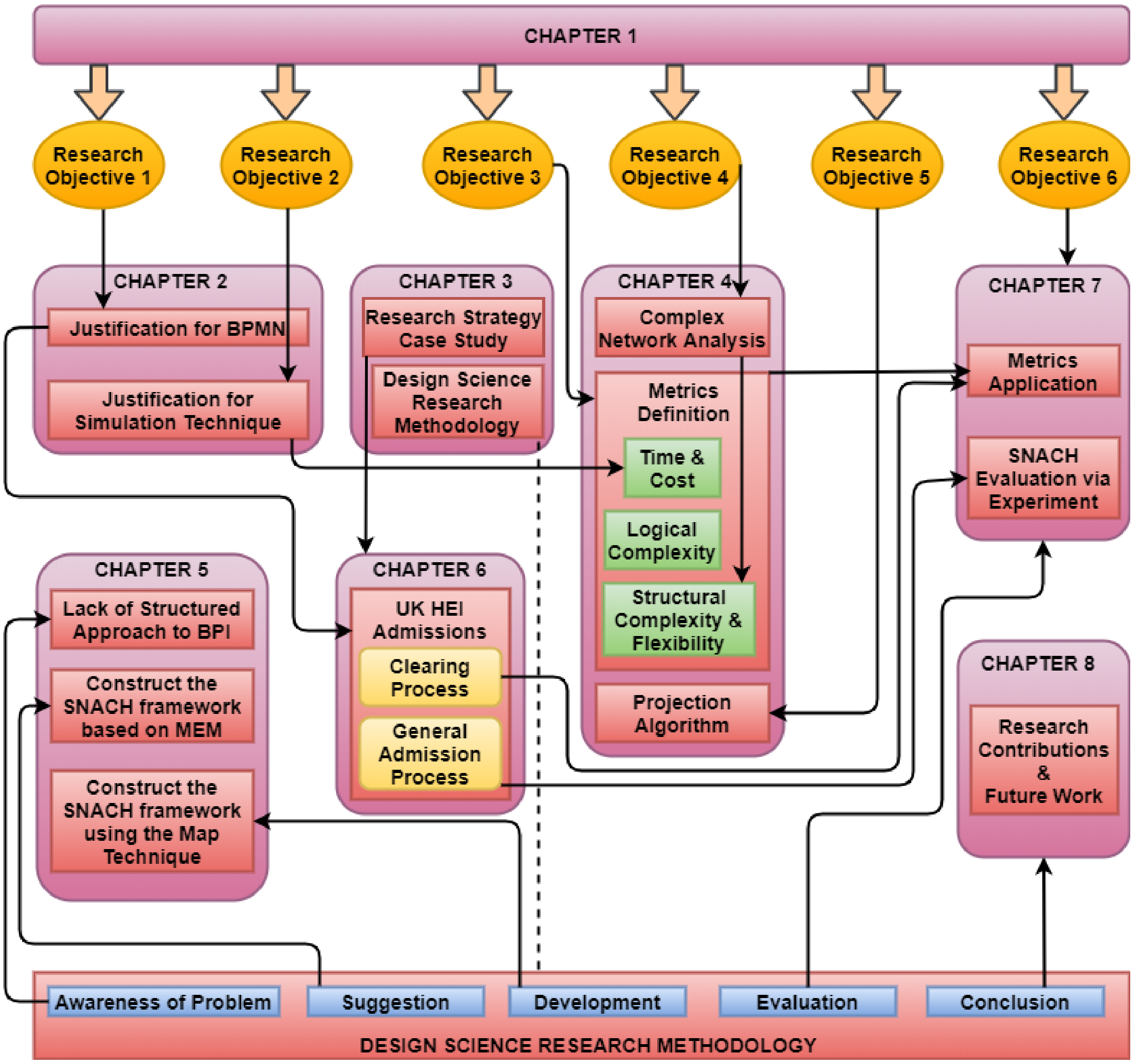


Figure 5: Research workflow

CHAPTER 2

BUSINESS PROCESS CONCEPTS & RELATED WORK

2.1 Introduction

This chapter explores and introduces the basic concepts of business processes, the classification of business processes, business process modelling approaches and the motivation for the modelling language in order to satisfy the first research objective. As progress is made into the chapter, a literature review on business process analysis is presented in order to identify the analysis technique that gives quantitative insight into the performance of a business process. In addition, literature is explored to find the appropriate process improvement measurable concepts to partially satisfy research objective 3.

2.1.1 Categories of Business Process Modelling Approaches

A business process may become a candidate for analysis and improvement not necessarily because of the presence of redundant or bottleneck activities but due to the use of an inappropriate modelling approach. There are several business modelling techniques with distinctive approaches that convey various aspects of a business process. Many authors have written about business process techniques focussing on different areas of emphasis. The need for different notational approaches for different modelling purposes and audiences cannot be over-emphasized (Phalp, 1998).

Aguilar-Saven (2004) classified business process modelling techniques/approaches on two dimensions with each dimension having different perspectives. The first dimension is classified based on whether the business process models are 1) Descriptive for learning 2) Enable decision support for process development/design 3) Enable decision support for process execution and 4) Allow IT enactment.

The second dimension is based on whether the model can interact with the user (active or dynamic model) or lacks interactivity with the user (passive model).

Vergidis et al. (2008a) proposed three classifications of business process modelling approaches:

1) Diagrammatic models: This entails the use of diagrams to graphically represent a business process model e.g. Flowcharts, Role Activity Diagrams (RADs). These techniques can be used to give fast and informal representation of a business process

but they lack the semantic capacity to depict more complex constructs.

2) Business Process Languages: These bridge the gap between the diagrammatical models and formal models. As diagrammatical models lack semantics to capture complex constructs and formal models are too complex to understand, business process languages based on XML tend to reduce the complexity of formal models without losing their consistency and capacity for analysis. Examples are UML 2.0 and BPML.
3) Formal or Mathematical Models: These models have been thoroughly and accurately defined and mathematically analysed for reasoning and to glean quantitative information. The disadvantage of mathematical models is that they can be complex to create, maintain the business process and retain its consistency. Petri-nets are both mathematical and diagrammatical models. Although, Vergidis (2008) classified YAWL as both a diagrammatical and business process language, we argue that YAWL falls in all the three classifications including the formal model classification (Wohed *et al.*, 2004). Therefore, we present a modified classification of business process modelling approaches in Figure 6.

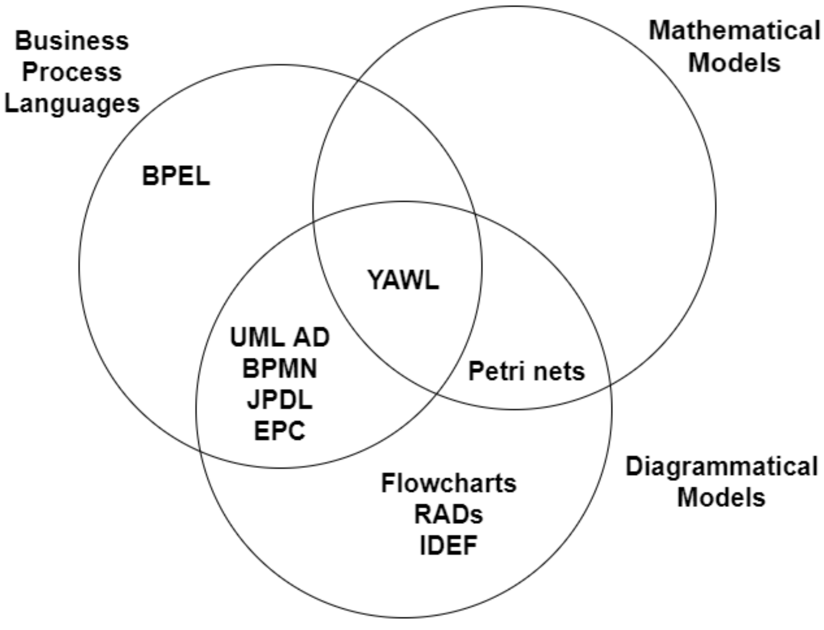


Figure 6: Classification of business process modelling approaches (Vergidis, Tiwari and Maieed, 2008a)

There are other various categorizations of business process models by researchers and practitioners based on different views. For example;

Milli et al. (Mili *et al.*, 2004) gave three different reasons for business process modelling which are: a) For describing a process, b) for analysing a process and, c) for enacting a process.

Markovic (Markovic, 2010) identified four views of a business process which are: the organisational view (who uses or manages the process), the functional view (what the process does), the dynamic view (the behaviour or performance of the process), and the informational view (how data is produced or managed by the process).

Lin and Krogstie (Lin and Krogstie, 2010) argue that business processes can be viewed from six perspectives when using process models which are: Structural, Operational, Control, Resources, Organisational and Data Transaction.

More refined perspectives were defined by Markovic (Markovic, 2010) which allows the various perspectives of the process design to be easily managed and to navigate through by the process modeller. These perspectives are described below:

1) Functional/Operational Perspective: This captures the activities or functions that organisations carry out to meet their business goals.
2) Motivational Perspective: This view is based on the motivation that drives the elements of business plans according to the OMG's Business Motivation Model.
3) Organizational Perspective: This captures intra and inter-organisational process flows and the participants or stakeholders involved.
4) Resource Perspective: This describes the applications, tools and resources such as IT infrastructure that are specified in order to execute certain process activities
5) Compliance Perspective: These are internal or external compliance requirements that must be satisfied before a process is executed, e.g. company policies, guidelines, laws and regulations.
6) Behavioural/Control Perspective: This is related to operational perspective as it represents the logical ordering, constraints of processes and their causal interrelationships.

The motivational perspective involves the design of a graphical model of the business motivation i.e. business goals and the means by which the company intends to achieve these goals. The compliance perspective models laws, regulations, company policies and guidelines. The above-mentioned perspectives are not considered relevant to our research objectives, therefore are outside the scope of our work. Our work relates to functional or operational activities that drive the business, the collaborating parties and stakeholders comprising of organisational units, roles and process owners, the IT systems that are used to enhance the performance of operational activities and finally the logical flow of activities and constraints. These elements are represented in the functional/operational, organizational, resource and behavioural/control perspectives, respectively.

Based on the above categories, we define the requirements for the suitability or appropriateness of the business process modelling approach below:

a) Relevant Perspectives: The appropriate modelling technique should be able to capture all the operational activities both within and across organisations, the logical structure, the behavioural properties and the resources required to effectuate the business process.
b) Expressive Notations: Not all modelling techniques or languages are expressive enough to capture all situations. The business process language should have notations or interface with sufficient expressiveness to represent all situations or control flow patterns.
c) Simplicity and Understandability: The modelling technique used has a direct impact on the complexity of the model. The size of a model is often proportional to its complexity. As modelling techniques differ in expressiveness, a modelling technique that can model a set of activities using fewer notations would be easier to understand and more suitable, and consequently facilitates easier communication between stakeholders.
d) Simulation Ready: Business process models have both static and dynamic properties. Static properties are features that can be measured during design time while dynamic properties are features that can be measured during execution time. Simulation offers the opportunity to capture these measures without executing the process in real life. There are several business process modelling tools that offer simulation capabilities but may be language specific. Therefore, the choice of modelling technique would be dependent upon the number of available tools that provides simulation support for that particular technique.
e) Compliance with Standards: A modelling technique that is compliant with standard specifications such as the Object Management Group (OMG).

The next section will explore appropriate modelling language options to fulfil these requirements.

2.1.2 Business Process Modelling Languages

Business process modelling languages can be grouped into three categories (Lin and Krogstie, 2010):

i) Informal languages: Natural languages used to describe business goals and business strategies.

ii) Semi-formal languages: Graphical modelling languages with a set of visual notations and semantic definitions encapsulated in the underlying meta-models, e.g. BPMN, EPC.

iii) Formal languages: These are modelling languages whose semantics (usually rigid and specific) are defined by formal logics or mathematics useful for the computation of model semantics. Petri-nets for example have only 4 elements: tokens, arcs, circles and squares but the resulting models may be more complex and use may be harder.

We focus on the graphical notations (semi-formal languages) due to their relevance to our research objectives and requirements defined earlier. The choice of graphical notation is determined by the business process lifecycle phase we wish to analyse and the objective of the analysis. We examine four categories of graphical notations (Tay, 2013):

1) Data-oriented Notations: The objective of this notation is to capture the flow of data when in motion and when it is at rest e.g. Data Flow Diagrams. As the study is not about how data is stored or transformed in a process, it is not considered relevant.

2) Role-oriented Notations: The objective is to capture the specific roles in an organisation and their interaction with others e.g. Role Activity Diagrams (RADs). RADs focus on individual actors (rather than their overall coordination) and their interactions. As this modelling language is dependent on human factors (Ibrahim, 2015), it is not considered relevant.

3) Process-oriented Notations: The objective is to capture the flow of operational activities in business processes or across processes. Examples of this include Business Process Modelling Notation (BPMN), Unified Modelling Language Activity Diagram (UML AD) and Event Driven Chains (EPC). The modelling languages that belong to this category are further investigated.

4) Notations for Capturing the Control Flow: This captures the flow of tokens through a set of interconnected activities where gateways are used to determine their execution ordering. Examples are BPMN and EPC. A comparison is carried out between BPMN and EPC.

The graphical notations have been narrowed down to two categories: process-oriented and control flow. We further examine the suitability of modelling languages that fall in these two categories:

1) Petri-nets.

Petri-nets were designed by Carl Adam Petri in 1962 as a mathematical tool for modelling distributed systems. It is broadly used in software design, workflow management, data analysis, concurrent programming, reliability engineering and programme diagnosis (Lin, 2008).

Petri-nets consist of place nodes, transition nodes and arcs linking places and transitions (t) together graphically. Places in Petri-nets can contain tokens (a simulation of the dynamic and concurrent activities of systems

Petri-nets are good for modelling the behavioural/control perspectives of a business process but have limited scope for modelling organizational perspective due to its limited number of modelling constructs (Lin, 2008), although it can be combined with other approaches (Xu and Zhang, 2007). It is therefore not fit for purpose.

2) Event-driven Process Chain (EPC)

EPC was introduced in the early 1990s as part of the ARIS framework (Markovic, 2010). EPC is a semi-formal graphical modelling language for capturing business process workflow. EPC has the following notations: events (hexagonal in shape), functions (rounded rectangle) and connectors e.g. AND, OR and XOR.

Business users find EPC simple and easy to understand (Tay, 2013). It is useful for modelling the organisational and informational process perspectives (Markovic, 2010). The downside of EPC is that the syntax and the semantics are not well defined (W. M. P. van der Aals, 1999). However, an XML based EPC (EPML – Event driven Process Chain Mark-up Language) has been proposed by Jan Mendling and Markus Nuttgens (Mendling and Nüttgens, 2006) with the aim of supporting data and model interaction between diverse Business Process Modelling tools. EPC is considered not suitable.

3) Unified Modelling Language Activity Diagram (UML AD)

UML AD is a semi-formal language for modelling the operational, organisational and control perspectives of a business process (Lin, 2008). It consists of the following elements; initial node and activity/final node, activity (rounded rectangle), flow/edge (arrow), fork and join, decision and merge and partition/swimlane. UML AD and BPMN have some common features therefore the two languages will be compared in section 2.1.3

4) Business Process Modelling Notation (BPMN)

BPMN is a semi-formal modelling language, business and technical users find it easy to understand (Lin and Krogstie, 2010). BPMN is a derivative of UML AD with capability for capturing B2B business concepts, collaboration process, choreographies, exception handling and transaction compensation (Mili *et al.*, 2004). Figure 7 presents the core elements of BPMN which are: event, activity, process/sub-process, sequence flow, message flow, pool, AND gateway, OR gateway

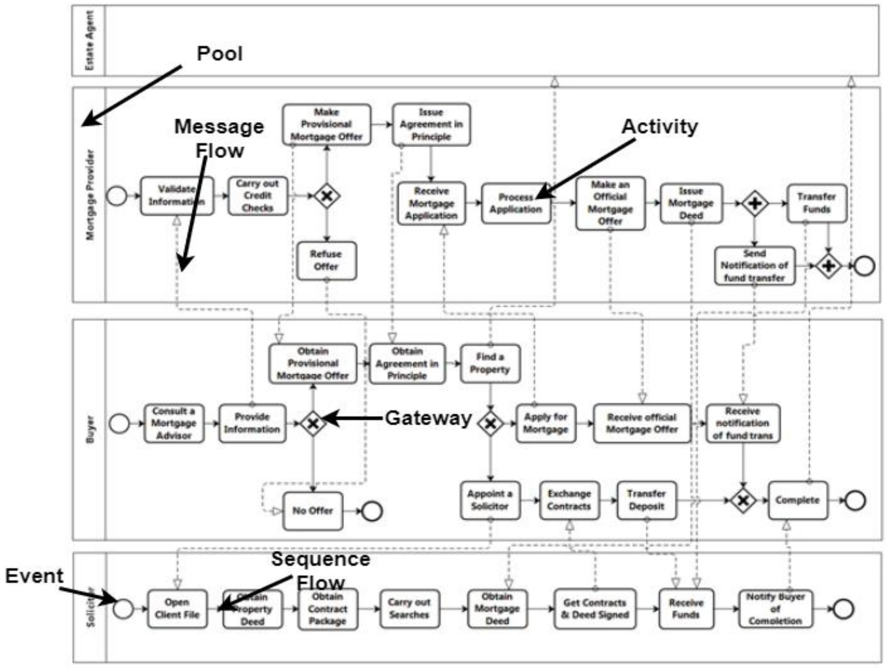


Figure 7: BPMN Example

BPMN is useful for capturing the operational, organisational (including collaborative processes), resource and control perspectives of a business process. BPMN can be further enriched semantically with information such business goals, business policies and rules, key performance indicators etc. This would allow automatic or semi-automatic model-driven verification as opposed to writing customized scripts for model verification (Markovic, 2010).

2.1.3 Comparison between BPMN and UML AD:

UML AD is a semi-formal language for modelling the operational, organisational and control perspectives of a business process. BPMN and UML AD have been extensively evaluated (Wohed *et al.*, 2004)(White and Corp, 2004)(Aalst *et al.*, 2003)(Wohed *et al.*, 2014).

BPMN and UML AD are compared using four criteria (Geambasu, 2013):

1) Adequacy of graphical elements to represent a business process: Geambasu (Geambasu, 2013) in her work concluded; a) the graphical symbols used for the representation of most parts of the case study are similar in BPMN and UML AD, and b) while UML AD uses a group of symbols to represent an activity, BPMN used only one symbol. This is because BPMN has model elements that do not directly correspond with UML 2.0 AD.

2) Understandability of Notations: Peixoto et al. (Peixoto *et al.*, 2008) conducted an experiment with a set of computer science students who were tasked with modelling a business case using BPMN and UML AD. None of the students were familiar with modelling techniques prior to the experiment. The outcome of the experiment demonstrated that the level of difficulty for understanding both notations is the same.

3) Mapping to Business Process Execution Languages: The OMG's (Object Management Group) specification for BPMN version 2.0 includes a mapping of BPMN to a business process execution language called WSBPEL (OMG, 2011). While the OMG's specification for UML AD does not include any specification of mapping UML AD to any business process execution language (OMG, 2015). This makes business process models created in UML AD non-executable.

4) Simulation of the Process Model: There are several BPMN-based simulation tools available both commercially and as open source. On the other hand, it is difficult to find UML AD-based simulation tools.

The BPMN key elements namely lanes, pools, activities (tasks or sub processes), gateway (for routing tokens), events (start, intermediate and end) and sequence flows are capable of capturing the operational, organisational and control perspectives in a business process. BPMN also has the capability to capture collaborative business process which UML AD cannot capture. BPSim (Business Process Simulation) standard allows enhancement of business process models captured in BPMN to provide robust analysis of business processes (*Bizagi*, no date), this is further concretized in section 2.2. We therefore conclude that BPMN is the preferred choice between the two.

2.1.4 Comparison between BPMN and Event Driven Chains (EPC)

In terms of control flow, both BPMN and EPC use the idea of token passing through a set of interconnected activities where gateways are used to determine their execution ordering such as sequence, choice, parallelism and join synchronization. Aalst et al (Aalst *et al.*, 2003) identified 20 workflow patterns for addressing business requirements in workflow style expression. In order to evaluate the control flow expressiveness of EPC and BPMN, Mendling et al. (Mendling, Neumann and Nüttgens, 2005) provide an analysis of EPC's support for the 20 workflow patterns while Wohed et al. (Wohed *et al.*, 2006) analysed BPMN's support. Table 1 below presents the notations and which workflow pattern they support. A plus sign (+) indicates that the workflow pattern can be modelled while the minus (-) sign indicate otherwise. The +/- sign indicates that it may be possible to model the workflow pattern although the notation lacks a direct element for it.

No	Pattern	BPMN	EPC
1	Sequence	+	+
2	Parallel Split	+	+
3	Synchronisation	+	+
4	Exclusive Choice	+	+
5	Simple Merge	+	+
6	Multiple Choice	+	+/-
7	Synchronising Merge	+/-	+/-
8	Multiple Merge	+	+
9	Discriminator	+/-	-
10	Arbitrary Cycles	+	+
11	Implicit Termination	+	+
12	Multi Instances without Synchronisation	+	-
13	Multi Instances with a priori Design Time Knowledge	+	-
14	Multi Instances with a priori Runtime Knowledge	+	-
15	Multi Instances without a priori Runtime Knowledge	-	-
16	Deferred Choice	+	-
17	Interleaved Parallel Routing	+/-	-
18	Milestone	-	-
19	Cancel Activity	+	-
20	Cancel Case	+	-

Table 1: Comparison between EPC and BPMN (Stein, 2015)

With regards to control flow, BPMN is found to be more expressive (it can capture more complex scenarios) than EPC.

In Summary, BPMN is found to have more expressive notations to represent a variety of situations and control flow patterns. It is capable of capturing the operational activities across organizational boundaries, the behavioural properties and the resources required to execute the business process. BPMN is simulation ready, its notations are easy to understand, and finally, it is the defacto standard. Therefore, BPMN is the preferred choice.

2.2 Business Process Analysis

It is impossible to improve a process that is not understood. The essence of business process analysis is to enhance the understanding of the 'as is' process, obtain relevant properties about the process model for reasoning in order to identify issues such as bottlenecks and logical flaws and check compliance with certain constraints with the aim to improve the process. It is a concept that has a broad application encompassing operations such as conformance checking, simulation, verification and performance analysis of business processes. There are many schools of thought concerning classification of business process analysis with overlapping categorizations (Vergidis, Tiwari and Maieed, 2008b)(Vergidis, 2008)(Dumas *et al.*, 2013). The techniques in each classification are investigated to determine their support for collaborative business process analysis. These classifications are discussed in the following sections beginning with Dumas et al (Dumas *et al.*, 2013):

2.2.1 The Dumas Classification:

Business process analysis is classified into two broad categories: Quantitative Process Analysis and Qualitative Process Analysis. Qualitative Process Analysis:

This identifies unnecessary parts of the business process and investigates impact in order to prioritize improvement efforts. The various types of qualitative analysis techniques are discussed as shown in Figure 8.

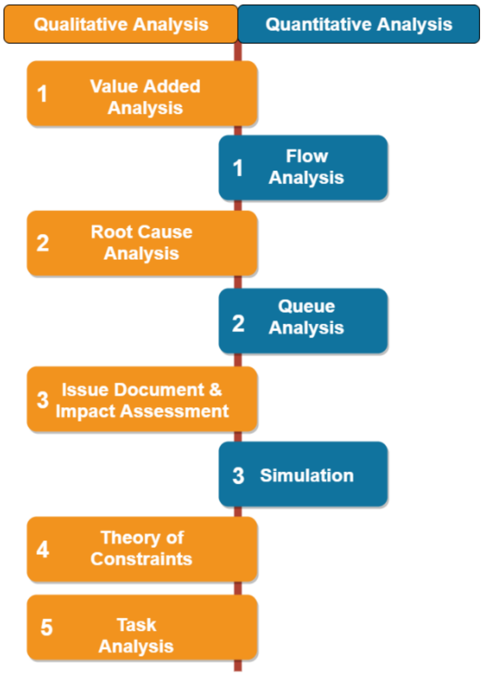


Figure 8: Process Analysis Categories

1. Value Added Analysis: It is a technique that allows the analyst to dissect a process model, identifies every task in the process and groups them into one of the three categories below for the purpose of minimizing or eliminating waste:
    a. Value-adding: Determines if the task adds value to the customer
    b. Business value-adding: Determines if the task is useful for the business
    c. Non-value adding: The task does not fall into any of the above categories.

This approach could be beneficial in that it helps to identify and eliminate waste, however, it would require significant amount of time and it may be difficult to determine the amount of work required to perform the whole task to the satisfaction of the customer.

2. Root Cause Analysis: This technique involves collecting data from multiple sources such as stakeholders, process owners, managers of organizational units involved in the process with the aim of identifying the problems in the process. There are other techniques contained in root cause analysis which are:
    a. Cause-effect diagram: This helps to identify unfavourable effects (issues) and causes of those effects e.g. software system failures, human errors etc. If the causes are eliminated, the process can be improved.
    b. Why-why diagrams: This is another kind of cause-effect but the emphasis is to ask the question – why has something happened? This question is asked several times until the root cause is identified.

3. Issue Documentation and Impact Assessment: This technique complements the Root Cause Analysis in that it documents the causes of the issues and conducts an impact analysis of these issues. The impact assessment strategy includes Pareto analysis, PICK charts etc.
4. Theory of Constraints (TOC): Is used to trace weaknesses in the processes to bottlenecks. The technique offers guidance to identify, plan and implement the changes (Goldratt, Cox and Whitford, 2005).
5. Task Analysis: Individual tasks are analysed instead of the whole process. The technique provides a set of checklists that must be satisfied with the aim of pointing out opportunities to improve the performance of the specified task (Harmon, WRLC EBSCO E-books and Safari Books Online (Firm), 2007).

Qualitative analysis techniques, despite their value, are subjective; stakeholders could have different perspectives on various issues and they heavily rely on the experience of the analyst. Due to its subjective nature, results are difficult to replicate and measure. Instead, quantitative measures are considered necessary in order to evaluate the improvements when comparing both the as-is and to-be processes (Vergidis, Tiwari and Maieed, 2008c). Unfortunately, qualitative analysis techniques are unable to provide such performance measures. Therefore, these techniques are not be taken forward in our analysis.

2.2.1.1 Quantitative Process Analysis:

This category of analysis techniques can provide performance measures in terms of cycle time, waiting time, and cost (Dumas *et al.*, 2013). There are three techniques in this category:

1) Flow Analysis: This can be used to calculate cycle time which is the average time it takes an activity to complete from the moment its ready for execution. The total cycle time for a sequential set of activities is the sum of the cycle time of each activity. However, if there are gateways involved, for example XOR-split, then the formulae is

$$CT = \sum_{i=1}^{n} Pi \text{ x } \mathrm{T}i$$

Where P1, P2 etc. denoted by P*i* are the branching probabilities and T*i* are the cycle times of the paths. For AND-split, the cycle time is

$$CT = Max\ (T_1,\ T_{2,\ldots,}\ Tn)$$

where the combined cycle time is determined by the slowest of the activities (Dumas *et al.*, 2013).

Flow analysis does not consider varying resource allocation for each activity, therefore it will not reflect a real-world scenario unless the resource allocation remains constant throughout.

2) Queueing Theory: This technique is applicable to analysing systems or activities that have limited resources to perform the required work, also known as resource contention. The queuing analysis technique allows analysts to estimate waiting times and queue length based on the assumptions that inter-arrival times and processing times follow an exponential distribution. Another limitation is that the technique deals with individual activity separately, that is, if several activities, events and resources are required to be analysed in a process model, the technique will not be useful.
3) Simulation: This is the most popular quantitative analysis technique and is considered to be the most suitable for obtaining performance measures such as cycle times, average waiting times, and average resource utilization. It has an advantage over other quantitative techniques in that it has the capacity to concurrently analyse all the activities, events and resources in a process model in a number of what-if scenarios (Wohed *et al.*, 2004).

Simulation is our preferred technique, the following section provides justification for our choice.

2.2.2 Business Process Phase Classification

A few authors classified process analysis based on the phase of the business process (Sánchez-González *et al.*, 2011)(van der Aalst, 2011) such as design phase analysis (pre-analysis) and run-time analysis (post-analysis). Design phase analysis entails all the analysis techniques described in this report while run-time analysis requires techniques for process mining which are: conformance checking, compliance checking and process discovery to check whether a business process behaves as expected. Run-time analysis is beyond the scope of this research, therefore these techniques will not be discussed further.

2.2.3 Vergidis Classification

Vergidis et al (Vergidis, Tiwari and Maieed, 2008a) classify process analysis techniques into 3 categories:

1) Observational analysis includes the inspection of the visual models and making changes to the process structure where necessary to ensure it captures the business logic. The approach is easy and simple to use if the modeller is familiar with the domain and proficient in model creation. On the other hand, the limitation of observational analysis is that it can be very difficult if the modeller is unfamiliar with the domain, therefore a domain expert would be needed to verify the model. Generally, observational techniques can enhance the understanding of the business process and can be helpful when making necessary corrections to the process model.

The technique was used by conducting interviews with domain experts in order to fine tune the process models used in this work to accurately reflect the admission and clearing processes. However, observational technique cannot adequately provide thorough analysis of process models due to its qualitative nature (Zakarian and Kusiak, 2000) therefore it should be used in conjunction with other relevant techniques.

2) Formal techniques follow a quantitative approach for analysing business processes using mathematical models, and those built around Petri nets (van der Aalst, 2010) to:

   a. Validate the process model, i.e. check if the business process behaves as expected based on requirement.
   b. Verify the process model, i.e., check for correctness and that the model is free from logical errors.
   c. Evaluate the process models performance, i.e. evaluate the performance based on certain measures such as cycle time, resource utilization etc.

Petri nets have a complete and well-developed set of analysable definitions but consequently this increases their complexity making it too tedious to use and unfriendly to non-technical users. Validation can be carried out by simulation of various scenarios while verification and performance analysis require more advanced analysis techniques (Aalst, 2004).

3) Simulation technique allows performance analysis to be carried out on a process model which helps to detect flaws, bottlenecks and human resource planning (Van der Aalst, Weske and Hofstede, 2003). Simulation is good for process validation and performance evaluation. The technique can be combined with the observational technique to verify and validate before evaluating the performance of a business process. With a good simulation tool, the simulation can be configured to define the quantity of resources, shifts and cost per units of the resources associated with the process execution. In the simulation results, the tool can provide the analyst with an evaluation of the business processes using what-if-analysis which can give insight into the performance of the business process based on different scenarios. This analysis technique is our choice based on its quantitative nature and the above-mentioned capabilities. The downside of simulation technique is that the performance analysis is highly reliant on the input data that is used to configure the simulation (Anand, Wamba and Gnanzou, 2013).

2.3 Business Process Improvement Measures

Performance analysis is the use of measurement information to allow organisations to acquire understanding of their existing process in order to improve performance and productivity. Measurement activities enhance the means to collect such information, with the view to organise and monitor improvement exercises, and communicate reasons for improving the process (Van Eijndhoven, Iacob and Ponisio, 2008). According to Drucker, “What is measured improves” (Kuend, 2000). There is enough evidence in literature to suggest that there is a strong connection between business process performance and organizational performance (Van Looy and Shafagatova, 2016). An improvement in the business process will have a positive impact on the organizational performance.

2.3.1 Measurable Concepts

Approximately 89% of software application measures could be applied to business processes due to the similarities that exists between them (González *et al.*, 2010), (Vanderfeesten *et al.*, 2007). These measures can be applied to business process model at design time and execution time. Design time measures are applicable to static properties of business processes and are based upon the business process model during design time while execution time measures are used to quantify the dynamic properties of business processes (González *et al.*, 2010). Design time measures can be used as performance indicators at the early stages of its lifecycle thereby enabling practitioners to detect and correct errors. On the other hand, execution time measures can be generated and these results can be compared with the expected results with the aim to improve the business process to achieve customer satisfaction (González *et al.*, 2010).

Design Time Measures	**Execution Time Measures**
Complexity	Functionality
Quality	Quality
Coupling	Usability
Entropy	Reliability
Density	Effectiveness
Cohesion	Efficiency
Modifiability	Cycle time

Table 2: Design Time and Execution Time Measures [25]

As seen on the Table 2, the quality measure is applicable to both design time and execution time models. Some of the execution time measures in table 6 can be considered as the attributes of quality. ISO 9126 (ISO 9126, 2000) defines 6 quality characteristics which are: Functionality, Reliability, Usability, Efficiency, Maintainability, and Portability. Most of these measures are qualitative in nature, therefore difficult to be quantified.

Rolon et al. (Aguilar *et al.*, 2006) define a set of metrics for the evaluation of the complexity of conceptual models of business processes based on the adaptation and extension of the FMESP (Framework for the Modelling and Evaluation of Software Processes). The research work was inconclusive as some experiments were yet to be performed to validate the proposed measures.

Some researchers have proposed measures specific to standard languages such as Event-driven Process Chain (EPC), BPMN, YAWL, Petri net, UML AD (Mendling, 2008), (Aguilar *et al.*, 2006).

There are various measurement activities in literature. Gonzalez et al (González *et al.*, 2010) examined a number of measures and concluded that there is lack of measurement validation and most authors do not place importance upon validating activities.

Bisogno et al. (Bisogno *et al.*, 2016) provides a method for detecting process criticalities and identifying the best corrective actions using BPMN and Business Processes Simulation to measure key performance indicators using criteria such as completion rate of process, throughput time, rate of resource utilization and resources service level. The outcome of the study needed further refinement. Given that simulation models can be time consuming and costly, financial costs should have been included as part of the indicators.

Vanderfeesten et al. (Vanderfeesten *et al.*, 2007) conducted a literature review on business process measures using the same classification as in software engineering such as coupling, cohesion, complexity, modularity and size. The researchers engaged the use of ProM tool, a process mining tool capable of supporting all kinds of analysis related to business processes (Van Dongen *et al.*, 2005). It allows for the calculation of several categories of quality metric through the use of various plug-ins to analyse the correctness, cohesion, coupling and size of a model which can be of great benefits. However, based on our experience the ProM tool is not straightforward to install and is unusable. The authors did not provide information about interpretation and applicability of these measures for both practitioners and researchers.

Jamila et al. (Oukharijane *et al.*, 2019) proposed an approach that uses existing quality metrics to evaluate the quality of BP models in terms of comprehensibility or understandability and modifiability or flexibility. These metrics are:

Control Flow Complexity (CFC): Complexity is a measure of simplicity and comprehensibility of the process model. Cardoso et al. (Cardoso *et al.*, 2006) adapted McCabe's cyclomatic number (Mccabe, 1976) as a complexity metric for business processes called CFC. It takes into account the number of gates, i.e. AND, OR, and XOR split constructs. It counts the number of decisions in the flow of control. The number of all possible decisions is increased by every split in the model.

Other metrics are: Interface Complexity (IC), Number of Activities (NOA), Number of Activities, Joins and Splits (NOAJS), and Coefficient of Network Complexity (CNC). CNC was proposed by Cardoso et al. (Cardoso *et al.*, 2006) and is the ratio of the total number of links in a process model to its total number of nodes.

Cross Connectivity (CC) was defined by Vanderfeesten et al. (Vanderfeesten *et al.*, 2008) to measure the strength of the arcs between process model nodes, Coupling metric (CP) was defined by Vanderfeesten et al. (Vanderfeesten, Cardoso and Reijers, 2007) to compute the degree of coupling which is the number of interlinks between the activities of a process model. The degree of coupling is dependent on the type of gateways (AND, OR, XOR) between activities and the complexity of the connections. Density (D) was defined by Mendling (Mendling, 2006) as the total number of links to the maximum number of links. Their approach was validated by developing a BP-Quality tool. Again, no information was provided about the interpretation and applicability of these metrics.

The conclusion drawn from the above metrics is that software metrics can be applicable in measuring business process models during design time and can be used to measure improvements. While some of the metrics can be determined such as the CFC, NOA by using relevant formulae, others are cannot be determined without the use of some software tool like PROM or some complex algorithm. No information was provided about how the measures were obtained except those obtained by the PROM tool but we had difficulties in installing the tool. Even when the measures were obtained as described above, there is no concrete interpretation in direct relation to the process model. Hence there is a need to consider complex network approaches and related works.

2.3.2 Complex Network Analysis Measures

Whilst several works have been conducted on business process measurable concepts, many of these measures are derivatives of quality measures and they lack guidance on how they can be concretized in practice (Van Looy and Shafagatova, 2016). We explore the use of a complex network analysis approach to provide information about the structural relationship and information exchange between process activities. This is being done in an attempt to answer research question number 2:

Can a reduced process model contribute towards improving and measuring business processes?

A business process model is converted into a network where the activities become nodes or vertices and the links become edges.

This approach could be used to calculate and evaluate metrics and interpret the results to give an insight into the structure of process and support decisions for process optimization.

Networks are a means to capture the patterns of connections or interactions between various parts of a system. Network analysis techniques have been applied to various disciplines such as mathematics, physics, biology, social science, computer and information sciences and many more (Newman, 2010).

The research community has taken advantage of the quantitative offerings of network analysis and its associated metrics in business process management. Mendling et al (Mendling, Neumann and Van Der Aalst, 2007) explored an analysis of the connection between formal errors such as deadlocks and a set of metrics inspired by social network analysis to capture the various structural and behavioural aspects of a process model.

Social network measures were used by Hassan (Hassan, 2009) to support and evaluate the task of designing IT-enabled business processes. The approach used in the research viewed nodes as actors/roles not as tasks and a bi-directional graph was used but in our work, nodes are used as tasks/activities within the business process.

Levina (Levina, 2012) used network analysis to quantitatively assess process similarity based on the information structure of the business process model. The paper provides information about the applicability of the metrics within a business context but it was difficult to determine how the metrics were derived as the commetrix software used in the work is no longer accessible. Another work conducted by Levina and Hillmann (Levina and Hillmann, 2012) reveals that process characteristics can be explored and analysed using network theory. The generated metrics of the network analysis of the structural properties of a business process was compared with real world networks. The outcome of this comparison indicate that business process networks comply with the definition of real-world networks, can therefore be used in our casestudy. A further work by Levina and Bobrik (Olga and Annette, 2013) demonstrated the robustness and flexibility of Social Network Analysis measures and content-based clustering for knowledge identification on process tasks to improve information management performance.

2.4 Conclusion

The chapter discussed the need to identify and use an appropriate business process modelling approach. Therefore, a set of requirements was defined in order to determine the appropriateness of a modelling approach. A variety of approaches were discussed and the ones relevant to this study were identified which are business process language and diagrammatical models, both approaches have overlapping entities. Given the multiple choices of languages that can be found in these approaches, a further study was carried out to define the requirement for the choice of the modelling language. The outcome was BPMN due to its exceeding capacity to satisfy all requirements.

Further to the above, a study was carried out on various sets of classifications of business process analysis. The choice of analysis class was quantitative analysis, the choice of analysis phase was design time, and the choice of technique was simulation.

The chapter concludes by considering process improvement metrics to actually determine how much improvement has taken place. Simulation technique reveals two execution time metrics which are time and cost. It is necessary to measure improvement based on the structure of the process. To this end, a number of metrics adopted from software engineering were discussed but some of these metrics lacked adequate interpretation and applicability. Complex network analysis metrics will be considered as suggested in literature to provide information on the structural relationship and information exchange between process activities providing answer to research question 2.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter starts by describing the research philosophies, research approaches, strategies etc. based on the research onion. It presents the comparison between research approaches and techniques in both quantitative and qualitative research. Furthermore, it provides a description and justification for the choice of methodology and research design.

3.1 Research Approach

A research approach specifies a clearly defined procedure that involves the application of methods to collect, analyse and interpret data. There are two types of research approaches: inductive and deductive. Inductive approach or reasoning (Figure 9) begins with the observation and theories that are proposed as an outcome of the research process as a result of observations (Dudovskiy, no date). It is a bottom-up approach.

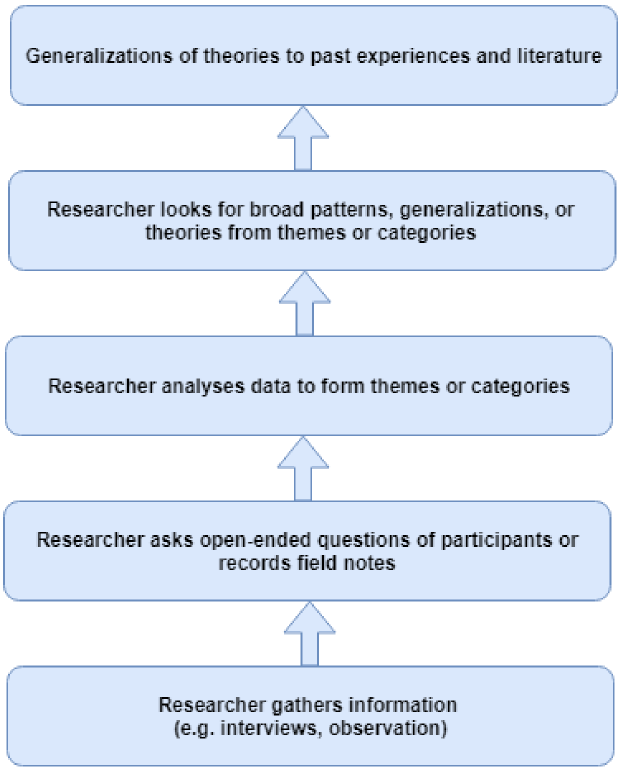


Figure 9: Steps in Inductive Approach [135]

On the other hand, deductive reasoning as presented in Figure 10, follows a top-down approach where hypotheses are developed based on existing theory and the hypotheses are tested using a research strategy designed specifically for the hypotheses. It entails moving from specifics to the general. While Inductive approach starts with observations and theories with the intention to find patterns in them, Deductive starts with expected pattern that is tested against observations.

Inductive approaches are used in most qualitative research where theories are developed after collecting and investigating data while deductive approaches are used in most quantitative research where hypotheses are tested.

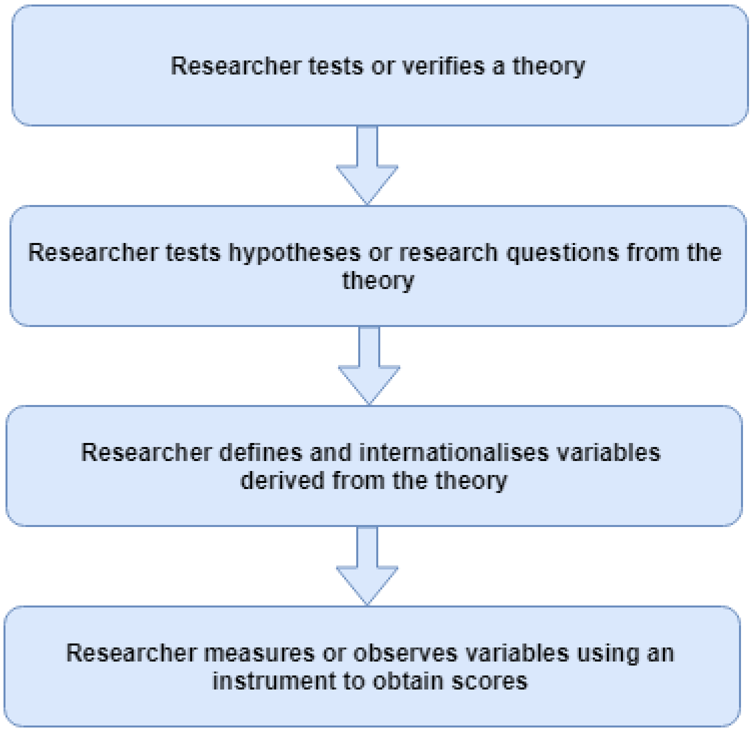


Figure 10: Steps in Deductive Approach [135]

In this thesis, we adopted both inductive and deductive approaches as they are relevant to answering our research questions. An inductive research approach was adopted to study business process analysis techniques, business process modelling techniques, existing business process improvement methodologies, admission process in UK Higher Education.

Procedurally, the inductive approach involved the following steps:

- Determination of the appropriate process analysis technique for this work including the motivation for the choice of tool
- Discuss and analyse existing process improvement methodologies based on the Mandatory Elements of a Method (MEM)
- Develop an algorithm for projecting a business process model into possible network projections using a complex analysis technique.

- Apply algorithm to 4 different process models to determine which network projection is more accurate.
- Formulate an improvement framework/method based on a combination of simulation, network analysis and improvement heuristics to systematically improve any process model.
- Conduct a case study on UK HEI Admission process
- Create an as-is model of the process using BPMN
- Use simulation analysis technique to analyse and creatively identify issues with the process
- Verify the issues identified by checking with domain experts
- Create a to-be process model and verify correctness
- Verify the SNACH framework by using the Admission Process.

On the other hand, the deductive approach involved the following steps:

- Formulation of hypotheses based on the SNACH framework
- Design of experiment to test the effectiveness and efficiency of SNACH
- Determine performance metrics to measure process improvements
- Presentation and discussion of experiment results to confirm either hypotheses

In line with both inductive and deductive approaches, we follow the mixed method data collection techniques namely: interviews, observation, document study and experiment.

3.2 Research Methodology

Generally, the research methodology would encapsulate a research method. According to Collis and Hussey (Collis and Hussey, 2013), a research methodology can be perceived as the overall approach to research, starting from the theoretical underpinning through the data collection and analysis of such data. The selection of research methodology is hugely dependent on its usefulness in fulfilling the research objectives and expected outcome of the study. There are a variety of research methodologies for carrying out research in information system (IS), for example, the Service Engineering Framework (SEF) research methodology was used by Silvia et.al (Silvia, Suhardi and Yustianto, 2016) for the improvement of a government public service via the analysis of the Key Performance Indicator (KPI) and Critical Success Factor (CSF), while the process was modelled using BPMN. The SEF has three phases: 1) Identification Phase (the performance of the existing business process using CSF and KPI analysis) 2) Design Phase (the current and proposed processes modelled using BPMN with Bizagi modeller software) and c) Design Validation was performed using the time analysis level of Bizagi modeller software. Another research methodology is Design Science which provides a set of techniques that entails the formulation of new knowledge or theory through the design of novel or innovative artefacts, followed by an analysis (which includes reflection and abstraction) of the performance of the artefacts to understand and improve the behaviour of the information system. Design Science is used in preference to SEF methodology because it is more aligned to the research steps outlined above and the overall research objectives. More justification is provided in the next section.

3.2.1 Design Science Research (DSR) Methodology

Design Science provides a set of synthetic and analytical techniques and perspectives for carrying out research in Information Systems (Hevner and Chatterje, 2004).

DSR is different from Design Research in the sense that Design Research spans across all design fields focussing on an investigation into or +about designs generally, e.g. product design, architectural design, etc., while Design Science Research is learning through artefact production, in other words, the research is carried out using design as a research method or technique (Vaishnavi, V., Kuechler, W., and Petter, 2017). Design science research is carried out using the design as a research technique. The process model is shown in Figure 11 below:

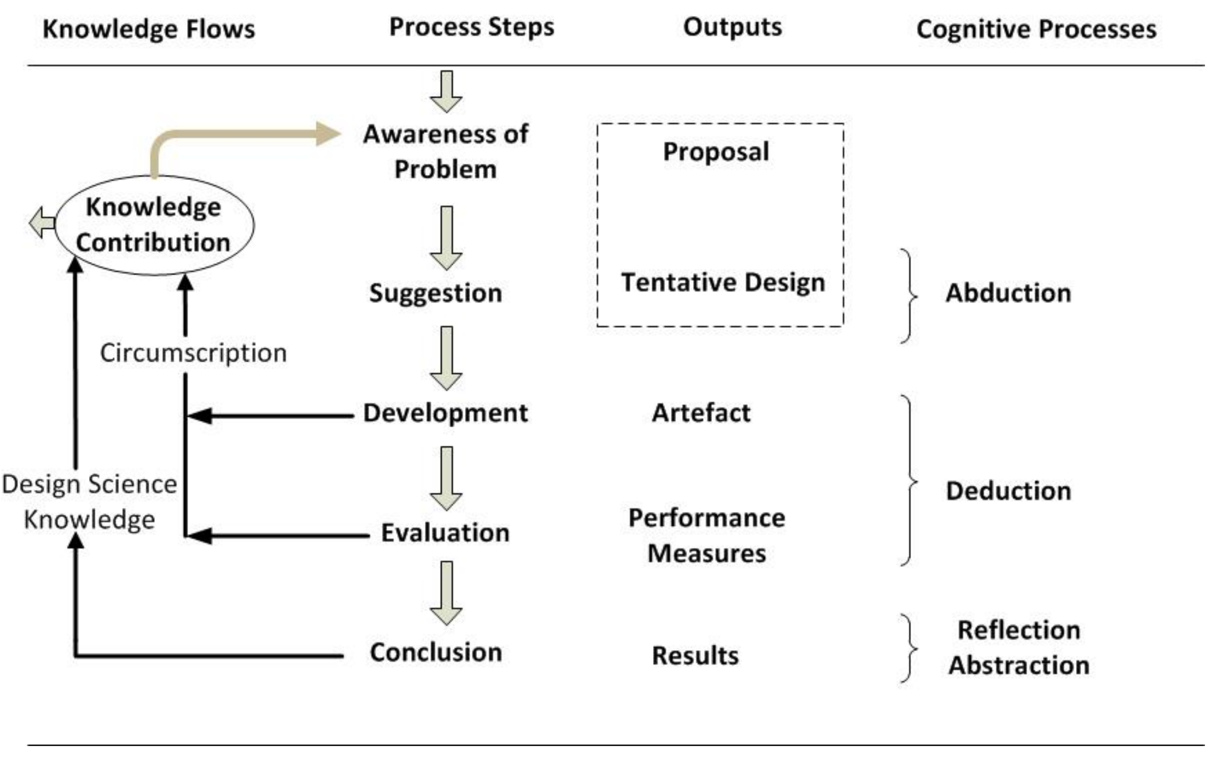


Figure 11: Design Science Research Process Model and Cognitive Processes [138].

3.2.2 Design Science Research Process Steps/Phases

Awareness of Problem: This may come from several sources such as experience of an area of challenge in an organisation, new developments in industry, and reviewing literature to investigate areas for improvement in an allied discipline. That is why the Design Science Research is often referred to as "Improvement Research" due to its problem solving and performance improving characteristics of the activity. The output from this phase is a Proposal.

Suggestion: This comes next after the proposal where suggestion is made in the form of a tentative design – a prototype. Sometimes the tentative design is regarded as a part of the proposal hence the dotted line around Proposal and Tentative Design. The cognitive process involved at this stage is Abduction, this is because the suggestions offered to solve the identified problems are abducted from the existing knowledge/theory based for the problem area as shown in Figure 11.

Development: The Tentative Design is then developed and implemented where the method used will depend on the artefact to be produced. For a business process a model or improvement method or framework will be designed and validated, for an expert system software will be developed using a tool, and for an algorithm a formal proof will be constructed for validation (correctness). The cognitive process involved at this stage is Deduction, this is because more understanding can be gained from the development and this cognitive process carries on to the evaluation stage.

Evaluation: This phase entails the evaluation of the artefact based on the criteria or functional specification that was set out in the Proposal. Deviations from expectations are thoroughly noted and explained. A further analysis is carried out where hypotheses are made about the behaviour of the artefact. The evaluation results and additional information gained during the development and running the artefact are put together and fed back into another round of suggestion then a new design is created. This is iteratively performed in the course of the research effort. This is indicated by the arrow called circumscription. According to Vaishnavi et al. (Vaishnavi, V., Kuechler, W., and Petter, 2017) referencing (McCarthy, 1980),

"*Circumscription is a formal logical method that assumes that every fragment of knowledge is valid only in certain situations. Further, the applicability of knowledge can only be determined through the detection and analysis of contradictions – in common language, the design science researcher learns or discovers when things don't work "according to theory.""*

Conclusion: This phase marks the end of the research cycle or the end of a particular design science research project. The results are written up including deviations in the behaviour of the artefact from the initial theoretical predictions. The conclusion is an opportunity to make a strong case for the knowledge contribution to the research community, therefore the research outcome needs to be appropriately positioned as a valuable contribution. The cognitive processes involved at this stage are reflection and abstraction. They are used to make a contribution to design science knowledge – advancing knowledge in the research discipline.

3.2.3 Application of Design Science in our Study

DSR Stage 1 – Awareness of Problem

The activity involved at this stage is identifying the specific research problem and defining the motivation. The research problem is to find a systematic approach to improve business processes in order to progress from the as-is to the to-be process. Other associated problems are how to identify bottleneck activities or unnecessary activities in a business process model and quantitatively measure the process performance both at design and execution time.

A review of existing business process improvement methodologies (section 5.3.1) shows that there is inadequate support for the actual act of improvement. Even though guidelines are provided in these methodologies, analysts and practitioners still rely on creativity and experience to improve processes. The output of this stage is a proposal, in our case a framework that supports the act of process improvement with integrated measurable concepts to track process improvement activities in a collaborative environment.

DSR Stage 2 – Suggestion:

A methodical approach to business process improvement is suggested as provided by method engineering; a discipline that supports the design, construction and adaptation of methods, techniques, and tools for developing information systems. A method in the context of BPI consists of elements that address the issues surrounding the unstructured approach to process improvement. These elements are referred to as Mandatory Elements of a Method (MEM); if these elements are found in a BPI methodology/framework, the act of process improvement will be fully supported. Our BPI framework was developed based on MEM.

In addition, a structured approach is sought with appropriate metrics to measure how much the to-be process has improved when compared to the as-is process. Therefore, a complex network analysis approach is investigated which involves reducing a business model to three projective spaces in other to analyse its macroscopic properties. Also, the simulation technique provides quantitative measurements in terms of time and cost. Other suitable metrics relevant to the complex network analysis technique are investigated.

This matches the abduction cognitive process involved in this stage. These are presented in chapter 4.

DSR Stage 3 – Development

The Map technique was utilized for the construction of the SNACH framework. The improvement framework comprises of the following fragments:

1) An algorithm (projection rules) for downscaling a process model to into three projective spaces
2) Application of simulation and complex network analysis techniques
3) Heuristic selection criteria
4) Application of process improvement heuristics
5) Techniques for measuring process improvements

Chapter 4 presents an investigation into the use of complex network analysis technique to analyse reduced business process models and to define measuring concepts. Chapter 5 presents the development of the improvement framework called SNACH – Simulation Network Analysis Control flow complexity Heuristics.

DSR Stage 4 – Evaluation

The evaluation stage is presented in chapter 7. Prior to the evaluation, a set of performance metrics were systematically selected as the basis for measurement and comparison. The evaluation is two stages: checking of the validity of the performance metrics and the evaluation of the SNACH framework using a case study.

The Design Evaluation method was used, the method comprises of 5 classes of evaluation approaches. The experimental class was employed consisting of two further sub-classifications: Controlled Experiment and Simulation. Consequently, the evaluation was therefore conducted using these two approaches:

1) Simulation: Both the as-is and to-be processes were assessed based on a set of selected metrics.
2) Experiment: The SNACH framework was evaluated in terms of its effectiveness and efficiency to support the act of process improvement. Another business process model was created for this purpose. The outcome of the experiment showed that the SNACH framework supports the act of improvement of business processes.

The term circumscription was fulfilled during the development and evaluation stages by making necessary modifications to the framework until it became fit for purpose.

Conclusion:

The findings and research contributions are presented in chapter 8. The above described steps are illustrated in Figure 12.

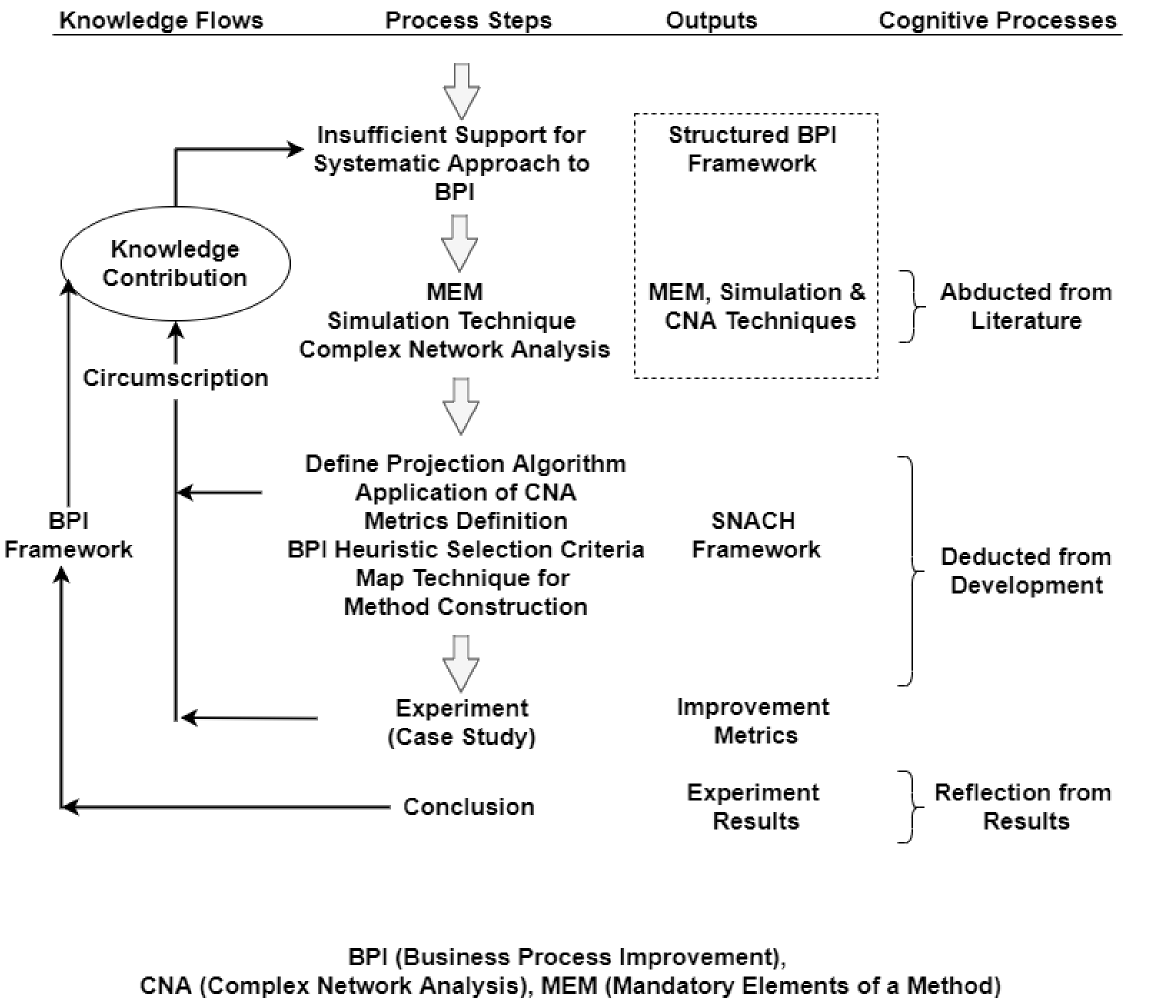


Figure 12: Design Science Research for SNACH Framework

3.3 Research Strategy: Case Study

A Case Study is usually considered when there is a need to understand a social phenomenon in a real life context such as individual life cycles, organisational and managerial processes, international relations etc. (Yin, 2003). It can be used depending on 3 conditions:

a) The nature of the research questions,

b) Whether the investigator has control over the behaviour of events

c) Whether the research is focussed on contemporary as opposed to historical phenomena.

The nature of the research questions implies the substance and the form such as “what”, “who”, “where”, “how” and “why” questions. “What” questions are more suited for surveys or archival strategies [141]. ‘How’ and ‘why’ questions are more explanatory and likely to engage the use of case studies, histories and experiments research strategies. In this case, the extent of the investigator’s control over and access to behavioural events will determine whether case studies, histories or experiments strategies will be used. When there is no access or control at all i.e. when dealing with a “dead” past, histories will be a more suited strategy. Primary documents, secondary and cultural and physical artefacts will be relied upon as main sources of evidence. Experiments are the preferred strategy when the investigator can manipulate behaviour (namely variables) directly, precisely and systematically. Case studies are preferred when the investigator has a small degree of control over events, but the relevant behaviours cannot be manipulated.

In a nutshell, case studies are preferred when ‘how’ and ‘why’ questions are being presented, when the investigator has a small degree of control over events, relevant behaviours cannot be manipulated and when the focus is on a contemporary phenomenon within some real-life context.

This research focusses on student recruitment process improvement in a Higher Education Institution with a particular focus on the clearing process. Therefore, case study is considered suitable for this research.

3.4 Conclusion

In this chapter, the research design for this work was presented. We adopted both the inductive and deductive research approaches. A case study research strategy was adopted whose strength lies in its ability to examine contemporary events, understand the problem domain and organisational process. For this study the case was the higher education admissions process and we used multiple sources of evidence such as document study, direct observation of events being studied, and interviews of the persons involved in the events. The design science research methodology was employed instead of the SEF methodology, due to its suitability to fulfil the research objectives. The next chapter will present complex network analysis.

CHAPTER 4

COMPLEX NETWORK ANALYSIS

4.1 Introduction

One of the research questions is to investigate if a reduced business model can contribute towards improving and measuring business processes. The intention is to obtain quantitative information about the structural properties of business processes, and to examine if changes made to these properties would contribute towards process improvement. This chapter will provide an algorithm for reducing a business process model into projective spaces (network structure or representation), use the appropriate network metrics to analyse and measure both current and proposed improved business process models, and finally, provide a comparison between both models. The measures are expected to show if there are any improvements.

4.2 Complex Network Analysis Metrics

A network is a group of connected points. The points are referred to as nodes and lines between them are called links. A network is often referred to as a graph in mathematical literature (Newman, 2010). In graph theory, a point is referred to as a vertex and a line is called an edge or arc. Although, Newman (Newman, 2010) in his book "Networks: an introduction" identified nodes as vertices and links as edges. In addition, most scientific literature use the terms network and graph interchangeably, the difference between the two is social in nature (Ferdinandy, no date); when a real system is modelled as a graph, it is often called a network and when abstract entities that cannot be mapped to real world phenomena are modelled, they are called graphs. In this report, the term network, node and links are used throughout. The pattern of the relationship between these nodes can be identified and measured using network theory (Jamali and Abolhassani, 2007).

Furthermore, there are four general classes of complex networks(Newman, 2010): technological networks (e.g. the internet), social networks (e.g. online social networking sites such as Facebook, interaction between actors in an organisation), information networks (e.g. the World Wide Web) and biological networks (e.g. a pattern of connections between brain cells, interaction between species in ecosystems). Specifically, business process models fall under the social network classification. In this report, we use the term social network where necessary but generally the term network is used.

A network is made up of 3 aspects which are (Newman, 2010): 1) The nature of the individual nodes, 2) The nature/pattern of the links and 3) The behaviour of the system. The pattern of links in a network on the internet, for example, affect how people spread information, learn, form opinions, gather news, discover and make new connections (Newman, 2010).

The study of the nature/pattern of links in a network can help give insight into the characteristics of the network. These characteristics are assessed using network metrics i.e. the metrics can be used to quantitatively analyse the structure of a network. As such a business process can be stripped of its details and reduced to its barest structure. The structural relationship between process activities can then be analysed to provide insight into the interaction and behavioural structure of the process activities. Table 3 shows the description of each metric, formulae, and interpretation. The definitions and formula are taken from *Social Network Visualizer* (no date) and Newman (2010) and some of the interpretations are derived from Olga and Annette (2013).

Thoughts about the relevance of each metric to business process models are also discussed.

Measures	Formula	Description	Relevance/Interpretation
Degree Centrality	$k_i = \sum_j x_{ji}$	It gives an indication of how connected the nodes are i.e. the number of links connected to a node. In undirected networks, it is the sum of the links attached to a node. In directed networks, it is the sum of outbound links from a node to all adjacent nodes (aka “out-Degree Centrality”)	Degree centrality can be a measure of the average complexity of the network. An individual node with a high degree of centrality means it is highly influential. It is used to identify the well-connected actors in a network.
Betweenness Centrality (BC)	$x_i = \sum_{st} \frac{n_{st}^i}{g_{st}}$ Where n_{st}^i is the number of geodesic paths from *s* to *t* that pass through *i*	The extent to which a particular node lies on the shortest path between other nodes. It can also be seen as a bridge between two clusters of network.	This corresponds to finding the node that has the greatest control over the network or the node that Influences the flow around a network. This could help identify a potential bottleneck area because a node with the highest betweenness can control

	while g_{st} is the total number of geodesic paths from *s* to *t*.		information transportation and dissemination.
Closeness	$l_i = \frac{1}{n}\sum_j dij$ Where $C_i = \frac{1}{li}$	It is used to measure the path length from a node to other actors. Nodes with high values of the closeness centrality are interpreted as being involved in close exchange with other actors. A small closeness centrality value indicates autonomous and independent node. It is the sum of the distance between a specific node and every other node in the network	The average closeness centrality of a network can provide insight on the collaboration and information distribution productivity within the network. The closeness property can also give an indication of a potential bottleneck area.
Clustering Coefficient (CC)		It measures the interaction of nodes within an ego-network including transitive connections and indicates the transitivity of the node, i.e. its ability to distribute information directly with its neighbour nodes. It quantifies how close each node and its neighbour are to being a complete sub-network (clique). For each node, the local CLC score is the proportion of actual links	The Higher the CC the higher the tendency of the actors to share information directly. We are not able to find its relevance to business process model.

		between its neighbours divided by the number of links that could possibly exist between them.	
Diameter		The longest geodesic path in the network. How far apart are the two most distant nodes?	It is the largest geodesic distance in the connected network. It can be used as a metric for network size or complexity. The higher the diameter, the more the complexity. It is considered relevant.
Density	D = No of Connected Links/Total No of Links	The ratio of links present in the network and the maximum number of possible links. The number of links in the network as a proportion of the maximum possible number of lines. The size of the network is inversely proportional to its density. Sparse density means not all nodes are connected with each other.	It can be used to refer to the stability of the network with respect to structural changes. With regards to business process, it can be used to test the modifiability or flexibility of a business process when changes are made. In order words, if a network is dense it would be less flexible because a change in the network would affect several other members of the network. It is therefore considered relevant. Flexibility is the degree to which a model can be effectively and efficiently modified without introducing defects or degrading existing product quality (Sánchez-González *et al.*, 2017).

Average Path Length		It is a measure of the average number of steps along the shortest paths for all possible pairs of network nodes	It is a measure for the efficiency of the information transport in the network. Increased average path length in the network can indicate less efficient information transport within the process. We are not able to find its relevance to business process model.
Reach		The degree of any member of the network to which it can reach other network members. Two nodes are reachable if there is a walk between them (their geodesic distance is non-zero).	It can be used to measure communication flow between processes. This is not considered relevant.
Connectivity		Indicates how many nodes need to be removed to separate the network into several groups	This is similar to density.

Table 3: Social Network Analysis Metrics

4.3 Projective Spaces

When a business process model is reduced to its network representation, there are 3 possible projective spaces which are explored in order to determine which projection is appropriate for process improvement.

There are 3 possible projective spaces (Newman, 2010):

a) Weighted Projection: At this level of projection, the links between the nodes have some numeric values assigned to them as shown in *Figure 13*. The value could represent the amount of data flowing through the links or the frequency of interaction between nodes (Hassan, 2009).
   P1: BPMN ➔WP

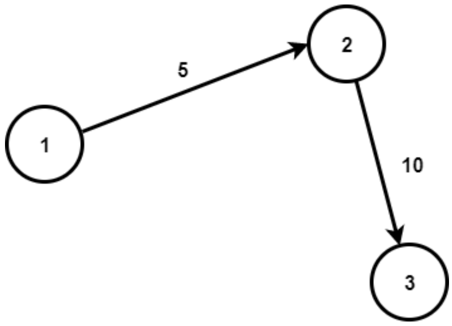


Figure 13: Weighted Projection

b) Directed Projection: At this level of projection, each link has a direction, pointing from one node to another. They are represented by lines with arrows on them as shown in Figure 14.

P2: BPMN ➔DP

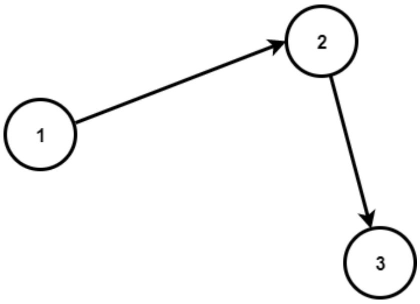


Figure 14: Directed Projection

c) Undirected Projection: At this level of projection (Figure 15), there are two directed links running in opposite directions between the same pair of nodes. The arrows on both ends may or may not be shown.

P3: BPMN ➔UP

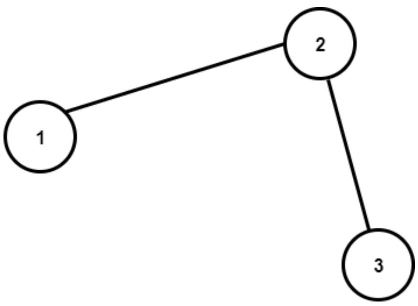


Figure 15: Undirected Projection

The BPMN space can be considered to be a four-dimensional (4D) space:

- Flow objects: activities, gateways, start/end events.
- Connecting objects: association, message flow.
- Swimlanes: pool or lane.
- Artifacts: data object, group, annotation

We project the business process model designed in BPMN onto a 3D space (node, directed link and weighted link) or 2D space (Node and directed link) or 1D (node and undirected link) as shown in *Figure 16*. Information is lost at these various levels of projection, therefore a need to investigate which of the projections is able to satisfy our objective of business process improvement.

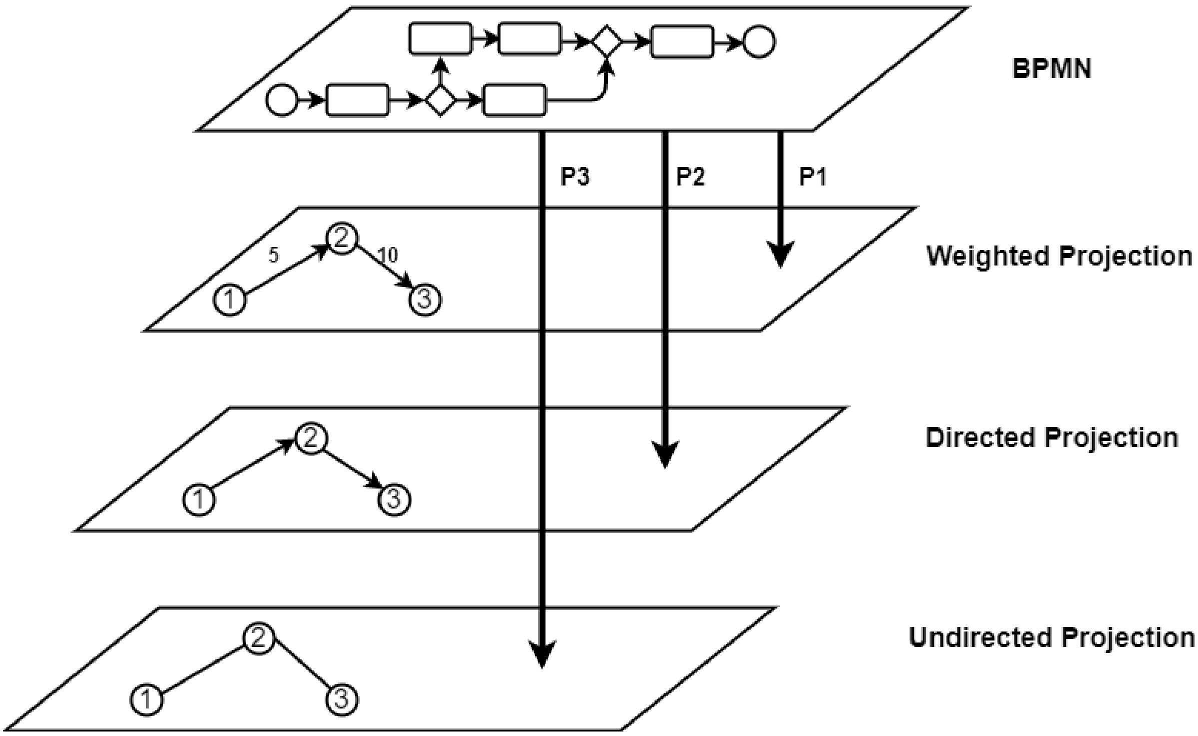


Figure 16: Projective Spaces

4.4 Approach for Analysing and Measuring Business Process Models

The simulation analysis technique of business processes can permit the virtual analysis of organisational processes and strategies, assist in visualizing process behaviour, in addition to measuring the operational performance of the process and finally observe the different what-if scenarios for improvement. The dynamic features of the processes of any system such as changing the order of steps in a process, switching to an alternate path or resource allocation can be captured in the control flow of the process model and then configured (based on historic data) in the simulation tool. The outcome of these dynamic features can be evaluated using what-if analysis based on multiple scenarios prior to it being implemented in a real environment. However, the weakness of the simulation only approach is that the structural complexity and flexibility of the process model are unknown hence the need to downscale the process to its basic network structure and then use complex network analysis to obtain some insights into its structure.

The three aspects of a process model being investigated are:

a) Simulation aspect: Quantitative measures that can be derived from simulation such as cycle time and cost.
b) Logical aspect: This considers the logical aspects of a model such as the Control Flow Complexity.
c) Structural aspect: This entails a network-oriented approach without considering the logical flow details of the process. Examples of metrics are: Size, Diameter, Average Degree Centrality, Degree centrality, Betweenness, and Density.

The focus of this chapter is to use network-based analysis to quantitatively assess the structural differences and similarities between the as-is and to-be business processes. The next section presents an algorithm for reducing the network to its basic structure.

4.4.1 Algorithm for Projection – Activity Centric Analysis

We adopt the idea of "levels of abstraction" such as used in Data Flow Diagrams (DFD). DFDs are a visual modelling technique for capturing data flows and express

No	Element	Notation
1	External Entity (Source/Sink)	Friend
2	Data Flow	Request for address →
3	Process	1.0 Get Address

4	Data Store	M Address Book

Table 4: Elements of a Data Flow Diagram

data transformation in a system (Li *et al.*, 2009). It comprises of 4 elements shown in Table 4.

Data flow diagrams can be used to show the processing of data in a system at either a higher level or at a lower level. These different views of the system are called levels of abstraction. The high-level of abstraction shows a general view of the system beginning at level-0 also known as the context level. For example, the mortgage application process described in chapter 1 is illustrated using a data flow diagram in Figure 17. The context level does not show the processing details of the mortgage application taking place by the mortgage provider.

The mortgage provider is the focus of analysis, therefore, other actors (buyer, solicitor, estate agent) are treated as external entities. The context level can be further decomposed into level-1 DFD by providing more details of individual processes. Level-1 DFDs can be further decomposed progressively into lower levels such as level-2 and level-3 DFDs by providing more detailed information about the various elements contained in the system. So at each lower level of abstraction more detail is provided, but only covers part of the overall system by investigating the details of a specific process from the level above.

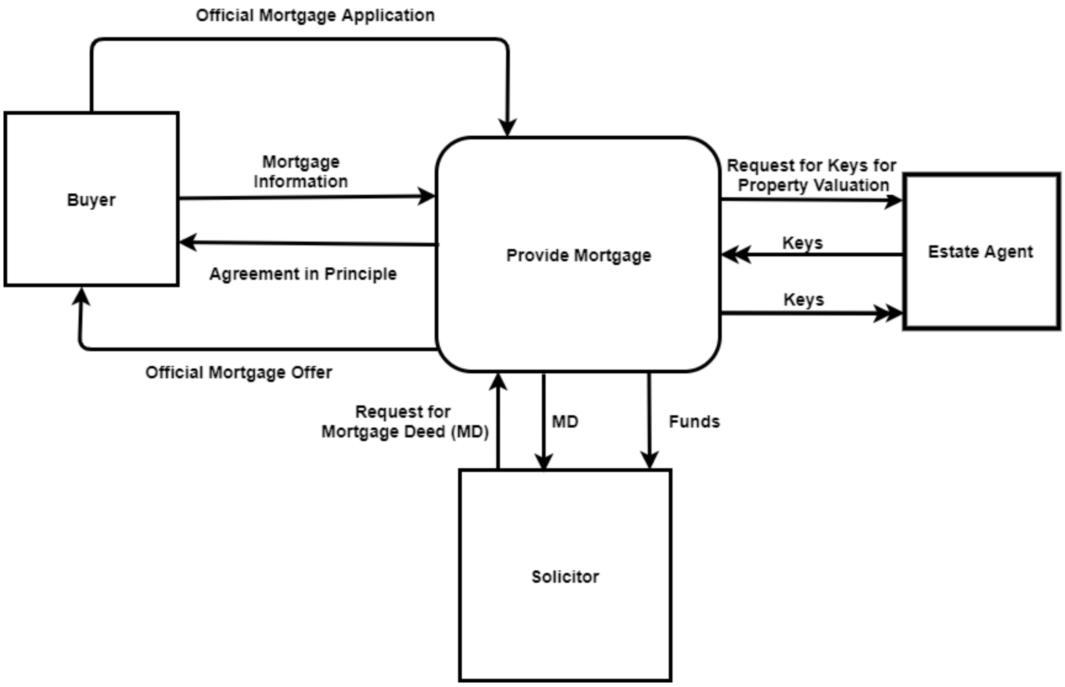


Figure 17: Context Level (Level 0) DFD for Getting a Mortgage

A level 1 DFD is illustrated in Figure 18 containing more detailed information about the processes and the flow/transformation of data in the system. To progress to a level 2 DFD, each process in the level 1 diagram is further decomposed into more processes. For example; Process 1 – Process Mortgage application could be decomposed into 2 processes: 1) validate information provided by the buyer, and 2) carry out credit checks.

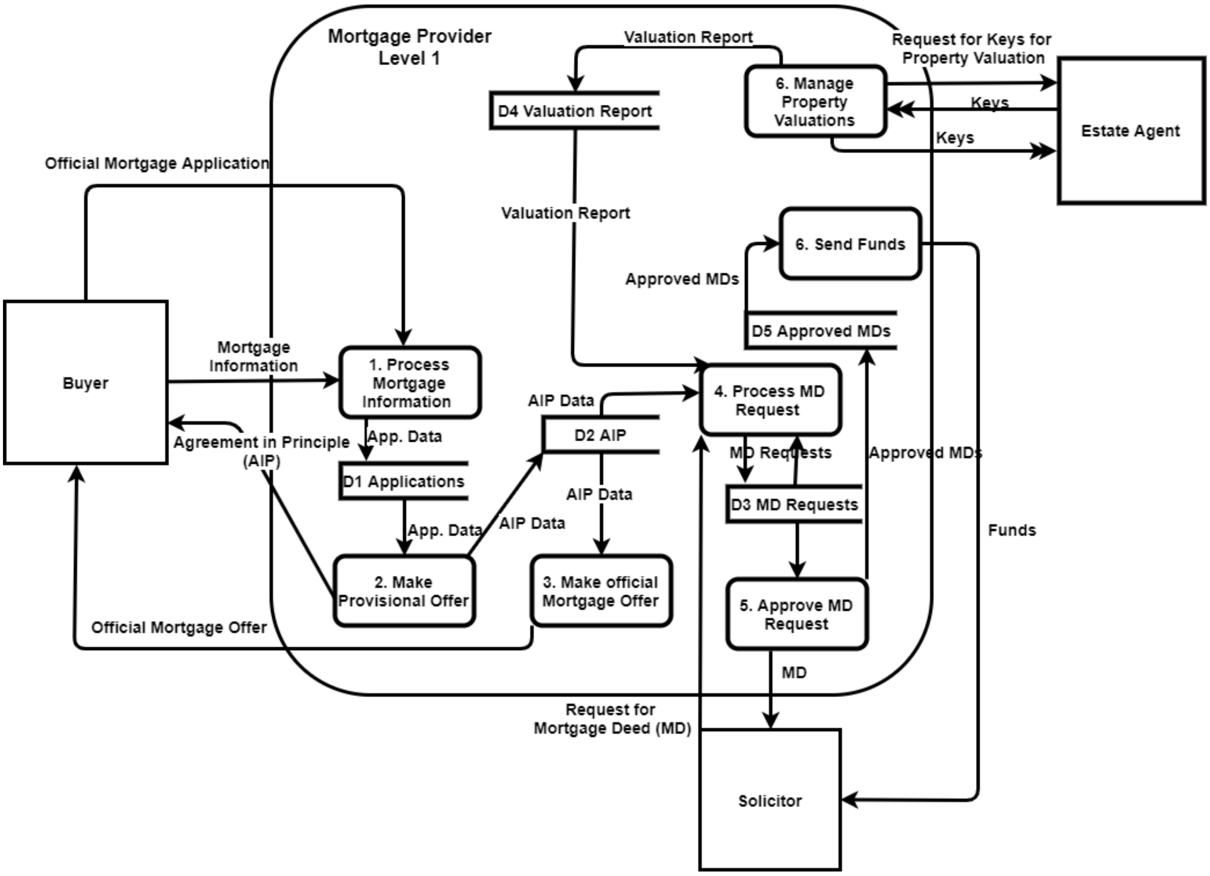


Figure 18: Level 1 DFD for Getting a Mortgage

Reducing a level-2 DFD to a context level DFD offers some benefits such as the scope and boundaries of a system are displayed at a glance, no technical knowledge is required to understand the system and it can enhance communication between stakeholder, analysts and developers (Adams, no date).

These levels of abstraction approach is adopted in this project to move from a low-level detailed business process model to a high-level network structure where some elements in the process model are removed. We present an algorithm for reducing a process model to its basic structure (projective space) for analysis:

I. Activities become nodes, and information flows (message flows) and material flows become links. Initially gateways were regarded as nodes when the rules were first created, and the corresponding network analysis data was generated. Some nodes turned out to have the lowest degree centrality or betweenness centrality (which could be an indication of redundancy and should be eliminated). If such nodes happen to be a gateway that implies that the gateway should be eliminated. This does not seem accurate; therefore, gateways are not considered as nodes because they are simply not activities. Gateways are decision controls that determines the logical flow of the system, such level of detail is not considered in a network analysis. The type or presence of gateways is measured using Control Flow Complexity (CFC).

II. Identify the right level of Analysis because business processes can be analysed at different levels such as (Hassan, 2009):

a. Individual level: analysis is based on a node and its relations
b. Dyad: Relationship formed by a pair of nodes
c. Triad: Relationship among three nodes
d. Complete Network: Relationship between all the nodes in the network. This is our preferred level of analysis.

III. Gateways, Pools and Lanes details are not considered because there are no elements in network diagrams to represent these. In addition, the reason for the reduction is to reduce the complexity of the process model and only consider the activities and the interactions between them.

IV. Notes, pictures or document links containing extra information are not included.

V. Sub-processes can be modelled as sub-networks but will not be considered in the main network.

VI. Decide on the type of relationship that exists between nodes. Nodal relationships exist in several forms such as directed, undirected and valued/weighted links. Using undirected relations in CNA keeps the analysis simple. In a directed network, the source and destination of the properties matter and the value of the properties may differ depending on which direction it takes.

In this thesis both directed and undirected links are investigated. The weight of the links represents the frequency of interaction. Since there is no relevant information on weight in the detailed business processes, this is not taken into account, therefore, the weighted projection (WP) will not be pursued further.

VII. Start and end nodes are not included.

VIII. Databases and other systems are not included.

4.4.2 Business Process Models and their Network Projections

In this section, we investigate which nodal relationship (directed or undirected) should be used when downscaling a process model. We present four business process models both the as-is and to-be processes for each which are: the clearing process model (original diagram) from our case study (section 6.1), along with models from research papers including a final thesis theme selection process model (Negin, Changizi and Kari, 2014), Intake Process model (Sánchez-González *et al.*, 2011) and an Incorporation of a new Employee process model (Sánchez-González *et al.*, 2017).

The process models are converted into individual network structures, creating both directed and undirected network versions which are analysed and the results compared to determine which nodal relationship should be adopted. All the process models obtained from other research papers were redrawn using Bizagi Modeller for better image resolution. The processes are presented below:

1) Business Process 1 (P1) – Clearing Process: This is the original case study considering how the student recruitment process into Higher Education might be improved to enhance performance. We provide both the as-is (Figure 19) and to-be (Figure 20) clearing process models.

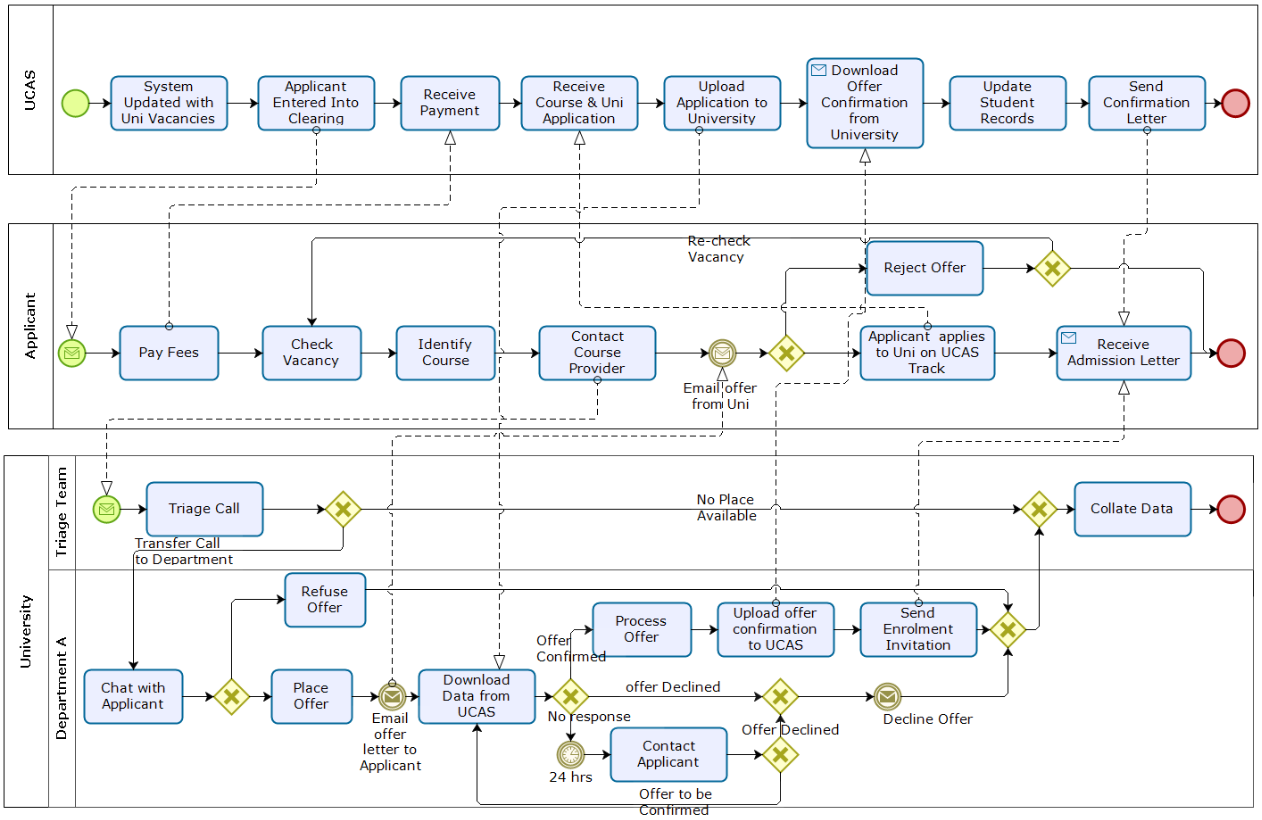


Figure 19: As-Is Clearing Process

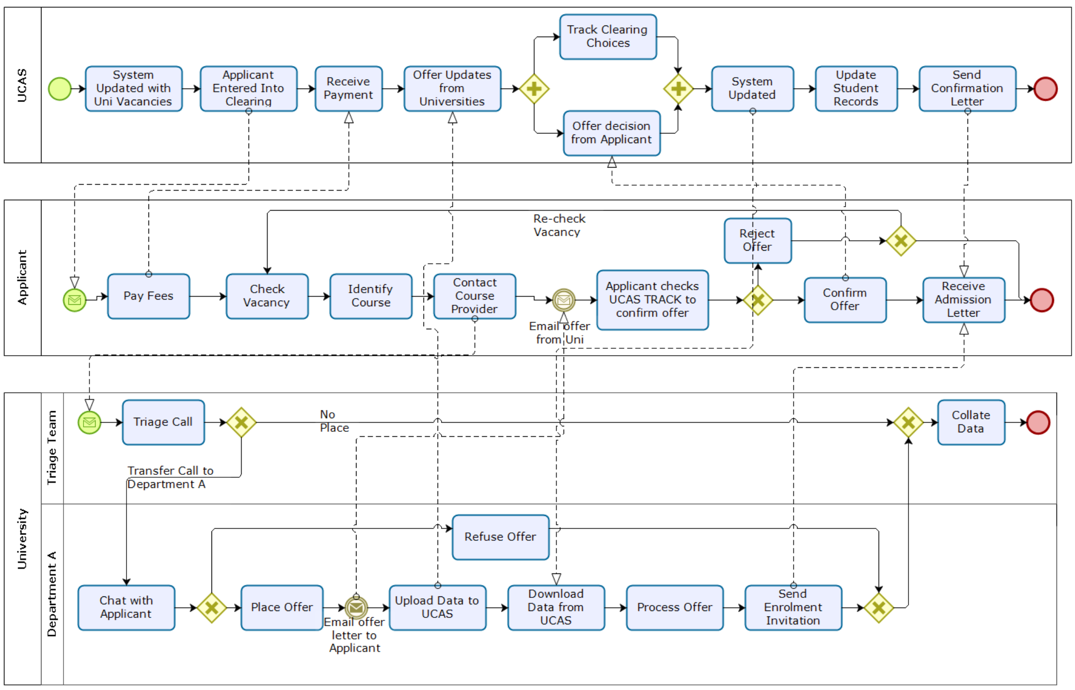


Figure 20: To-Be Clearing Process

2) **Business Process 2 (P2) – Final Thesis Theme Selection:** A business process capturing the process of nomination and selection of final thesis themes for undergraduate and graduate students (Vukšić, V.B., Bach and KatarinaTomičić-Pupek, 2014). The as-is (Figure 21) and to-be (Figure 22) process models are shown.

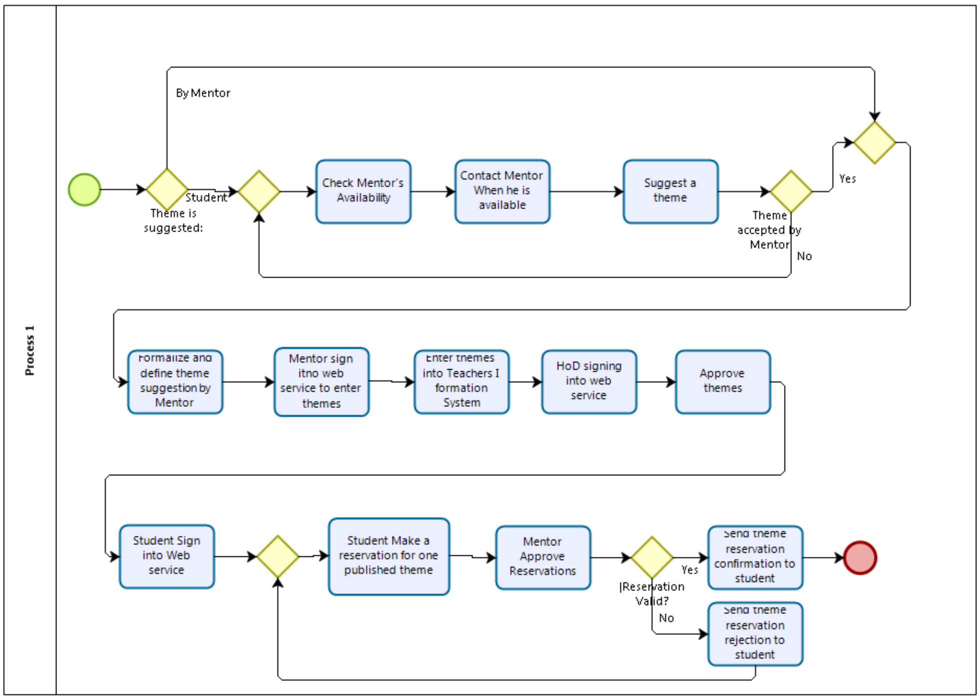


Figure 21: As-Is Final Thesis Selection (Negin, Changizi and Kari, 2014)

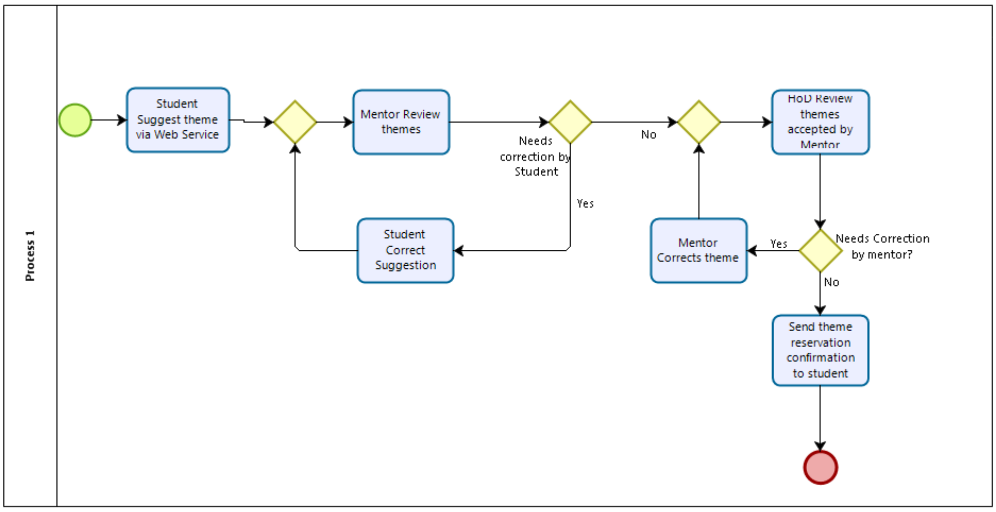


Figure 22: To-Be Final Thesis Selection (Negin, Changizi and Kari, 2014)

3) **Business Process 3 (P3) – Intake Process:** A process that receives notices from potential patients and assigns in-takers to them in order to determine treatment. The as-is (Figure 23) and to-be (Figure 234) process models are shown.

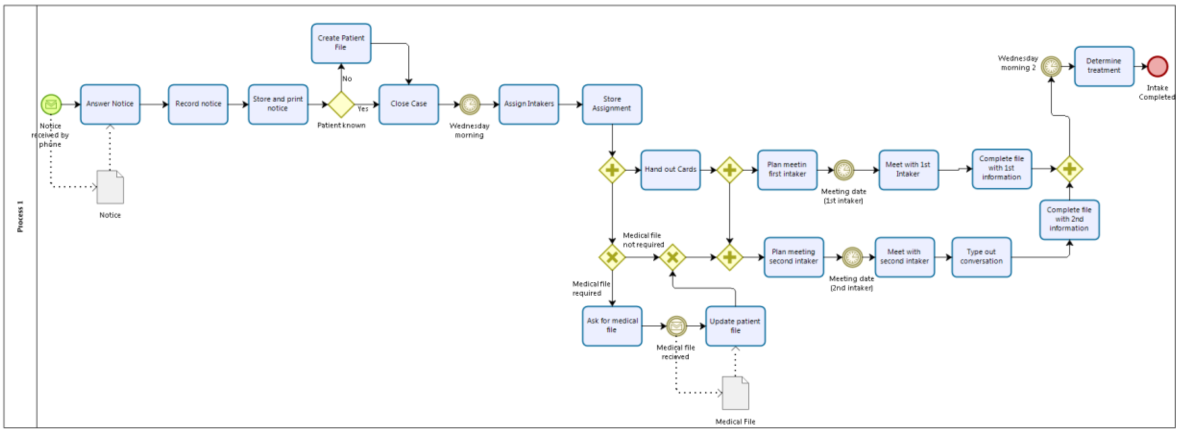


Figure 23: As-Is Intake Process (Sánchez-González *et al.*, 2011)

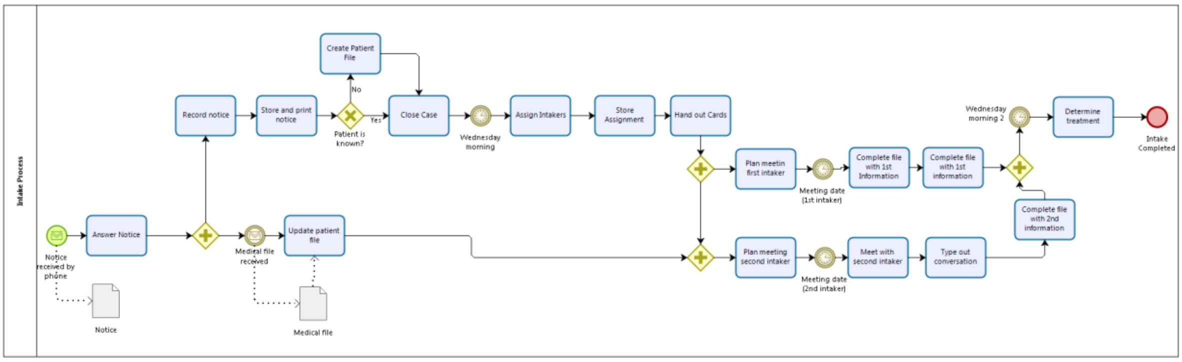


Figure 24: To-Be Intake Process (Sánchez-González *et al.*, 2011)

4) **Business process 4 (P4) – Incorporation of a new Employee:** This is an administrative process for incorporating a new employee to a General Hospital. The process includes the plan for training and adaptation, and the provision of relevant information for all personnel involved in the hospital to ensure that the new employer is welcomed and can be easily integrated into their new role. The as-is (Figure 25) and to-be (Figure 26) process models are shown below.

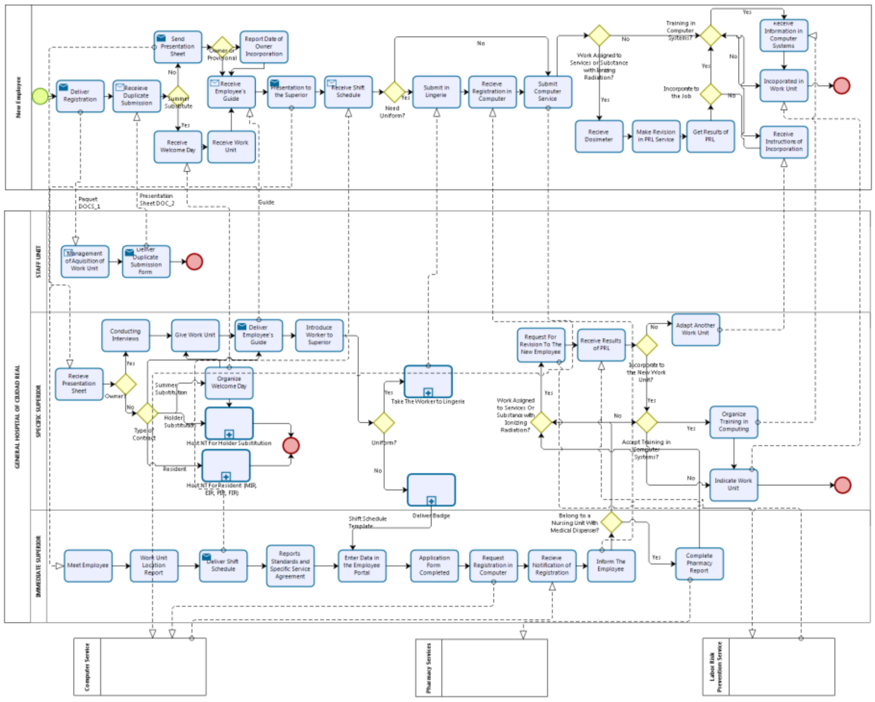


Figure 25: As-Is Incorporation of New Employment (INE) (Sánchez-González *et al.*, 2017)

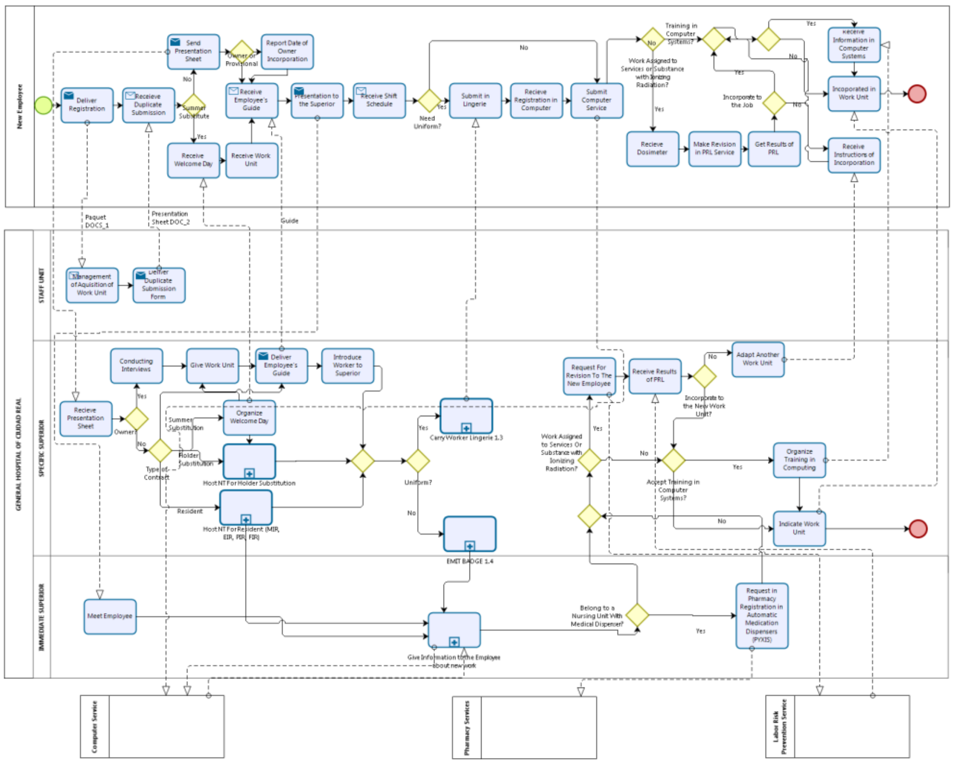


Figure 26: To-Be Incorporation of New Employment (INE) (Sánchez-González *et al.*, 2017)

All literature we consulted with regards to using complex network analysis used undirected networks because it appears to be more straightforward and simple to analyse (Hassan, 2009). We converted all business process (both as-is and to-be) to network projections using both directed and undirected networks making 16 projections. The networks were analysed, and measurements were compared to determine which is more accurate, this is discussed in a later section. The next section presents the choice of network analysis tools considered for this analysis.

4.4.3 Social Network Analysis Tools

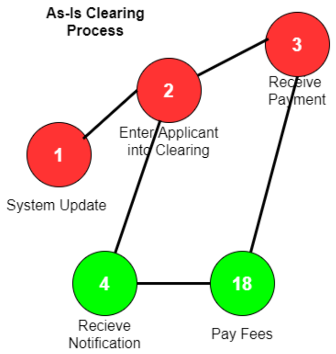
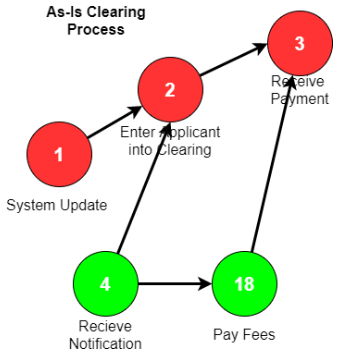
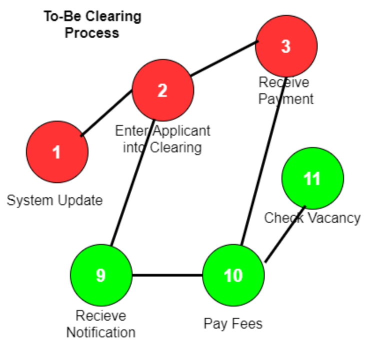
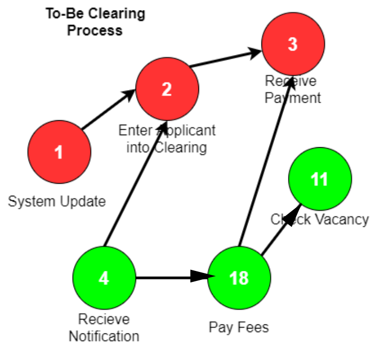
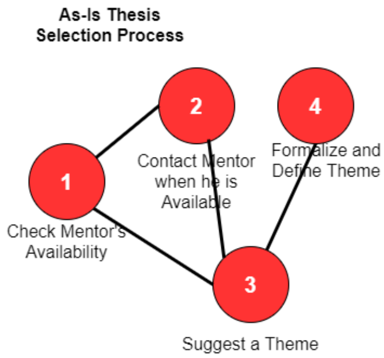
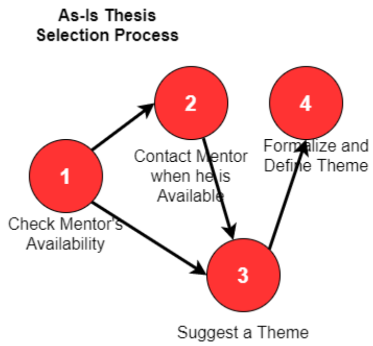
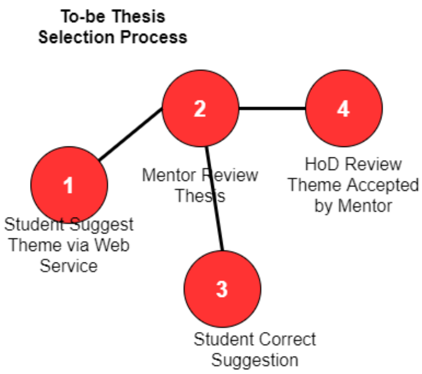
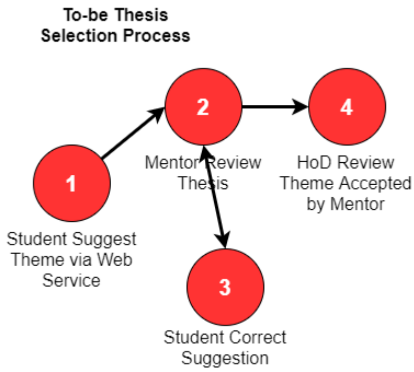
Three Network Visualization and Analysis software tools were investigated:

a) Commetrix: Commetrix was suggested by Levina (Levina, 2012). It is an explorative tool for dynamic network data. More information about Commetrix can be found on their website (*Commetrix*, no date). The software was not used because it was not available.
b) Social Network Visualizer (SocNetV): It is a free and open-source tool for social network analysis. It is available from (*Social Network Visualizer*, no date).
c) Gephi Graph Visualization and Manipulation Software: The software has various application such as Social Network Analysis, Exploratory Data Analysis, Link Analysis, Biological Network Analysis and Poster Creation. Further information about Gephi can be found at (Bastian, Heymann and Jacomy, 2009). Gephi version 0.9.2 was not built to create social networks but to import, visualize, spatialize, filter, manipulate and export all types of networks (Bastian, Heymann and Jacomy, 2009).

In this research, Gephi was used to visualize the networks created using SocNetV and to check if the data generated from the Gephi analysis matched those from SocNetV. The analysis data matched and the data was exported in excel format from Gephi.

4.4.4 Network Projection of four Business Processes

The network projection for each process is shown in the Table 5 but only shown as illustrative examples to made them readable. The complete versions are available in appendix 4. The coloured nodes simply show the nodes in the same BPMN lane.

<table>
<tr><th></th><th>Undirected Projection</th><th>Directed Projection</th></tr>
<tr><td rowspan="2">P1</td><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td rowspan="2">P2</td><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
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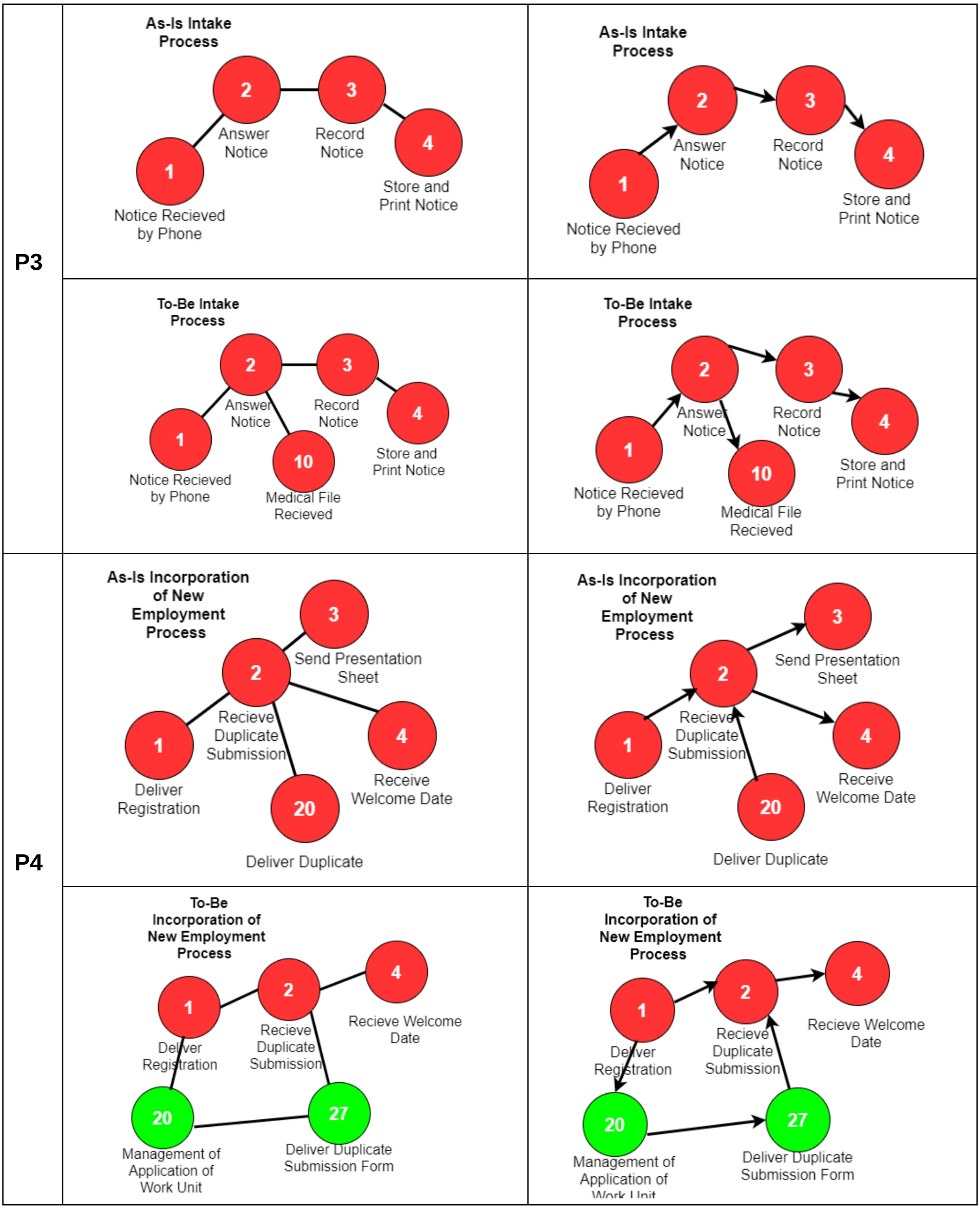


Table 5: Downscaled network versions of business process models

4.4.5 Data for Each Projection

The data for undirected projection is presented in Table 6 and the data for directed projection is presented in Table 7.

UnDirected	No of Nodes	No of Links	ADC	Betweenness Centrality			Closeness Centrality			Density	Diameter	Ave. Distance	Clustering Co-eff
Process Models				**Max BC**	**Min BC**	**Ave. BC**	**Max CC**	**Min CC**	**Ave. CC**				
P1 As Is	29	40	N 23 = 0.178 | 2.759	N 4 = 0.231	N 1 = 0	0.09	N 23 = 0.359	N 1 = 0.019	0.295	0.099	8	3.47	0.051
P1 To Be	30	40	N4 = 0.138, | 2.667	N 4 = 0.251	N 1 = 0	0.96	N 30 = 0.341	N 1 = 0.192	0.277	0.092	8	3.676	0
P2 As Is	13	14	N3 = 0.25| 2.154	N 7 = 0.546	N 1 = 0	0.3	N 7 = 0.308	N 12 = 0.179	0.243	0.18	10	4.269	0.333
P2 To Be	6	5	N2= 0.60 | 1,667	N 2 = 0.700	N 1 = 0	0.233	N 2 = 0.714	N 1 = 0.455	0.258	0.333	3	1.933	0
P3 As IS	20	22	N4= 0.158 | 2.2	N 8 = 0.543	N 1 = 0	0.19	N 8 = 0.322	N 1 = 0.144	0.236	0.116	11	4.416	0.088
P3 To Be	19	21	N2 = 0.167 | 2.21	N 9 = 0.418	N 1 = 0	0.171	N 9 = 0.340	N 17 = 0.205	0.262	0.123	8	3.912	0.093
P4 As Is	45	67	N21 = 0.136 | 2.978	N 9 = 0.374	N 6 = 0	0.082	N 9 = 0.306	N 19 = 0.154	0.226	0.068	10	4.528	0.121
P4 To Be	38	65	N32 = 0.189 | 3.421	N 32 = 0.244	N 5 = 0	0.08	N 8 = 0.33	N 19 = 0.173	0.265	0.092	9	3.871	0.189

Table 6: Data from undirected network projection

Directed	No of Nodes	No of Links	ADC	Betweenness Centrality			Closeness Centrality			Density	Diameter	Ave. Distance	Clustering Co-eff
Process Models				**Max BC**	**Min BC**	**Ave. BC**	**Max CC**	**Min CC**	**Ave. CC**				
P1 As Is	29	41	N23=0.107| 1.414,	N 23 = 0.15	N 1 = 0	0.064	N 8 = 28	N 27 = 0	4.28	0.051	10	4.47	0.03
P1 To Be	30	40	N2 = 0.068 | 1.333,	N 27 = 0.13	N 1 = 0	0.054	N 8 = 29	N 16 = 0	3.48	0.046	12	4.529	0
P2 As Is	13	14	N3 = 0.167 | 1.077	N 7 = 0.273	N 12 = 0	0.164	N 11 = 3	N 12 = 0	0.907	0.09	11	4.35	0.154
P2 To Be	6	7	N2 = 0.400 | 1.167	N 2 = 0.350	N 1 = 0	0.117	N 4= 2.5	N 6 = 0	1.001	0.233	3	1.824	0
P3 As IS	20	22	N4 = 0.105 | 1.1	N 8 = 0.246	N 1 = 0	0.086	N 18 = 19	N 20 = 0	3.247	0.058	11	4.542	0.042
P3 To Be	19	21	N2 = 0.111 | 1.105	N 9 = 0.175	N 1 = 0	0.075	N 15 = 18	N 17 = 0	3.234	0.061	10	4.144	0.044
P4 As Is	45	67	N21 = 0.114 | 1.489	N 41 = 0.094	N 1 = 0	0.035	N 17 = 44	N 18 = 0	4.17	0.034	15	5.186	0.058
P4 To Be	38	65	N21 = 0.135, 1.711	N 8 = 0.109	N 1 = 0	0.035	N 16 = 37	N 17 = 0	3.88	0.046	10	4.111	0.094

Table 7: Data from directed network projection

Comparing the data from both directed and undirected projections:

I. **Number of Nodes and Links:** In P1 the number of nodes in both projections is 29 but the number of links is not the same with more links in the directed projection, indicating that directed projection appear to be more information and accurate than undirected networks.

   Apart from P2 To-Be (whose number of links in the directed network are more than the number of links in the undirected network,) the remaining processes have equal numbers of nodes and links in both directed and undirected networks.

II. **Degree Centrality:** In the P1 As-Is, the node with the highest degree centrality in both projections is node 23 (Download Offer), indicating that it is a highly influential node. The average degree centralities of all the directed projections are lower than all the undirected projections indicating that the directed projections version appears to be less complex than the undirected contrary to findings in (Newman, 2010)**.**

III. **Betweenness Centrality:** We are interested in the node with the highest betweenness centrality because it gives an indication of potential bottleneck. The node with the highest betweenness centrality in the As-Is Clearing process (P1) undirected projection is Node 4 (Receive Uni Application) while that of the directed projection is Node 23 (Download offer)**.** Logically and visually, the download offer node appears to be more accurate as the biggest bottleneck indicating that directed projection gives more accurate data.

   For the P1 To-Be undirected projection, Node 4 (offer update) has the highest betweenness centrality, while for the P1 To-Be directed projection Node 27 (update system) has the highest betweenness centrality. Logically and visually, both nodes 4 and 27 would qualify for nodes with potential bottlenecks since they both have an equal number of inbound and outbound links.

   For the P2 As-Is undirected projection the node with the highest betweenness centrality is Node 7 (HoD signing into web service) and for directed network it is equally Node 7, there is no difference.

   For the P2 To-Be undirected network it is node 2 (Mentor Review Themes), and P2 To-Be directed network it is node 2 (Mentor Review Themes), again there is no difference.

   For the P3 As-Is undirected projection, it is node 8 (Store Assignment), and for the P3 As-Is directed projection, it is also node 8 (Store assignment), no difference.

   For the P3 To-Be undirected projection it is node 9 (Hand out Cards), and for the P3 To-Be directed projection it also node 9.

   For the P4 As-Is undirected projection, it is node 9 (Receive Shift Schedule), and for the directed projection it is node 41 (Application form completed).

For the P4 To-Be undirected projection it is node 32 (Give information to the Employee) and for the directed projection it is Node 8 (Presentation to the Superior). Logically and visually speaking, node 8 appears to be more accurate because it is the linking point between three clusters.

IV. **Density**: The network density is the proportion of links present in the network to the maximum number of links possible. The density of the network is often interpreted as the level of connectedness or cohesion of the nodes. The lower the density the higher the modifiability or flexibility of the process. The densities of all the processes in the modelled directed network are lower than the densities in the modelled undirected network implying that they have higher flexibility or modifiability.

V. **Diameter:** The higher the diameter, the more the complexity of the network. The diameters of the modelled directed networks are higher than the modelled undirected network except P2 To-Be and P3 As-Is. The data gathered shows that directed projections are less complex than the undirected.

VI. **Average Distance or Average Path Length:** Average distance or average path length indicates the effectiveness of information transport. The figures of the average distance of all the processes in the directed projection are higher than the undirected which means that the directed network is more distributed.

Based on the above analysis, a directed network projection has more information, more distributed, less complex, more flexible, and gives a better indication of bottle neck area than an undirected network projection. Therefore, a directed network projection will be used to measure the improvement between the as-is and to-be processes.

Furthermore, we believe that the directed network approach is more accurate because the interaction between two activities in a business process is directed. The next section presents the measures for the 4 business processes using directed network data.

4.5 Using Directed Network Data to Analyse the 4 Business Processes

1. **Size:** One of the ways to determine the size of a network is to consider the number of nodes. Grun and Laue (Laue, no date) used the idea of "lines of code" count in software to represent program size. They argue in favour of the "number of activities" as a measure for the size of a BPM. Fernandez-Ropero et al. (Fernández-Ropero, Pérez-Castillo and Piattini, 2013) used the number of nodes in a business process model to measure its size; the higher the size the higher the complexity of the business process model (Mendling, Reijers and van der Aalst, 2010). It is safe to say that size is directly proportional to the complexity of the business process. The comparisons between the as-is and to-be processes in terms of size are shown below:

I. **Clearing process:** There is no significant difference in the size of the as-is and the to-be processes.

II. **Thesis Theme Selection process:** The number of nodes in the to-be process reduced significantly indicating a reduction in the complexity of the process.

III. **Intake Process:** There is no significant difference in the size of the as-is and to-be processes.

IV. **Employment process**: The size of the to-be process is significantly lower than the as-is process indicating that the complexity of the to-be process is reduced.

2. **Betweenness Centrality:** With betweeness centrality the most influential node is identified i.e. the node that has the greatest control over the network.

    I. **Clearing process:** Node 23 (Download Offer) in the As-Is process has the highest betweenness centrality while in the to-be process, it is Node 27 (Update System). Both Download Offer and Update System nodes are both potential bottleneck nodes.

    II. **Thesis Selection Process:** Node 7 (HD Signing into web service) has the highest betweenness centrality in the as-is process while in the to-be, it is Node 2 (Mentor Review Themes).

    III. **Intake Process:** Node 8 (Store Assignment) has the highest betweenness centrality in the as-is process while it is Node 9 (Hand out cards) in the to-be process.

    IV. **Employment Process:** Node 41 for as-is (Application form submitted), Node 8 for to-be (Presentation to the superior).

To avoid or resolve bottlenecks in these nodes the capacity or resources of these nodes should be increased. This will help reduce queue time.

Network Projection	**Lowest ABC**	**First Activity**	**Last Activity**
P1 As-Is	N28 (Contact Applicant), N16 (Receive Admission Letter)	N1 (Update System)	N27 (Collate Data)
P1 To-Be	N16 (Receive Admission Letter)	N1 (Update System)	N26 (Collate Data)
P2 As-Is	-	-	N12 (Send theme reservation confirmation)
P2 To-Be	-	-	N6 (Send theme reservation confirmation)
P3 As-Is	N5 (Create Patient File)	N1 (Notice Received)	N20 (Determine treatment)
P3 To-Be	N5 (Create Patient File)	N1 (Notice Received)	N20 (Determine treatment)

P4 As-Is	N6 (Report Date of owner Incorporation), N18 (Incorporate in Work unit), N27 (Host for Substitute), N28 (Host for Resident)	N1 (Deliver Registration)	N45 (Complete Pharmacy report)
P4 To-Be	N5 (Report Date of), N16 (Receive Information), N17 (Incorporate in Work unit), N33 (Request in Pharm), N37 (Organize Training)	N1 (Deliver Registration)	N38 (Indicate Work Unit).

Table 8: Nodes with Lowest Betweenness Centrality

The Betweenness Centrality can also be used to identify potential non-value adding activities by considering the nodes with the lowest average betweenness centrality (ABC); usually they are all the nodes with zero values. It should be noted that first activity (after the start node) and last activities (before the end node) in a business process usually have 0 betweenness centrality when converted to a network, but it does not necessarily mean that these activities are unnecessary. The following nodes in Table 8 are potential non-value activities:

3. **Density:** The lower density of the to-be Clearing process indicate a slight increase in the modifiability or flexibility of the business process making it more efficient. Also the reduced density makes the to-be process less communication intensive and other processes/systems considered.
4. **Diameter:** The higher the diameter the more the complexity of the network. The results indicate the to-be clearing process is more complex than the as-is clearing process. The to-be processes of the clearing and hospital models have a higher diameter meaning increased complexity but it is not the same for the Intake and Employment processes. The lower diameters, especially with the employment process indicate that the complexity has reduced. It is observed that the size is directly proportional to density and diameter.
5. **Average Distance or Average Path Length:** An increased average path length indicates that a process is more distributed but less effective in information transportation. The to-be clearing process has a higher average distance making it less effective in information transportation. The same is applicable to the hospital process. However, the to-be processes of both the Intake and Employment models have lower average distances making their to-be processes more effective in information transportation.

We have not provided an analysis of the Clustering Co-efficient and Closeness Centrality since we are not sure of their interpretations with respect to business process.

4.6 Measures Selection

The measures in Table 9 are being considered for selection to measure the performance of the business processes and to check their relevance to satisfy our third research objective.

No	Measures	Description	Source	Quantifiable?
1	Understandability	Attributes of models that have an impact on the user's ability to recognize the logical flow and the applicability of the model. Understand ability is enhanced by less complexity.	[115]	Yes Using multiple metrics
2	Flexibility	The degree to which a model can be effectively and efficiently modified without introducing defects or diminishing quality.	[115]	Yes
3	Coupling	Defines the strength of the links between nodes	[113] [27]	No
4	Cohesion (Density)	The connectedness of the nodes	[113] [167]	Yes
5	Connectivity Level	Defines the strength of the links between nodes	[113]	No
6	Complexity	Same as understandability	[123] [11]	Yes
7	Activity, control flow, data-flow and resource complexity	Used to measure complexity of a BPEL service	[168]	No
8	Error probability	It was used to qualify the complexity of an EPC model. A number of factors can be used to determine the error probability such as the number of nodes, diameter, density, depth etc.	[169]	No
10	Structuredness	This thesis focusses on defining two metrics which quantify the different aspects of structuredness and unstructuredness for parts of a BP model	[28]	No
11	Diameter	Measures structural complexity	[11]	Yes

12	Size	It measures the number of nodes or activities in the model.	[167]	Yes
13	Accuracy and Operability	User satisfaction	[25]	No
14	Entropy	Measures the uncertainty or variability of workflow process models	[25]	No
15	Suitability	Data exchangeability between activities, ease of access, functional adequacy, functional completeness, IT usage by activities and functional accuracy.	[170]	No
16	Resource Behaviour (Cost)	Total Cost of execution, cost of resources and final productivity of the execution of the process	[171][25]	Yes
17	Quality	There are many other definitions of quality due to multi-dimensional perspectives. One definition is the degree to which a model does not have workflow errors or faults. This is difficult to quantify.	[25]	No
18	Cycle Time	Aggregation of setup time, wait, queue, process and some other time.	[172]	Yes
19	Modularity	The degree to which a process model is decomposed into several modules.	[167]	No

Table 9: Metric Selection Table

Based on the selected metrics in Table 9, we categorize the metrics into 5 aspects as shown on Table 10.

No	**Aspect**	**Metric**
1	Simulation	Cycle Time, Cost
2	Logical Complexity	Control Flow Complexity
3	Structural Complexity	Size (Number of nodes), Diameter
4	Structural Flexibility	Inverse of Density (Cohesion)

Table 10: Selected Metric Table

Our choice of performance metrics are Time, Cost, Complexity and Flexibility.

The next section provides some guidelines for improving a business process based on its structural properties

4.7 Rules/Guidelines for Improvement based on the network structure:

1) Reduce the number of nodes: This entails finding unnecessary or non-value adding node in the network. A way to identify potential unnecessary tasks is to consider nodes with the lowest average betweenness centrality. In the case of the as-is clearing process, it would be System Update, Receive Admission Letter, Collate Data and Contact Applicant. These nodes could then be further investigated to determine which one(s) would be the most redundant and then removing it from the system. This could be accompanied by considering heuristics such as by reducing or eliminating contact with third parties where possible (Improvement heuristics are discussed in section 6.5.1). This may not be always possible especially where information exchanges are inevitable but these contacts could perhaps be combined as suggested by Reijers (H.A. Reijersa; and S. Liman Mansar, 2005).

   Another heuristic would be to combine small activities into composite activities or sub-processes as in the case of the to-be employment process example where 8 tasks were combined into one. Another heuristic is to reduce the number of nodes by re-sequencing, i.e. re-ordering activities in a more practicable order as seen in the clearing process. Reducing the number of nodes will reduce the complexity of the process.
2) Reduce the density: Reduction in the density increases the flexibility of the process as identified in the clearing and hospital processes. This can be done by reducing the links in the network. Non-relevant information or material flows that do not perform any business logic in the organisation should be removed. This saves a considerable amount of time and cost, reduces complexity and increases flexibility. According to our data, size and density have an inverse relationship; that is, if the size decreases the density will increase and vice versa. The combining of small activities into a sub-process decreases the number of message flows as seen in the employment process. A network with a low density has the potential for automation (Levina, 2012).
3) Consider the average distance or path length. The higher the number of nodes, the higher the average path length which implies the process is a distributed process indicating that there may be less efficient information transportation. The heuristic to apply here would be the introduction of a document management system or cloud solution with access for all process actors. This can be seen in the clearing process where offers are uploaded to the cloud and the downloaded from UCAS when the system is updated. This would help improve the efficiency of the system.

4) Pay attention to nodes with the highest degree centrality or betweeness centrality: These nodes indicate areas for potential bottlenecks in the process. Therefore increasing the number resources will help reduce queue time, although this could translate into extra cost. Another heuristic would be to give workers more decision-making authority and reduce middle management, or engage the use of specialists to help speed up the process.
5) Reduce the diameter: The higher the diameter the higher the complexity of the model. An approach to reducing the diameter could be to combine small activities into composite activities. Another approach is to avoid using routing gateways in the process model if possible.

4.8 Conclusion

Complex network analysis metrics were applied to analyse the structural properties of business processes. An algorithm for projecting a business process into its network structure was defined borrowing the idea of moving between levels of abstraction as used in Data Flow Diagrams. In order to validate the algorithm and to determine which nodal relationship to be adopted when downscaling the process model, 4 business process models were investigated, each process had both the as-is and to-be versions making 8 process models in total. The process models were downscaled using the algorithm, considering both directed and undirected networks, and each model had both as-is and to-be projected states making a total of 16 projections.

The data obtained from the network analysis showed that the downscaled directed network was more accurate than the equivalent downscaled undirected network, making one of the unique contributions of this work. Therefore, given the evidence presented, we recommend whenever complex network analysis is used to analyse a business process model, directed networks should be used.

In summary, the outputs from this chapter are:

- Projection algorithm for downscaling a business process model fulfilling research objective No 5.
- Directed networks are preferred over undirected networks.
- A selection of quantifiable metrics to measure the structural complexity, flexibility and efficiency of a business process.
- Guidelines for process improvement based on the network structure.

CHAPTER 5

BUSINESS PROCESS IMPROVEMENT:

THE PROPOSED SNACH APPROACH

5.1 Introduction

It has been demonstrated in the previous chapter that a business process can be analysed and improved based on its structural properties by using complex network analysis. This chapter introduces the concept “act of improving a business process” and related works in this area. It then progresses to discuss the Mandatory Elements of a Method (MEM) and reviews research based and popular industry-based business process improvement methodologies. Finally, it presents our approach for business process improvement.

5.2 The act of Improving a Business Process

A process is said to be improved when there is positive change in the effectiveness and efficiency of the process (Harrington, 1991b; Damij *et al.*, 2008) evidenced by relevant improvement measures such as reduction in costs and time, reduced complexity, flexibility, quality, availability etc.

Damij et al (Damij *et al.*, 2008)presented the use of an object oriented methodology called TAD (Tabular Application Development). The methodology consists of six phases: 1) identify the business processes of the enterprise, 2) model the identified processes by developing an activity table using either a letter-oriented or symbol-oriented approach; 3) business process improvement (main interest) involving a team of knowledgeable and experienced employees to examine the activity table in order to suggest necessary changes and to find new ideas to improve the process. The phase concludes with process simulation via the execution of “what-if” simulation scenarios; 4) Object model development using the information collected in the tables; 5) Designing the system and preparing it for implementation; 6) Implementation of the models developed in the previous phases. Their approach focusses on both business process improvement and implementation of information systems that supports the improved business processes.

Reijers and Mansar (H.A. Reijersa; and S. Liman Mansar, 2005) defined 29 BPR heuristics that can support the improvement of business process in various industries and business processes. These heuristics are gleaned from literature and their qualitative evaluation is presented in terms of quality, flexibility, time and cost which can be used as a checklist by practitioners to justify their business process improvement. Although this work did not provide concrete evaluation of these heuristics against the above stated metrics. Furthermore, these heuristics are described textually but their description is not entirely consistent(Falk *et al.*, 2013).

Getting from the ‘as-is‘ process to the ‘to-be’ process requires gaining insight into the current process with the aim of finding process alternatives that need to be considered. A comprehensive methodical framework was created by Vanwersch et al (Vanwersch *et al.*, 2016a) which serves as a catalogue for process improvement use cases and a means for generating process improvement ideas. The framework contains six key methodical decision areas which are: a) Aim, b) human actors, c) the input, d) the output, e) the technique and f) the tool. These improvement ideas are still based on experience and creativity and did not provide any quantitative evaluation of the approach.

Kim et al. (Kim *et al.*, 2010) put forward a list of 16 business process change patterns which are based on the workflow patterns by van der Aalst et al (Aalst *et al.*, 2003). Their approach only deals with the control-flow perspective of a business process. Falk et al. (Falk *et al.*, 2013) presents a metamodel for BPI patterns for practical implementation of process improvement. The metamodel uses a repository of improvement patterns derived from literature and selection guidelines for identifying and selecting appropriate patterns. A follow up paper (Lang, M., Wehner, B., Falk, T., Griesberger, P., & Leist, 2015) shows an evaluation of the BPI pattern approach using case studies and validated by simulation. The BPI patterns used are not different from the BPI heuristics available in literature and there is no clear criterion or approach for appropriate heuristics selection.

Braun *et al.* (2005) discussed the scientific approaches to information systems research, appropriate conceptualizations of ‘method’ and ‘method construction’ including the Mandatory Elements of a Method (MEM). Zellner (2011) provided an evaluation of business process improvement methods and techniques (14 approaches in total) and their contribution to the actual act of improving the process and concluded that there is still a lack of support for the act of improving the process according to Mandatory Elements of a Method (this will be further discussed in the next section).

This work supports the evaluation of BPI methods according to Mandatory Elements of a Method because it is an analysis method that can be used to check if an approach is methodological supported, in addition its constituent elements have been endorsed by several researchers (Alt *et al.*, 2001; Baumoel, 2005; Braun *et al.*, 2005; Zellner, 2011).

5.3 Mandatory Elements of a Method (MEM)

It is widely agreed amongst BPI researchers and practitioners that the act of improving a business process is poorly supported (Sharp and McDermott, 2001; Forster, 2006; Vergidis, Tiwari and Maieed, 2008b; Vanwersch *et al.*, 2016a) partly because BPI is considered as an art than science (Gyngell, 2008). The solution to this challenge is to create or follow a method that supports the act of improvement. In order to methodically improve a process model, the goal must be clear and a systematic approach must be followed.

This methodical approach is provided by method engineering; a discipline that supports the design, construction and adaption of methods, techniques and tools for developing information systems (Zellner, 2011). A “method” is regarded as an approach that uses a specific technique consisting of a set of activities and rules structured in a systematic way to develop systems or products (Brinkkemper, 1996). The techniques are used as a procedure that enables the execution of activities such as design, creation, and the use of tools to create systems or some artefact.

The MEM elements address the issues surrounding the unstructured approach (i.e. lack of systematic approach) to improving a business process. The procedure model offers the opportunity to define step by step guide which would help practitioners not to mistakenly ignore important aspects of the improvement project. MEM can support the act of improving a process model using the elements described below (Zellner, 2011):

1. Procedure model: As mentioned earlier, there are many guidelines available in various methodologies but these guidelines are often unstructured or lacks a specific set of clearly defined steps. This is what the procedure model offers; a specific set of clearly defined steps or activities that if followed by BPI practitioners will help them to understand which tasks have to be performed and in what specific order.
2. Technique: Each activity tends to generate results and these results may be needed to support another activity within the improvement plan. Identifying the appropriate results to be produced and instructions for the creation of such results are needed during the execution of an activity. Such instructions or set of rules are referred to as techniques. In a nutshell, techniques are a set of rules which supports the activities and a way of generating the results.
3. Results: an artefact created by an activity e.g. documents, outputs etc.
4. Role: During the act of improving a process, the roles responsible for each activity should be identified i.e. the process owner.
5. Information model: The information model could be a set of repeatable steps or patterns such that if followed could help achieve repeatable or reproducible outcomes

since process improvement will always be a continuous task. It can consist of the above-described elements and their relationships. Information models are also used to represent the results.

5.3.1 Analysis of Selected BPI Methodologies Based on MEM

Zellner (Zellner, 2011) reviewed 14 BPI methodologies based on MEM, we decided to review other BPI (not BPR) methodologies based on MEM separate from the 14 already reviewed by Zellner. Table 11 shows a mixture of traditional/industrial and recent research based methodologies namely: Lean thinking, Lean Six Sigma, TQM, Benchmarking methodology, Plan-Do-Check-Act (PDCA), Kaizen, Methodical Framework for Generating Improvement Ideas, Tabular Application Development (TAD), BPI Patterns, Agile Business Process and Practice Alignment Methodology (BPPAM), AB-BPM (Business Process Management) methodology, Ubiquitous Decision-aware Business Processes and Object-Process Methodology (OPM).

Lean thinking (Womack, J. P., & Jones, 2000) focuses on identifying non-value adding activities and elimination of waste. It is built on five principles which aligns with the *procedure element* of MEM. Its second principle requires a *technique* for determining the activities that add value to the customer. R*oles* and *results* are not explicitly mentioned. There is no suggestion for *Information models*.

			MEM				
No	**Authors**	**Approach**	**Procedure**	**Technique**	**Role**	**Result**	**Information Model**
1	Womack and Jones (2000)	Lean Thinking	F	F	P	P	N
2	Bevan et al (2010)	Lean Six Sigma	F	F	P	P	N
3	Deming (1999)	TQM	F	N	F	N	N
4	Dragolea and Cotirlea (2009)	Benchmarking methodology	F	N	N	N	N
5	Sokovic et al (2010)	PDCA	F	F	N	P	N
6	Manos (2007)	Kaizen Methodology	F	F	N	P	N
7	Vanwersch et al (2016)	Methodical Framework for Generating Improvement Ideas	P	N	N	N	N

8	Damij et al (2008)	Tabular Application Development (TAD)	F	F	F	F	N
9	Falk et al (2013)	BPI Patterns	F	F	N	F	F
10	Martins et al (2017)	Agile Business Process and Practice Alignment Methodology (BPPAM)	F	N	N	F	N
11	Satyal et al (2019)	AB-BPM (Business Process Management)	F	F	N	F	N
12	Yousfi et al (2019)	Ubiquitous Decision-Aware Business Processes	N	F	P	F	N
13	Casebolt et al (2020)	Object-Process Methodology (OPM)	F	F	N	P	F
F: Fully accomplished or mentioned; P Partly accomplished or implicitly mentioned; N: Not accomplished or not mentioned							

Table 11: Analysis of BPI Methodologies based on MEM

Lean Six Sigma (Radnor, 2010) is a combination of lean and six sigma. It consist of five phases known as DMAIC which are Define, Measure, Analyse, Improve and Control. The improve phase relates to the act of improving a business process, as such it contains some techniques for process improvement such as brainstorming, theory of constraints, root-cause analysis etc. The results obtained are not explicitly mentioned since most of these techniques are qualitative in nature. A 'role' is not explicitly mentioned in the improvement phase. There was no mention of an information model.

TQM (Nwabueze, 2012) was created to improve quality management at every phase of business operation. It consists of 14 principles to be utilized by managers to drive quality improvement across all departments. There are elements of procedure and roles with regards to MEM but there is no explicit mention of techniques, results or information models.

Benchmarking Methodology is an approach to improve processes by comparing organizational processes and performance with competitor organizations with the aim of gaining competitive advantage, for budgeting and strategic planning. It comprises of 5 phases (Planning, Analysis, Integration, Actions and Maturity) and has a series of steps within each phase arranged in a certain order (procedure model). There is no mention of techniques, roles, results, or information models.

PDCA (Plan-Do-Check-Act) Methodology(Sokovic, Pavletic and Pipan, 2010) supports quality improvement on a continual basis. It lays emphasis on the planning phase (procedure model), which comprises of several analysis techniques (Cause and Effect diagram, Pareto diagrams, flow charts etc.) of what needs to be improved (Soković *et al.*, 2009). The check phase focusses on the control and measurement of processes (result) in accordance with changes made in previous steps, although the results are not quantitative. There is no mention of roles or information models.

Kaizen Methodology is geared towards continuous improvement. It is an approach that involves everyone in the organisation. It has 7 steps (procedure model) which are (Bhoi, Desai and Patel, 2014): Select Target Process, Create Team, Set Project Goals & Plans, Observe the Process, Analyse the Process, Create Improvement, Implementation and Presentation. Although, there are no specific or standard techniques for Kaizen, the following techniques have been used with it: 5 Whys, 5S (Sort, Stabilize, Shine, Standardize and Sustain), Poka-Yoke "Mistake Proofing" etc. Results are mentioned in the form of benefits but not quantitatively. There is no mention of roles or information models.

Methodical Framework for Generating Improvement Ideas (Vanwersch *et al.*, 2016b) is a framework for generating process improvement ideas. The framework consists of various categorizations of improvement frameworks under the following categories: Aim, Tool, Actors, Input, Output and Technique but does not suggest any specific approach to support the act of improvement.

Tabular Application of Development (Damij *et al.*, 2008) comprises of 6 phases as described earlier in section 6.2. The first phase identifies the business processes of the organisation, the second phase presents a new idea, the third phase defines ways to improve the business process, the fourth phase develops the systems object model, the fifth phase designs the system and the last phase implements the system. Each phase has specific steps (procedure model) and the methodology uses the term "entity" to define a user (role model) e.g. employer, customer, supplier or other system. Process analysis is carried out in the third phase where the simulation analysis technique is used (technique). The results are measured quantitatively in terms of cycle time. There is no explicit mention of information models.

BPI Patterns approach was introduced by Falk et al. (Falk *et al.*, 2013; Lang, M., Wehner, B., Falk, T., Griesberger, P., & Leist, 2015) as a means for identifying relevant patterns that can be applied to a business process to support the act of improvement. One of the benefits of process improvement patterns is that they are reusable instructions for achieving a desired result. Patterns can be seen as an information model that supports the act of improvement such that if a pattern is applied to another process within a similar context it will achieve similar results. The authors proposed a specification of BPI-Patterns in order to facilitate their reuse. Each pattern has a specific instruction (procedure model) to follow and apply to a specific problem. They also developed a technique for pattern selection. There was no mention of Roles in their approach.

Agile Business Process and Practice Alignment Methodology (BPPAM) was introduced by Martins and Zacarias (Martins and Marielba Zacarias, 2017) to discover changes in business processes, identify new opportunities, and reacting quickly to them. They argue that traditional business process methodologies follow strict action sequence but may not always responds quickly to dynamic organisations, therefore a need to adopt an agile approach.

Agile BPPAM as a hybrid approach encompasses three phases: 1) Business Process Discovery provides an initial process specification through interviews and collaborative methods; 2) Business Process Supervision assures daily practices are aligned with base business process models; 3) Business Process Assessment and Improvement (BPAI) serves as a mean for organisations to identify the strength, weaknesses, existing improvement activities and key areas for improvement. With regards to MEM, the procedure model is followed in the 3 phases, the results are gathered during assessments to enable improvements. There is no mention of technique, role and information model either implicitly or explicitly.

Satyal et al. (Satyal *et al.*, 2019) provide the AB-BPM (Business Process Management) methodology which offers process improvement validation in two phases: Simulation and AB tests. Their approach is intended to address the uncertainty of success that comes with the implementation of business process improvement projects (Holland and David Cochran, 2005). The AB-BPM approach extends the redesign, implementation, execution and monitoring phases of the business process life cycle with the aim to provide support for rapid validation of process improvement ideas.

The methodology comprises of the following steps (procedure model): 1) Define redesign goal and the Process Performance Indicators (PPI), 2) Design of the new version, 3) Simulation of the new version (version B) using data from old version (version A), 4) Compare the two versions and note the differences, 5) Advance to the AB testing stage if there are considerable differences between the two versions else the new version is further improved; 6) The PPIs are summarized in a numerical value that acts as a feedback or reward; 7) Both versions are deployed simultaneously and the best performing version is noted.

With regards to MEM, the steps depict the procedure model, there is an implementation of the simulation technique (technique) in the methodology, and the results of the PPI are captured in step 6 which represents the result model. However, there is no specific mention of the role model and information model in the methodology.

Yousfi et al. (Yousfi, Batoulis and Weske, 2019) propose an approach for BPI using Ubiquitous Decision-Aware Business Processes by setting a roadmap for automatic process improvement by taking advantage of contextual data generated in ubiquitous environments. Their argument is based on the inability of process improvement efforts to keep up with the considerable amount of data being generated in a dynamic and modern business environment. Therefore, a decision-aware business process have the ability to evaluate context and respond according by making decision on-the-fly on behalf of the participants.

The limitation of the approach is that it is not generalized, therefore, only applicable to some specific business processes (Yousfi, Batoulis and Weske, 2019). There are no specific steps or guidelines to follow to make the approach replicated in other process models, therefore lacking the procedure model and information models. Decision table technique is recommended in the decision logic level in the decision partition architecture. The role model is implicitly mentioned to capture the role of the participants. Result are implied in the to-be business process in terms of time and cost saving.

The Object-Process Methodology (OPM) is a conceptual modelling language and cross-system lifecycle methodology that uses visual modelling with auto-generated text-based language to build and validate a system. It is based on the ISO-19450:2015 Object-Process Methodology (Dori, Linchevski and Manor, 2010). The methodology has been applied across diverse industrial domains including software engineering, electronic consumer appliances and molecular biology.

When used as an approach to improve a business process, the following steps (procedure model) are followed (Casebolt, Jbara and Dori, 2020): 1) Decomposition: The process model is decomposed into its entities so that it can be evaluated. Each entity is identified as either a process or an object; 2) Rationalization: The process entities (processes and objects) are separated into the operand objects (major objects transformed by the system), value-related objects and processes, and supporting processes and objects. The relationship between these entities are further rationalized; 3) Optimization: The operand objects, and value-related objects and processes are considered as entities that truly add value to the business while the supporting objects and processes are considered as nonvalue-adding entities, therefore, should be minimized or eliminated to maintain efficiency. Optimization occurs through any combination of one or more of the following actions: (i) delete, (ii) combine, (iii) reduce/simplify, (iv) automate, (v) offload/outsource, and (vi) upgrade.

With regards to MEM, the procedure model is identified and followed in the methodology as per the 3 steps. There is no particular technique or method applied in the selection of the value-related processes and objects in the rationalization stage; in addition, the selection is subjective to the views of the process analyst. There is a mention of an information model in form of the OPM meta-model for the problem solving process. Results are partially fulfilled in form of the improved process but not quantitatively. There is no mention of role.

The following section presents a technique for the construction of methods from method engineering.

5.4 Map Models for the SNACH Framework

We follow the map technique for method construction as suggested by (Henderson-Sellers and Ralyté, 2010). A map is illustrated as a directed labelled graph comprising of nodes and edges (Rolland, Prakash and Benjamen, 1999). The method construction process usually involves two elements: 1) Objectives to be satisfied i.e. goals (a.k.a. intentions), and 2) Strategy that suggests the way in which the goal can be achieved. The objectives are represented using nodes while the strategies are represented using edges. A method is constructed when a map technique is defined and followed. Furthermore, a method consists of small components known as fragments (atomic part of the method) and chunks (combination of fragments) which are contained in the adopted strategy (Henderson-Sellers and Ralyté, 2010).

Setting a 'method construction goal' is an objective that can be realised with various strategies while the choice of strategy is dependent on the situation. In our case, the map in *Figure 27* has two objectives: the first is 'Construct a BPI method based on MEM' can be accomplished with two strategies (Henderson-Sellers and Ralyté, 2010); (I) A method-based approach where an existing methodology is adapted and modified, or (II) From scratch. We adopted the 'From Scratch' strategy because no existing BPI method/methodology is capable of adequately supporting the act of process improvement based on MEM (from our analysis in section 5.3.1).

The second objective in *Figure 27*, '*Construct the SNACH Framework*' can be accomplished with one of three different strategies: (I) Assembly-based strategy, the fragments/method components already exist or can be abstracted from existing methodologies, (II) Extension-based strategy, the method fragments are obtained by using patterns already applied to existing methods and then extended, (III) Paradigm-based strategy, the method fragments are instantiated from a meta-model.

We follow the 'Assembly-based' strategy (*Figure 27*) because the method is requirement driven, that is to create a BPI method based on MEM. Since the fragments already exist, the choice of fragments is made based on the evaluation of business process modelling techniques (chapter 2), business process analysis techniques (chapter 2), and investigation of the complex network analysis (chapter 4), selection business process improvement measures (chapter 4) and business process heuristics (chapter 5). The selected fragments are integrated to form chunks, and finally, the assembled chunks (SNACH) are validated.

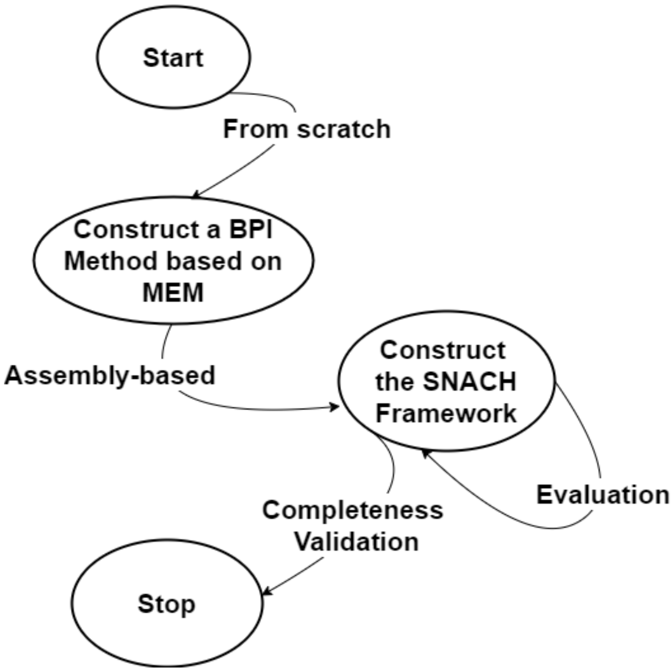


Figure 27 Modified Map Model for the SNACH Framework – Adapted from (Ralyté, Deneckère and Rolland, 2003)

The process is illustrated in the map shown in Figure 28. Aside the 'Evaluation' strategy, there are other strategies available for realizing the objective 'select fragment for the BPI Method', namely: 'by decomposition' and 'by aggregation' but they are not applicable to our case because there are no fragments to decompose or aggregate.

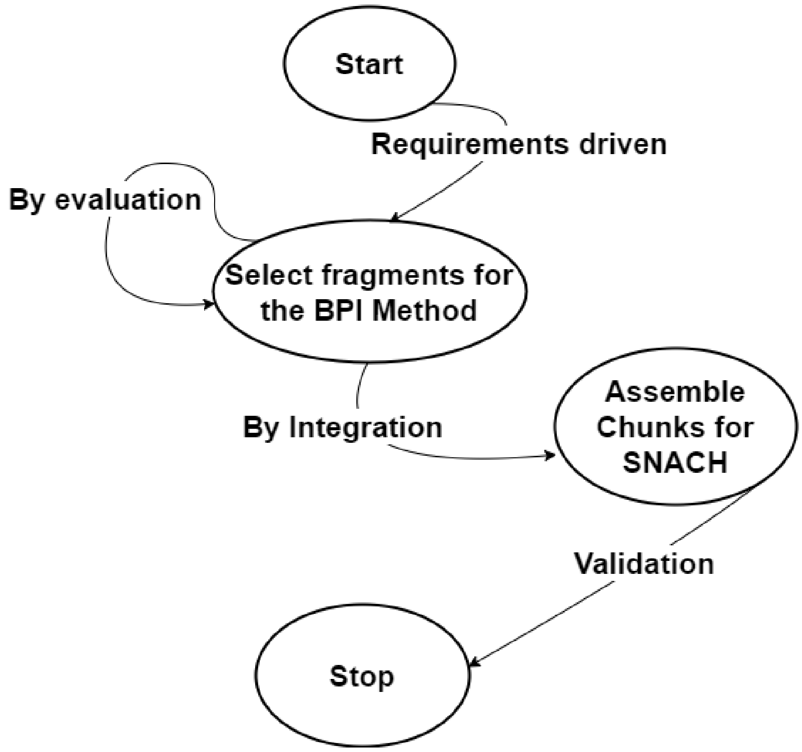


Figure 28: Assembly-based Model for the SNACH Framework – Adapted from (Ralyté, Deneckère and Rolland, 2003)

5.5 Constructing the SNACH Framework

Based on the discussions on MEM in section 5.3 and the above map models, we present our approach to business process improvement called Simulation Network Analysis Control and Heuristic (SNACH), a framework to support the act of process improvement with integrated measuring concepts. The objective is to construct the SNACH framework using an assembly-based strategy as described in the previous section. We use the elements of MEM as requirements for each stage in the framework where each stage contains method fragments intended to satisfy an element in MEM. The method chunks are assembled to form the SNACH framework as illustrated in *Figure 29*.

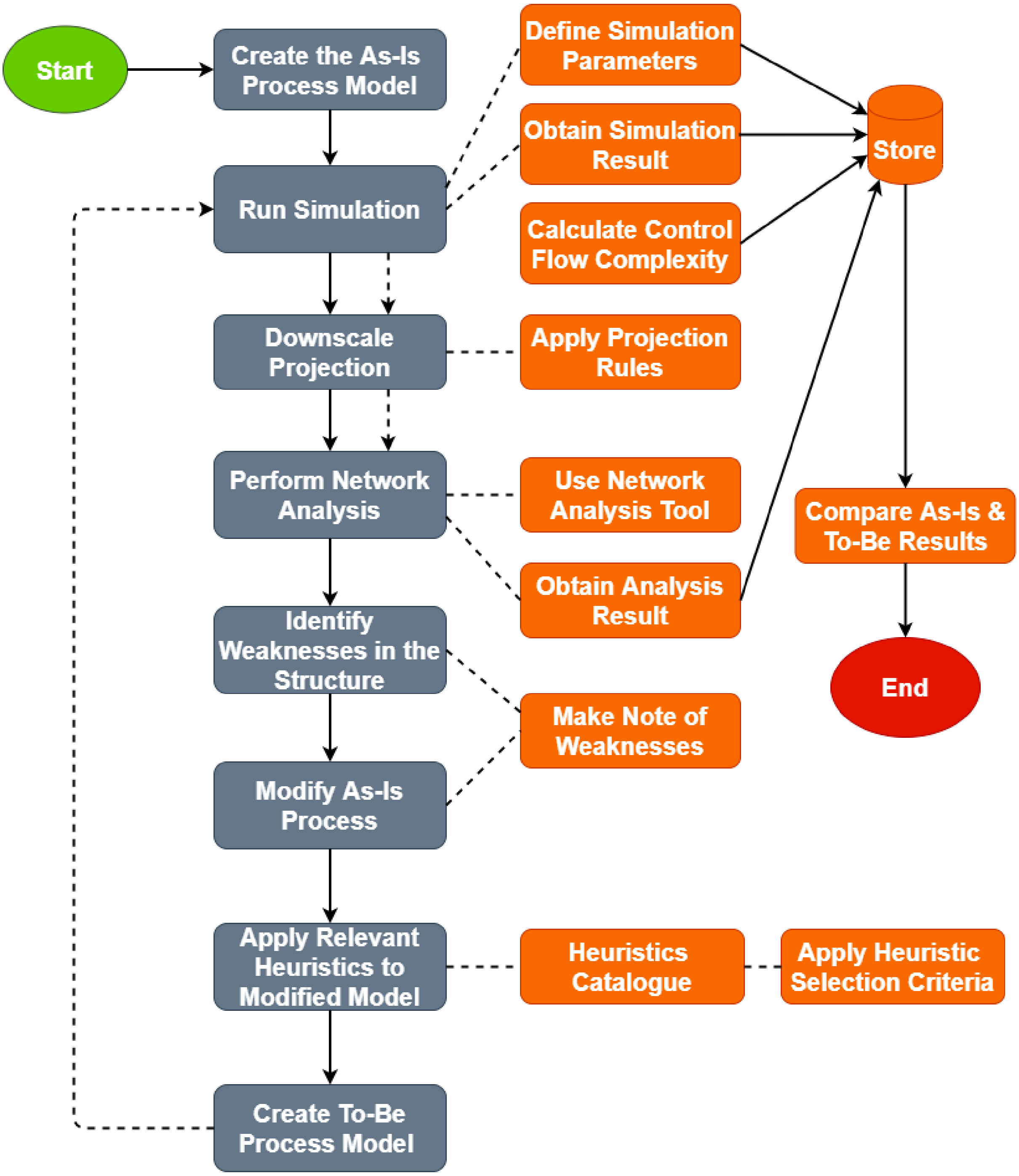


Figure 29: SNACH Framework

The following sections will discuss the method fragments of SNACH in terms of MEM i.e. procedure model, technique, role, result and information model.

5.5.1 Procedure model

The procedure model consists of eight phases:

1. **Create the as-is Process Model**

   This phase focusses on identifying the business processes in an organisation. Not all organisations have all their process modelled and analysed. It is therefore important to identify key processes that are of strategic importance to the organization's growth and continuity. To do this, management at different levels, process analysts and process owners have to meet to discuss these key processes and the ones that should receive urgent attention. These processes are identified and mapped out into a series of activities, this way a business process model is generated – a collection of logically related activities performed in a coordinated manner involving roles, resources and constraints to achieve predefined business goals.

   The very first step toward process improvement is to model the process using an appropriate modelling language, we favour BPMN based on our evaluation of business process modelling languages in chapter two. Modelling the as-is process may require several interviews with the key players, stakeholders, and everyone whose role will be captured in the model. The model should then be checked for validity and free from logical errors.

2. **Run Simulation**

   The next goal is to identify issues with the business process. The selection of the simulation analysis technique (fragment) is based on the evaluation of the process analysis techniques carried out in chapter 2. The simulation technique is selected due to its process validation and performance evaluation capabilities.

   The purpose of running a simulation is to carry out further analysis on the 'as-is' process with the objective of identifying run time weaknesses, and to identify areas for further improvements.

   The simulation of the process can be run by setting up multiple what-if scenarios to give an insight into the performance behaviour of the model. The following steps should be taken when simulating a process model:

   a) Load the process model into a simulation tool. A tool such as Bizagi Modeller has a simulation feature.
   b) Define the process simulation parameters and run the simulation
   c) Carefully analyse the simulation results

d) Make necessary changes to improve the process or to fine tune the model where possible
e) Return to (b) if changes have been made.

2.1 Process Model Metrics

It is important to store the details of the simulation parameters and the accompanying results as the same simulation parameters will be used for the to-be process and the results of both processes will be compared. The SNACH framework has provision for the storage of the simulation parameters and results. The broken lines (*Figure 29*) represent the link between each phase and their associated activities. The broken lines with arrow heads represent the movement of the to-be process within the framework.
The framework allows analysts to quantitatively measure any process model from 3 different aspects but in 4 dimensions (cycle time, cost, complexity and flexibility). The justification for the choice of metrics have been clearly laid out in chapter 4.
The 3 aspects are:

a) Simulation aspect: Quantitative measures that can be derived from simulations such as cycle time and cost. The results of the simulation of both the as-is and to-be processes are stored and compared.
b) Logical aspect: This considers the control flow aspect of the model by calculating the Control Flow Complexity (CFC) to measure the logical complexity of the process model. The CFC of both the as-is and to-be processes are stored and compared.
c) Structural aspect: This entails a complex network oriented approach to analyse the structural properties and measure the structural complexity and flexibility of the process model. The structural complexity is defined as the average of the size and diameter of the network while the flexibility is defined as the inverse of the network density. The analysis is performed in phases 3 and 4 of the framework and the results are stored for comparison.

As implied above, we consider complexity from two facets namely; logical complexity and the structural complexity. This is because the logical complexity only takes into consideration the decision nodes within the process model but does not give any information about the structural complexity. The logical complexity is determined by the control flow complexity (CFC) of the model which is the sum of all the split AND, XOR and OR gateways. The structural complexity is determined by the average of the size and diameter of the network abstraction of the model.

The formulae for the CFC is:

$$cfc\ (bp) = \sum_{AND-split} \mathrm{CFC}\ (\mathrm{C}) + \sum_{OR-Split} \mathrm{CFC}\ (\mathrm{C}) + \sum_{XOR-Split} \mathrm{CFC}\ (\mathrm{C})$$

Where AND-split = + n, XOR-Split = + n, OR-Split = 2^{n-1}

The formulae for the structural complexity is defined as:

$$(s + d)/2$$

We define the formulae for the overall complexity as:

$$C = \frac{cfc + (\mathrm{s}+\mathrm{d})/2}{2},$$

Where cfc = control flow complexity, s = size, d = diameter

These measures are determined by downscaling the process model. The next phase describes this process.

3. **Downscale Projection**

   This reduces the business process model to its basic structure i.e. to a network based on projection rules. These rules or algorithm were defined in section 4.4.1:

   I. Activities become nodes, and information flows (message flows) and material flows become links.

   II. Identify the right level of Analysis because business processes can be analysed at different levels such as (Hassan, 2009):

   b. Individual level: analysis is based on a node and its relations
   c. Dyad: Relationship formed by a pair of nodes
   d. Triad: Relationship among three nodes
   e. Complete Network: Relationship between all the nodes in the network. This is our preferred level of analysis.

   III. Gateways, Pools and Lanes details are not considered because there are no elements in network diagrams to represent these.

   IV. Notes, pictures or document links containing extra information are not included.

   V. Sub-processes can be modelled as sub-networks but will not be considered in the main network.

   VI. Directed network is used to capture the links between nodes.

VII. Start and end nodes are not included

VIII. Databases and other systems are not included

4. **Perform Network Analysis**

   The downscaled network structure is analysed using a network analysis tool e.g. Social Network Visualizer (SocNetV). The results of the analysis are obtained and stored.
5. **Identify Weaknesses in the Network Structure**

   The weaknesses revealed by the analysis result are noted e.g. nodes posing as potential bottle neck areas, non-value adding nodes etc.
6. **Modify the As-Is Process Model Based on Identified Weaknesses**

   The as-is process model is modified based on the analysis results from both simulation analysis and network analysis techniques.
7. **Applying Relevant Heuristics to the Modified Process Model**

   The already modified process model is further modified by applying relevant improvement heuristics which are selected from a catalogue of heuristics using the heuristics selection process flow in Figure 30.
8. **Create the To-Be Process Model**

   The to-be process model is created and the model is fed back into phases 2-4. The results are obtained and compared with the as-is process models to measure the extent to which the to-be process model has been improved.

5.5.2 Technique

A technique is defined as a way of performing a development activity (Brinkkemper, 1996). It refers to the choice of approaches to support the above defined phases in the procedure model in order to create the improved process model. Three techniques are used to support the improvement activities and to generate results:

a) Simulation: Simulation technique provides a means to investigate a business process by obtaining an assessment of its current process performance (Abate *et al.*, 2004). The quantitative measures that will be taken into account are cost and time analysis.
b) Control Flow Complexity (CFC): This is the number of mental states that have to be considered when developing a process (Laue, no date). CFC is chosen over other complexity metrics because its validity has been verified via experiments. However, the limitation in CFC as described by Gruhn and Laue (Laue, no date) is that the number of possible decisions in a model does not give adequate information about its structure, such that two models may have the same CFC but one may be more difficult to comprehend more than the other because it has more depth and is less linear.

However, using social network analysis metrics take into account the structure of the BPM and can be used in conjunction with CFC metrics to overcome these limitations.

c) Complex Network Analysis: This provides a way to measure the structural composition of the process model after it has been converted to a network. The metrics to be considered in order to determine the structural complexity are the size and diameter of the network. The density of the network is used to determine the flexibility.

The technique (SNA, CFC and Simulation) entails a mechanism for generating results that are needed to proceed to the next step within the improvement procedure.

5.5.3 Results

There are two types of results to be considered: 1) The outcome of analyses (i.e. Process model metrics explained earlier in the Run Simulation phase), and 2) The artefact. In terms of the outcome of analyses, results are obtained from two phases in the procedure model – the 'Run Simulation' and 'Perform Analysis of the Network' phases. In the 'Run Simulation' phase, simulation is performed on both the as-is process model and the to-be process model, results are obtained in the form of time and cost. In addition, the control flow complexity (CFC) of the models (as-is and to-be) is calculated. In the 'Perform Analysis of the Network' phase, the downscaled versions of the business process models (as-is and to-be) are analysed and the results are obtained in the form of structural complexity (average sum of the size and diameter of the network) and flexibility (inverse of the network density). The outcomes of both models (time, cost, complexity and flexibility) are compared to determine the extent of the improvement in the to-be process model. In terms of the artefact, the to-be business process model is considered as the result.

5.5.4 Role

The role relates to identifying roles and their functions, usually obtained from interviews, observations and understanding of the organisational structure and strategy (Negin, Changizi and Kari, 2014). Some new roles may need to be defined or existing roles replaced with a new one. The role helps to identify the process owner in order to validate the process activities. The SNACH framework contains a catalogue of 29 heuristics that need to be assessed by the process improvement analyst and perhaps in consultation with stakeholders in order to determine which heuristic is applicable to further improve the business process. The improvement heuristics are presented in section 5.6.

5.5.5 Information model

The information model consists of all the activities mentioned above and how the results are presented. The information model as shown in figure 45 shows the relationship between all the elements, the respective outputs at the end of each phase and activities involved in the framework. The information model can assist practitioners and researchers because it gives a clear overview of all the activities and their relationships (Negin, Changizi and Kari, 2014). The information model consists of the blueprint of the results which describes the various parts and the relationships between them.

5.6 Improvement Heuristics Analysis

We present an algorithm for selecting an appropriate heuristic from process improvement best practices suggested by Reijers and Mansar (H.A. Reijersa; and S. Liman Mansar, 2005). These best practices turned heuristics are derived from experience gained within big corporations and with consultants involved in BPR projects. A heuristic is defined as an approach to help someone to solve problems on his or her own by evaluating possible answers or solutions or by trial and error (Dictionary.com, no date). These 29 heuristics are applicable within the context of business process irrespective of the domain. They should be taken as guidelines that can support practitioners or analysts to implement an improved business process. As suggested by Reijers and Manser (H.A. Reijersa; and S. Liman Mansar, 2005), the heuristics should be embedded within the adopted business process redesign methodology. In our case, the heuristics are embedded as method chunk within the SNACH framework.

5.6.1 Analysis of Heuristics

The heuristics are analysed within the context of modelling language and modelling perspective in direct application to a practical case study, in our case we use the UK HEI admissions clearing process (figure , the clearing case study is presented in the next chapter). The choice of heuristic is obviously dependent on the business domain, the modelling technique and the business process perspective. The flow chart in Figure 30 shows the process for the choice of heuristic based on activity oriented modelling technique, operational and control perspectives within the clearing process.

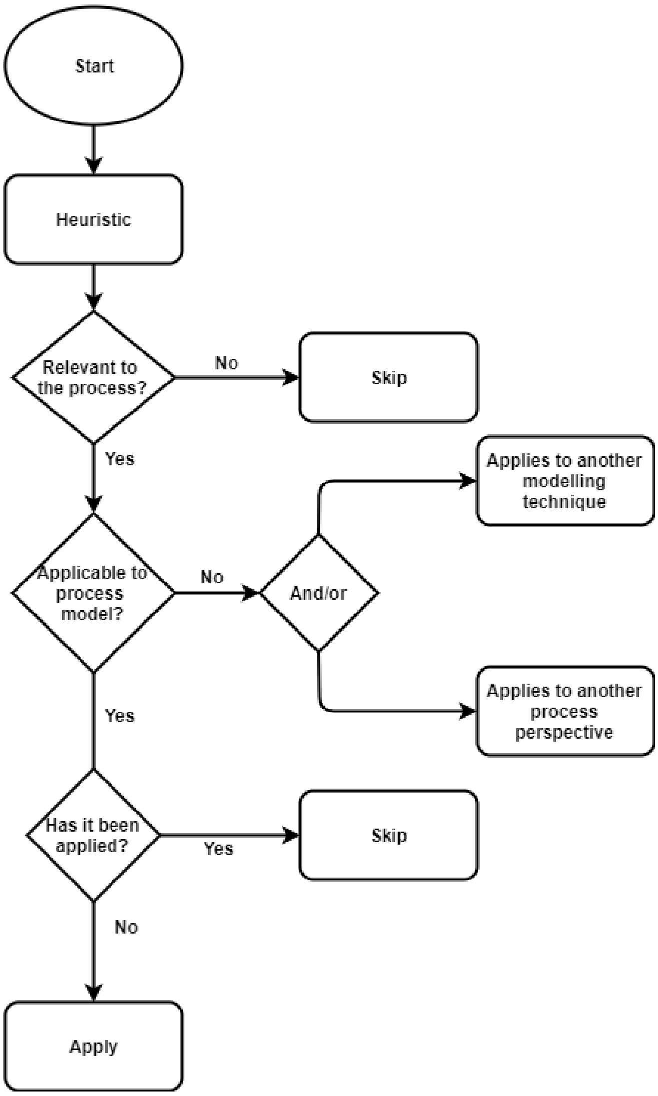


Figure 30: Heuristic Selection Process flow

Some heuristics may be relevant to a business domain but may not be applicable to other process perspectives, for example a heuristic that is concerned with making organisational changes is relevant to the organisational perspective, but may not be relevant to the operational, resource or behavioural/control perspectives that are captured in the process model, therefore such heuristic may not actuate any changes to the as-is clearing process model (Figure 31).

Some heuristics are applicable regardless of the modelling technique used while some are not despite being relevant to the domain of interest, for example a heuristic that relates to a data-oriented modelling technique cannot be applied to improve the as-is clearing process model because the process model was created using a process-oriented modelling language.

On the other hand, if a heuristic is considered relevant and already applied, the heuristic is skipped. Finally, a heuristic is applied if it is relevant, applicable but yet to be applied to the as-is process.

The heuristics are grouped thematically in the following categories (H.A. Reijersa; and S. Liman Mansar, 2005) where each category encompasses the property the heuristic attempts to optimize:

i) Customers: The heuristics in this category focus on improving contacts with customers.
ii) Business Process Operation: Heuristics that focus on how to implement the workflow.
iii) Business Process Behaviour: Heuristics that focus on when the workflow is executed.
iv) Organizational Structure and Resource Allocation: Heuristics that consider both the structure of the organization i.e. the allocation of resources and the number/type of resources involved.
v) Information Creation and Usage: Heuristics related to the information the business process uses, creates, may use or may create.
vi) Technology Deployment: Heuristics practices related to the technology the business process uses or may use.
vii) External Environment: Heuristics that focus on how to improve upon the collaboration and communication with the third parties.

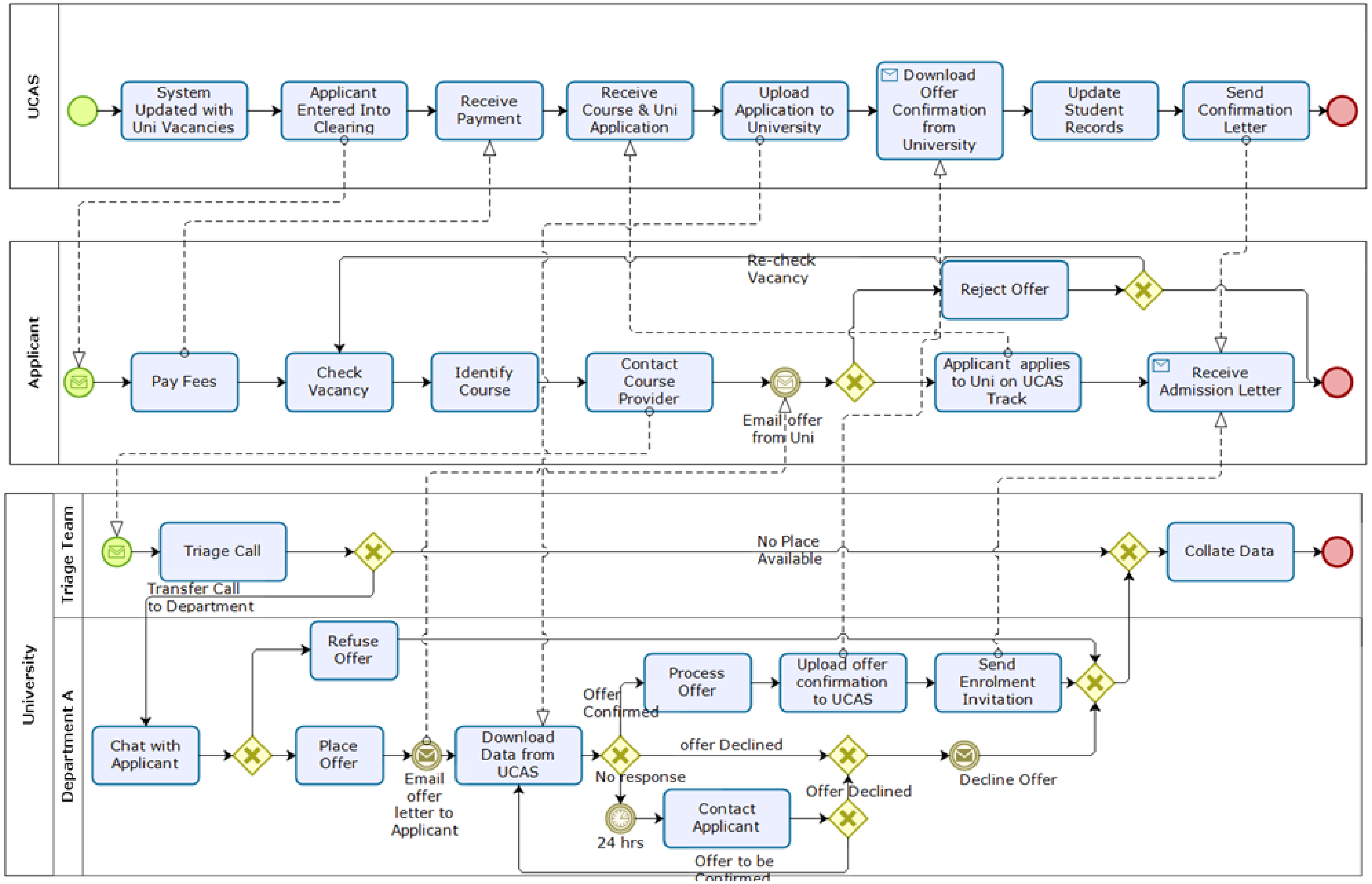


Figure 31: As-Is Collaborative clearing process between UCAS, Applicant and University

The 29 heuristics are presented below and summarised in Table 12.

5.6.1.1 Customer Interaction

1) Control Relocation: This entails moving some operational control that is part of the business process towards the customer. This can be implemented independently of the modelling technique used. In our use case (the clearing process case study), the applicant is given verbal confirmation of an offer which comes with three options; to either confirm the offer, reject the offer or give no response. In the case of no response, they will be contacted by the HEI via telephone. If control is moved towards the applicant, where an offer letter is emailed to the applicant and uploaded to UCAS TRACK system, the applicant can either confirm or reject the offer, eliminating the 'Contact Applicant' activity (figure 29) and the TRACK system becomes more efficient. This heuristic is language independent and relates to the operational perspective of the business process, it is therefore considered relevant and applicable to the as-is clearing process model.
2) Contact Reduction: This entails reducing the number of contacts with customers and third parties. This is because the activity may not be beneficial and can be time-consuming. In the clearing process example, the 'Contact Applicant' activity is to be eliminated as explained in the 'Control Relocation' heuristic. The 'Contact Reduction' heuristic is considered relevant and applicable to the as-is clearing process model.
3) Integration: This entails the integration with a business process of the customer or a supplier. This heuristic is applicable where two or more partners have to collaborate on a service they jointly render. For example, the UCAS TRACK and university admission processes can be better integrated for a quicker exchange of data between the two parties. Integrated business processes should offer a more efficient execution, in terms of cost and time. The heuristic is aligned with activity-oriented notations and is related to operational, organisational and compliant perspectives of the business process. The heuristic is considered relevant and has already been applied, although the integration could be improved to increase the speed of data exchange.

5.6.1.2 Business Process Operation

4) Order Types (Task Separation): Determine whether tasks are related to the same type of order and, if necessary, distinguish new business processes. Some tasks in a business process model may not be related to the business process they are part of. The tasks should be separated and be included in a new business process. This

heuristic is relevant and already applied to the existing clearing process, for example the separation of accommodation and confirmation processes from the clearing process. The benefit of this heuristic is that it yields faster processing times and perhaps, less cost.

5) Task Elimination: Elimination of unnecessary tasks from the business process. A way to identify unnecessary tasks is to check if such tasks do not add value from a customer's point of view. This heuristic is considered relevant and applicable to the clearing process.
6) Order based work: Some orders are processed periodically and in a batch. This could be due to occasional availability of resources such as humans or computers. Removing this constraints can increase processing time but may be costly. This heuristic is relevant and applicable to the clearing process from the UCAS perspective, for instance; admission data is available to HEIs every two hours, making the data readily available can improve admission processing time.
7) Triage: This entails the division of a general task into more alternative tasks which would bring about improvement of the quality and better utilization of resources. This is relevant to the clearing process and has already been applied.
8) Task Composition: This is defined as combining small tasks into composite tasks and dividing large tasks into workable smaller tasks. The benefit of combining small tasks is that setup time is reduced. Conversely, large tasks could reduce flexibility and quality as tasks could become difficult to manage. A balance need to be struck between knowing how large a composite task can become. This is considered relevant to the clearing process and already applied in the 'Triage Call' activity, in that 3 different tasks are performed by the triage activity; 1) Check if an applicant meets entry requirement, 2) Confirms if space is still available, and 3) Transfer applicant to the relevant department.

5.6.1.3 Business Process Behaviour

9) Re-sequencing: This entails moving tasks to more appropriate places. In the as-is clearing process model, the 'Download Data from UCAS' activity precedes the 'Upload Data to UCAS'. These tasks can be re-sequenced in the to-be process model where 'Upload Data to UCAS' comes before 'Download Data from UCAS' because it is more logical and efficient for universities to upload (offers) to UCAS, applicants then confirms/rejects the offer on UCAS TRACK, before universities can Download (confirmation) Data from UCAS (already explained in section 4.5.2). This heuristic is considered relevant and applicable.

10) Knock-out: Some business processes have conditions that must be satisfied to deliver a desired result. If the conditions are not met that aspect of the business process may be knocked-out. This heuristic therefore advises removing “knocking-out” task(s) that require excessive effort to check their conditions. This is another type of re-sequencing or task elimination. For example, the effort required to check the number of applicants that are yet to respond to offers could be diverted to more productive tasks if that ‘checking task’ is knocked-out. This is considered relevant and applicable.
11) Parallelism: This considers whether tasks may be executed in parallel. The benefit of splitting tasks into parallel paths is that throughput time is reduced. This is can be implemented in the to-be clearing process from the UCAS perspective where ‘Tracking Clearing Choices’ and ‘Offer Decision from Applicant’ are carried out in parallel. This is considered relevant and applicable.
12) Exception: This is defined as designing business processes for typical orders and isolating exceptional orders from the normal flow. This is considered relevant to the clearing process and is already implemented in the as-is process model in that the Triage Team already does the task of separating applicants who do not meet the criteria and only transfer applicant who potentially meet the entry requirements. This is considered relevant and already implemented.

5.6.1.4 Organisational Structure and Resource Allocation

13) Order Assignment: Allows workers to perform as many steps as possible for single orders. This would mean that the resource assigned to this case will become familiar and would require less setup time. This is already implemented in the as-is clearing process where the staff involved in the process are trained to become familiar with the admission system and processes. This considered relevant but not applicable to improve the current process.
14) Flexible Assignment: Assign resources in such a way that maximum flexibility is preserved for the near future. For example, if a task can be executed by either of two available resources, assign it to the most specialized resource. This implies that the more general resource is available to execute another task. This is already applied to the as-is clearing process where academics have more specialized skills than the triage team, therefore, if a query comes from an applicant, the query could be transferred to the academic to free up the triage team. Since this heuristic is already applied, it is not applicable to improve the current clearing process.
15) Centralization: Treat geographically dispersed resources as if they are centralized. This implements the use of a Workflow Management System. This is already

implemented in the clearing process as UCAS and HEIs are in different locations, yet the UCAS Track system is centralized. This relevant and has already been applied.

16) Split Responsibilities: Avoid assignment of task responsibilities to people from different functional units. This is already implemented in the clearing process in that academics from various departments recruit specifically for their department. This is relevant but not applicable to improve the current process.
17) Customer Teams: Consider assigning teams out of different departmental workers that will take care of the complete handling of specific sorts of orders. This is already implemented in the process in that various people handle specific queries from applicants. For example, there are specific teams trained to handle calls regarding marketing, clearing, accommodation, and confirmation. This is an organisational based heuristic and already implemented.
18) Numerical Involvement: Minimize the number of departments, groups and persons involved in a business process. There are obvious arguments in favour and against this course of action. The benefit is that there may be less coordination issues. However, the downside is that reduced number of groups can reduce quality and cause delay. With regards to the clearing process, having more people especially at peak times will get the queue moving. This is not considered relevant nor applicable.
19) Case Manager: This entails appointing one person (case manager) as responsible for the handling of each type of order. The clearing process has managers overseeing various aspects of the process. The heuristic is considered relevant and has already been applied.
20) Extra Resources: If capacity is not sufficient, consider increasing the number of resources. This is relevant and applicable.
21) Specialist-generalist: Consider making resources more specialized or more generalist. This implies that resources can be transformed from specialists to generalists and vice versa. With regards to the clearing process, the academics (specialists) may be able to triage calls (generalist) but the triage team cannot perform the tasks for the academics, therefore, this heuristic is not relevant and applicable.
22) Empower: Give workers most of the decision-making authority and reduce middle management. This is already applicable in the clearing process where all academics involved in the process have the authority to make or refuse offers. This is relevant and has already been applied.

5.6.1.5 Information Creation and Usage

23) Control Addition: Check the completeness and correctness of incoming materials and check the output before it is sent to customers. This increases quality but will require

more time. This heuristic has already been adopted in the current clearing process in that members of the academic team confirm the correctness and completeness of data with applicant before making an offer, therefore, it is considered relevant and already applied.

24) Buffering: Buffer information by subscribing to updates instead of requesting it from an external source. Gathering information from external parties could take plenty of time causing delay in the process. This challenge can be tackled by subscribing to other reliable sources of information. In circumstances where the information is only available from one source, more resources could be made available to reduce queuing time when the information becomes available. This is not considered relevant to the clearing process because no information is required from an external source.

5.6.1.6 Technology Deployment

25) Task Automation: This increases throughput speed and reduces running costs, although the process of creating an automated system could be expensive. There are certain aspects of the clearing process that are already automated such as email generation. This is relevant, applicable and partly applied.
26) Integral Technology: Elevate physical constraints in a business process by applying new technology. A new technology can change the traditional way of executing business processes. For example, the use of cloud storage/sharing or a Document Management System can help improve storage and sharing of information. This is relevant and applicable to the clearing process; for instance, if students' data is available for immediate access then HEIs do not need to wait for 2 hours before the data is available for download.

5.6.1.7 Relationship with External Environment

27) Trusted Party: Engage the use of results of trusted parties to determine or verify information. This can be applicable when dealing with international applicants where NARIC (UK National Agency for the Recognition and Comparison of International Qualifications and Skills) validates and compares international qualifications and skills. This is considered relevant but is outside the scope of this work as international applicants are not considered, therefore not applicable.
28) Outsourcing: Consider outsourcing a business process in whole or part of it. This is not considered relevant or applicable.
29) Interfacing: Consider a standardized interface with customers and partners. This ensures compliance with policies and avoidance of mistakes or incomplete

applications. This is relevant and already applied to the clearing process from the UCAS perspective.

	BPR Heuristic	Heuristic Category	Modelling Language	Perspective	Relevant (R) Applicable (A)
1	Contact Relocation	Customer Interaction	Independent	Operational	R A
2	Contact Reduction		Independent	Operational	R A
3	Integration		Activity Oriented	Operational/Organisation/ Compliance	R A
4	Order Types	Business Process Operation	Activity Oriented	Operational	R A
5	Task Elimination		Activity Oriented	Operational	R A
6	Order Based work		Activity Oriented	Operational/Organisation	R A
7	Triage		Activity Oriented	Operational	R A
8	Task Composition		Activity Oriented	Operational	R
9	Re-sequencing	Business Process Behaviour	Activity Oriented	Operational/control	R A
10	Knock-out		Activity Oriented	Operational/control	R A
11	Parallelism		Independent	Operational/control	R A
12	Exception		Independent	Operational/control	R A
13	Order Assignment	Organisational Structure and Resource Allocation	Independent	Operational/Organisational	R
14	Flexible Assignment		Role Oriented	Resource/operational/organisational	R A
15	Centralization		Activity Oriented	Resources/Operational/ Organisational	R
16	Split Responsibility		Role Oriented	Organisational	R A
17	Customer Teams		Role Oriented	Organisational	R A
18	Numerical Involvement		Role Oriented	Organisational	-
19	Case Manager		Role Oriented	Organisational	R A
20	Extra Resources		Activity Oriented	Organisational/Operational	R A
21	Specialist		Role Oriented	Organisational	-
22	Empower		Activity/Role Oriented	Operational/Organisational	R A
23	Control Addition	Information Creation and Usage	Activity/Role Oriented	Operational/Organisational/ Compliance/Resource	R A
24	Buffering		Language Independent	Operational/Organisational	-
25	Task Automation	Technology Deployment	Activity Oriented	Operational/Resource	R A

26	Integral Technology		Language Independent	Operational/Resource	R A
27	Trusted Party	Relationship with External Environment	Language Independent	Compliance	R
28	Outsourcing		Language Independent	Organisational	R
29	Interfacing		Language Independent	Organisational/Compliance	R

Table 12: Heuristic Analysis Based on Clearing Process

5.7 Conclusion

This chapter has presented the Simulation Network Analysis Control and Heuristic (SNACH) framework as the main contribution of this work. Earlier in the chapter, the "act of improving a business process" was presented as a structured approach for improving a business process rather than relying on the skills, experience and creativity of the analyst. Some related works that support the actual act of process improvement were presented.

Furthermore, the Mandatory Elements of a Method (MEM) was applied as a method that contains elements that address the issues surrounding the unstructured approach to improving a business process. Recent BPI methodologies and existing approaches that partially support the act of process improvement were analysed based on MEM criteria.

Finally, the map technique was applied to construct the SNACH framework, the construction was based on the Mandatory Elements of Method (MEM) and was presented as an integrated approach that supports the act of improving processes. SNACH satisfies all the requirements of MEM. It comprises of 8 phases and combines simulation analysis technique, complex network analysis technique and heuristics to improve any business process. The extent of process improvement in the to-be process model can be determined in terms of time, cost, complexity and flexibility.

CHAPTER 6

A SNACH CASE STUDY: HEI ADMISSIONS

6.1 Introduction

We come now to a detailed application of the SNACH approach to a complex business system to show how it works in real-world settings. This case study is based on the admission process to a large university. There are two scenarios in this case study; 1) The Clearing Process, 2) General Admission Process. Both scenarios were developed from interviews, observation and document study, and their as-is process models were created. The to-be clearing process model was created using a combination of the simulation technique and creativity. The clearing process models were part of the process models used in chapter 4 (section 4.4.2) to investigate which nodal relationship (directed or undirected) should be used when downscaling a process model to their projected spaces. The clearing process models were also used to check the validity of the process improvement metrics as shown in section 7.2. The second scenario (General Admissions Process) was used to evaluate the SNACH framework in chapter 7. We demonstrate that the SNACH approach can produce improvements in a complex business system.

6.2 Motivating Scenario

Globally, the Higher Education Institutions (HEI) have become increasingly more efficient and effective for the services they provide (Seng and Churilov, 2003; Casu and Thanassoulis, 2006; Brown, 2012), this is due to huge investments in a variety of process improvement methods. Studies reveal that HEIs have improved the performance of key processes such as student services (e.g. recruitment, accommodation) (Judith, 2005).

A UK-wide study on the income and impact of the higher education sector on the UK economy reveals that Universities receive £35.7 billion as income and generate around £73 billion in output (UK, no date)(Ong, 2016).

Since the ‘Great Debate’ on UK education in 1976 (Cave M, Hanney S, Henkel M, 1997), UK HEIs have been made to become accountable for their activities, use of resources, and performance in service delivery (Casu and Thanassoulis, 2006). Over these years, the number of HE providers and students have at least doubled (Casu and Thanassoulis, 2006), coupled with the transformation of polytechnics and colleges into new universities in 1992.

Around 700,000 prospective students seek admission through the Universities and Colleges Admissions Services (UCAS) to over 380 HEIs in the UK each year (Attenda, 2013). There is fierce competition amongst universities to recruit and retain students with almost 50% of universities' income being sourced from tuition fees (UK, no date; Fakorede, Davies and Newell, 2019). The higher education sector relies on students' data to make strategic decisions during recruitments to enable the recruitment of better students, provision of adequate resources for students and good experience for staff.

As most UK universities recruit students through Clearing, each institution have a team dedicated to supporting, managing and monitoring student recruitment in line with the strategic goals of the university and developments in the higher education sector. From an economical point of view, 'student as customer' idea has become more apparent since the increase in tuition fees by the coalition government and it is harder to fill up places due to the dynamics of Clearing especially if applicants' expectations are not met; therefore it is expedient to optimize the student recruitment process for improved efficiency and effectively managing the application process.

6.3 Review of UK Higher Education Admissions (HEI)

This chapter lays out the case study which was conducted in a UK HEI. The chapter begins with a literature describing the complex nature UK HEI admission process and improvements that have been happening since 2003. It further discusses the organisation responsible for centrally managing admission services across the entire United Kingdom. The study focussed on investigating the admission process into the UK Higher Education Institutions from 3 perspectives: Student, University and UCAS demonstrating the collaborative nature of the business process. The data gathered from interviews, observation and document study were used to create an as-is clearing process with the intention to analyse and improve the process.

In 2003, the then Secretary of State for Education and Skills, Charles Clarke, requested an independent review of the options that English higher education institutions should consider when assessing the merit of applicants for their courses and for a report to be created detailing the high-level principles underpinning these options. A steering group was formed and chaired by Professor Steven Schwartz. The steering group comprising of various stakeholders produced a report setting out five principles as recommendations for a fair admission process. According to the report (Schwartz, 2004), a number of issues need to be addressed to improve the admissions process. The issues are mentioned below:

- There are differing interpretations of merit and fairness.
- It can be difficult for applicants to know how they will be assessed.

- The information used in assessing applicants may not be equally reliable and consistent.
- Some courses have high drop-out rates, which may be related to admissions processes.
- For courses that are over-subscribed, it can be difficult for admissions staff to select from a growing pool of highly-qualified applicants;
- Some applicants face a burden of additional assessment.
- There is uneven awareness of and response to the increasing diversity of applicants, qualifications and pathways into higher education.
- Most offers depend on predicted grades, not confirmed examination results.
- The legislation applicable to admissions is complex and there is uneven understanding of what it means for admissions policies and processes.

6.3.1 Defining a Fair Admission System

The steering group was able to describe considerations for a fair admission system such as:

1) Applicants should be chosen on merit where merit could mean applicants with higher examination marks or take a broader look at the applicant's potential or past achievements.
2) Equal examination grades do not always mean equal potential; therefore, consideration should be given to applicants who have responsibilities at home or at work or circumstances interrupting their schooling thereby affecting their educational achievement.
3) Consideration should be given to applicants who have had to overcome certain obstacles as latent talent and potential may not be fully demonstrated by examination results.
4) All relevant factors including the context of applicants' achievements, backgrounds and relevant skills should be taken into account to allow all applicants equal opportunity to demonstrate achievements and potential.
5) A diverse student community should be pursued as this is likely to enhance all students' skills of critical reasoning, teamwork and communication leading to producing graduates who are better able to function and contribute to a diverse society.
6) A fair admission system should encourage the autonomy of institutions over admissions policies and decisions rather than the Government choosing students.

As a result of the above issues a set of principles were define called the five 'Schwartz principles' or principles of fair admission which are:

1) A fair admissions system should be transparent: Universities and colleges should provide, consistently and efficiently through appropriate mechanisms, the information applicants need to make an informed choice. This should include the institution's admissions policy and detailed criteria for admission to courses, along with an explanation of admissions processes. It should include a general indication of the weight given to prior academic achievement and potential demonstrated by other means.
2) A fair admissions system should enable institutions to select students who are able to complete the course as judged by their achievements and their potential: Ability to complete the course must be an essential criterion for admission. In assessing applicants' merit and potential, institutions may legitimately consider other factors in addition to examination results, including: the educational context of an applicant's formal achievement; other indicators of potential and capability (such as the results of additional testing or assessment, including interviews, or non-academic experiences and relevant skills); and how an individual applicant's experiences, skills and perspectives could contribute to the learning environment.
3) A fair admissions system should strive to use assessment methods that are reliable and valid: Assessment can legitimately include a broad range of factors. Some of these factors are amenable to 'hard' quantifiable measures, while others rely on qualitative judgements. This should continue both legal and lay opinion place value on the use of discretion and the assessment of applicants as individuals.
4) A fair admissions system should seek to minimise barriers of applicants: Admissions processes should seek to minimise any barriers that are irrelevant to satisfying admissions requirements. This could include barriers arising from the means of assessment; the varying resources and support available to applicants; disability; and the type of an applicant's qualifications (e.g. vocational or academic).
5) A fair admissions system should be professional in every respect and underpinned by appropriate institutional structure and processes: An institution's structures and processes should be designed to facilitate a high quality, efficient admissions system and a professional service to applicants. Structures and processes should feature: clear lines of responsibility across the institution to ensure consistency; allocation of resources appropriate to the task; and clear guidelines for the appointment, training and induction of all staff involved in the admissions. Its 'been recommended by the steering group that the admission process should be managed either partly or fully by a central admissions team.

6.4 Universities and Colleges Admissions Service (UCAS)

UCAS is an independent charity in charge of providing information, advice and admissions services to inspire and facilitate educational progression (UCAS, no date a). The organisation was formed in 1993 through the amalgamation of the former university admissions system UCCA (Universities Central Council on Admissions), the former PCAS (Polytechnics Central Admissions System) and SCUE (Standing Conference on University Entrance). Although UCCA existed since 1961 to support universities in effectively managing multiple applications from students (UCAS, no date a).

According to UCAS Corporate Strategy 2015 – 2020 (UCAS, 2015b), UCAS has defined her vision to be at the heart of connecting people to higher education. This vision is driven by six strategic objectives and a ten-point strategy to deliver those objectives, all available at (UCAS, 2015b). UCAS offers several services for disparate audiences such as UCAS Undergraduate, UCAS Conservatoires, UCAS Teacher Training, UCAS Postgraduate (UKPASS), UCAS Progress and UCAS Media (UCAS, no date c). UCAS.com is one of the most accessed websites in the United Kingdom, coping with 2.5 million applications to be processed for about 700,000 prospective students seeking admission to over 380 UK Higher Education Institutions. UCAS have had difficulties in managing the demands on their IT infrastructure during the clearing and confirmation period. To cope with this challenge, the UCAS infrastructure had to be enhanced to successfully manage the Confirmation and Clearing process. A cloud solution was implemented by Attenda on Amazon AWS leading to handle a peak demand of 180 hits per second and over 1.1 million log-ins (Attenda, 2013)

6.5 Recruitment from HE Perspective

UCAS has been instrumental in assisting thousands of students find a place in universities and colleges across the UK. The competition for places between universities has meant that each university needs to manage specific factors that may influence student’s choice of attending a particular university (Brown, Varley and Pal, 2009). Earning capacity was ranked in the first position in terms of priorities while social life was found to be the least influential. Other factors include: ranking in league tables, location of university, course content, experience during open days, financial considerations, availability of support, cost of living and entrance requirements (Moogan, Baron and Harris, 1999). As early as 18 months prior to enrolling at a university, students begin to seek information regarding their degree course and university offerings. These early stages information gathering may include reading prospectuses, attending university open days, talks by universities in schools. From September, students are able to enter the UCAS system for the following year entry in October.

6.5.1 Choice of Higher Education (HE)

The chosen methodology for this research is Design Science Research Methodology. The first phase of the methodology – Awareness of Problem requires that the researcher should have experience in the area of challenge or access to sources to investigate areas for improvement in the domain. The researcher is a member of staff of the HEI where the case study is conducted and has been involved in the clearing process. Since admissions/clearing staff are colleagues, access to interviews with these domain experts was more realistic than trying to make contacts with another university.

6.5.2 Data Collection Methods Revisited

In this study, the research strategy applied was case study and data was gathered from three sources: Interviews, Document Study and Observation as described earlier in chapter 3.

6.5.2.1 Observation

Participation in the yearly clearing activity over a 3 year period resulted in a clear understanding of the process from the university perspective. Any member of staff participating in clearing is required to attend a training session facilitated by members of the admissions team.

6.5.2.2 Document Study

Several documents on HE admissions such as resources on the UCAS website, admission reports and minutes were examined to enhance understanding of the process.

6.5.2.3 Semi-structured Interviews

In the course of this research, both structured and semi structured approaches were adopted to allow flexibility and adaptation where necessary and to elicit more in-depth and personalised responses.

Seven interviews were conducted involving six members of staff from the university comprising of a senior management team member, academic staff, admissions staff, administrative staff, a business intelligence team member, and one member of staff from UCAS who visited the university for the annual UCAS fair. These participants were carefully chosen to ensure that adequate information covering all aspects of the clearing process was obtained. It was not considered necessary to interview students because the information gathered from the participants already covered the student perspective. The interviews varied between 20 minutes to 80 minutes duration, they were recorded and transcribed for analysis. Both personal data and materials gathered were considered confidential. The interviews covered areas such as the student recruitment process, the clearing process from UCAS perspective, HE perspective and student perspective, admission target setting, how admission estimates are generated, benefits of improving the process and verification of process models. The interviews were categorized and made relevant to the area of expertise of the participants.

The information gained from the interviews, document study and observation were used to create the as-is process models.

Interview questions can be inspired by practise or experience, theory or previous research (Jennifer Rowley, 2012); this research is informed by experience. According to (Daniel W. Turner, 2010), researchers are advised to select questions that will allow the participants to share rich experiences and knowledge in order to gain maximum data from the interviews. The interview questions were created based on the recommendations given by (McNamara, 2009) and are available in appendix 1.

6.5.3 Interview Analysis

Template analysis is an approach used for thematically analysing qualitative data such as data gathered in the form of interview transcripts (which may also include other kinds of textual data such as text from electronic interviews), open-ended question responses on a written questionnaire or diary entries (King, 2007). In order to analyse and interpret the text, a coding template is defined which entails coding the data, categorizing the text into small units, assigning a label to each unit and then grouping the codes into themes in a meaningful and useful manner (Creswell, J. W., & Clark, 2011; Creswell, J. W., & Poth, 2018)(King, 2007). According to (King, 2007), the analysis begins with priori codes based on prior research or theoretical perspectives.

In this study, a priori list of codes (Table 13) was constructed based on the personal experience and knowledge of the researcher. The initial template was generated by coding the interview into broad themes according to the research objectives and interview questions.

1	Admission Targets
2	Admission Estimates
3	Offers
4	Data Exchanges
5	Historic Data
6	Process Improvement

Table 13: Priori List of Codes

Final Template: The initial template was modified based on the evaluation of the interview transcripts and a final template was produced shown in Table 14.

1	Admission Targets
	1. Enrolment position per course in the previous year
	2. Growth areas
	3. Areas in decline
	4. Open day attendance
	5. Information received from UCAS
	6. Resources available to students
	7. Well subscribed courses
	8. Under subscribed courses
	9. Lowered tariffs
2	Admission Estimates
	1. Application status
	2. Application weighting
	3. Historical Data
	3.1 Application Targets by course
	3.2 Application numbers by course
	3.3 Applications converted by course
	4. QlikView Software data presentation
3	Offers
	1. Verbal Offers
	2. Rejections
	3. Confirmed offers
	4. Offer letter via email
	5. Enrolment Invitation
4	Data Exchange
	1. Offers/rejections Uploads to UCAS
	2. Confirmation downloads from UCAS
	3. All data exchanges (both offers and rejections) stored in SITS
5	Issues

	1. Collaborative Process between UCAS, Applicant and University
	a. Offers are made verbally by University
	b. Verbal offers are not registered with UCAS
	c. Verbal offers could end up being wasted
	d. Applicants may select University on UCAS Track without a prior offer from University
	e. Upload of offer confirmation to UCAS happens only when the university is selected by the applicant, if the applicant selects another University, there is no way they would know. Since staff are required to chase offers up, this activity would be a waste of time and resources
	2. University Clearing Process
	a. University is restricted by UCAS
	b. Lack of structured methodology to generate admission estimates
	c. Although QlikView business intelligence tool provides visualization of data sources there is lack of a visualization tool to simulate the clearing process to enhance decision making
	d. Admission estimates may not be accurate and applicable to every course.
	e. Estimate generation only relies on just one-year's data
6	Process Improvement
	1. UCAS to track offers made by University
	2. Once offers are made to an applicant by a university, the data should be uploaded to UCAS
	3. Only offers made available by a university should be made available on UCAS Track for selection by applicant
	4. Upload offers to UCAS activity to happen before downloading of data from UCAS
	5. More realistic and applicable estimates
	6. Manage constraints such as academic staffing, accommodation, lecture and seminar room,s etc
	7. Provision of visualization tool to simulate the clearing process
	8. Accurate simulations to enhance decision making

Table 14: Final Template

6.5.4 UCAS Admissions Application Process Description

For 2020 entry into universities and colleges in the UK, UCAS Undergraduate Apply opened on 21st May 2019. After this, applicants are able to start their applications and send them out for references and approval until 4th September when universities and colleges can start making decisions on submitted applications. Upon receipt of application, offers are made based on predicted exam results due to be published in mid-August 2020. Applicants wishing to study medicine, dentistry or veterinary science can select up to four course choices and had until 15 October 2019 to enter the system including applicants applying to Oxbridge, while other applicants, except some art and design courses, can select up to five course choices (choices have no ranking) and their cut-off date is mid-January 2020.

As illustrated in *Figure 32* above, the process begins when a student's application is received via the UCAS website. The application is processed and if approved, it becomes available to the chosen universities via the "TRACK" service. The universities can then enter their decision on TRACK; decisions can be Unconditional Offer (UF), Conditional Offer (CF) or No Offer.

Choosing from their offers received, applicants must select their 'Firm' and 'Insurance' choices and decline the rest by the end of April. On 25th February, UCAS Extra opens for applicants who have used all five choices and still do not have any offers. They can take advantage of UCAS Extra to secure another choice in TRACK.

If an applicant firmly accepts an unconditional offer, then it means they are committed to taking up that place unless they withdraw from the UCAS application process (they will not be able to consider an insurance option). Applications received after 30th June are automatically entered into Clearing. A level results are announced by mid–August (13th August 2020) and applicants have until the end of August to meet all conditional offer conditions; else the university might not accept them. If a student isn't accepted onto their firm choice, then they can consider the insurance choice provided they meet the offer requirements.

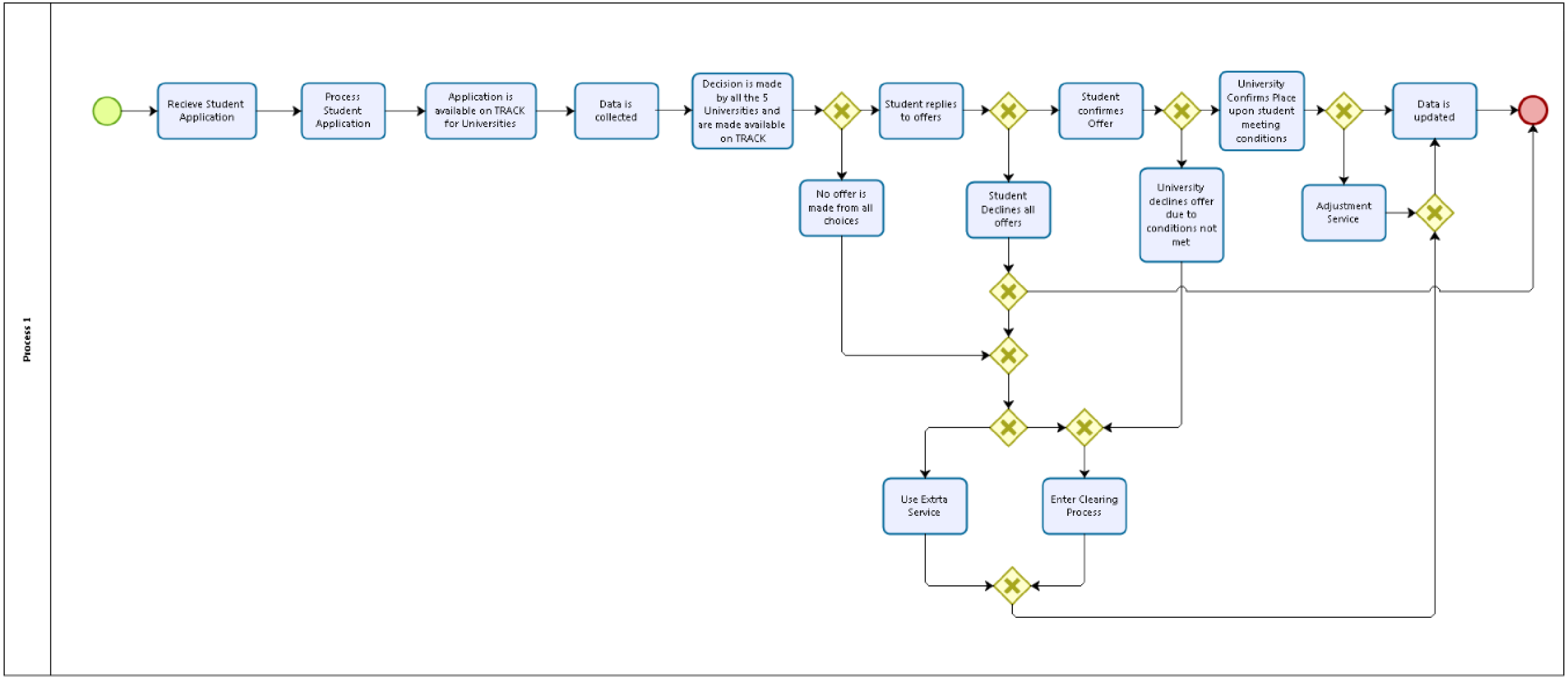


Figure 32: General Admission Process from UCAS Perspective

In a situation where a student has met and exceeded the offer conditions, the UCAS Adjustment service can be used to find alternative courses while still holding the original confirmed place.

If an offer is declined by their chosen universities, students may use the Extra service to find and apply for alternative courses or go into clearing if it has started. The same is applicable if a student declines an offer, they can use the Extra service or go into clearing.

Applicants can take advantage of UCAS 'EXTRA' between end of February and early July if they have already made 5 choices, received decisions from all of the choices and have either had no offers or declined the offers. If offers have been declined applicants will forfeit the option to accept them at a later date.

The adjustment service enables applicants who have firmly accepted a conditional offer and exceeded the conditions to consider alternative courses that may still have places available on them, yet the original choice is still kept valid. The last date to submit applications for 2020 entry is 21st September 2020.

6.5.5 UCAS Clearing Process

Clearing is an extension of the higher education institution application process run by Universities and Colleges Admissions Service (UCAS) which can be used by applicants who do not have a place lined up at a University or a higher education college (UCAS, 2015a). Clearing allows applicants who did not achieve the grades offered by their firm and insurance choices to find institutions with courses that still have places available. The process begins at the end of the admission period, usually from July till the end of September. After the clearing process institutions with available places can still advertise places and admit students directly (UCAS, 2015a). An applicant is entered into clearing if an application is made after 30th June, or no offer is received or accepted, or conditions of offers are not met.

The UCAS system gets updated with university vacancies as illustrated in Figure 33, and then applicants are entered into clearing. Once payment is received from the applicant, they are eligible to apply to one university at a time. When an offer is made by the university, the UCAS system gets notified and updated. A tracking service is part of the process to ensure that applicants don't have more than one offer at a time. When an applicant confirms an offer, the system gets updated and a confirmation letter is sent to them.

To become eligible for clearing students must not hold any offers. The activities of the clearing process are outlined below (UCAS, 2015a):

- Students must be eligible
- Fees must be paid
- Student check vacancies on the UCAS website in August
- Identify course and contact the course provider
- Place offered/refused by university
- Place accepted/declined by prospective student
- Clearing choice of university is added on Track (one at a time)
- Offer is confirmed by university on Track
- UCAS sends confirmation letter to student
- Cycle closes in September
- Student can apply to university directly or reapply during next cycle.

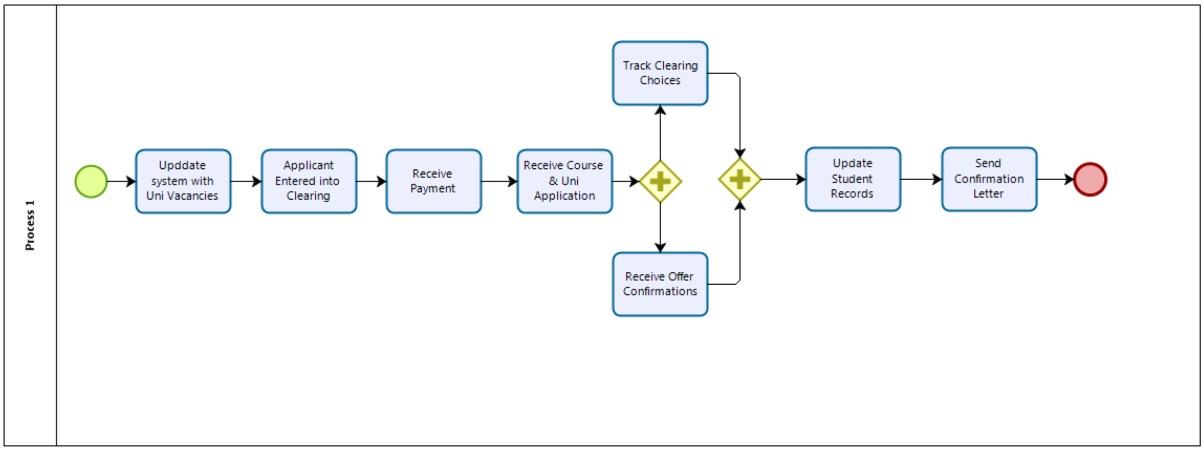


Figure 33: Clearing Process from UCAS Perspective

6.6 Modelling the Clearing Process in BPMN

About four versions of the clearing process models were iteratively created with repeated input from stakeholders before creating the final model (Figure 34), which is believed accurately captures the clearing process. The iterative development of the process models increased the understanding of the clearing process giving more insight into how the process can be improved.

The process begins when the UCAS system is updated with University vacancies available for applicants to view. The details of the applicants who do not hold any offers are entered into clearing on the UCAS TRACK system. The applicant is notified to pay clearing fees if they wish to partake in clearing. Once the fees are paid they can check available vacancies in various universities, identify the course they would like to study and contact the course provider (university) by making a phone call.

The Triage team from the university receives the call, discusses entry requirements with the applicant and confirms if spaces are still available on the desired course. If entry requirements are met, the call is transferred to the relevant department. Each department would have three to four academics (depending on available spaces) ready to chat with the applicant. As the applicant has met the entry requirements before being transferred to an academic, most applicants would be given an offer at this stage. An admission letter is then emailed to the applicant. The applicant applies to the University via UCAS TRACK (they have 24 hours to apply).

All applications made on UCAS TRACK are uploaded to the university every two hours. The university downloads data from UCAS and processes the offers. Once the offer is processed, offer confirmation is uploaded to UCAS. UCAS then updates the applicant's record and sends a confirmation letter to the applicant. Similarly, the university sends an enrolment invitation to the applicant.

When the university downloads applications from UCAS TRACK and realises that an applicant who had been given an offer has not applied, the applicant will be contacted to be reminded to apply via UCAS TRACK and if required a further 24 hours will be given.

All phone calls, enquiries, offers, declines and refusals data is collated and stored in SITS (Strategic Information Technology Services) a student records management system used to store, administer and manage all aspects of student information from initial enquiry and application through to Degree Completion (King, 2007).

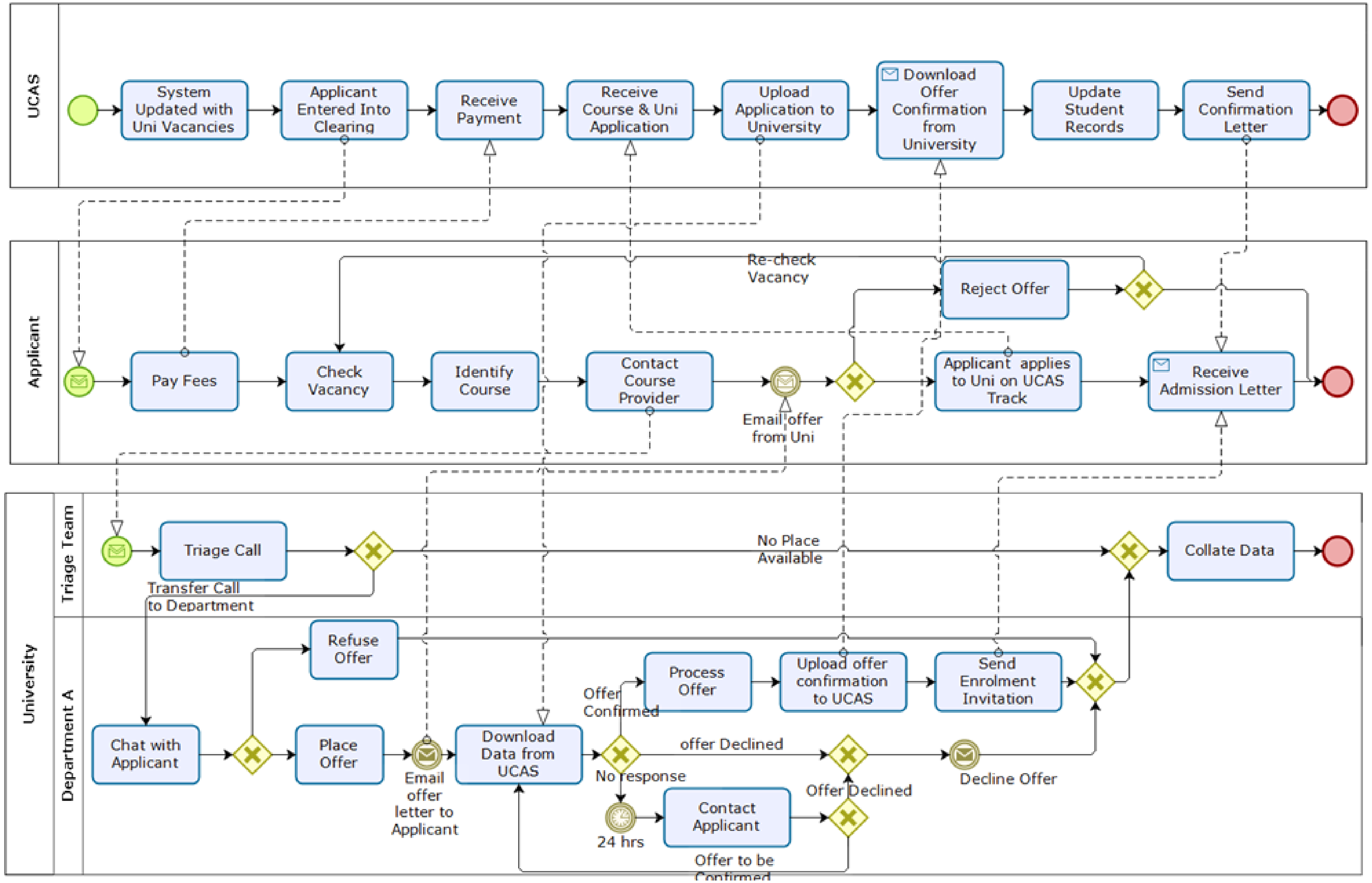


Figure 34: As-Is Collaborative clearing process between UCAS, Applicant and University

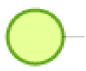
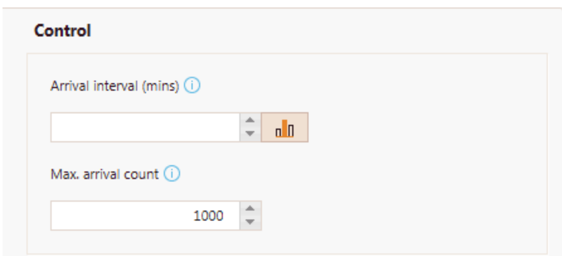
6.6.1 Analysing the As-Is Clearing Process using the Simulation Technique

Bizagi modeller is the preferred choice of simulation tool due to its ease of use, flexibility, what-if-analysis capabilities and exportation of models in Word, PDF, Web, Visio, XPDL or BPMN (*Bizagi*, no date). Simulation require statistical analysis of input and output data, hence the need to consider the impact of variability of the input parameters from an operation perspective. Variability in processing times, demands and capacity could lead to an unbalanced use of resources (Laguna and Marklund, 2018).

Bizagi modeller allows practitioners to carry out what-if analysis (based on multiple runs or scenarios) on processes to compare and evaluate the results of all scenarios. This analysis provides answers to questions like: how would processing time be impacted if the number of available resources is increased by 50%? What would be the cost benefit of reducing the processing time in an activity? Bizagi takes into account the variability of the input parameters therefore, recommends using 30 replications for each run to ensure the simulation reaches a stable state (*Bizagi*, no date). These replications are included in the simulation configuration.

From the university perspective, the model includes a call centre and one department within a faculty. The simulation configuration of the tool is based on historic (confidential) data gathered from interviews with admission staff. The process begins when a phone call is received from an applicant seeking a place in one of the departments in the faculty. The Triage team has a call volume of 8,000 throughout the clearing period, on 180 lines across 20 call takers. The duration of the call is around 5 minutes before the call gets transferred to the relevant department. Using the Simulation mode provided by Bizagi, the model was configured as shown in Table 15.

Level one: Process Validation Configuration:

No	Process	Element	Configuration
1	UCAS	 The number of token instances was set to 1000	

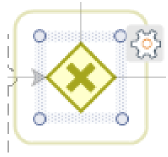
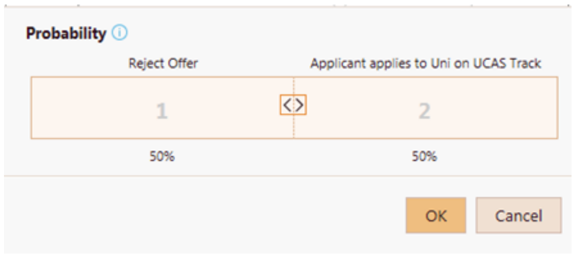
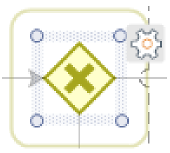
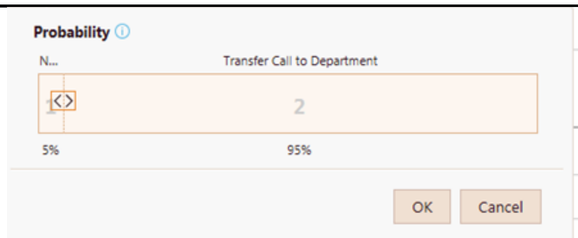
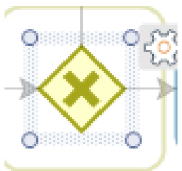
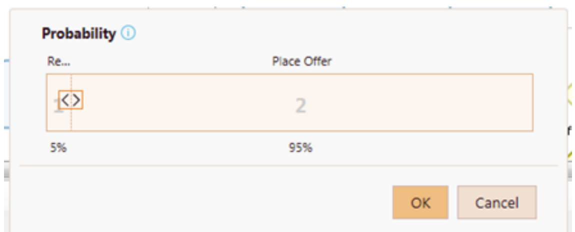
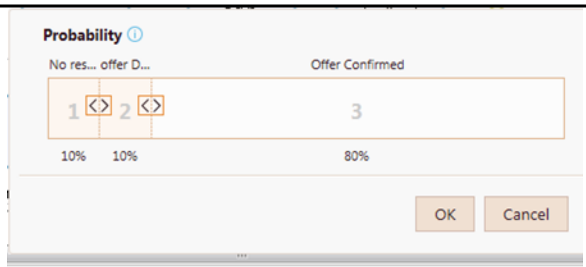
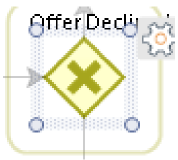
2	Applicant	 50% | 50%	
3	Triage Team	 5% | 95%	
4	Department	 5% |95%	
5	Department	 10%|10%|80%	
6	Department	 20% | 80%	

Table 15: Level one process validation configuration

The level one phase of the Bizagi tool can be used to validate the correctness of a process model; an invalid model (logically incorrect) would prevent the tool from switching to simulation mode. The as-is model was validated by the matching transfer of tokens between process messages, e.g. Upload application to University (442 tokens) and Download application from UCAS (442 tokens), and matching Enrolment letters and UCAS confirmation letters (348 tokens for both) as shown in Figure 35.

The UCAS process receives 1,000 tokens at the start event (representing 1,000 applicants). It is assumed that all the 1,000 applicants are registered for clearing, paid the required fees, checked vacancies and contacted the course provider. As UCAS and applicant processes are outside the control of the university, they were not configured in the simulation mode. The Triage Team receives 1000 tokens, based on the configuration, 940 tokens are transferred to a department while the remaining 60 are refused (this could be for various reasons in reality).

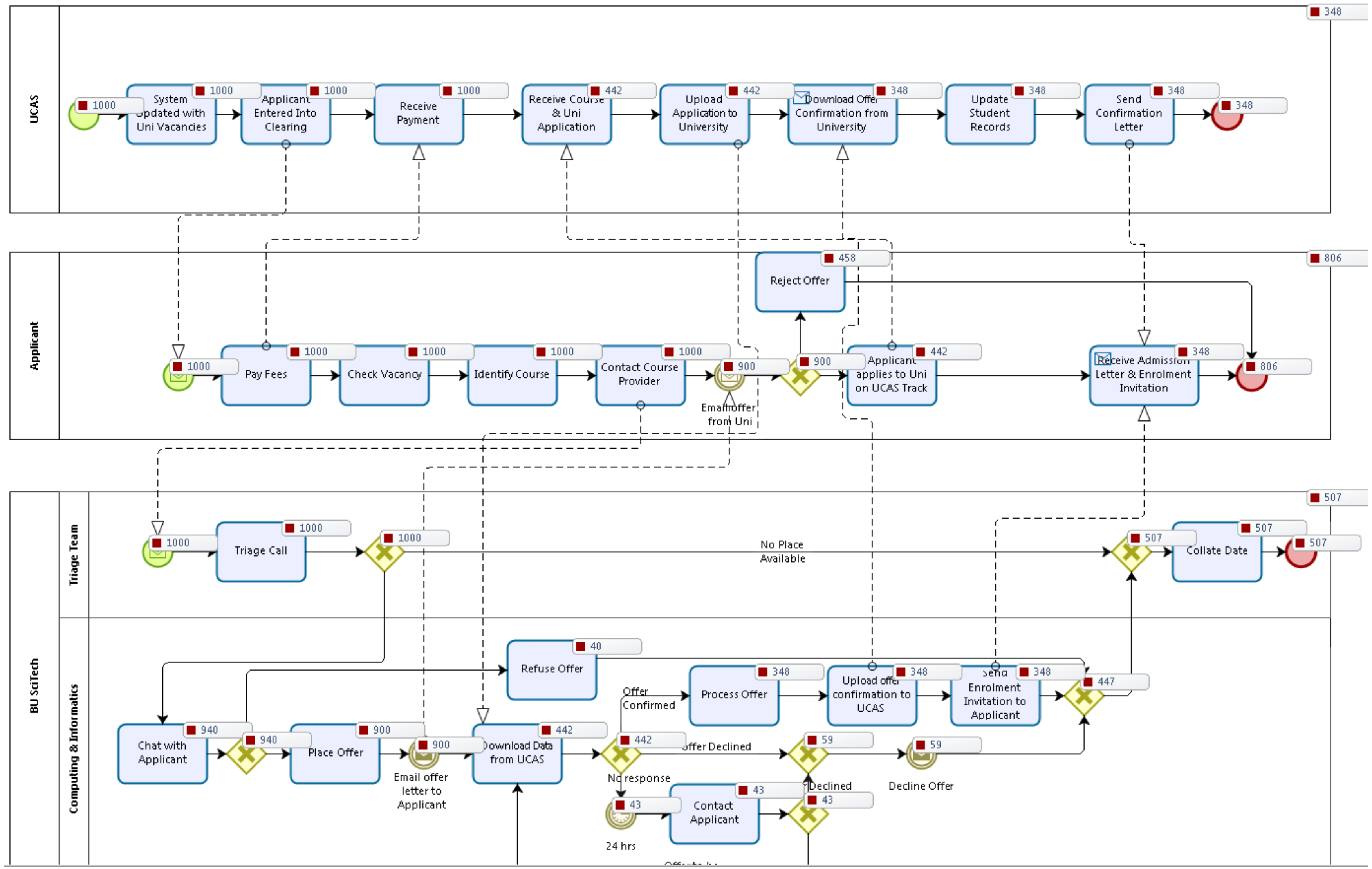


Figure 35: Simulation of the current clearing process

Out of the 940, 900 would be offered a place and offer letters emailed to them. In the applicant lane, 900 applicants receive emails containing offer letters. These offers are not tracked by UCAS, so an applicant could end up with several offers before making their choice. The applicant goes to UCAS TRACK to apply to any University that has made them an offer. Out of the 900, only 442 applied to the University. The 442 applications are uploaded to the university, and consequently downloaded by the department. Some of these applicants who have applied to the University on UCAS TRACK may change their minds and eventually decline the offer (59 tokens). Also, some of the students who did not confirm their offer by applying to the university on TRACK will be contacted by the university but unknown to the university the applicant (43 tokens) may have confirmed an offer from another university. Eventually 348 applicants will receive an enrolment invitation and confirmation letter from the university and UCAS respectively.

Levels two (Table 16), three (Figure 36 and Figure 37) and four configurations (Table 17) are shown below:

Level two: Time Analysis Configuration:

No	Activity	Processing Time (min)	Waiting Time (min)
1	Triage Call	3	3
2	Chat with Applicant	3	3
3	Place Offer	3	0
4	Download Data	1	0
5	Refuse Offer	0	0
6	Processing Offer	3	0
7	Contact Applicant	3	0
8	Upload offer Confirmation to UCAS	1	0
9	Send Enrolment Invitation to Applicant	1	0

Table 16: Time Analysis configuration

Level three: Resource Analysis Configuration:

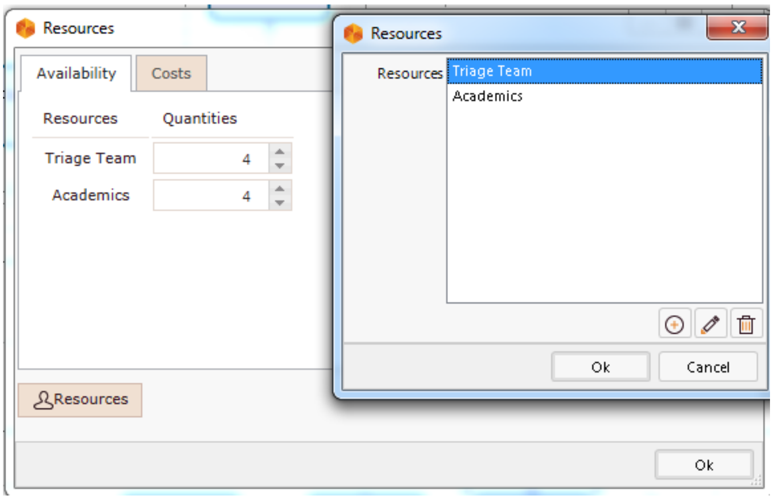


Figure 36: Resource availability configuration

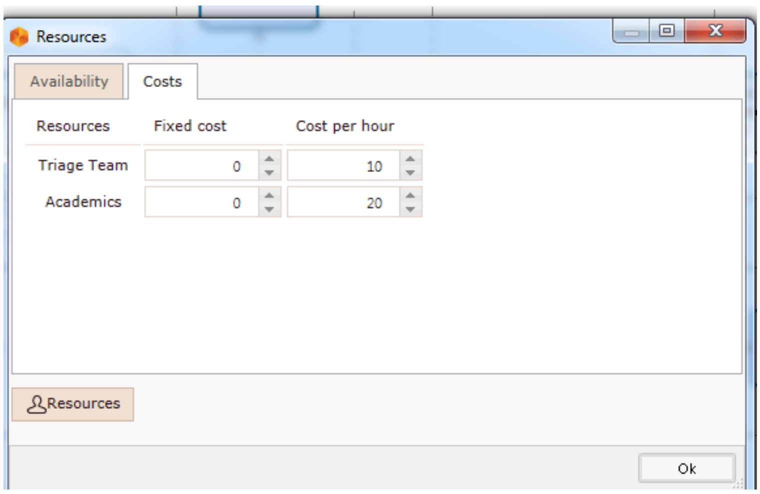


Figure 37: Showing the cost of resources configuration

Level four: Calendar Analysis Configuration

No	Resource	Quantity	Cost/hr	Morning Shift 8am – 12pm	Afternoon Shift 12pm – 4pm	Evening Shift 4pm – 8pm
1	Triage Team	4	10	4	4	2
2	Academics	4	20	4	4	4

Table 17: Showing the quantity of resources allocated to the activities.

6.6.2 Simulation Results of the As-Is Clearing Process

The outcome of the simulation is shown in Figure 38 and exported to Microsoft Excel (Table 18) to show resource utilization and cost while Figure 39 presents the time analysis. As shown in the spreadsheet below: The resource utilization for the Triage team was 90.91% and Academics was 91.29%. The total cost was £12,033.67 for the clearing process for the department of computing and informatics. The process was set to run for 7 days.

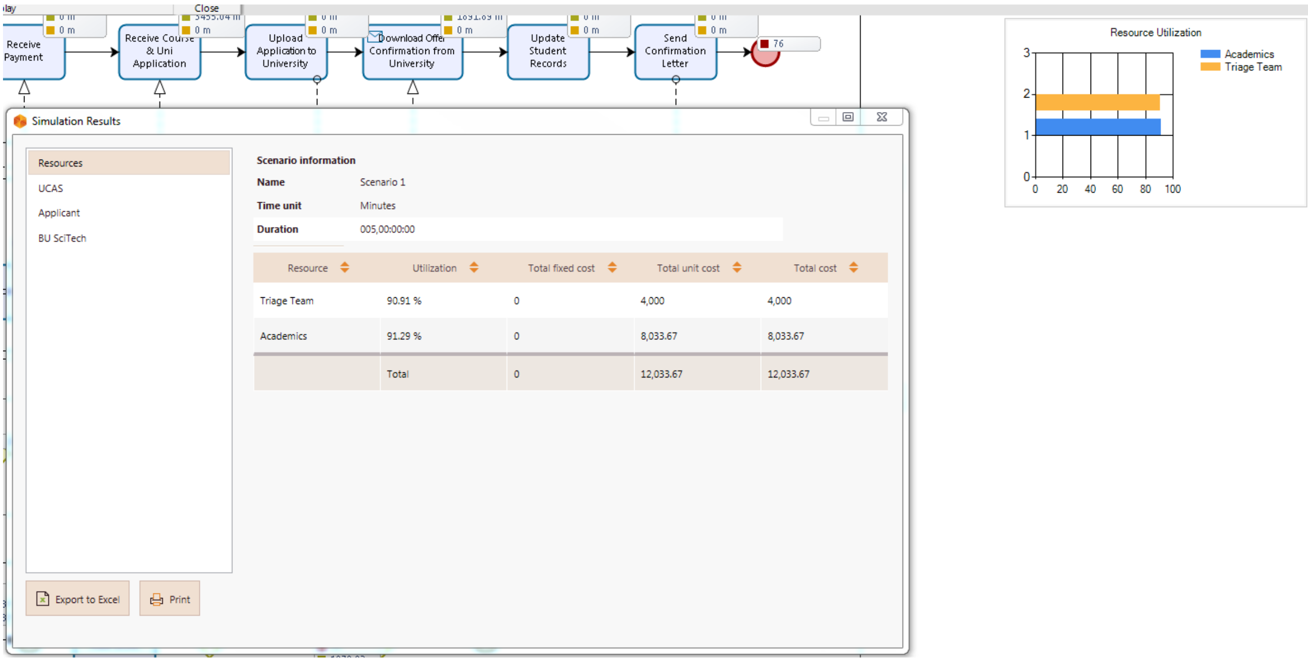


Figure 38: Simulation Result for Current Clearing Process

Resource	Utilization	Total fixed cost	Total unit cost	Total cost
Triage Team	90.91%	0	4000	4000
Academics	91.29%	0	8033.666667	8033.666667

Total Cost = £12, 033.67

Table 18: Cost and Resource Analysis for the Current (as-is) Process

Name	Type	Instances completed	Instances started	Min. time (m)	Max. time (m)	Avg. time (m)	Total time (m)
BU SciTech	Process	174	1000	46	6679	3239.488779	4682605.166
ExclusiveGateway	Gateway	1000	1000				
ExclusiveGateway	Gateway	197	197				
ExclusiveGateway	Gateway	10	10				
ExclusiveGateway	Gateway	30	30				
ExclusiveGateway	Gateway	118	118				
ExclusiveGateway	Gateway	174	174				
NoneEnd	End event	174					
24 hrs	Intermediate event	11	11				
Email offer letter to Applicant	Intermediate event	462	462				
Decline Offer	Intermediate event	30	30				
Triage Call	Task	1000	1000	6	6201	3207.9	3207900
Chat with Applicant	Task	677	678	6	1934	984.6129985	666583
Download Data from UCAS	Task	197	197	1	1130.252967	411.046389	80976.13863
Process Offer	Task	121	121	21	1937.747033	1148.072615	138916.7864
Contact Applicant	Task	10	10	65	1907.747033	1070.92411	10709.2411
Refuse Offer	Task	33	33	0	0	0	0
Collate Date	Task	174	174	0	0	0	0
Upload offer confirmation to UCAS	Task	76	76	39	1528	891.6052632	67762
Send Enrolment Invitation to Applicant	Task	55	55	35	1841	991.2545455	54519
MessageStart	Start event	1000					
ExclusiveGateway	Gateway	677	677				
Place Offer	Task	462	462	9	1934	985.3658009	455239

Figure 39: Time Analysis Spread Sheet for the as-is Process

6.7 Issues Identified in the Clearing Process.

Examining the current clearing process models based on a combination of creativity, understanding and the above simulation analysis, the following issues were identified:

a) Offers are made by universities before applicants can apply to the university on TRACK. These offers are verbal confirmations from as many universities as possible. There is no way UCAS can track these admissions offers because they are not registered with UCAS until the applicant goes to TRACK and selects the university. Then the university gets the application when UCAS uploads the data to the university. The university can then confirm that an offer has been made to the applicant.

b) As a result of the above, the verbal confirmation, time and the resources utilized to speak to the applicant could end up being wasted as the applicant may choose not to accept the offer from the university. When the data from UCAS is eventually downloaded, the clearing staff would have to chase up the applicant after 24 hours expending more time and resources on an applicant that may have accepted an offer from another University.

c) The whole essence of TRACK is defeated as UCAS is supposed to track admissions and ensure that applicants don't have more than one offer.

6.7.1 Changes made in the Proposed Clearing Process

The 'Upload Data to UCAS' activity is introduced immediately after an offer is emailed to the student 'intermediate event' as shown in Figure 40.

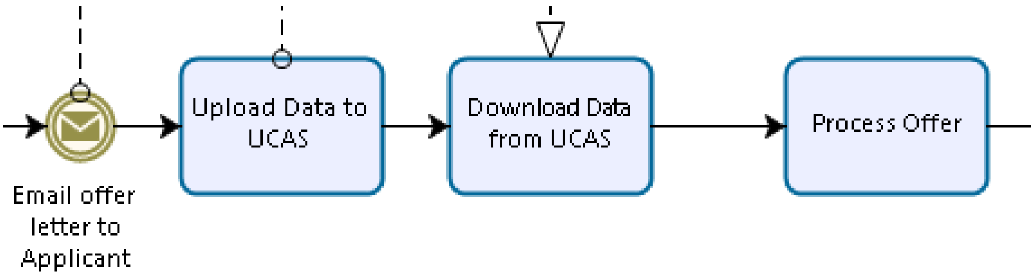


Figure 40: Modified Upload Data to UCAS activity

With this new activity, the offer is immediately uploaded to UCAS so that UCAS can get offer updates from the University. Since applicants can accept several offers from various Universities and these offers are uploaded to UCAS for tracking (each applicant would have these offers in their TRACK accounts), a new activity called 'Track Clearing Choices' is introduced and two parallel gateways (Figure 41). Applicants can only select one offer at a time. When the offer is selected, the UCAS system is updated and data is uploaded to the University for Download.

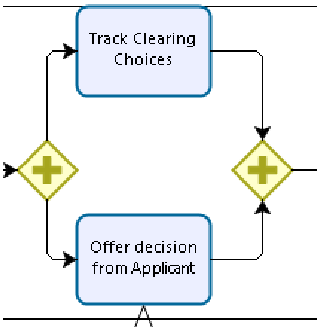


Figure 41: Tracking Activity

This tends to eliminate unnecessary activities/gateways from the HEI clearing process. The 'contact applicant' (Figure 42) activity would no longer be necessary because if an applicant does not confirm an offer, they might have accepted an offer elsewhere or no longer interested in the offer.

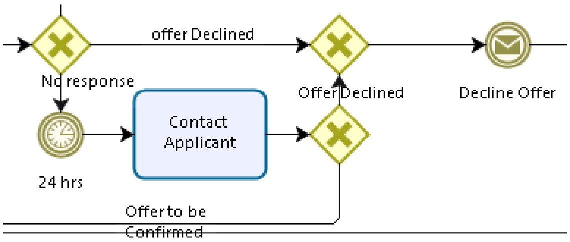


Figure 42: Removed 'Contact Applicant'

The modified clearing process model is illustrated in Figure 43.

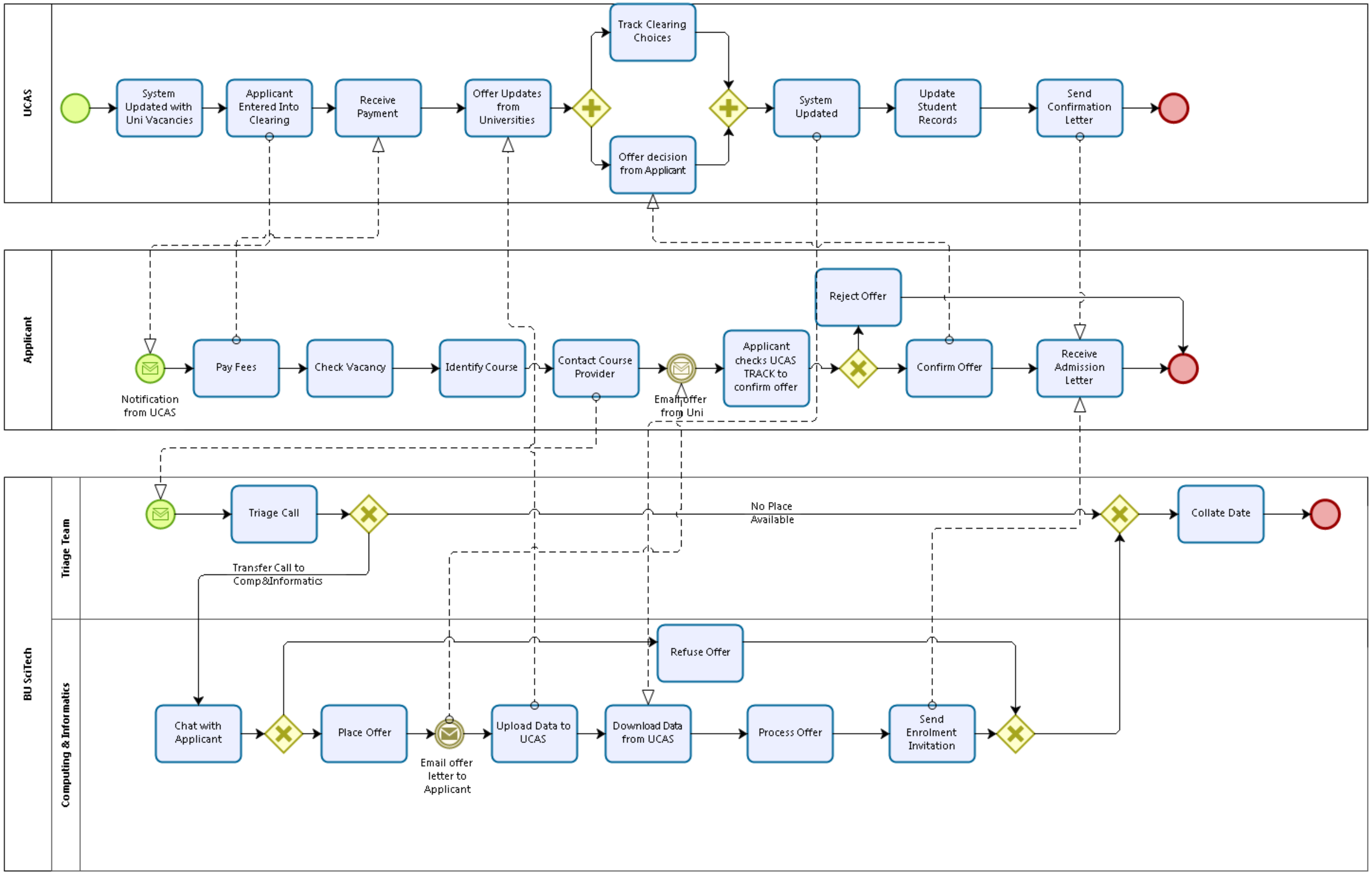


Figure 43: To-be Clearing Process

6.7.2 Description of the To-Be Clearing Process

Beginning from when an applicant (Figure 43) is made an offer, an offer letter is emailed to the student by the university. The university also uploads all offers to UCAS. When the applicant gets the offer letter they can go to UCAS to confirm the offer and formally apply to the university (alternatively the applicant can reject the offer).

Meanwhile, a tracking activity called "Track Clearing Choices" is introduced into the UCAS pool which runs parallel to the activity "offer decision from Applicant" a notification offer from the applicant. Then UCAS TRACK is updated. The confirmations and rejections are uploaded to the university for download. Once downloaded by the university the offer confirmations can be processed and invitations for enrolment can be sent to confirmed applicants.

6.7.3 Simulation of the To-Be Clearing Process.

The to-be clearing process was also simulated using the same configuration settings as before (i.e. as tested with the as-is process) and the results are shown in Figure 44 and Table 19.

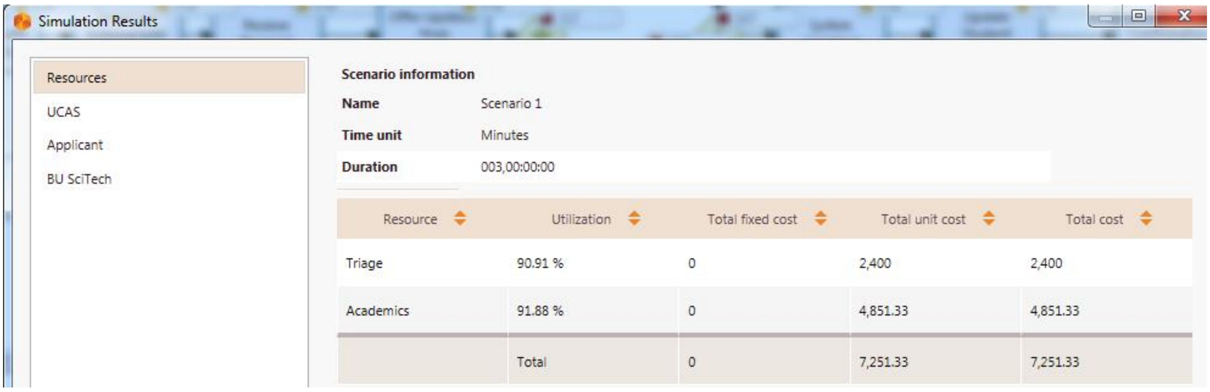


Figure 44: To-be simulation result in terms of cost and resource utilization

Resource	Utilization	Total fixed cost	Total unit cost	Total cost
Triage	90.91%	0	2400	2400
Academics	91.88%	0	4851.333333	4851.333333

Total Cost = £7, 251.33

Table 19: Resource and cost Analysis for the to-be Process

6.7.4 Simulation Results Discussion:

Simulation analysis helps to understand how processes behave under certain resource constraints. When resources are required tokens have to wait to be processed at a given moment resulting in bottlenecks and an increase in cycle time, thereby limiting the performance of the process. A resource can be a person, equipment or space necessary for the execution of a specific task. From the simulation results for both the current and improved processes, there is no real difference in the high utilization of resources.

As this simulation is still work in progress, a What-if-analysis is yet to be performed on the improved process to determine how much extra resources should be introduced to reduce service and waiting times and thereby reducing cycle time. However, an inefficient use of resources was identified in the 'contact applicant' activity and removed, this would have a positive impact on cost and time saving. The time analysis for the as-is process in table 15 shows the average time expended in contacting applicants is 1070.92 minutes. This time is saved in the to-be process. Similarly, the resource analysis for the as-is process (Table 18) shows a total cost of £12, 033.67 while the resource analysis for the to-be process (Table 19) shows a total cost of £7, 251.33, a saving of £4, 782.34.

It is worth noting that the simulation analysis was carried out based on only one department. It can therefore be imagined the total savings/utilization in one faculty and across all faculties in the university.

The benefit of this improved process is that applicants will end up with all the offers they have received in their TRACK account and they simply select the university they want to study at, and the University receives notification of this decision. The benefit for the university is that it would save the time, cost and resources expended in chasing applicants who may have accepted an offer from another university.

6.8 Summary

This chapter highlighted the case study which commenced with a literature review on focussing the UK HEI admissions process and gradually progressed to investigating the admission process from three perspectives namely: UCAS, University and Student. The information gathered from various sources were consolidated to design the collaborative clearing process and general admission models using the appropriate business process modelling language identified in chapter 1 from an analysis of disparate modelling languages.

Using the simulation analysis technique and creativity, some issues were identified in the clearing process especially the detection of an unnecessary activity (contact applicant), and a disorderly sequence of activities (download data and upload data) from the university perspective. These issues were rectified in the to-be clearing model and a new tracking activity was introduced to the UCAS lane.

The to-be clearing process was evaluation only in the time and cost dimensions.

In the next chapter, the improved clearing process will be evaluated in the complexity and flexibility dimensions in order to validate our choice of performance metrics. Finally, the SNACH framework will be applied to the general admission process in order to evaluate the efficiency and effectiveness of the framework.

CHAPTER 7

EVALUATION OF APPROACH

7.1 Introduction

The Design Science Research (DSR) methodology has five stages: Awareness of the problem, Suggestion, Development, Evaluation and Conclusion. This chapter focusses on the evaluation stage involving two sets of artefacts: 1) the as-is and to-be clearing process models, and 2) the SNACH framework as an approach to support the act of systematically improving business processes. The first stage of the evaluation intends to check if our choice of process improvement metrics is capable of providing quantitative measures to track and visualize process improvements. The clearing process will be used for the first stage evaluation. The second stage of the evaluation provides an assessment of the effectiveness and efficiency of the SNACH framework. The general admission process will be used for the second stage evaluation.

7.2 Performance Analysis Metrics

Performance metrics enable practitioners and researchers to measure how much the to-be business process has improved compared to the as-is business process. The efficiency of a business process determines the degree of performance excellence that an organization can achieve (Lam, C.Y., Chan, S.L., & Ip, 2018). Nowadays, it is common for organizations to invest their human and financial resources into performance measurement systems (Harris and Davenport, 2017). It is worth noting that there is a bold connection between business process performance and organizational performance as is evident in literature (Kuend, 2000). Practitioners and academia have developed a variety of performance measurement models and frameworks. Kaplan and Norton (Van Looy and Shafagatova, 2016), (Kaplan and Norton, 2007) produced a 4-dimensional approach known as the Balanced Scorecard (BSC). Dumas et al (Dumas *et al.*, 2013) alternatively established time, cost, quality and flexibility as significant performance metrics. We consider performance measures and performance indicators as synonyms.

7.2.1 The Quadrangle

We revisit the metric selection from section 4.6 as shown in Table 10. The selected metrics are Time, Cost, Complexity and Flexibility. The interpretation of these metrics can be context sensitive, so their effectiveness will not be assessed in every possible way. Time and Cost metrics are obtained from simulation results. Control Flow Complexity (CFC), which is the sum of all the split AND, XOR and OR gateways, is used to measure logical complexity. CFC only considers the decision node elements (Sánchez-González *et al.*, 2011) but in order to determine the overall complexity of a model, structural complexity must be measured. Structural complexity is measured by considering the size and diameter of the downscaled network version of the process. One of the contributions of this work is to combine logical complexity with structural complexity to give the aggregate complexity of the process model.

The overall complexity (C) is denoted with the formulae:

$C = \frac{cfc+(\mathrm{s}+\mathrm{d})/2}{2}$, where cfc = control flow complexity, s = size, d = diameter

$$cfc\ (bp) = \sum_{AND-split} \mathrm{CFC\ (C)} + \sum_{OR-Split} \mathrm{CFC\ (C)} + \sum_{XOR-Split} \mathrm{CFC\ (C)}$$

Where AND-split = + n, XOR-Split = + n, OR-Split = 2^{n-1}

No	**Aspect**	**Metric**
1	Simulation	Cycle Time, Cost
2	Logical Complexity	Control Flow Complexity
3	Structural Complexity	Size (Number of nodes), Diameter
4	Structural Flexibility	Inverse of Density (Cohesion)

Table 10: Selected Metric Table

We define flexibility is the degree to which a model can be effectively and efficiently altered without introducing errors into the model or reducing the model’s quality. This is measured by considering the density of the network; the lower the density the higher the flexibility.

The formulae of Flexibility is:

F=1/D

We pay particular attention to complexity and flexibility metrics due to the collaborative nature of the business process under study.

The highest betweenness centrality gives an indication of a node or activity with a high potential of a bottleneck while the lowest betweenness centrality gives an indication of an unnecessary node or activity.

Brand and Van der Kolk (Brand, N., Van der Kolk, 1995) describe the effects of process improvements activities on the metrics of time, cost, quality and flexibility using a quadrangle.

In this work, we replace quality with complexity as shown in Figure 45 because quality is considered broad, multifaceted and unquantifiable.

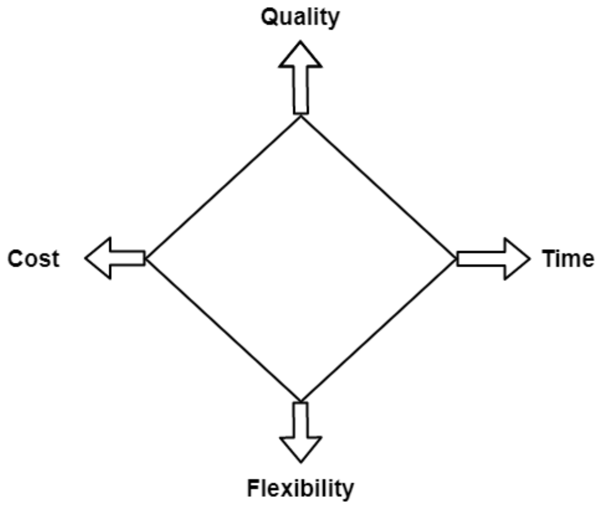


Figure 45. Modified Quadrangle (Brand, N., Van der Kolk, 1995)

Brand and Van der Kolk's model does not have independent quantities and is structured so that an improvement in one dimension could have a negative impact on another. Thus, it is possible that a reduction in delivery time might prompt increased costs to deliver the product because, for instance, you may have to hire more people to facilitate a quicker process. This is an expectation of the way that many systems work. If we did find that the reduction in one quantity produced a corresponding increase in another quantity, there would be no overall improvement.

This means that modelling a complex system is not straightforward as not only are the parameters not independent, but they may be connected in ways which are unpredictable and there may be unforeseen connections at a deep and undiscoverable level. Consequently, a different approach is proposed here which in the first instance assumes independence between our four metrics of Cost, Time and Complexity and Flexibility. It is intended to measure these metrics independently and for both the as-is and to-be models and then look for an overall decrease in the volume of the phase space (quadrangle) defined by these metrics as a measure of improvement of the system. Therefore, if a change in one parameter affects another then it is not considered an issue. The cogent issue here is whether there is a change in volume and not in how the volume changes. Hence, it is not expedient to take account of the possible connections between these parameters to determine if an improvement has been obtained.

It is important to be clear about this. It is not a concern whether or not the parameters are independent as the only intention here is to look for an overall decrease in volume of the phase space as a measure of efficiency. In order to accommodate this each axis is treated individually and the negative polarities of the X-axis and Y–axis which are measures of cost and flexibility respectively are ignored, for instance a decrease in cost would mean the arrow will move inwards instead of moving outwards (to reflect the behaviour of a negative axis).

Furthermore, the flexibility dimension is even more unique. As mentioned earlier an overall decrease in the volume of the phase space is an indication of overall improvement in the four dimensions. An increase in flexibility is an improvement but that means the point plot on the graph will move outward implying an increase in the volume of the phase space but that is not we want, therefore the scale on the flexibility axis is in reverse order to accommodate our intention. Again, for the purpose of this work, an overall decrease in the volume of the phase space is an indication of improvement; this is illustrated in Figure 46.

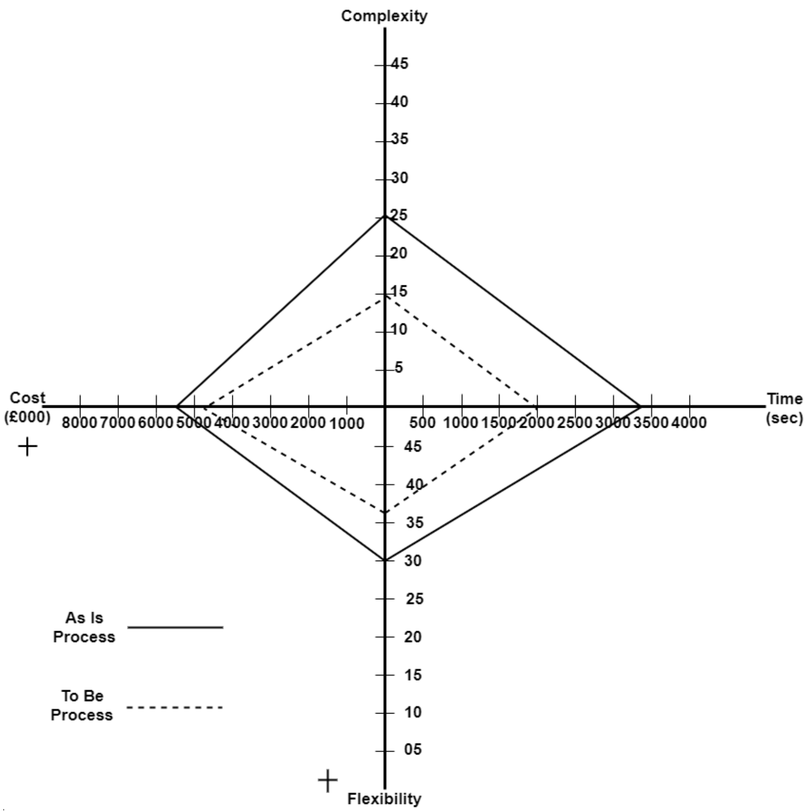


Figure 46: Scaled Reversed-Y Quadrangle

Thus, if the measured outputs are used, regardless of their dependence or independence it can be inferred that a reduction in phase space volume is a measure of improved efficiency. For this reason, the measured outputs can be treated as independent. In the case of optimization an overall improvement of the process is sought. The intention here is not to model how the system works but how the outcome does have independent qualities and is structured so that an improvement in one dimension could have a negative impact on another. Of course it may not be possible to reduce one parameter without affecting the others but that is an internal consideration of the particular process. All that can be said for now is that if changes are made and a reduction is visible then the process has therefore been improved.

With regards to the scale used for each independent metric, it is noted that Time is measured in seconds (it could be measured in minutes or hours depending on the peculiarity of the business process) and the numbers are marked at intervals of 500 therefore, the time scale used is 1:500, Cost is measured in thousands and therefore the cost scale used is 1:1000, complexity is 1:5 and Flexibility is 1:5. The scale used is dependent on the peculiarity of the business process. The goal is not to compare the metrics to each other, as this is not the intention, so scale normalization will not be required. The goal is to compare the volume of the overall metric in the quadrangle of the as-is model to that of the to-be model. This goal is clearly achieved as there is a noticeable improvement in the proposed to-be clearing system. As scales can have any unit as required to solve any problem, the scales used here are relative and not absolute.

7.3 Evaluation of the To-Be Clearing Process

In chapter 6, the clearing process was evaluated in the time and cost dimensions only (Table 20). The Scaled Reversed-Y Quadrangle will be used to track and visualize improvements in any of the 4 dimensions.

Metric	AS IS	TO BE	Difference	% Difference
Time	57 mins	0	57	100%
Cost	£12,033.67	£7,251.33	£4,782.34	49.60%
Complexity	?	?	?	?
Flexibility	?	?	?	?

Table 20: Evaluation outcome for Time and Cost Dimensions

Table 20 shows the values for each metric while the quadrangle in Figure 47 shows the reduction in the size of the phase space in the time and cost dimensions.

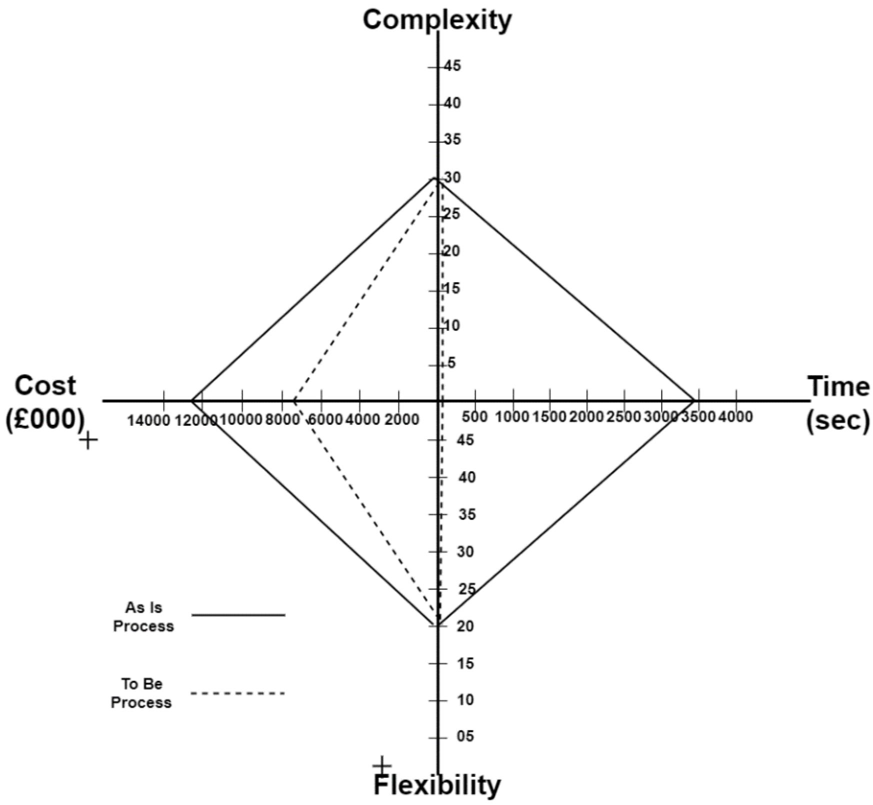


Figure 47: Time and Cost Visualization

The next section will calculate the complexity and flexibility dimensions.

7.3.1 Evaluating Complexity and Flexibility

Complexity as earlier defined is the aggregation of logical complexity and structural complexity. Logical complexity (i.e. Control Flow Complexity) is measured by counting the number of decisions in the flow of control in the process model**.** A low CFC indicates that the process model is easy to understand. Splits in the model adds to the CFC number as follows: OR-split with *n* will add 2^{n-1} to the CFC metric, AND-split will add 1 to the CFC metric and XOR-split with *n* outgoings will add *n* to the CFC metric of the model (Laue, no date)(Makni *et al.*, 2010).

$$\text{CFC (BP)} = \sum_{AND-split} \text{CFC (C)} + \sum_{OR-Split} \text{CFC (C)} + \sum_{XOR-Split} \text{CFC (C)}$$

Where AND-split = + n, XOR-Split = + n, OR-Split = 2^{n-1}

There are 6 OR-splits, 0 AND-splits and 0 XOR-splits in the as-is model, so applying the formulae, we have $2^{6-1} = 32$. While in the to-be there are 4 OR-splits, 1 AND-splits and 0 XOR-splits, so applying the formulae, we have $(2^{4-1}) + 1 = 9$, implying that there has been an improvement in the logical complexity.

The structural complexity measures are obtained from the result of the Social Network Analysis performed in section 4.4.5. Referring to the Table 7 below, the clearing process model is denoted by P1.

Directed	No of Nodes	No of Links	ADC	Betweenness Centrality			Closeness Centrality			Density	Diameter	Ave. Distance	Clustering Co-eff
Process Models				**Max BC**	**Min BC**	**Ave. BC**	**Max CC**	**Min CC**	**Ave. CC**				
P1 As Is	29	41	N23=0.107| 1.414,	N 23 = 0.15	N 1 = 0	0.064	N 8 = 28	N 27 = 0	4.28	0.051	10	4.47	0.03
P1 To Be	30	40	N2 = 0.068 | 1.333,	N 27 = 0.13	N 1 = 0	0.054	N 8 = 29	N 16 = 0	3.48	0.046	12	4.529	0
P2 As Is	13	14	N3 = 0.167 | 1.077	N 7 = 0.273	N 12 = 0	0.164	N 11 = 3	N 12 = 0	0.907	0.09	11	4.35	0.154
P2 To Be	6	7	N2 = 0.400 | 1.167	N 2 = 0.350	N 1 = 0	0.117	N 4= 2.5	N 6 = 0	1.001	0.233	3	1.824	0
P3 As IS	20	22	N4 = 0.105 | 1.1	N 8 = 0.246	N 1 = 0	0.086	N 18 = 19	N 20 = 0	3.247	0.058	11	4.542	0.042
P3 To Be	19	21	N2 = 0.111 | 1.105	N 9 = 0.175	N 1 = 0	0.075	N 15 = 18	N 17 = 0	3.234	0.061	10	4.144	0.044
P4 As Is	45	67	N21 = 0.114 | 1.489	N 41 = 0.094	N 1 = 0	0.035	N 17 = 44	N 18 = 0	4.17	0.034	15	5.186	0.058
P4 To Be	38	65	N21 = 0.135, 1.711	N 8 = 0.109	N 1 = 0	0.035	N 16 = 37	N 17 = 0	3.88	0.046	10	4.111	0.094

Table 7: Data from Directed Network

Applying the defined formulae for the overall complexity,

$$C = \frac{cfc + (s+d)/2}{2},$$

As-Is Overall Complexity; $C = \frac{32 + (29+10)/2}{2}$,

$$C_{As\text{-}Is} = 25.75$$

To-Be Overall Complexity; $C = \frac{9 + (30+12)/2}{2}$,

$$C_{To\text{-}Be} = 15$$

The calculation above shows that the to-be process model is less complex than the as-is process model which indicates that there has been an improvement in the complexity.

Structural Flexibility: The structural flexibility is measured by the inverse of the density of the network.

From Table 7: $D_{As\text{-}Is} = 0.051$, Flexibility (F) = 1/Density, F = 19.61

$D_{To\text{-}Be} = 0.046$, Flexibility (F) = 1/Density, F = 21.74

There is an improvement in the flexibility of the to-be clearing process. The evaluation outcome is shown in Table 21.

Metric	AS IS	TO BE	Difference	% Difference
Time	57 mins	0	57	100%
Cost	£12,033.67	£7,251.33	£4,782.34	49.60%
Complexity	25.75	15	10.75	52.76%
Flexibility	19.61	21.74	2.13	10.30%

Table 21: Evaluation Outcome

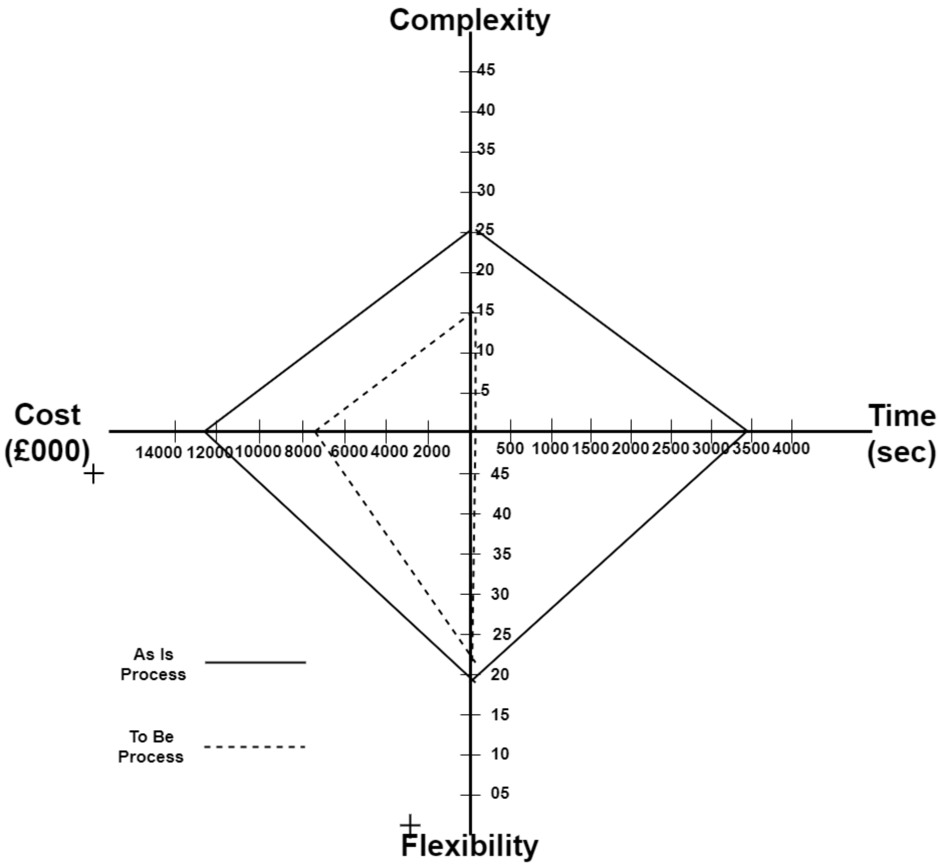


Figure 48: Reversed-Y Quadrangle for the Clearing Process

We can therefore conclude that there has been an overall improvement in the clearing process as shown in Table 21 and Figure 48.

7.3.2 Clearing Process Result Discussion

Comparing the time and cost metrics (Table 21) of the as-is and to-be process models shows the time saved by eliminating the activity “Contact Applicant” from the model.

The “Contact Applicant” activity was eliminated because it could cause an unnecessary delay in the process. In terms of cost saving, around £4,782.34 is saved in the to-be clearing process.

Examining the data from the network analysis for the as-is clearing process the node with the highest betweenness centrality indicates a node with a potential bottle neck. According to Table 7, N23 (contact applicant) is one of the nodes with the highest degree centrality which further confirms that the node should be eliminated to reduce delays, throughput time and cost. Although N16 (Receive Admission Letter) is one of the nodes with the highest betweenness centrality this node does not have any potential to cause any delay in the process because the applicant is not expected to return any information to the process.

In terms of complexity, the to-be process is less logically complex than the as-is process according to the CFC analysis. This is beneficial because there is less decision making in the process resulting in a decrease in delays and throughput time. However, in terms of structural complexity the as-is process is favoured over the to-be process. This is as a result of the to-be process having a higher diameter which translates into less efficient information transport between the nodes. Since a more distributed system requires more attention to be placed on information access relevant improvement heuristics could be introduced to enhance the efficiency of the process such as integration between the UCAS and University systems and/or introduction of a document management system. In terms of the overall complexity the to-be clearing process is significantly less complex than the as-is clearing process.

The density indicates the amount of connections in a network. It is a measure of flexibility, the higher the density the lower the flexibility. From Figure 48 we can see the to-be process is more flexible and efficient than the as-is process.

7.4 Evaluation of the SNACH Framework

The second part of the evaluation stage will evaluate the SNACH framework. It is imperative for the choice of evaluation methods to be suitable for the designed artefact. Table 22 shows twelve Design Evaluation methods grouped into five classes by Hevner at al (Hevner and Chatterje, 2004).

Design Evaluation Methods		
1	Observational	Case Study: In-depth study of artefact in a business environment.
		Field Study: Monitor the use of artefact in multiple projects.
2	Analytical	Static Analysis: Examine structure of artefact for static qualities (e.g., complexity).

		Architecture Analysis: Study fit of artefact into technical IS architecture.
		Optimization: Demonstrate inherent optimal properties of artefact or provide optimality bounds on artefact behaviour.
		Dynamic Analysis: Study artefact in use for dynamic qualities (e.g., performance).
3	Experimental	Controlled Experiment: Study artefact in controlled environment for qualities (e.g., usability).
		Simulation: Execute artefact with artificial data.
4	Testing	Functional (Black Box) Testing: Execute artefact interfaces to discover failures and identify defects.
		Structural (White Box) Testing: Perform coverage testing of some metric (e.g., execution paths) in the artefact implementation.
5	Descriptive	Informed Argument: Use information from the knowledge base (e.g. relevant research) to build a convincing argument for the artefact's utility.
		Scenarios: Construct detailed scenarios around the artefact to demonstrate its utility.

Table 22: Design Evaluation Methods

Evaluation activities can be classified into artificial evaluation (e.g. laboratory experiment, field experiments, simulations, critical based analysis, theoretical arguments and mathematical proofs) and naturalistic evaluation (e.g. case studies, subject-based experiments, surveys, hermeneutic methods, and interviews) (Venable, Pries-Heje and Baskerville, 2012). Artificial evaluation offers the benefit of scientific reliability because they are quantifiable. Peffers et al. (Peffers *et al.*, 2007) criticises naturalistic forms of evaluation as too specific, subject to subjective opinion which may impinge on the generalizability of the results (Lang, M., Wehner, B., Falk, T., Griesberger, P., & Leist, 2015). In this work we employ both controlled experiment and simulation evaluation methods (artificial evaluation) in the experimental class of evaluations.

A controlled laboratory experiment has been conducted to evaluate the effectiveness and efficiency of the SNACH framework as a means to support the act of improving business processes. The controlled experiment is the second part of the experimental class of evaluations in relation to Table 22. The experiment comprises of two groups of randomly chosen participants: one group (SNACH group) uses the SNACH framework to improve a business process while the second group (Creative group) engages their creativity to improve the business process in an unstructured manner.

7.4.1 Experiment Design

The hypotheses of the experiment are shown in Table 23:

Effectiveness of SNACH: The degree of improvement of the To-Be process is greater than that of the As-Is process.	
Hypo01	The use of SNACH does not yield more productive improvement changes than merely using average creative skills would provide within a set time frame.
Hypo1	The use of SNACH yields more productive improvement changes than merely using average creative skills would provide within a set time frame.
Efficiency of SNACH: How much improvement could be achieved within a specified time?	
Hypo02	The use of SNACH does not increase the time efficiency during the improvement process.
Hypo2	The use of SNACH increases the time efficiency during the improvement process.

Table 23: Hypotheses of the Experiment

The dependent variables are:

1) Effectiveness of SNACH and

2) Efficiency of SNACH

Within the context of this experiment, effectiveness is defined as the extent to which the performance of the to-be process has been improved in comparison to the ‘as-is’ process. This intends to determine if the performance metrics of the to-be process are better than that of the as-is process using both the SNACH approach and creative skills. ‘Creative skills’ refers to the average creativity of the whole creative group while each member of the group is considered an average worker or modeller (not an expert) and will not be using any structured approach. The participants (SNACH group and Creative group) will both seek to improve an as-is process model given a specific amount of time. Both groups will be given a set of instructions to follow hoping that they will identify potential improvements and create a to-be process. The null hypothesis for this variable states that the use of SNACH does not yield more productive improvement changes than merely using average creative skills would provide within a set time frame.

The second variable, Efficiency of SNACH will be measured based on how much improvement could be achieved within a specific amount of time. This is calculated as achieved process improvement relative to the time needed for their development when compared to the time it took to improve an as-is process model. Both groups will seek to improve the as-is process model within a given period, when the time elapses both to-be models are compared to determine which one is better improved. The null hypothesis for this variable states that the use of SNACH does not increase the time efficiency during the improvement process.

Certain factors are taken into consideration when performing the experiment to ensure that the result is not diluted. Such factors include: domain knowledge, process understanding, problem identification skills, and business process improvement experience. In order to reduce or eliminate these factors, participants are made to provide information via a questionnaire about their knowledge of the HEI admissions process, business process improvement experience, and problem identifying skills. The answers to these questions are taken into account when analysing and interpreting the results.

7.4.2 Experiment Implementation

Since the clearing process had been used as the main case study, a different case study had to be used to evaluate the framework. The case study needed to be realistic, practical, adequately complex to ensure that potential improvements are not easily detected and manageable within the timeframe of the experiment. To fulfil these criteria, the overall/general UK HEI admission process was designed using Bizagi modeller, see Figure 49. The goal of the experiment was to improve the admission process within 90 minutes.

The eleven participants in the experiment were from varying backgrounds and they were all presented with participant information sheet and completed the participant agreement form indicating their consent to take part in the experiment.

The Creative group comprises of 6 participants: one professional, one recent post-graduate student, one post-graduate, one placement and two final year students while the SNACH group comprises of 5 participants: two professionals, one recent post-graduate student, one recent graduate and one final year student, therefore yielding a balanced design with equal group size. The group size was kept small because it is a realistic match with real world project team sizes with high proximity. Since the team members will be working closely together in the same room it is more effective to keep the teams small because a large group could limit team performance and degree of interaction. In addition, the task requires the individual contribution of each team member, the larger the size of a team, the less the chances are of this happening.

Prior to the commencement of the experiment the two groups were presented with a questionnaire to understand their background, BPI experience and familiarity with the UK HEI admission process. Within the creative group all of the participants had been involved in business process creation, redesign or improvement in the past and 66.7% (4 out of 6) of them were familiar with the UK HEI admission process. Similarly, all the participants in the SNACH group had been involved in business process creation, redesign or improvement in the past and 60% (3 out of 5) of them are familiar with the UK HEI admission process.

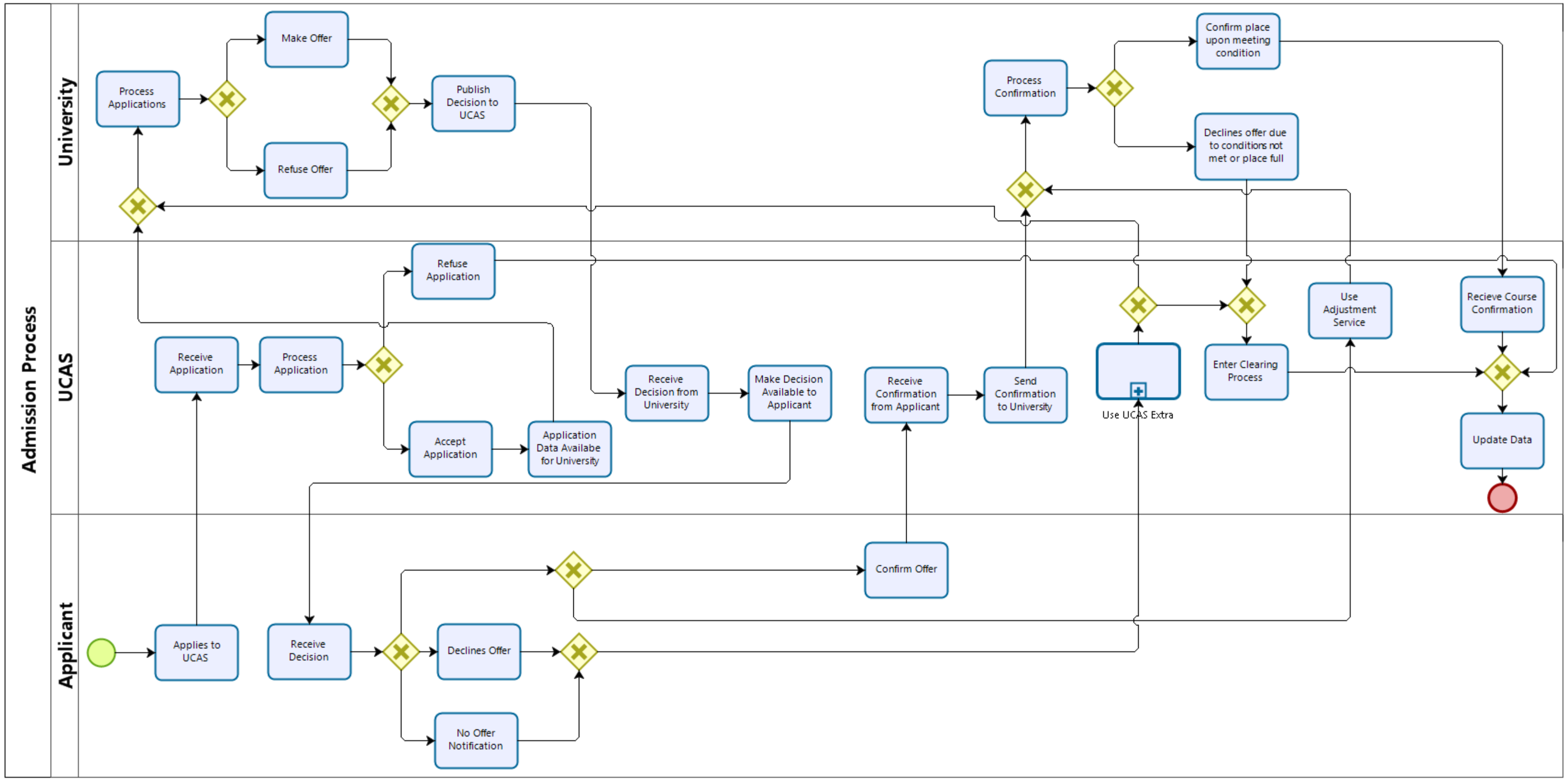


Figure 49: HEI Admission Process

The same materials were provided to all participants (in both groups) such as a textual description of the as-is admission process, the admission process model in BPMN, and the hypotheses of the experiment.

Guidelines specific to each group were provided to ensure they are led through the experiment in a step-by-step fashion. The guidelines are available in appendix 3. In addition to the guidelines, the experiment procedure was explained to the participants to further solidify its comprehension.

7.4.3 Instructions for SNACH group are as follows:

1) Read the provided case study - UK HEI Admission Process Description
2) Study the model to further understand the admission process
3) Follow the steps in the framework to improve the process
    a) Ignore the "Create the As-Is Process Model "step (already done see Figure 49)
    b) Ignore the "Run Simulation" step – already done (see section 7.4.4)
    c) Downscale Projection – already done (see the network projection Figure 57)
    d) Perform Analysis of the Network
        a. No of Nodes: 26
        b. No of Links: 32
        c. Average Degree Centrality: N13=0.160
        d. Max. Betweenness Centrality: Node 13 (Potential Bottleneck node), Min. Betweenness Centrality: Node 4, (Refuse Application)
        e. Density: 0.049
        f. Diameter: 14
        g. Average Distance: 5.64
    e) Ignore the "Upscale Projection to Match Stored Process Details" step
4) Check the model against the heuristics to generate ideas for improvements.
5) Create the new 'To Be' process model.

As some of the members of the SNACH group were unfamiliar with simulation, network analysis using a SNV (Social Network Visualizer) tool and control flow complexity calculations, these tasks were performed in advance by the researcher and made available to the participants; these tasks are explained in the next section.

7.4.4 Simulation of the ‘As-Is’ Admission Process

The simulation began by loading the process model in Bizagi tool. The process validation level successfully ran showing the number of tokens passing through each sequence flow and activity, equal numbers of tokens at both start and end node and, finally, checking that the model is error free. The process validation configuration was done depending on the ratio of instances handled by the process. This is expressed by the probability values allocated to exclusive OR split gateways in Table 24. The goal of the simulation is to compare two simulation results – as-is and to-be models, therefore it is not necessary for the configuration parameters to mirror real life data.

<table>
<tr><th>Lane</th><th>Element</th><th colspan="3">Configuration</th></tr>
<tr><td>UCAS</td><td>Process Application</td><td colspan="2">Accept 90%</td><td>Refuse 10%</td></tr>
<tr><td>University</td><td>Process Application</td><td colspan="2">Make offer 70%</td><td>Refuse offer 30%</td></tr>
<tr><td>Applicant</td><td>Decision notification</td><td>Offer 70%</td><td>Decline offer 10%</td><td>No offer 20%</td></tr>
<tr><td>Applicant</td><td>Offer Notification</td><td colspan="2">Confirm offer 70%</td><td>Adjustment service 30%</td></tr>
<tr><td>UCAS</td><td>UCAS Extra</td><td colspan="2">Clearing 50%</td><td>New Application 50%</td></tr>
<tr><td>University</td><td>Process Confirmation</td><td colspan="2">Confirm place 60%</td><td>Declines offer 40%</td></tr>
</table>

Table 24: Level one Simulation Configuration

A time and resource analysis is done which introduces resource constraints where tokens have to be processed by the relevant resource within a specified time. Insufficient allocation of resources could result in bottlenecks and an increase in cycle time. Resource configuration allows activities to be processed in terms of costs. Both time and resources analysis are configured and executed at the same time. Since UCAS data for each activity was unavailable, various simulation scenarios (Table 25) were carried out to determine what is considered to be a reasonable configuration; these scenarios and the rationale behind their configuration settings are explained below.

The following abbreviations apply: Scenario (S), Resources (R), Quantity (Q), Processing Time (PT), Waiting Time (WT), UCAS Track (UT), Admission Staff (AS), and University IT System (UIT).

Activity	**Cost**	**S1 R**	**S2 R**	**S3 R**	**S1 Q**	**S2 Q**	**S3 Q**	**S1 PT**	**S2 PT**	**S3 PT**	**WT (s)**
Applies to UCAS	10	UT	UT	UT	1	10	100	10	30	30	0
Receive Application	10	UT	UT	UT	1	10	100	1	1	1	10
UCAS Process Application	10	UT	UT	UT	1	10	100	3	20	20	0
Application Data Available	10	UT	UT	UT	1	10	100	1	1	1	0
University Process Application	20	AS, UIT	AS, UIT	AS, UIT	11	11	20	3	30	30	0
Publish Decision to UCAS	10	UIT	UIT	UIT	1	1	10	2	2	2	0
Receive Decision from University	10	UT	UT	UT	1	10	100	2	2	2	0
Make Decision Available to App.	10	UT	UT	UT	1	10	100	2	2	2	0
Receive Decision from UCAS	10	UT	UT	UT	1	10	100	2	2	2	0
Receive Confirmation from App.	10	UT	UT	UT	1	10	100	2	2	2	0
Send Confirmation to University	10	UT	UT	UT	1	10	100	0	0	0	0
University Process Confirmation	20	AS, UIT	AS, UIT	AS, UIT	11	11	20	3	3	3	0
UCAS Extra	10	UT	UT	UT	1	16	100	10	10	10	0
Clearing Process	S1 10 S2 30 S3 30	UT	UT, UIT, AS	UT, UIT, AS	1	21	120	10	10	10	0
Use Adjustment Service	S1 10 S2 30 S3 30	UT	UT, UIT, AS	UT, UIT, AS	1	16	120	5	5	5	0
Receive Course Confirmation	10	UT	UT	UT	1	10	100	1	1	1	0
Update Data	10	UT	UT	UT	1	10	100	1	1	1	0

Table 25: Simulation Scenario Configurations

The following settings apply to all the scenarios - Duration = 150 days (to cover the application period from when A levels results are released), Replication = 30 (to get a more accurate simulation outcome), Seed = 1, Arrival interval = 10mins, Maximum arrival count = 1,000 instances and resource configuration is shown in Figure 50.

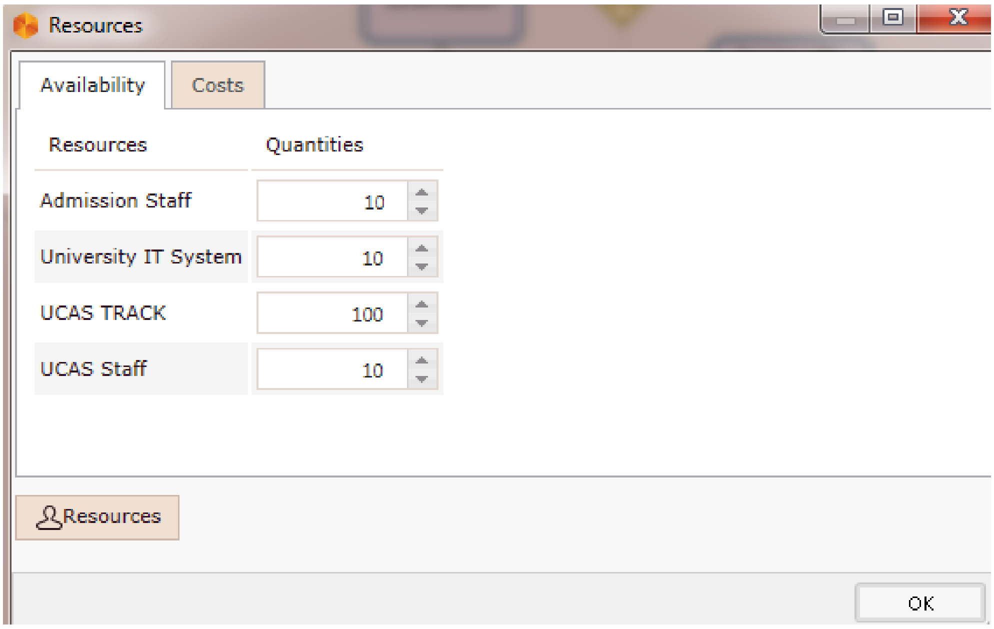


Figure 50: Resource Configuration

7.4.5 Simulation Outcome

Scenario 1: The simulation outcome reveals that UCAS TRACK is being over-utilized as shown in Figure 51. This is because the quantity of the resource allocated to UCAS TRACK was 1, resulting in full utilization of the system; therefore delays are inevitable until the resource becomes available. Consequently, the allocated resource must be increased to reduce service and waiting times. It is also observed that both admission staff and university systems are under-utilized. The total cost for Admission staff is £17, 800, UCAS TRACK is £104, 720 and the university IT System is £28, 330 for a period of 150 days. Figure 52 shows the cycle time for the process execution.

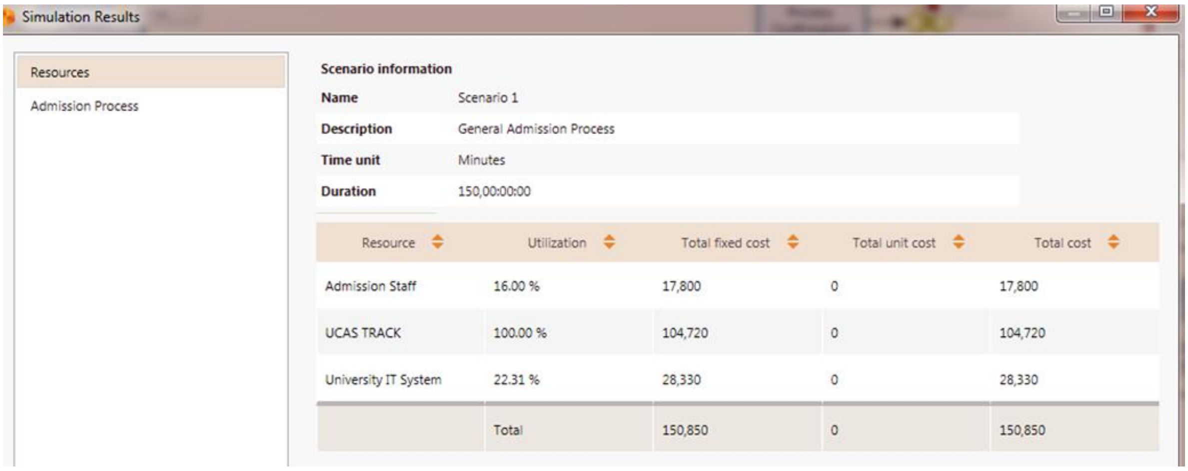


Figure 51: Scenario 1 simulation result – Cost and Resource Utilization

Scenario information	
Name	Scenario 1
Description	General Admission Process
Time unit	Minutes
Duration	150,00:00:00

Name	Type	Instances completed	Instances started	Min. time	Max. time	Avg. time
Admission Process	Process	1,000	1,000	1h 5m 40s	21d 19h 54m 40s	15d 1h 33m 59s
NoneStart	Start event	1,000				
Applies to UCAS	Task	1,000	1,000	10m	2d 23h 35m 30s	1d 11h 52m 47s
Receive Application	Task	1,000	1,000	11m 10s	2d 23h 28m 20s	1d 16h 21m 15s
Process Application	Task	1,000	1,000	14m 10s	2d 23h 30m 10s	1d 13h 59m 6s

Figure 52: Scenario 1 simulation result - Time

Scenario 2: More resources (quantities increased from 1 to 10) are now allocated to the UCAS system, this could be in the form of increased IT Infrastructure. This is a true reflection of the difficulties UCAS had in 2013 when it was a challenge to manage the demands on their IT infrastructure during clearing and confirmation. In order to cope with the challenge, a cloud solution was implemented by Attenda (now Ensono) using Amazon AWS infrastructure to enhance the UCAS system enabling it to handle a peak demand of 180 hits per second and over 1.1 million log-ins (*AWS Case Study: UCAS*, no date; Attenda, 2013) during the 2014 clearing and confirmation period. The processing time setting for the activity ‘Applies to UCAS’ is increased from 10 minutes to 30 minutes as well as ‘University Process Application’ activity to reflect the actual time it takes to complete and apply for admission (UCAS, no date b). In addition, the ‘Clearing Process’ and ‘Use Adjustment Service’ activities are now being supported by the University IT system and Admin staff as shown in Table 25.

Resources

Admission Process

Scenario information	
Name	What if - Scenario 2
Description	General Admission Process
Time unit	Minutes
Duration	150,00:00:00

Resource	Utilization	Total fixed cost	Total unit cost	Total cost
Admission Staff	46.45 %	28,630	0	28,630
UCAS TRACK	79.31 %	104,720	0	104,720
University IT System	51.32 %	39,160	0	39,160
	Total	172,510	0	172,510

Figure 53: Scenario 2 simulation results – Cost and Resource Utilization

The simulation results (Figure 53) show that there is an increased utilization of resources of admission staff (46.45%) and the University IT System (51.32%) while UCAS TRACK utilization is reduced to 79.31%. The total cost for Admission Staff is £28, 630, UCAS TRACK is £104,720 and the University IT System is £39, 160. It is noted that the cost of the UCAS TRACK remains unchanged, this is because the more resources allocated to an activity, the less time it would take for the activity to be executed, thus maintaining the same efficiency. Finally, the processing time for the University process application activity increases from 3 minutes to 30 minutes as shown in Figure 54

Scenario information	
Name	What if - Scenario 2
Description	General Admission Process
Time unit	Minutes
Duration	150,00:00:00

Name	Type	Instances completed	Instances started	Min. time	Max. time	Avg. time
Admission Process	Process	1,000	1,000	1d 9h 14m 10s	61d 3h 40m 40s	50d 15h 1m 44s
NoneStart	Start event	1,000				
Applies to UCAS	Task	1,000	1,000	30m	15d 11h 57m 30s	7d 18h 12m 27s
Receive Application	Task	1,000	1,000	1h 1m 10s	15d 11h 44m 50s	8d 23h 53m 2s
Process Application	Task	1,000	1,000	3h 52m 20s	15d 12h 3m 40s	7d 10h 39m 3s

Figure 54: Scenario 2 simulation results – Time

Scenario 3: The parameters used in scenario 3 are similar to scenario 2 except that additional resources are allocated to the UCAS system (quantities were increased from 10 to 100).

Scenario information	
Name	What if - Scenario 3
Description	General Admission Process
Time unit	Minutes
Duration	150,00:00:00

Resource	Utilization	Total fixed cost
Admission Staff	48.95 %	28,630
UCAS TRACK	69.52 %	104,720
University IT System	51.32 %	39,160
	Total	172,510

Figure 55: Scenario 3 simulation result – Cost and Resources Utilization

The simulation results (Figure 55) show that there is an increased utilization of resources of admission staff (48.95%) and the University IT System (51.32%) while UCAS TRACK utilization is reduced to 69.52%. The total cost for Admission staff is £28,630, UCAS TRACK is £104,720 and University IT System is £39, 160, which is the same costs as with scenario 2 (but as noted previously this includes higher admissions staff and university IT system costs compared to scenario 1).

The simulation results in terms of the time dimension are shown in Figure 56. The simulation results in Scenario 3 appear to be stable and more workable therefore scenario 3 parameters will be selected for both the as-is and to-be simulations. Even though we cannot certify the accuracy of the parameters due to lack of admission data from UCAS what is important is that the variables for both processes are the same.

Scenario information	
Name	What if - Scenario 3
Description	General Admission Process
Time unit	Minutes
Duration	150,00:00:00

Name	Type	Instances completed	Instances started	Min. time	Max. time	Avg. time
Admission Process	Process	1,000	1,000	1d 9h 14m 10s	61d 3h 40m 40s	50d 15h 1m 44s
NoneStart	Start event	1,000				
Applies to UCAS	Task	1,000	1,000	30m	15d 11h 57m 30s	7d 18h 12m 27s
Receive Application	Task	1,000	1,000	1h 1m 10s	15d 11h 44m 50s	8d 23h 53m 2s
Process Application	Task	1,000	1,000	3h 52m 20s	15d 12h 3m 40s	7d 10h 39m 3s
ExclusiveGateway	Gateway	1,000	1,000			
Refuse Application	Task	116	116	1m	1m	1m
Accept Application	Task	884	884	1m	1m	1m
Application Data Availabe for University	Task	884	884	12h 18m 10s	15d 9h 10m 20s	6d 10m 50s

Figure 56: Scenario 3 simulation result – Time

The simulation's output (based on simulation 3 parameters) in terms of average time and cost for the as-is admission process are presented in Table 26. The figures will be compared with the simulation output of the two to-be admission process that will be created by the creative and SNACH groups.

Activity	Average Time (mins)	Cost (£)
Applies to UCAS	11172.46	10000
Receive Application	12953.34	10000

UCAS Process Application	10719.06	10000
Application Data Available	8650.73	8840
University Process Application	5643.46	21060
Publish Decision to UCAS	6727.59	10530
Receive Decision from University	2619.72	10530
Make Decision Available to Applicant	1293.224	10530
Receive Decision from UCAS	1151.32	10, 530
Receive Confirmation from Applicant	1133.82	4920
Send Confirmation to University	786.55	4920
University Process Confirmation	5364.77	14540
UCAS Extra	6978.87	9780
Clearing Process	2892.81	15660
Use Adjustment Service	7274.91	7050
Receive Course Confirmation	479.82	3620
Update Data	1538.09	10000
Overall	**87,380.544**	**172,510**

Table 26: Simulation Result in time and cost dimensions

7.4.6 Control Flow Complexity (CFC)

This section will calculate the CFC for the as-is admission process. The logical complexity (CFC) is calculated by summing up the number of decisions in the flow of control in the process model i.e. the number of OR-splits, AND splits and XOR-splits in the process model**.**

A low CFC indicates that the process model is easy to understand. The splits in the model adds to the CFC number as follows: OR-split with *n* will add 2^{n-1} to the CFC metric, AND-split will add 1 to the CFC metric and XOR-split with *n* outgoings will add *n* to the CFC metric of the model.

OR-Split = 2^{n-1}, where n = 6 (based on figure 51)

CFC = 32

The next section shows how the structural complexity is determined to yield the aggregate complexity for the admission process.

7.4.7 Downscale Projection

The process model is downscaled using projection algorithm in section 4.4.1.

The social network visualizer was used to create the network diagram as shown in Figure 57:

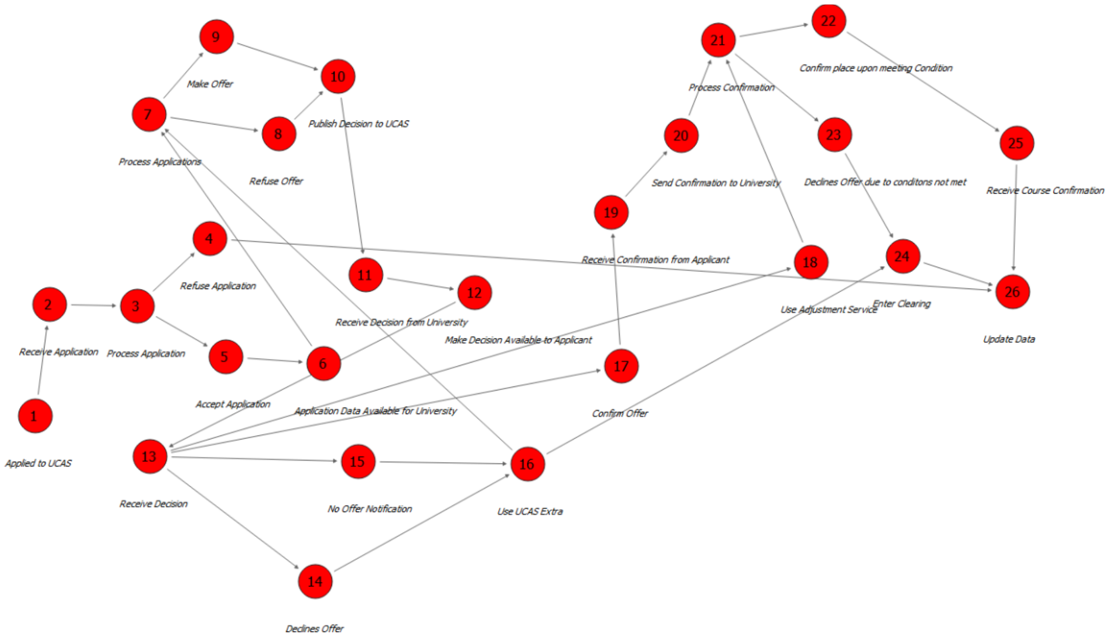


Figure 57: As-Is General Admission Network Diagram

7.4.8 Analysis of the Network

The network was analysed using both SNV and Gephi. The following results were obtained as shown in Table 27:

Metric	Value	Note
No of Nodes	26	
No of Links	32	
Average Degree Centrality	Node 13 (Receive Decision) = 0.160	
Max. Betweenness Centrality	Node 13 (Receive Decision)	Potential Bottleneck node
Min. Betweenness Centrality	Node 4 Refuse Application	Unnecessary Node
Density	0.049	
Diameter	14	

Table 27: Network Analysis Result for the As-Is Admission Process

The metric values for the as-is general admission process are as follows:

Time: 87,380.544 minutes = 1,456.34 hours

Cost: £172,510

Complexity $C = \frac{cfc+(\mathrm{s}+\mathrm{d})/2}{2}$,

where s (number of nodes) = 26 and d (diameter) = 14 and cfc = 32

$C = \frac{32+(26+14)/2}{2}, \frac{32+20}{2}$, = 26

Flexibility is the inverse of Density (D):

Flexibility = 1/D

Flexibility = 1/0.049 = 20.41

7.4.9 Creation of the 'To-Be' Process Model by the SNACH Group

The SNACH group used 9 (out of the 29) pre-selected business process improvement heuristics which are considered relevant to the admission process based on the heuristic selection process flow in Figure 30 - Heuristic selection process flow. The heuristics are: contact reduction, integration, task elimination, task composition, re-sequencing, knock-out, parallelism, task automation based on predefined rules and integral technology. The pre-selected heuristics implemented by the SNACH group were reviewed for validity and highlighted as follows:

Knockout: The task 'Process Application' in the UCAS lane and its subsequent outcomes of the OR-Gateway are knocked out because the processing of application could be performed by the university and the conditions required in the UCAS lane can be passed on to the University lane. Implementing this heuristic means that through put time is shortened and less resource is required.

Re-Sequencing: The apparent effect of implementing the knockouts means that the task 'Data Made Available to University' is now connected to the 'Receive Application' task.

Integral Technology: With technology such as WfMS (Workflow Management System), it is believed that the 'Process Application' task can be improved to change the traditional way of processing applications to reduce physical constraints and delays resulting in less through put time. More cost may be incurred by introducing the WfMS but this should be neutralized by the lower number of human resources required and time saving benefits of the improved process.

Automation: One of the purposes of introducing technology is to drive automation. As university admission is a complex decision, a fully automated process may not be possible due to a set of varying entry requirements depending on the course and university of interest. For example, it is a general requirement for all students applying to Universities of Cambridge and Oxford to attend an interview, and a portfolio submission may be required from students applying to study a course in a hands-on subject area. However, UCAS does use Tariff points to help simplify and translate heterogeneous qualifications and grades into numerical value. Therefore, a form of automated support for assisting the resources executing the 'process application' task is possible.

Task Elimination: The tasks 'Receive Decision from University' in the UCAS lane and 'Receive Decision' in the Applicant lane were eliminated, while 'Make Decision Available to Applicant' moved to the Applicant lane. These tasks are considered redundant because they do not add any value. Instead the decision from the University is made available to the applicant through the UCAS system.

Contact Reduction: As a result of implementing task elimination heuristics multiple contacts or communications made with applicants were reduced.

Task Composition: The 'Receive Confirmation from Applicant' and 'Send Confirmation to University' tasks are both merged with the 'Process Confirmation' task for greater efficiency.

Integration: Integration of Universities' and UCAS' systems can make the admission process operate more efficiently in terms of time and cost. For example, UCAS started a digital transformation programme that is due to be completed in 2020 which will require all universities and colleges to connect to UCAS using an external API driven user interface to drive continuous innovation and improvement (Saran, no date).

Parallelism: Three tasks 'Enter Clearing Process', 'Use UCAS Extra' and 'Use Adjustment Service' are connected in parallel allowing them to be performed concurrently saving throughput time. Applicants whose applications were unsuccessful can use UCAS Extra or go for the Clearing option. Those who decline their offers from the university due to performing better than anticipated can use the Adjustment Service, UCAS Extra or Clearing. Furthermore, applicants who confirmed their offers from universities but unfortunately had their confirmations declined due to

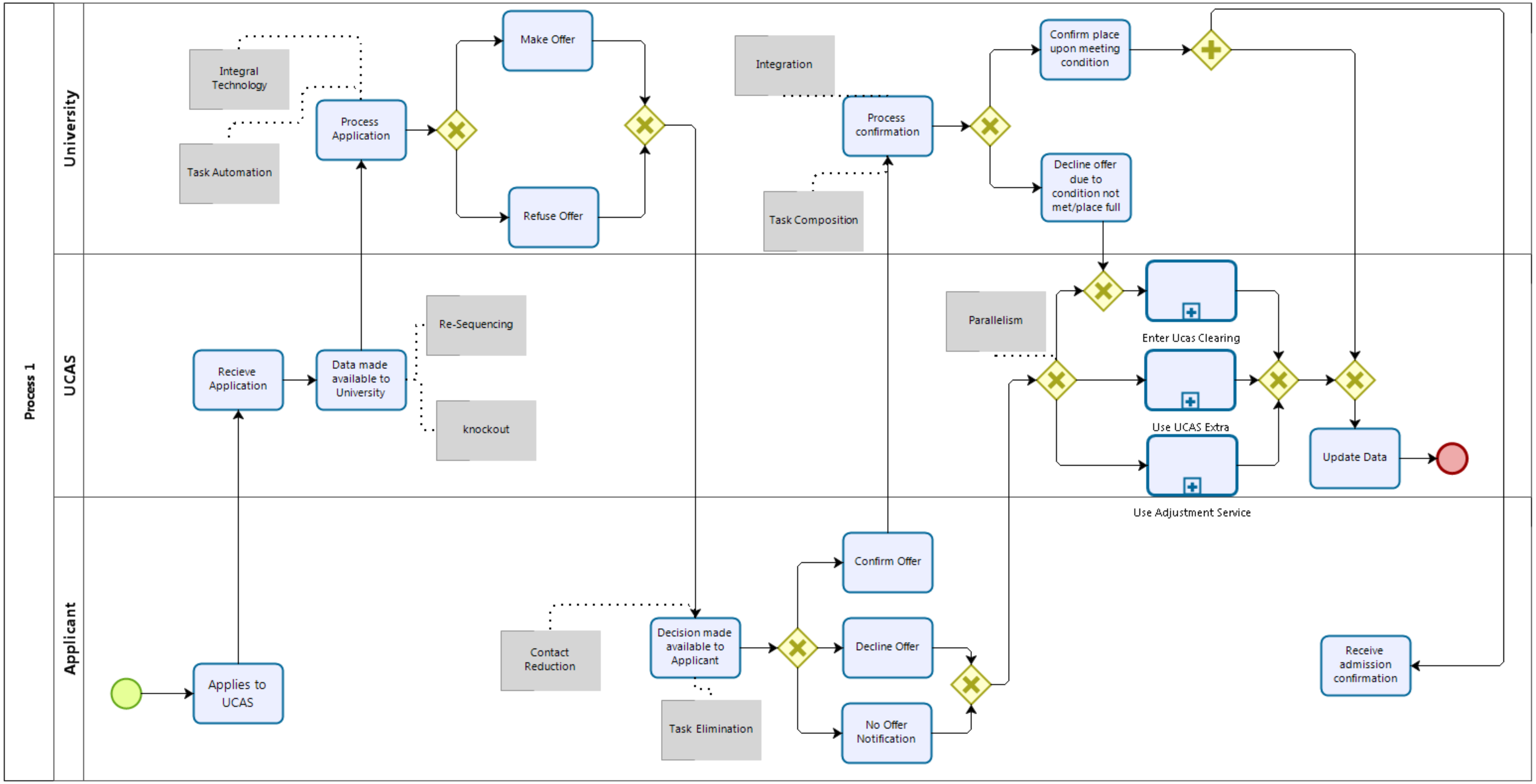


Figure 58: To-Be Admission Process

either failure to meet their admission conditions or course places being full can use Clearing.

At the end of the 90 minutes, the SNACH group created the ‘to-be’ admission process model shown in Figure 59.

7.4.10 Instructions for Creative Group

1) Read the provided case study – UK HEI Admission Process Description.
2) Study the model to further understand the admissions process.
3) Create a new/improved process model to the best of your ability on the provided sheet.

As you can see, this is the same as the instructions the SNACH group had with the exception of the use of the SNACH framework to assist them in establishing suitable improvements. This allows testing of the hypothesis that the use of SNACH produces better improvements than would happen if it was not used (i.e. relying on creativity alone).

The creative group followed the above instructions relying on brainstorming and individual creativity skills. There were a few improvement possibilities available to them which are: identify potential delays, identify and remove non-value adding activities, re-sequence some activities in a more logical way and combine or decompose activities. They were unfortunately unable to create any improved process models in the allocated experiment time. Except that a member of the group suggested after the experiment was over that the second ‘Process Application’ activity in the university lane could be eliminated if UCAS has a robust application process in place. The suggestion is not workable because UCAS does not process applications for Universities.

7.4.11 Simulation of the SNACH Group’s ‘To-Be’ Admission Process

As only the SNACH group were able to create a ‘to-be’ model in the time available we only have one proposed ‘to-be’ model to simulate (with the creative group having no output to share). This also means we are unable to compare outputs from both groups to see which group produced better improvement ideas, but as the SNACH framework helped the SNACH group to complete a ‘to-be’ model, while those who relied on creativity alone (i.e. they didn’t use SNACH to assist them) were unable to produce anything, this shows SNACH is effective at aiding identification of process improvements.

To simulate the ‘to-be’ admissions process (as proposed by the SNACH group) the Bizagi software settings were configured in the same way as was used for the ‘as-is’ process to ensure comparable results. The model is free from logical errors validated by Bizagi software and the scenario 3 (being the most suitable scenario) configuration (from Table 25) is used and is shown in table 36. The simulation is shown in Figure 60

Activity	**Cost**	**S3 R**	**S3 Q**	**S3 PT**	**WT (s)**
Applies to UCAS	10	UT	100	30	0
Receive Application	10	UT	100	1	10
UCAS Process Application	10	UT	100	20	0
Application Data Available	10	UT	100	1	0
University Process Application	20	AS, UIT	20	30	0
Publish Decision to UCAS	10	UIT	10	2	0
Receive Decision from University	10	UT	100	2	0
Make Decision Available to Applicant	10	UT	100	2	0
Receive Decision from UCAS	10	UT	100	2	0
Receive Confirmation from Applicant	10	UT	100	2	0
Send Confirmation to University	10	UT	100	0	0
University Process Confirmation	20	AS, UIT	20	3	0
UCAS Extra	10	UT	100	10	0
Clearing Process	10	UT, UIT, AS	120	10	0
Use Adjustment Service	10	UT, UIT, AS	120	5	0
Receive Course Confirmation	10	UT	100	1	0
Update Data	10	UT	100	1	0

Table 28: Scenario 3 Configuration Settings Extracted from Table 25

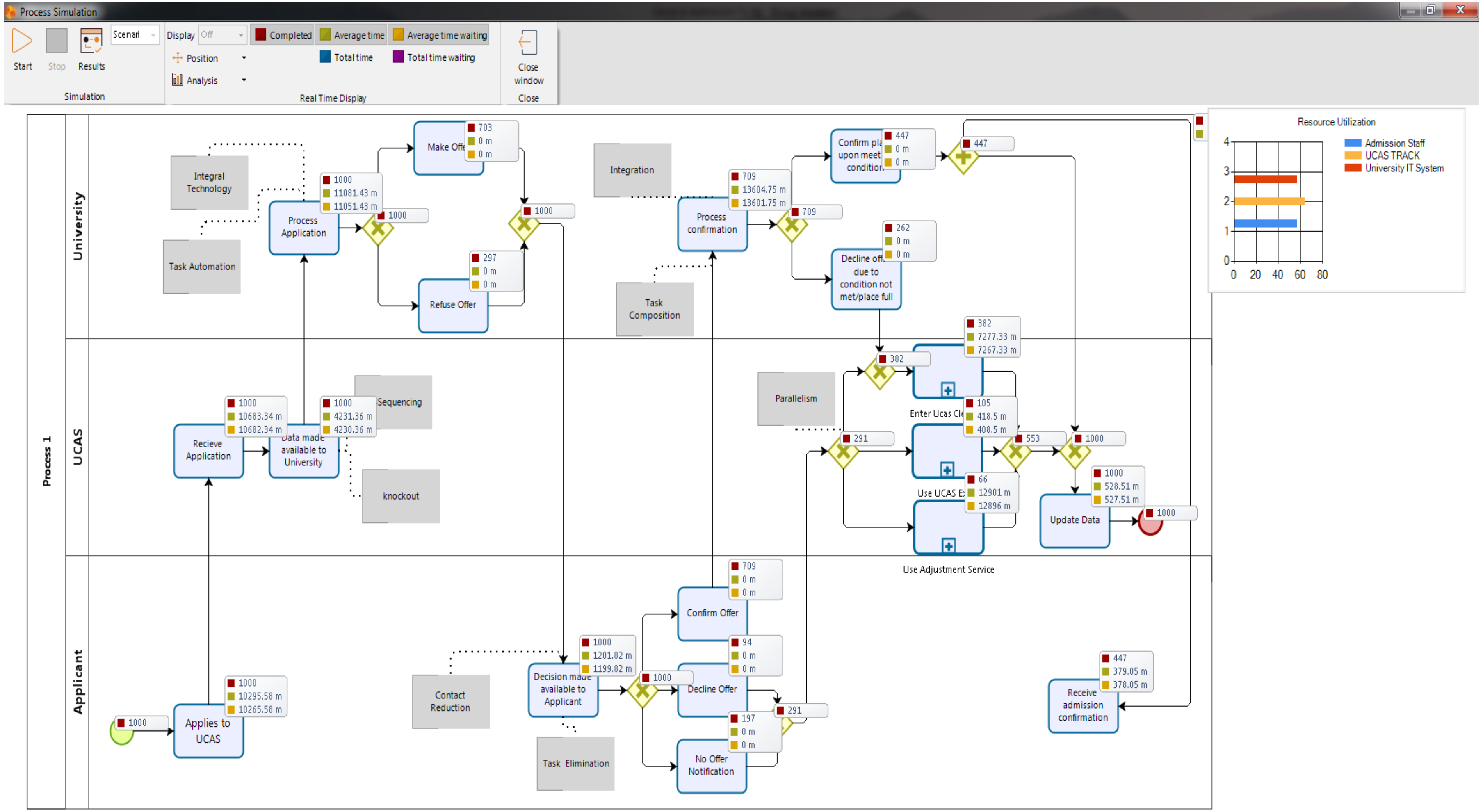


Figure 61: Simulation of the To-Be Admission Process

7.4.12 Simulation Outcome

Resource utilization and total costs are shown in Figure 62 while average cost and time for each activity are shown in Table 29. As there are less activities in the ‘to-be’ process time and costs are positively impacted.

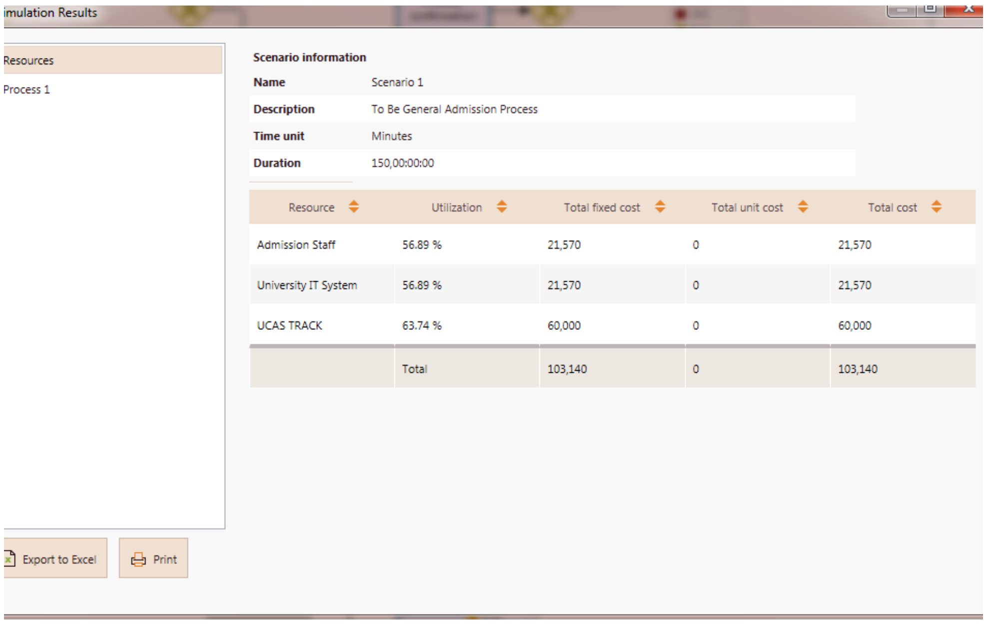


Figure 62: Resource utilization (to-be admissions process)

Activity	**Average Time (mins)**	**Cost (£)**
Applies to UCAS	10295.58	10,000
Receive Application	10683.34	10,000
Application Data Available	4231.36	10,000
University Process Application	11081.43	20,000
Make Decision Available to Applicant	1201.83	10000
University Process Confirmation	13604.75	14180
UCAS Extra	418.51	1050
Clearing Process	7277.33	11460
Use Adjustment Service	12901	1980
Receive Admission Confirmation	379.05	4470
Update Data	528.51	10000
Total	**72,602.69**	**103, 140**

Table 29: Average time and cost for each activity (to-be admissions process)

7.4.13 Control Flow Complexity (CFC)

The CFC for the to-be process is calculated below:

$$CFC = OR\text{-}Split + And\text{-}Split$$

$$OR\text{-}Split = 2^{n-1}, \text{ where } n = 4, \ And\text{-}Split = 1$$

$$CFC = 2^{4-1} + 1 = 9$$

7.4.14 Downscale Projection

The to-be process is downscaled using the projection algorithm in section 4.4.1. The social network visualizer was used to create the network diagram as shown in Figure 63.

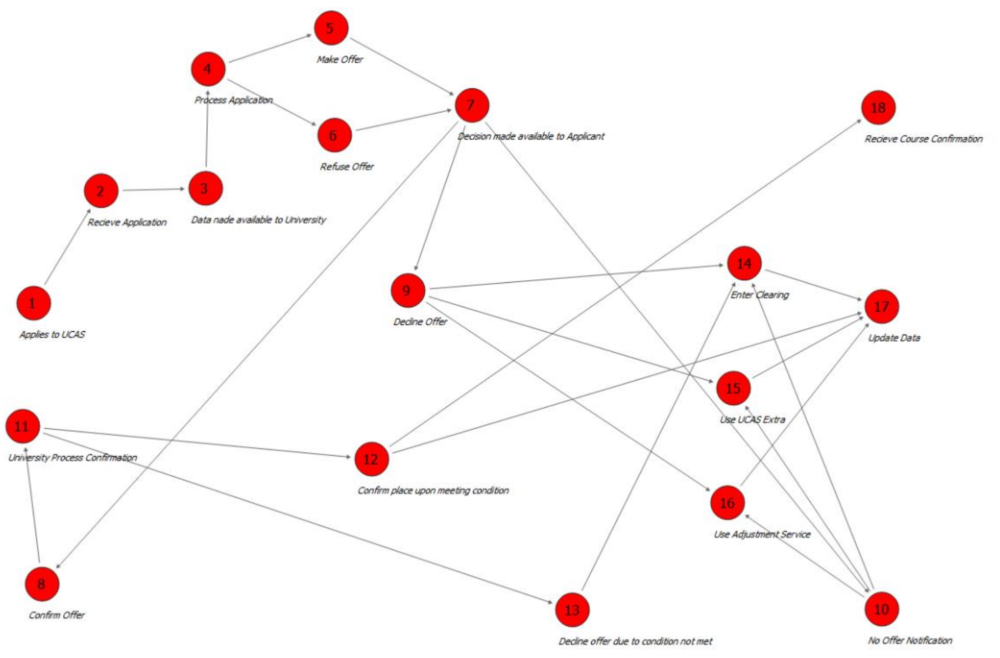


Figure 63: To-Be Admission Process Directed Graph

7.4.15 Perform Network Analysis

The network projection was analysed using both SNV and Gephi and the following results were obtained as shown in Table 30

Metric	Value	Note
No of Nodes	18	
No of Links	25	
Average Degree Centrality	1.389	
Max. Betweenness Centrality	Node 7(Decision made Available)	Potential Bottleneck node
Min. Betweenness Centrality	Node 17 (Update Data) and Node 18	Unnecessary Node
Density	0.082	
Diameter	9	

Table 30: Network Analysis Data

The metric values for the to-be general admission process are as follows:

Time: 72,602.68 minutes = 1210.044 hours

Cost = £103,140

Complexity $C = \frac{cfc+(s+d)/2}{2}$,

Complexity, $C = \frac{9+(18+9)/2}{2}$, = 11.25

Flexibility is the inverse of Density (D):

Flexibility = 1/D = 1/0.082 = 12.20

7.4.16 Admission Process Results Discussion

The second stage of evaluation is regarding an experiment performed to evaluate the effectiveness and efficiency of SNACH. Table 31 shows the measures for the as-is and to-be admission processes (with 'to-be' being from the group who used SNACH to assist them) while Figure 64 visualises the improvement.

Metric	**AS IS**	**TO BE**	**Difference**	**% Difference**
Time	1,456.34 hours	1,210.044 hours	246.30	18.47%
Cost	£172,510	£103,140	£69,370	50.33%
Complexity	26	11.25	14.75	79.20%
Flexibility	20.41	12.20	8.21	50.35%

Table 31: Admission Process Results

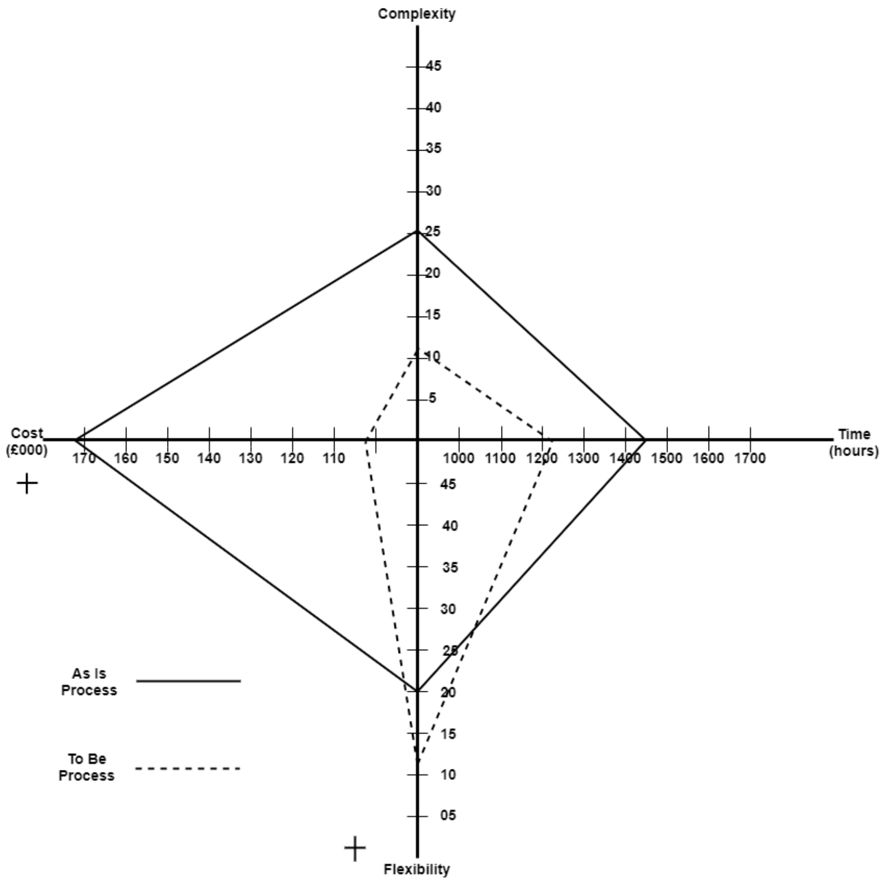


Figure 64: Reversed-Y Quadrangle for the Admission Process

The overall outcome of the experiment shows that the SNACH framework approach supports the act of improvement and is preferred over the use of creative skills or an unstructured approach to improvements in terms of effectiveness and efficiency.

The result of the experiment shows there is significant benefit of using an approach that supports the act of improvement. At the end of the experiment each group were presented with a questionnaire about the process model. When asked 'what problems could you identify in the current admission process that may or could cause a delay in the process?' the Creative group responded that no problems were identified. On the other hand, the SNACH group identified two problems: 1) Two-point verification (UCAS process application and University process application activities) could introduce a delay in the process. They dealt with the problem by merging the two activities into one. 2) The process of receiving, sending and confirmation could cause a delay and these activities could be automated to reduce delays.

This coincided with the result of the complex network analysis; the node with maximum betweenness centrality was identified as Node 13 (Receive Decision) which is indicative of a potential bottleneck area. This is important to note because the complex network analysis was used as an approach to identify potential bottleneck areas and unnecessary tasks which provides answers for one of our research questions: how can unnecessary or bottleneck activities be identified in a business process? Of course the technique can only identify potential problematic nodes, these are still subject to human scrutiny; if it is a bottleneck area more resources could be added to the node or a relevant heuristic could be applied, or if considered unnecessary the node can be eliminated, or if it is actually considered relevant the node can be left unmodified.

Surely the use of the heuristics used by the SNACH group helped them to generate improvement ideas. Having reviewed their choice of heuristics some amendments were carried out with regards to the improved process model because in reality offer confirmations are necessary to ensure that the right choices are made; for example, students need to confirm offers and universities need to confirm places upon students meeting admission conditions. However, some 'Receive Decisions' activities were eliminated in order to reduce contact and save resources.

When the creative group were asked if they could identify any irrelevant or unnecessary activities in the current process their response was 'none'. On the flip side, the SNACH group referred to the 'Receive & send' application stages, as identified earlier. The SNACH group were asked if they found any of the heuristics irrelevant and why, and they found all the heuristics relevant and applicable which validates our heuristic selection algorithm (flowchart).

Several authors (Zellner, 2011; Thomas *et al.*, 2013; Lang *et al.*, 2015; Vanwersch *et al.*, 2016b) have suggested that having structured approaches that support the act of improvement would facilitate process improvement, making processes more efficient and effective. This has been proved to be correct as revealed in the results of the experiment. The Creative group could not generate any valid improvement ideas nor find any issues with the admissions process and consequently no to-be artefact was produced by them, whereas the SNACH group were able to create a to-be process using the Heuristics within the SNACH framework.

Although both groups were given 90 minutes to improve the process some other activities within the SNACH framework had been done and results provided to the group before applying the Heuristics. So technically, with the learning curve effect of having to use the complex network tools, the SNACH group would require more time if they were to carry out all the activities in the framework. Yet, it is believed that the SNACH framework would still produce more productive improvement changes than relying on creative skills if given an equal time frame.

We revisit the hypotheses of the experiment in table 23:

Effectiveness of SNACH: The degree of improvement of the To-Be process is greater than that of the As-Is process.	
Hypo01	**The use of SNACH does not yield more productive improvement changes than merely using average creative skills would provide within a set time frame.**
Hypo1	**The use of SNACH yields more productive improvement changes than merely using average creative skills would provide within a set time frame.**
Efficiency of SNACH: How much improvement could be achieved within a specified time?	
Hypo02	**The use of SNACH does not increase the time efficiency during the improvement process.**
Hypo2	**The use of SNACH increases the time efficiency during the improvement process.**

Table 23: Hypotheses of the Experiment

From Table 31, there are improvements in the following dimensions: 16.91% in cycle time, 40.21% in cost and 56.73% in complexity but unfortunately there is a 40.23% reduction in flexibility. The reduction in flexibility is due to the application of certain heuristics. For example, applying the integration heuristic means that dependence across organisations increases and this may have a negative impact on flexibility. Another heuristic that was applied is Automation which could potentially reduce flexibility due to less options or manoeuvring that could be explored by human resource. A way to tackle this challenge is to consider establishing automated support for the resource executing the task instead of fully automating the task (H.A. Reijersa; and S. Liman Mansar, 2005).

The results of the experiment confirm hypotheses Hypo1 and Hypo2.

7.5 Conclusion:

This chapter focussed on the evaluation stage of the Design Science Research Methodology. The evaluation was carried out to validate the choice of process improvement performance metrics and the SNACH framework.

The experimental evaluation method was employed which comprises of Simulation and Controlled Experiment. The performance metrics are indicators that enable practitioners to measure the extent of process improvement between the as-is and to-be processes. The

Reversed-Y quadrangle was introduced to accommodate our choice of metrics which are cycle time, cost, complexity and flexibility. This allows the visualization of the extent of process improvement in these four dimensions such that an overall reduction in the phase space is an indication of improvement. The modified quadrangle showed that there was an improvement in both the clearing and admission processes.

The SNACH framework was evaluated by conducting an experiment to gauge its effectiveness and efficiency. The evaluation has revealed the suitability of the various components of the framework in achieving the goal of supporting the act of process improvement. The outcome of the experiment confirms the following hypotheses: 1) The use of SNACH yields more productive improvement changes than using average creative skills within a set time frame and, 2) The use of SNACH increases the time efficiency during the improvement process.

CHAPTER 8

CONCLUSIONS AND FUTURE WORK

8.1 Introduction

This chapter summarizes the work presented in this thesis, its contributions and future research work. It begins by revisiting the research objectives and presents a discussion on how the objectives have been achieved. The thesis' contributions to knowledge are also presented.

8.2 Research Objectives

The overall objective of this research was to develop a framework that supports the act of process improvement with integrated measurable concepts to track process improvement activities in a collaborative environment. The collaborative environment was illustrated by using a case study of processes across organisational boundaries in a bid to demonstrate the complexity of the business process model since processes in a collaborative environment are typically more complex. As identified in literature, there are many process improvement methodologies that have various phases and guidelines but lack a step by step approach that can support practitioners or analysts to progress from an as-is process model to a to-be process model. Braun *et al.* (2005) discussed the scientific approaches to information systems research, appropriate conceptualizations of 'method' and 'method construction' including the Mandatory Elements of a Method (MEM). Zellner (2011) proposed MEM as a method that contains elements that support the act of process improvement. Many process improvement methodologies were evaluated against MEM but none was able to meet all the requirements.

The research objectives were:

1) **To determine an appropriate choice of modelling approach and language with explicit constructs that supports the analysis technique.**

   This objective is based on research question 4. The choice of business process modelling language must have adequate constructs to capture: a) the operational activities of business processes; b) the collaborating parties that make up the organisational units; c) the process owners; d) the IT systems that drive the business; e) the logical flow of activities and constraints, and f) compatible with the choice of business process analysis technique.

2) **To determine an appropriate process analysis technique that supports collaborative business process improvement.**

This objective is also based on research question 4. There are several classifications of business process analysis techniques depending on the purpose of the analysis. In our case, the purpose of the process analysis is to give quantitative insight into the performance of a business process, facilitating the identification of weaknesses in order to create a to-be business process.

3) **To determine an appropriate choice of process improvement measurable concepts to quantitatively measure process improvement both at design and execution stages.**

   This objective is based on research question 3. It involves the selection of measurable concepts that will be used to track and visualize process improvements.

4) **To demonstrate the application of complex network analysis as a technique:**
   a. **That supports the Identification of potential bottle-neck activities in business process models.**
   b. **That supports the analysis, improvement and measurement of business processes.**

   This objective is based on research question 2. We propose a new idea to explore the use of complex network analysis approach to provide information about the structural relationship and information exchange between process activities with the aim to support the analysis, improvement and measurement of business processes.

5) **Develop an algorithm for reducing a process model to its network structure.**

   This objective is also derived from question 2. It will perform an analysis of different types of networks in order to determine the appropriate type of network to be used in our case. In addition, it will determine the amount of detail that will be removed when a business process model is projected into a network.

6) **Evaluate the process improvement framework by conducting an experiment.**

   This objective is based on the research aim and research question 1. We propose the Simulation Network Analysis Control flow complexity and Heuristics (SNACH) framework, a novel approach to support business process improvement. The framework will be evaluated by conducting an experiment using a case study.

8.3 Research Contributions and Findings

The outcome of this research is a framework that supports the act of improving any business process which is usable by analysts, practitioners or an ordinary user as revealed by the experiment performed in chapter 7.

The following noteworthy contributions are realised in line with the research questions defined in Chapter 1.

Research Question 1: How can a systematic approach that supports the act of process improvement be defined or developed?

Contribution 1: This is the main contribution of this research based on the answer to the above research question. This contribution is presented in chapter 5 as *Figure 29*. A business process improvement framework called SNACH (Simulation Network Analysis Control flow complexity and Heuristics) was developed based on the Mandatory Elements of a Method (MEM) using the Map technique for method construction. MEM elements tackle the issues surrounding the unstructured approach that currently exist in business process improvement projects.

The SNACH framework consists of a procedural set of activities that provides improvement guidelines to analysts. It uses three techniques to support improvement activities and to generate results: 1) It engages the simulation technique to analyse the business process by obtaining an assessment of its current process performance in terms of time and cost, 2) It engages the Control Flow Complexity (CFC) technique to analyse the complexity of the logical decisions that exists in the business process. Since CFC only accounts for the logical complexity of the process and does not take into consideration the structural complexity we employed the use of, 3) Complex Network Analysis (CNA) technique metrics to overcome this limitation. Specifically, the size and diameter metrics of the downscaled projection of the business process. These were used in conjunction with the CFC to arrive at the final complexity metric of the business process. The density metric of the CNA was used to determine the flexibility of the business process. The node with the highest betweenness centrality gives an indication of potential bottleneck area while the node with the lowest betweenness centrality gives an indication of unnecessary activity in the business process.

Contribution 2: When the weaknesses in the business process model have been identified through the above analysis techniques the analyst needs to know what to do next to fix these weaknesses. The SNACH framework includes a set of 29 process improvement heuristics (based on industry best practices) that can be applied in order to enhance the improvement process and serve as a practical guide for analysts**.** An analysis of these heuristics was carried out and a heuristic selection process flow was defined.

The SNACH framework was evaluated in Chapter 7 by conducting an experiment using the General Admission Process into UK HEI. The outcome of the experiment confirmed the two hypotheses: Hypo1) The use of SNACH yields more productive improvement changes than using average creative skills within a set time frame, Hypo2) The use of SNACH increases the time efficiency during the improvement process.

These first two contributions satisfy:

- **The Main Objective:** *To develop a framework that supports the act of process improvement with integrated measurable concepts to track process improvement activities in a collaborative environment.*
- **Objective 6:** *Evaluate the process improvement framework by conducting an experiment.*

Question 2: Can a reduced process model contribute towards improving and measuring business processes?

Research Finding: The outcome of this research shows that a reduced process model in the form of downscaling a business process model to projective spaces specifically 2D space (directed network) using complex network analysis technique can contribute towards improving and measuring business processes.

Contribution 3: In the process of applying the Complex Network Analysis (CNA) technique to business processes, an algorithm that supports the downscaling of a business process to projective spaces was defined. It was composed in a similar way to the approached employed in Data Flow Diagrams (DFDs) where analysts can move from a lower level DFD (e.g. level 1) to a higher level DFD (e.g. context level or level 0). When this is done some details in the lower level DFD are stripped off. In a similar manner some details contained in the downscaled business process model are stripped off leaving only the nodes and links in the network structure.

This contribution satisfies:

- **Research Objective 5:** *Develop an algorithm for reducing a process model to its network structure.*

Contribution 4: When downscaling a business process to its network structure (or projective space) a choice has to be made between choosing either a directed network or undirected network. So far and to the best of our knowledge, there is no justification in literature to use either of the above. Some related works as presented in Chapter 2 used undirected networks because they are simple to implement, our results were contrary to this. In order to determine the appropriate type of network four business processes (both as-is and to-be) were converted to their individual network structure and analysed. The results of the directed network made more logical sense and were less complex than undirected network as discussed in Chapter 4.

This contribution satisfies:

- **Research Objective 4a and 4b:** *To demonstrate the application of complex network analysis as a technique:*
    a. *That supports the identification of potential bottleneck activities in business process models*
    b. *That supports the analysis, improvement and measurement of business processes*

Our CNA approach satisfies objective 4a by using the betweenness centrality metric. The node that has the highest betweenness centrality is a potential bottleneck area. Therefore, more resources should be allocated to such nodes to reduce delays. The identification of such node matched the activity that had high utilization of resources during the simulation of the business process.

Our CNA approach satisfies 4b as revealed in the evaluation (Chapter 7).

Research Question 3: What metrics or measurable concepts are appropriate for quantitatively measuring process improvement at both design and execution stages?

Contribution 5: An appropriate set of metrics was required to evaluate both the as-is and to-be processes to be able to measure the scale of the improvement. In addition, the last stage of the DSR methodology used required an evaluation of the artefact which must be carried out using an appropriate set of metrics.

In Chapter 1 we differentiated between design time and execution time measurable concepts. In Chapter 7 the use of a quadrangle was adopted whose metrics are time, cost, quality and flexibility. Time and Cost were chosen as execution time metrics using the time and cost outcomes of the simulation analysis technique. Since quality is a multi-dimensional metric and difficult to measure quantitatively it was replaced with complexity, a metric more relevant to the collaborative nature of the business processes under investigation. Logical complexity was measured using CFC (control flow complexity) while structural complexity was measured using the complex network analysis metrics size and diameter. Flexibility was determined using the inverse of the density of the network. In summary, the quadrangle metrics are cost, time, flexibility and complexity. When comparing the as-is and the to-be models a decrease in the volume of the phase space of the quadrangles is an indication of improvement.

This contribution satisfies:

- **Research Objective 3:** *To determine the appropriate choice of process improvement measurable concepts to quantitatively measure process improvement at both design and execution stages.*

Research Question 4: Which process analysis technique is most suitable for quantitative analysis of process models in a collaborative environment?

Research Finding: The type and nature of the analysis technique used determines the measures that will apply depending on the purpose of the analysis. In an attempt to answer the question, a review of business process analysis techniques was carried out based on three classifications.

The first was Dumas classification which is based on a choice between qualitative or quantitative process analysis techniques. A number of qualitative process analysis and quantitative process analysis approaches were discussed. Quantitative analysis techniques were chosen over qualitative due to its performance measurement capabilities. Within the Quantitative analysis techniques, simulation was chosen as a result of its many benefits as described in Chapter 2.

The second classification considered was phase classification which is based on a choice between design time analysis and runtime analysis. Runtime analysis was beyond the scope of this work.

The third classification considered is based on the work of Vergidis who classified process analyses into three categories: 1) Observational, 2) Formal Techniques, and 3) Simulation.

The simulation technique was chosen due its ability to offer what-if analysis which can give insight into the performance of the business process based on multiple scenarios, which was a requirement for our choice of process analysis technique. However, simulation is unable to analyse the multiple structural properties of a business process model, therefore another approach was also used, namely complex network analysis, to analyse the structural relationship and behavioural structure of the process activities.

- This research finding satisfies: **Research Objective 2:** *To determine the appropriate process analysis technique that supports collaborative business process improvement.*

In order to satisfy **Research Objective 1 "***To determine the appropriate choice of modelling approach and language with explicit constructs that supports the analysis technique"* in chapter 2 a set of requirements were defined for appropriate business process languages. This revealed that the Business Process Modelling Notation (BPMN) was appropriate because it satisfied all the requirements.

8.4 Limitations

In this section we highlight some of the limitations of our research. Some limitations were encountered with respect to the interpretation and application of other Complex Network Analysis metrics such as clustering co-efficient, connectivity coefficient, average path length, reach etc. Finding the accurate interpretations and applications of these metrics would give further insight into the structural properties of a reduced business process model. Although, the size and diameter metrics used were sufficient to provide a measure for the structural complexity of the reduced business process, and density was sufficient to give an indication of its flexibility.

Another limitation was applicability of the weighted network projections to business process models, so far we could not find the relevance of the weights in relation to business processes. It might be worthwhile to investigate the weighted directed and weighted undirected projections, analyse the network projections at both levels, and compare the outcomes.

However, the evaluation of the SNACH framework revealed that it is capable of supporting the act of improving a business process and it satisfies all the elements of MEM.

8.5 Further Work

The work presented in this thesis was defined to construct the SNACH framework that supports the act of process improvement with integrated measurable concepts to track process improvement activities in a collaborative environment. From the related work it was revealed that existing BPI methodologies do not adequately support the actual act of improving a business process, i.e. progressing from an as-is model to a to-be model. Our proposal is that using SNACH can provide better business process improvement support.

With regards to potential future research directions such research will consider the following areas:

- Exploration of the interpretation and applicability of complex network metrics to business process models to provide further insight into its macrostructure.
- Explore the applicability of weighted directed networks and if relevant and applicable further projections can be considered to provide further comparison between non-weighted directed networks and weighted directed networks.
- The proposed SNACH framework will be tested against usability criteria.
- Lastly, the SNACH framework to be fully tested from start to finish with more case studies to monitor validity and generalization.

8.6 Summary

The research challenge was lack of adequate support for the systematic improvement of a business process. The inductive research approach was chosen, the research strategy was case study (the admission process in the UK HEI comprising of the clearing process and general admission process), and the research data was collected through the following methods: Interviews, Document Study and Observation. The Design Science Research Methodology was adopted.

The following research contributions were made:

1) Development of SNACH, a process improvement framework consisting of quantitative analysis techniques, improvement heuristics and metrics to compare the results of both the as-is and to-be process models.

2) Creation of an algorithm or guidelines to downscale a process model to its basic network structure.

3) Evidence to show that directed networks are more accurate for capturing a downscaled process model than undirected networks.

4) Creation of process improvement guidelines based on the structural properties of the process model.

5) Creation of improvement heuristics selection criteria from a catalogue.

6) Systematic selection of model-based quantitative measurable concepts to measure process improvement at both design and execution stages.

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APPENDIX 1

Interview Questions

Name:	Date:
Job Title:	Duration:

Purpose: Improve Understanding of the Clearing Process
1. Please could you describe the clearing process focussing on SciTech
2. When applicants phone in, what sort of questions do they get asked?
3. Is the result evaluation done over the phone or the applicant is contacted via email or a call back?
4. How do they get notified of an offer or rejection – phone of email?
5. If the applicants are given a rejection on phone, what happens if the University reduces the entry requirements for the course, do they get contacted again?
6. How does UCAS get notified of offers? Does the University wait until the end of clearing before the data is sent to UCAS?
7. Is the Clearing Process entirely managed by UCAS?
8. Have there been occasions where an admission was made without the knowledge of UCAS?
9. I understand student must confirm offer within 24 hours, if they don't confirm the offer, do they get a call back or that is an automatic rejection?
10. When students finally get admitted, do they get a confirmation letter through the post?
11. Do you collate all Data – Confirmation, rejection and refusal? Are they sent to UCAS?
12. Please check the Clearing Process model. Is there anything missing or inaccurate in the diagram?
13. Do you consider International students application?
Note: International Recruitment isn't included in the process model.
14. What are the University plans to optimize international recruitment?
15. Are there UCAS standards that must be adhered to by the University?
16. What are the current challenges with the system?
17. How do you think it can be improved?

Name:	Date:
Job Title:	Duration:

Purpose: Admissions Target Setting from SciTech Perspective
1. How are admission targets set? 2. What are the variables and constraints that determines the target for each course?
3. What happens if a course does not meet its target during clearing?
4. Some courses meet their targets during the normal admission cycle, so they don't have to enter clearing. Is possible for those courses to be asked to admit more students to make up for those who courses that are under-subscribed to meet the overall University targets?
5. Most of the students who enter clearing didn't make the grade required for their chosen course/University, therefore they may settle for an alternative course. Clearing is usually accompanied by lowering tariffs to get the student numbers requirements thereby attracting students with lower qualification. Do you know if there is any statistical data to show that students who got admitted through clearing could have a lower performance/grade than students who got admitted through the normal admission cycle?
6. The Clearing Process is centrally managed, what are the benefits compared to having it been managed by each department in the faculty?
7. What are the current clearing process challenges and how do you think they can be improved.
8. What happens if a course meets its target during clearing?
9. What happens if a course is under-subscribed during clearing and the University target is yet to be reached?
10. How long does clearing take place – 5 days?
11. How much time is spent on the phone with the applicant?
12. How many people per course or department interview students?
13. In monetary terms, how much per person for hour?
14. In your opinion, what do you this is the impact of lowering tariffs during clearing?
15. What is the percentage increase in the number of offers made when tariffs are lowered?
16. What is the average number of students who apply during clearing?
17. How do you think the clearing process can be improved?

Name:	Date:
Job Title:	Duration:

Purpose: Admissions Target Setting from University Perspective
1. From the University perspective, how does the Clearing process work?
2. I am aware that admissions target is set by the University and this cascade down to faculties, departments and courses. What happens if a course or department does not meet its target during clearing? Does that mean that the overall University target remains unmet?
3. Admission estimates are made before the admission cycle begins. How are these estimates arrived at and what business intelligence tools or software are used to create simulations of the admission or clearing process?
4. Would visual representation of the clearing or admission process useful in decision making?
5. How is Recruitment Data managed during clearing?
6. Is it a manual process or automated process?
7. BUCAT meets daily during clearing to analyse clearing data and updates the clearing staff on the status of the clearing process e.g. if targets are over, under or on track. What sorts of decisions are made with those data?
8. IS it possible to have a business Process Simulation ahead of the clearing process to help give some intelligence into the clearing process such that decisions can be made even before clearing?
9 What are the current challenges with the Clearing Process from the University's point of view and how do you think it can be improved?
10. The new system we have in place – SITS is well integrated with UCAS system, the data gotten from SITS is fed into QlikView. Is there a system architecture that explains how all these works?
11. I have a BPMN model here that captures the Collaborative Clearing Process between UCAS, Student and University. Please could you check to see if the process is correctly captured?
12. In your opinion, what do you this is the impact of lowering tariffs during clearing?

13. Some academics believe that some students who come through clearing perform or engage less compared to students who come in through the normal admission cycle.
Is any statistical evidence to support this view?
14. Is there a significant increase in the number of offers made when tariffs are lowered? Percentage?
15. Some courses may be asked to recruit more students, how is that decision made?
16. How much time is spent on a student during Clearing?
17. How do you think the clearing process can be improved?

Name:	Date:
Job Title:	Duration:

Purpose: Admissions Estimates
1. Admission estimates are made before the admission cycle begins. How are these estimates arrived at?
2. Are these estimates applicable to all courses within the University or per faculty?
3. What business intelligence tools or software are used to create simulations of the admission or clearing process?
4. What sort of Business intelligence do you gather before clearing or admission?
5. You use historical data; how far back do you go?
6. I am aware you use QlikView to visualize data. Would simulation of the clearing or admission process useful in decision making?
7. The new system we have in place – SITS is well integrated with UCAS system, the data gotten from SITS is fed into QlikView. Is there a system architecture that explains how all these works?
8. Some academics believe that some students who come through clearing perform or engage less compared to students who come in through the normal admission cycle. Is any statistical evidence to support or oppose this view?

APPENDIX 2

Clearing Data

(Confidential)

APPENDIX 3

Experiment Instructions

Evaluation of SNACH Framework

SNACK stands for (Simulation, Network Analysis, Control flow and Heuristic). It is a novel framework created to support the act of improvement of business processes.

The Experiment will test the two hypotheses below:

Effectiveness of SNACH: The degree of improvement of the To-Be process is greater than that of the As-Is process.	
Hypo01	**The use of SNACH does not yield more productive improvement changes than merely using average creative skills would provide within a set time frame.**
Hypo1	**The use of SNACH yields more productive improvement changes than merely using average creative skills would provide within a set time frame.**
Efficiency of SNACH: How much improvement could be achieved within a specified time?	
Hypo02	**The use of SNACH does not increase the time efficiency during the improvement process.**
Hypo2	**The use of SNACH increases the time efficiency during the improvement process.**

Participants will be given a case study that describes the admission process of UK universities accompanied by an ‘as is’ business process model. Your goal is to create a ‘to be’ process model. Participants are randomly divided into two groups:

1) Creative Group: Improve the process using their creative skills
2) SNACH Group: Improve the process using the framework.

Each group will have 90 minutes to study the ‘as is’ process and create a ‘to be’ process.

Instructions for the Creative Group

Please use the following steps:

1) Read the provided case study – UK HEI Admission Process Description
2) Study the Model to further understand the process
3) Create a new/improved process model to the best of your ability on the provided sheet.

Instructions for the SNACH group

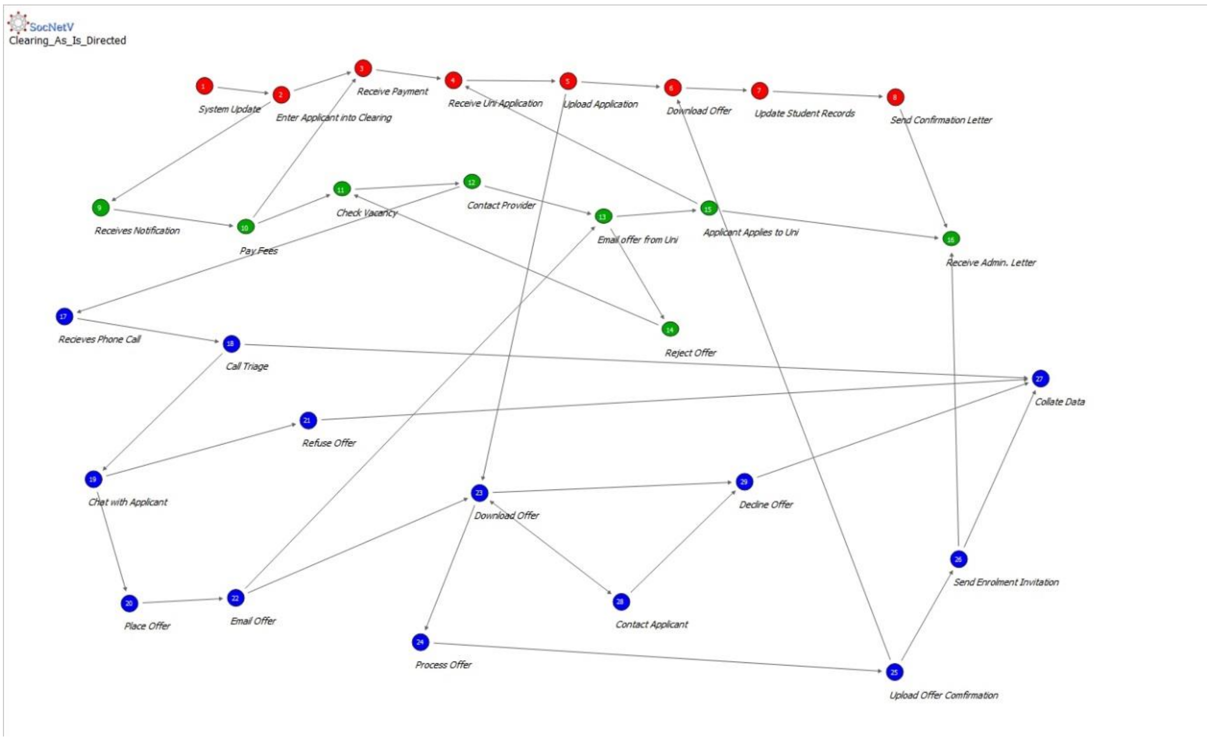
6) Read the provided case study - UK HEI Admission Process Description
7) Study the Model to further understand the admission process
8) Follow the steps in the framework to improve the process
    f) Ignore Create the As-IS Process Model
    g) Ignore Run Simulation
    h) Downscale Projection – Already done please see the network diagram (X)
    i) Perform Analysis of the Network
        a. No of Nodes: 26
        b. No of Links: 32
        c. Average Degree Centrality: N13=0.160
        d. Max. Betweenness Centrality: Node 13 (Potential Bottleneck node), Min. Betweenness Centrality: Node 4, Refuse Application, Receive Course Confirmation, Declines offer and Update Data.
        e. Density: 0.049
        f. Diameter: 14
        g. Average Distance: 5.64
    j) Ignore Upscale Projection to Match Stored Process Details
9) Check the model against the heuristics to generate ideas for improvements.
10) Create the new 'To Be' process model.

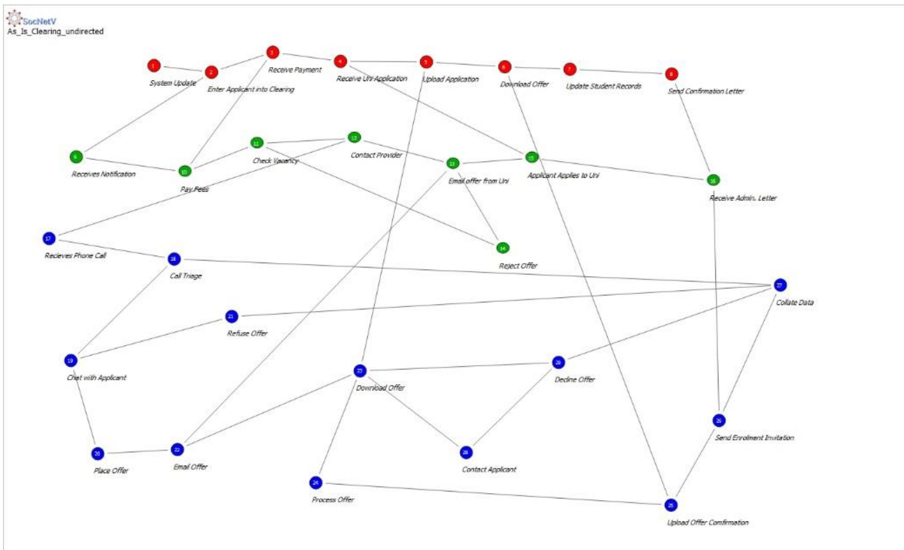
Improvement Heuristics

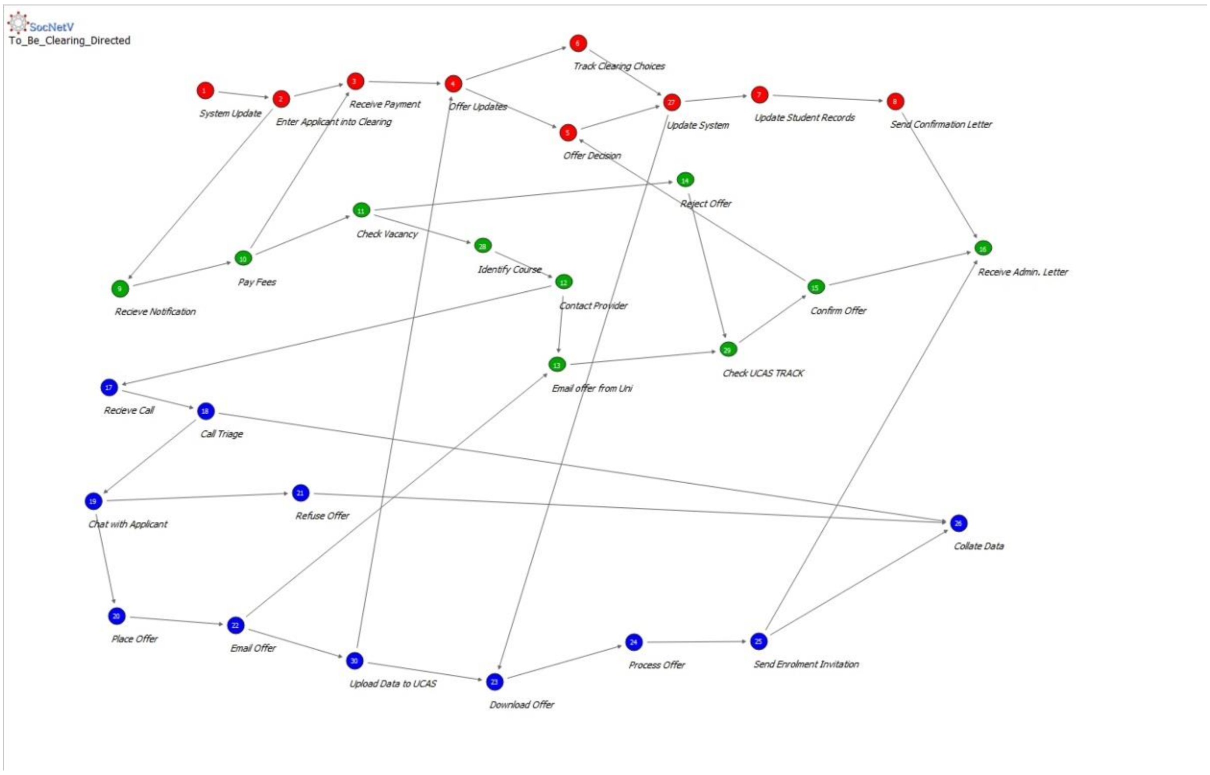
1) **Contact Reduction:** Where possible the number of contacts with customers and third parties should be reduced.
2) **Integration:** This heuristic is applicable where two partners have to collaborate on a product or service they jointly produce.
3) **Task Elimination:** Elimination of tasks that add no value to the business goals e.g. customer satisfaction.
4) **Task Composition:** This is defined as combining small tasks into composite tasks and divide large task into workable smaller tasks.
5) **Re-sequencing:** This entails moving tasks to more appropriate places in the process model.
6) **Knock-out:** Some business processes have conditions that must be satisfied to deliver a desired result. If the conditions are not met, that aspect of the business process may be knocked-out. This is another type of re-sequencing or task elimination.
7) **Parallelism:** 'consider whether tasks may be executed in parallel." This entails restructuring sequentially performed tasks within the business process to allow it to be performed simultaneously. The benefit of splitting tasks into parallel paths is that throughput time is reduced.
8) **Task Automation based on predefined rules:** The increases throughput speed and less running cost although the process of creating an automated system could be expensive.
9) **Integral Technology:** Elevate physical constraints in a business process by applying new technology. A new technology can change a traditional way of executing business. For example the use of cloud storage/sharing or Document Management System can help improve storage and sharing of information.

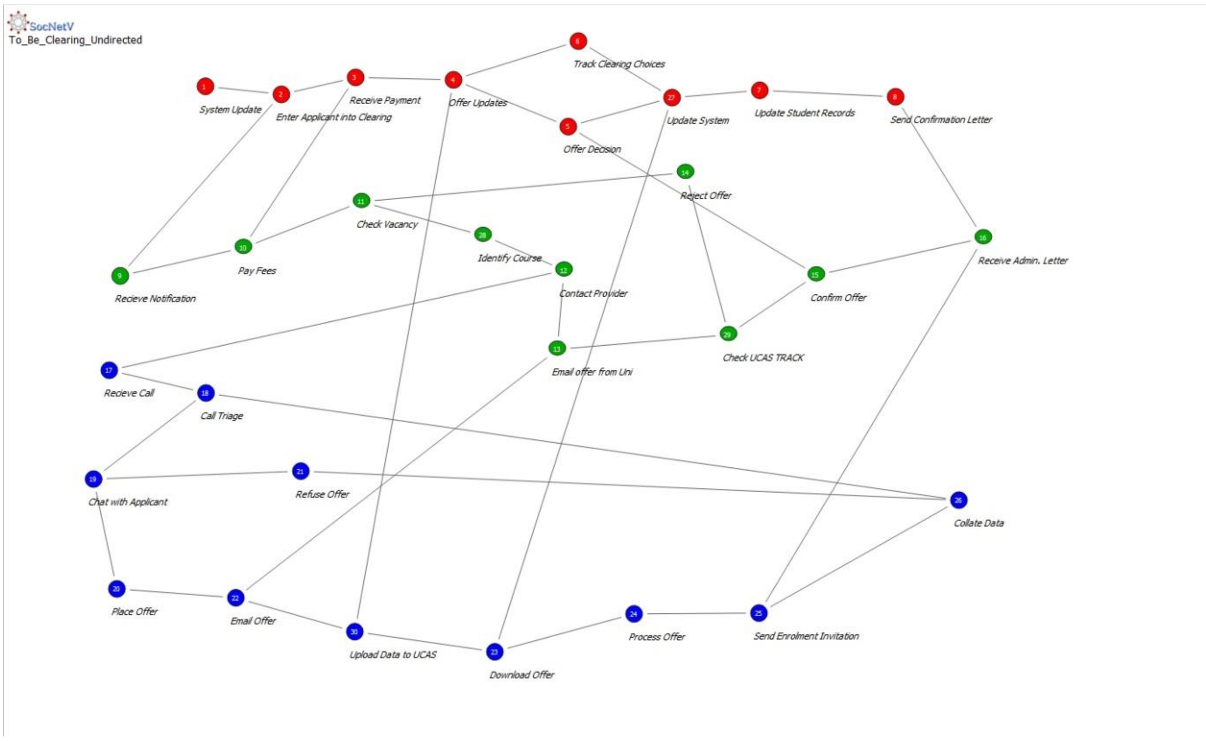
APPENDIX 4

Network Projections


SocNetV
Clearing_As_Is_Directed
System Update
Enter Applicant into Clearing
Receive Payment
Receive Uni Application
Upload Application
Download Offer
Update Student Records
Send Confirmation Letter
Receives Notification
Pay Fees
Check Vacancy
Contact Provider
Email offer from Uni
Applicant Applies to Uni
Receive Admin. Letter
Reject Offer
Recieves Phone Call
Call Triage
Collate Data
Refuse Offer
Chat with Applicant
Download Offer
Decline Offer
Send Enrolment Invitation
Place Offer
Email Offer
Contact Applicant
Process Offer
Upload Offer Confirmation


SocNetV
As_Is_Clearing_undirected
System Update
Enter Applicant into Clearing
Receive Payment
Receive Uni Application
Upload Application
Download Offer
Update Student Records
Send Confirmation Letter
Receives Notification
Pay Fees
Check Vacancy
Contact Provider
Email offer from Uni
Applicant Applies to Uni
Receive Admin. Letter
Reject Offer
Recieves Phone Call
Call Triage
Collate Data
Refuse Offer
Chat with Applicant
Download Offer
Decline Offer
Send Enrolment Invitation
Place Offer
Email Offer
Contact Applicant
Process Offer
Upload Offer Confirmation


SocNetV
To_Be_Clearing_Directed
System Update
Enter Applicant into Clearing
Receive Payment
Offer Updates
Track Clearing Choices
Update System
Update Student Records
Send Confirmation Letter
Offer Decision
Reject Offer
Check Vacancy
Identify Course
Contact Provider
Pay Fees
Recieve Notification
Receive Admin. Letter
Confirm Offer
Check UCAS TRACK
Email offer from Uni
Recieve Call
Call Triage
Chat with Applicant
Refuse Offer
Collate Data
Place Offer
Email Offer
Upload Data to UCAS
Download Offer
Process Offer
Send Enrolment Invitation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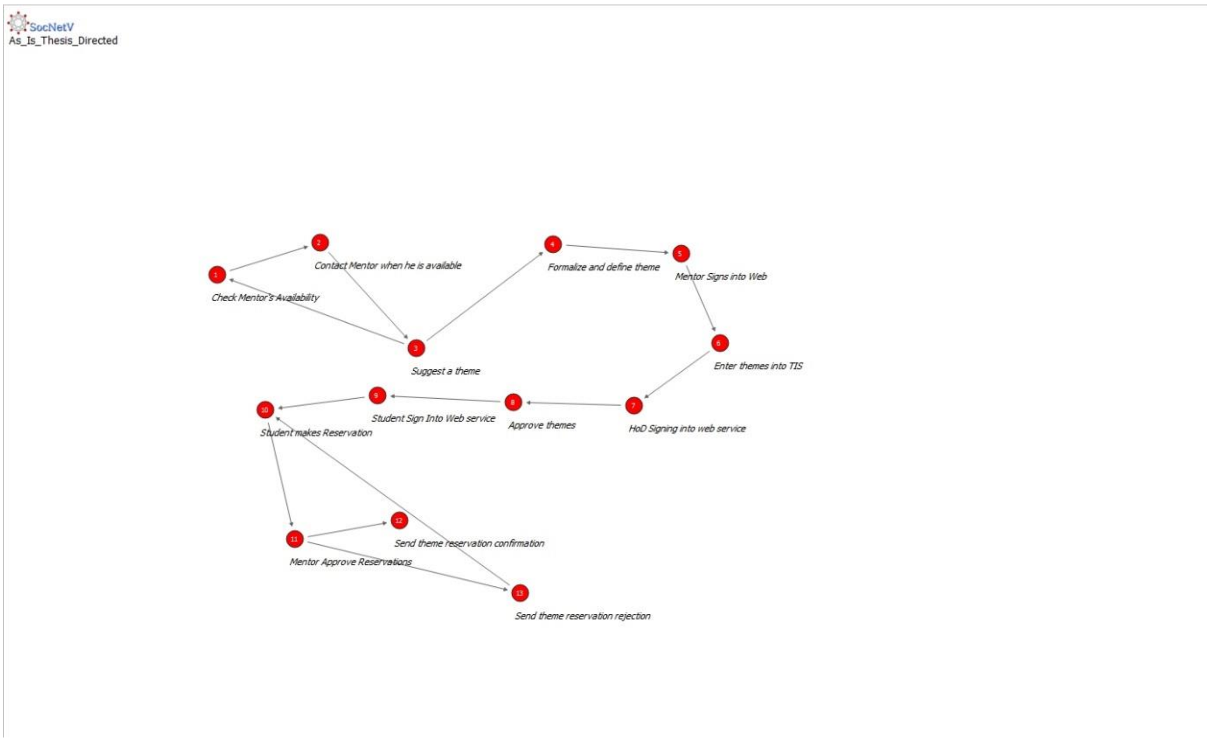
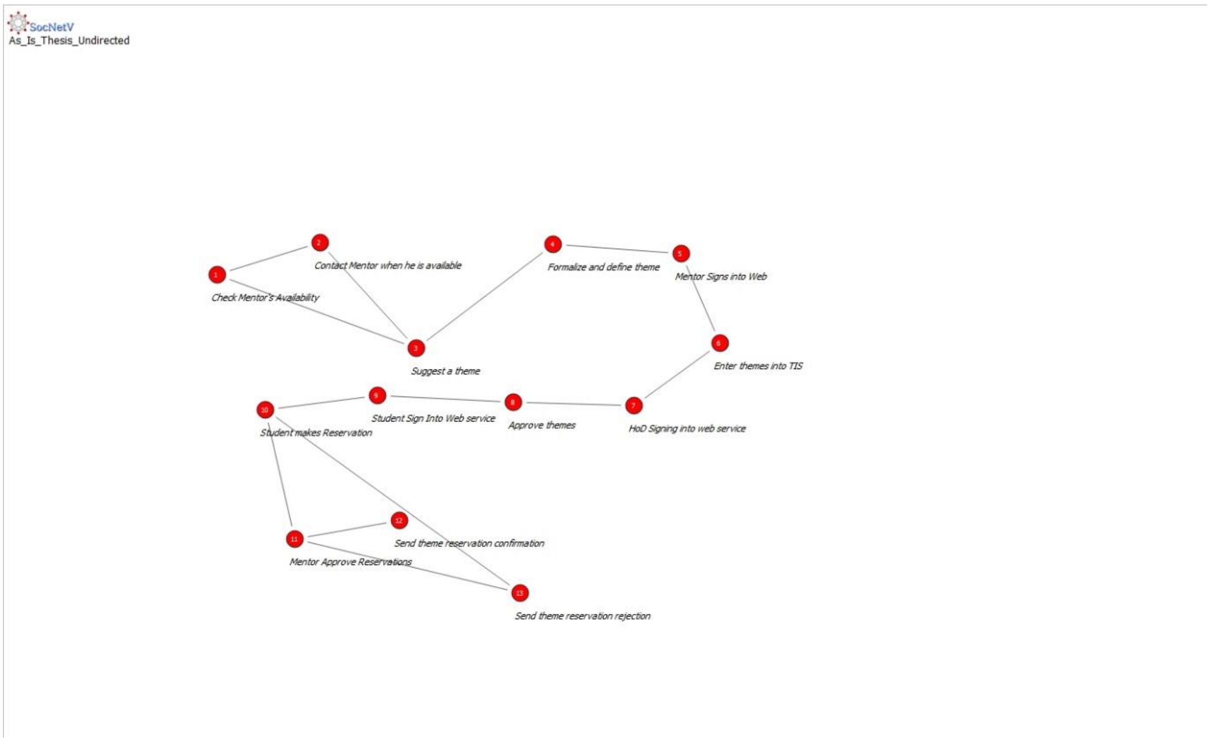

SocNetV
As_Is_Thesis_Directed
Check Mentor's Availability
Contact Mentor when he is available
Suggest a theme
Formalize and define theme
Mentor Signs into Web
Enter themes into TIS
HoD Signing into web service
Approve themes
Student Sign Into Web service
Student makes Reservation
Mentor Approve Reservations
Send theme reservation confirmation
Send theme reservation rejection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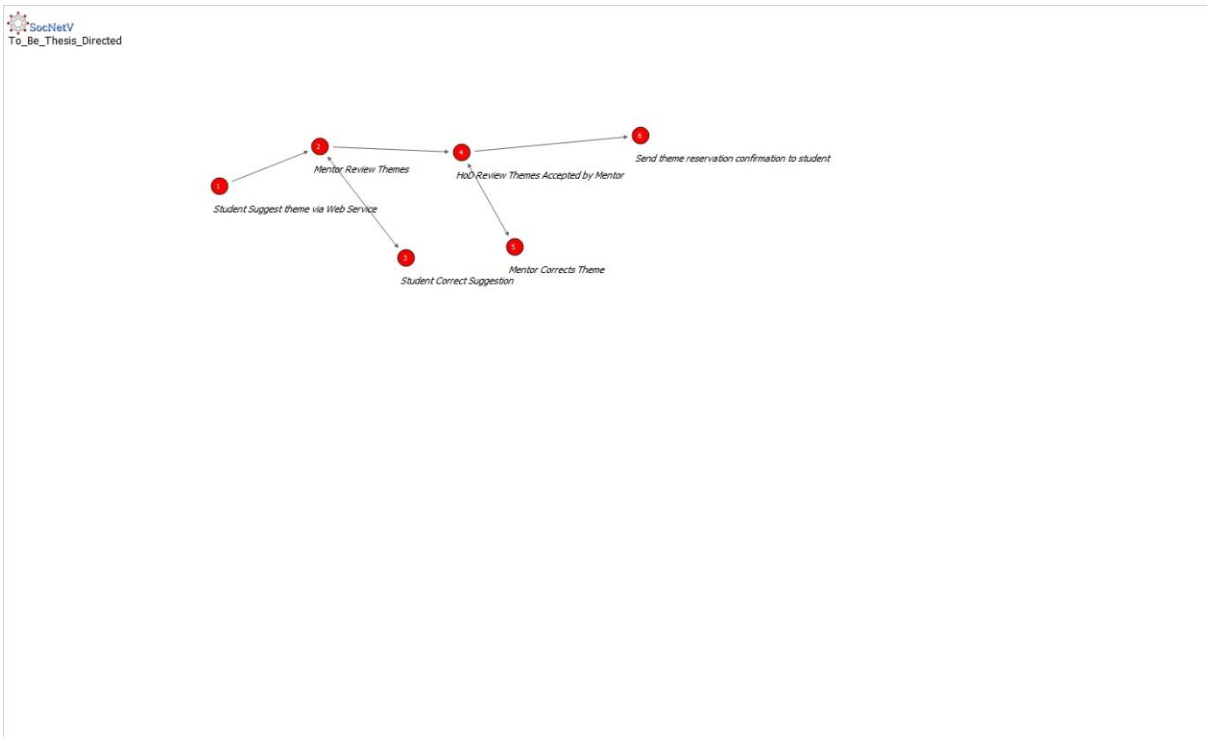
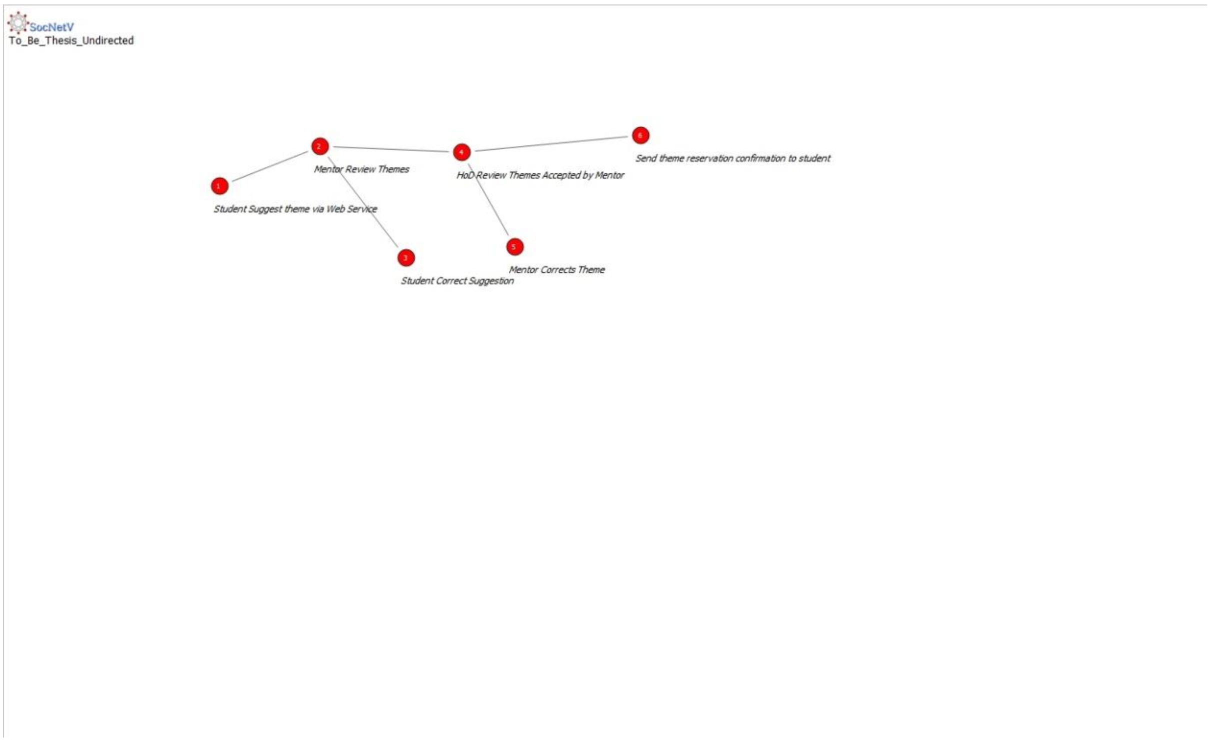

SocNetV
To_Be_Thesis_Directed
Mentor Review Themes
HoD Review Themes Accepted by Mentor
Send theme reservation confirmation to student
Student Suggest theme via Web Service
Mentor Corrects Theme
Student Correct Suggestion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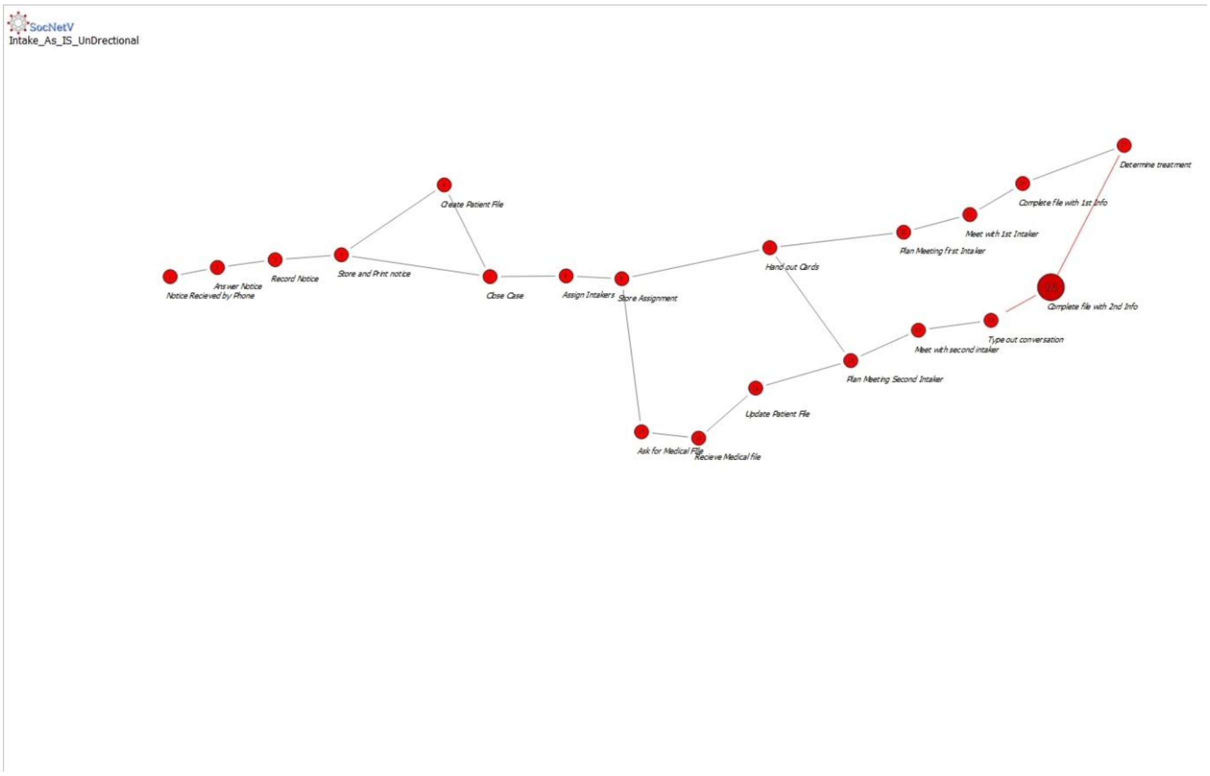
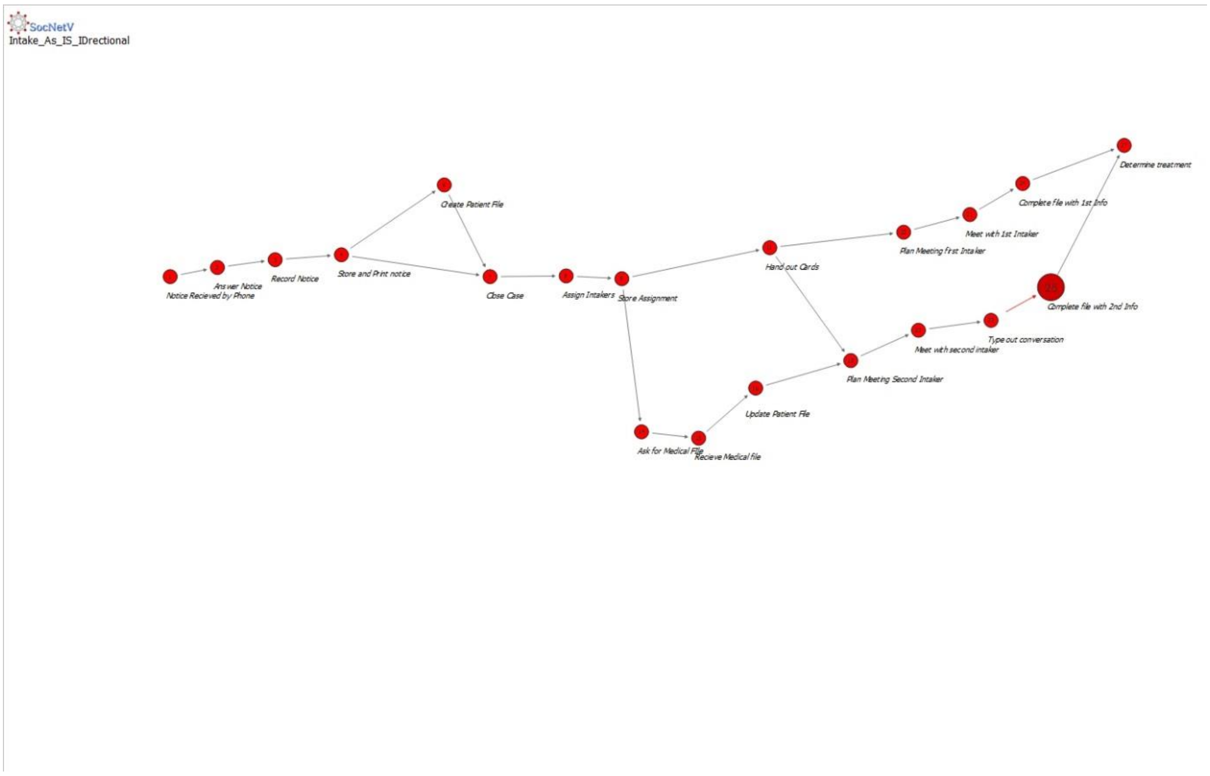

SocNetV
Intake_As_IS_UnDrectional
Notice Recieved by Phone
Answer Notice
Record Notice
Store and Print notice
Create Patient File
Close Case
Assign Intakers
Store Assignment
Ask for Medical File
Recieve Medical file
Update Patient File
Hand out Cards
Plan Meeting Second Intaker
Meet with second intaker
Type out conversation
Complete file with 2nd Info
Plan Meeting first Intaker
Meet with 1st Intaker
Complete file with 1st Info
Determine treatment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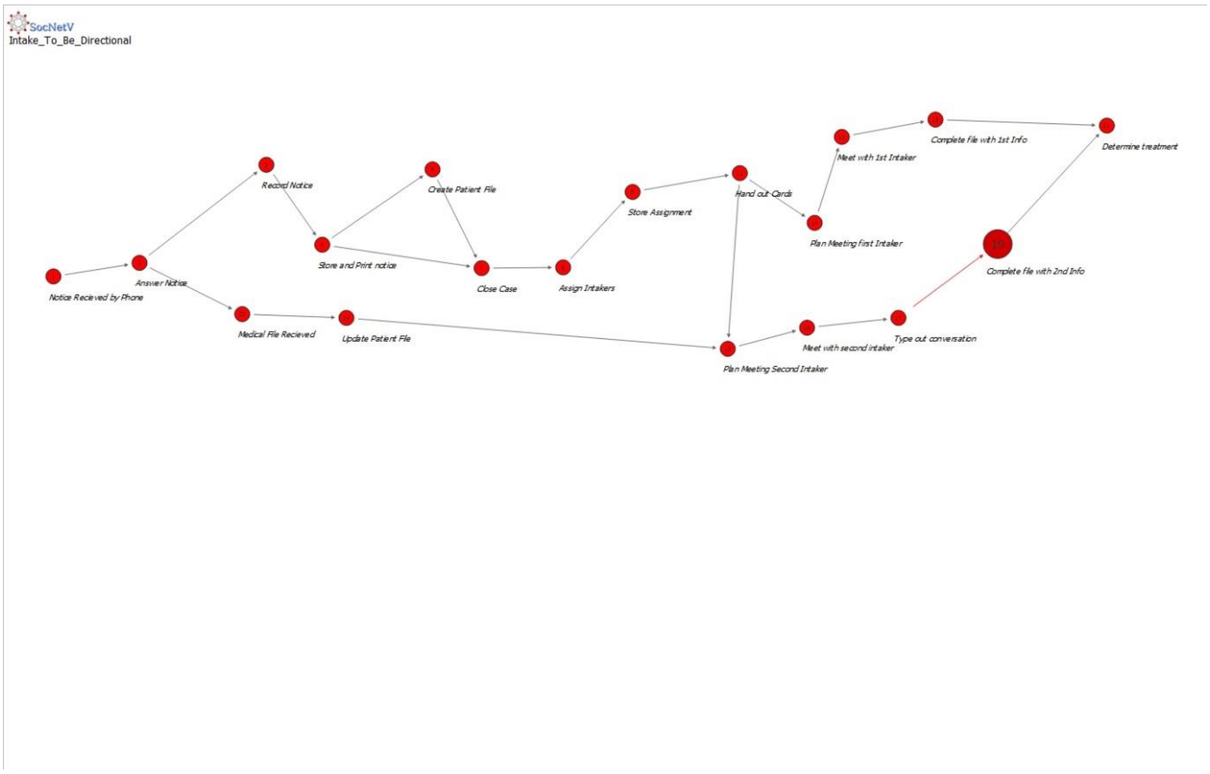
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Record Notice
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Update Patient File
Store and Print notice
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Close Case
Assign Intakers
Store Assignment
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Meet with second intaker
Type out conversation
Complete file with 1st Info
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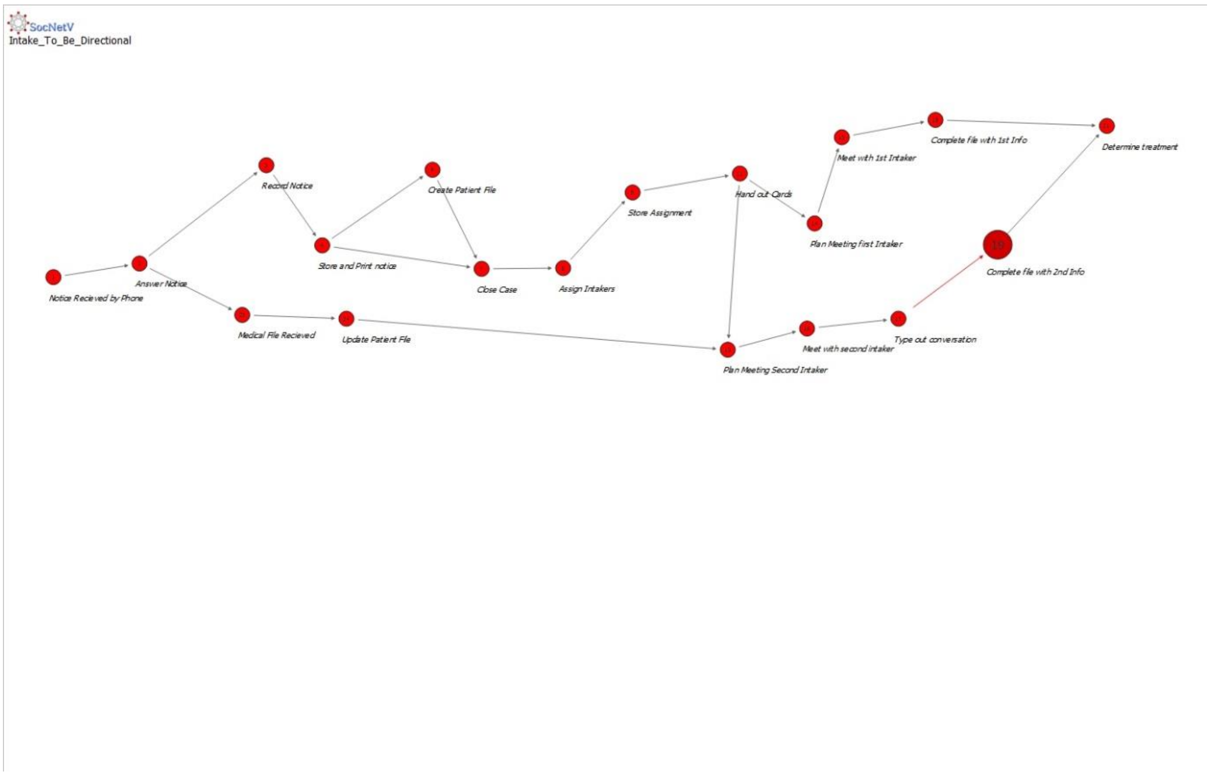
Determine treatment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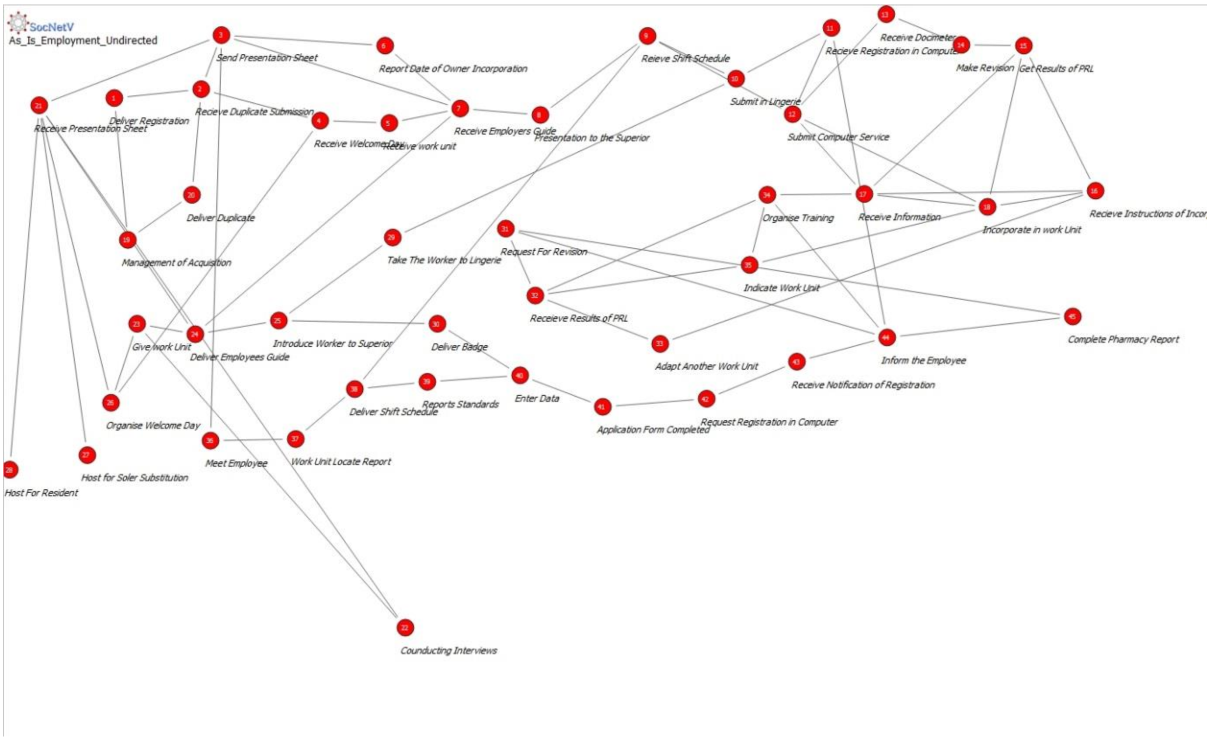
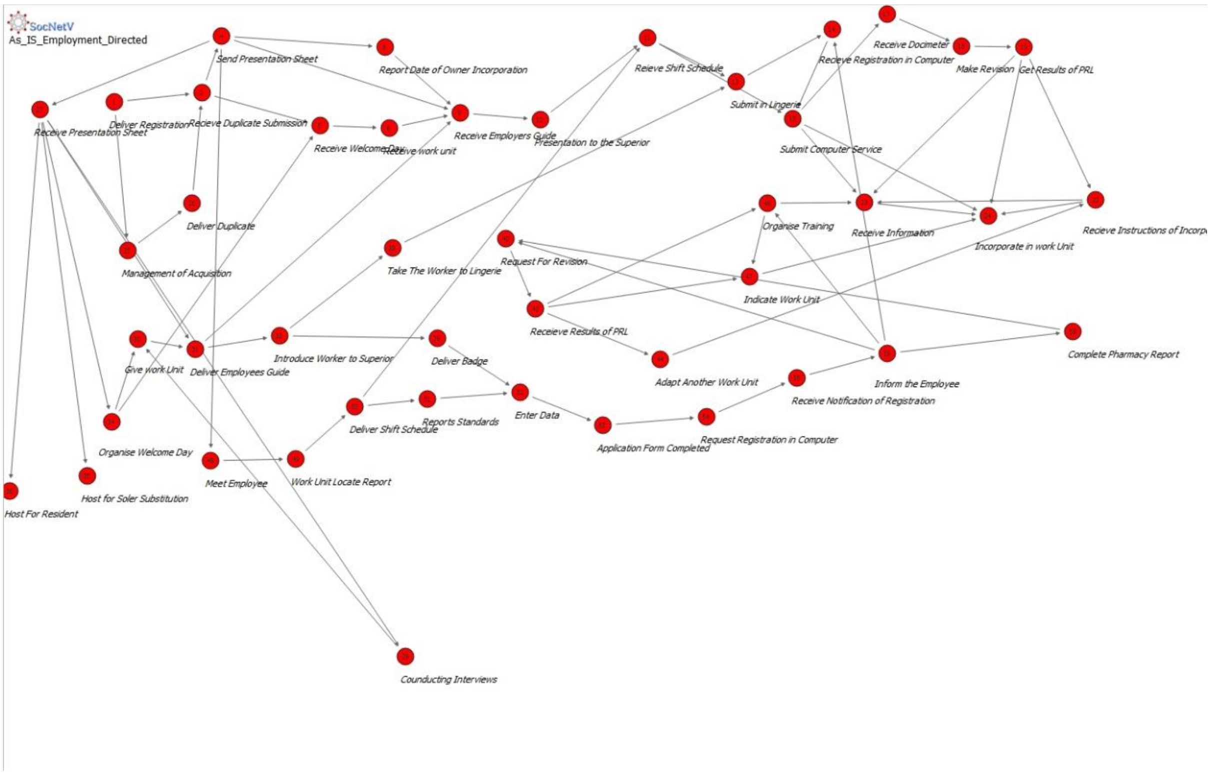

SocNetV
As_Is_Employment_Undirected
Send Presentation Sheet
Report Date of Owner Incorporation
Reieve Shift Schedule
Submit in Lingerie
Recieve Registration in Computer
Receive Docimeter
Make Revision
Get Results of PRL
Receive Presentation Sheet
Deliver Registration
Recieve Duplicate Submission
Receive Welcome Day
Receive work unit
Receive Employers Guide
Presentation to the Superior
Submit Computer Service
Deliver Duplicate
Management of Acquisition
Organise Training
Receive Information
Incorporate in work Unit
Recieve Instructions of Incor
Take The Worker to Lingerie
Request For Revision
Indicate Work Unit
Give work Unit
Deliver Employees Guide
Introduce Worker to Superior
Deliver Badge
Receieve Results of PRL
Adapt Another Work Unit
Inform the Employee
Complete Pharmacy Report
Receive Notification of Registration
Organise Welcome Day
Deliver Shift Schedule
Reports Standards
Enter Data
Application Form Completed
Request Registration in Computer
Meet Employee
Work Unit Locate Report
Host for Soler Substitution
Host For Resident
Counducting Interviews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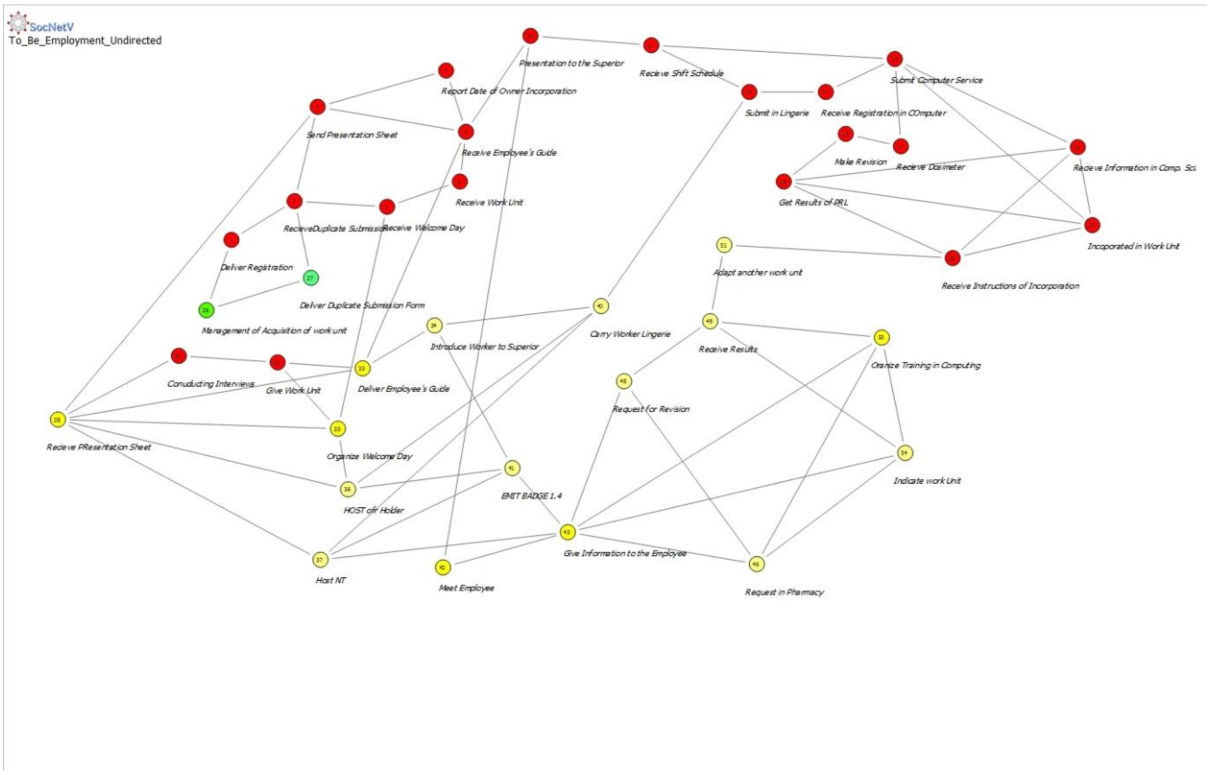
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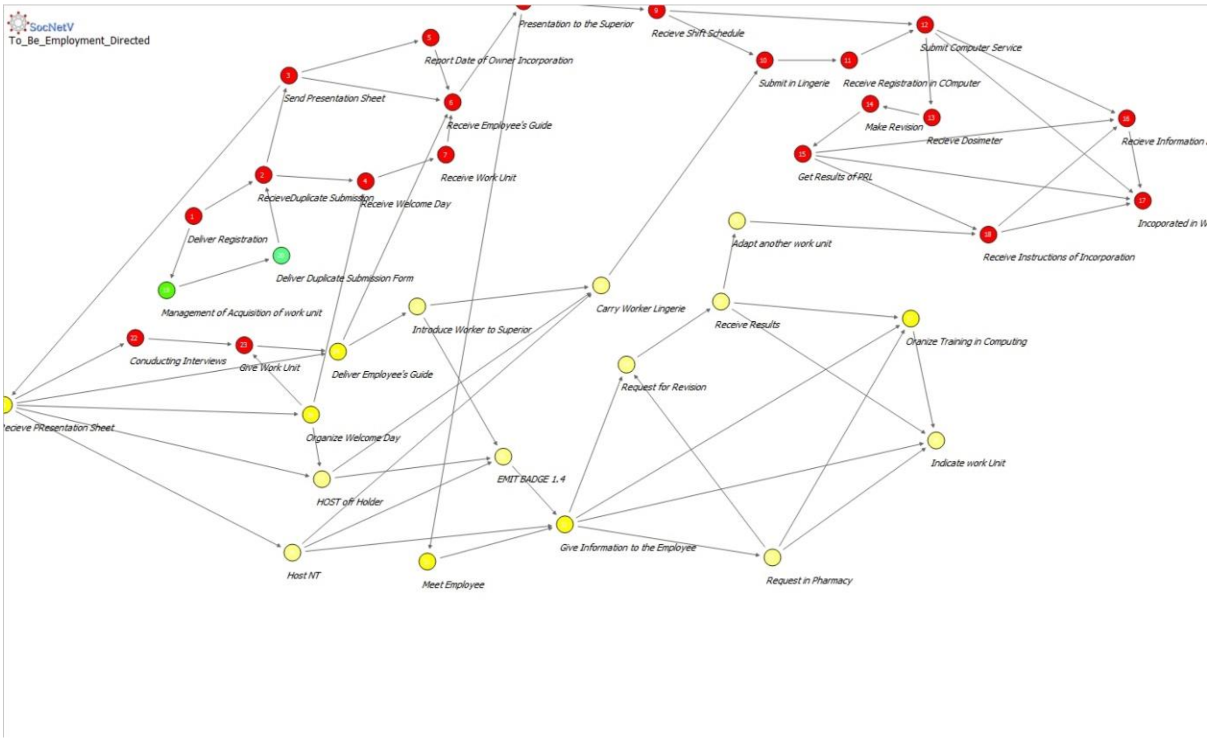
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