Integration of System Dynamics and Action Research with Application to Higher Education Quality Management

by

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Declaration

I, Benedict Oyo, have solely taken an initiative to carry out this study, I hereby declare that the work is my own and original except where references have been made. It is to the best of my knowledge that this study has never been submitted.

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Publications

During the course of this research, several publications in journals, book chapters and conference proceedings were made. A summary of these publications are listed below:

Journals

i. Oyo, B., Williams, D., & Barendsen, E. (To appear). A System Dynamics Decision Support Tool for University Quality Management in Uganda. *International Journal of Simulation and Gaming*.

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ii. Oyo, B., Williams, D., & Barendsen, E. (2008). Impact of funded research on university quality. In J.M, Kizza, J., Aisbett, V., Mbarika, D., Patel & F., Tushabe (Eds.), *Special Topics in Computing and ICT Research: ICT for Sustainable Development*. Kampala: Fountain Publishers, Vol 4.

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i. Oyo, B., Williams, D., & Barendsen, E. (2007, February). *A preliminary model for academic quality management in higher education*. Paper Presented at the 2007 International Conference in Computer Science and Informatics, February 5-7 2007, School of Computing & Informatics, University of Nairobi, Kenya.

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Contents

Declaration i

Acknowledgement ii

Publications iii

List of Acronyms xv

Abstract xvi

1 INTRODUCTION **1**

1.1 Background 3

1.1.1 The Higher Education Quality Management Case 5

1.2 Problem Statement 8

1.3 Aims and Objectives 8

1.3.1 Specific Objectives 9

1.4 Research Questions 9

1.5 Dynamic Hypothesis 10

1.6 Scope 12

1.7 Justification of the Research . . . 13
1.8 Theoretical Terms Used . . . 14
1.9 Thesis Organisation . . . 16

2 LITERATURE REVIEW **17**

2.1 Introduction . . . 17
2.2 Trends in HE Quality Management Research . . . 17
2.2.1 Quality Perceptions . . . 18
2.2.2 Excellence Models . . . 20
2.2.3 Quality Management Frameworks . . . 25
2.3 Current Approaches to Quality Management in HE . . . 29
2.3.1 System Dynamics Modelling . . . 29
2.3.2 Data Mining . . . 34
2.3.3 Analytic Hierarchy Process . . . 34
2.3.4 Goal Programming . . . 35
2.3.5 Hierarchical Linear Modelling . . . 36
2.3.6 Balanced Scorecard . . . 37
2.3.7 Participatory Action Research and System Dynamics . . . 41
2.4 The State-of-Practice of Higher Education Quality Management Tools . . . 48
2.4.1 UNIGAME . . . 49

2.4.2 Quality Measurement System (QMS2000) 50
2.5 Critique of Causes of Problems in HE Quality Management 51
2.6 Conclusion 52

3 Methodology 53

3.1 Introduction 53
3.2 Philosophical and Theoretical Foundations 53
3.2.1 Philosophical Underpinnings 53
3.2.2 Theoretical Underpinning 58
3.3 Evaluation of the Current Methods 61
3.4 Proposed Methodology 63
3.4.1 The SyDPAR Modelling Architecture 64
3.5 Field Studies 68
3.5.1 Stakeholders 68
3.5.2 Data Collection 68
3.6 Conclusion 71

4 Research Issues and Field Study Findings 72

4.1 Introduction 72
4.2 Research Issues 72
4.2.1 The Conceptual HE Quality Management System Structure 73

4.3 Field Study Findings . . . 76
4.3.1 Nature of HE Quality Problems . . . 76
4.3.2 Research Publication Trends in HE . . . 78
4.4 Conclusion . . . 79

5 Application of SyDPAR to HE Quality Management 81

5.1 Introduction . . . 81
5.2 Quality Management System Overview . . . 81
5.2.1 Scope of the Model . . . 81
5.2.2 Assumptions . . . 82
5.2.3 Audience, Purpose and Use . . . 83
5.2.4 Time Horizon . . . 84
5.3 Model Development . . . 84
5.3.1 Dynamic Patterns in HE Quality . . . 87
5.3.2 Model Control Statements . . . 89
5.4 Model Structure . . . 90
5.4.1 Stocks and Flows Diagrams . . . 90
5.5 Model Calibration . . . 101
5.6 Model Validation . . . 102
5.6.1 Structural Validation . . . 103

5.6.2 Behavioural Validation . . . 106
5.7 Evaluation of QMT09 . . . 109
5.7.1 Policy Analysis . . . 110
5.7.2 Analysis QMT09 versus IUCEA Quality Checklists . . . 116
5.8 Validation of SyDPAR . . . 118
5.8.1 Analysis of SyDPAR by Theoretical Research Aims . . . 119
5.9 Conclusion . . . 120

6 Discussions and Conclusions 121

6.1 Introduction . . . 121
6.2 Discussion of Findings . . . 121
6.2.1 Nature of Quality Problems . . . 122
6.2.2 Measurement of Quality . . . 123
6.2.3 Research Questions Analysis . . . 124
6.2.4 Policy Directions for HE Quality Management . . . 126
6.3 Conclusions . . . 127
6.3.1 Overall Conclusions . . . 127
6.3.2 Summary of Contributions . . . 127
6.3.3 Contributions by Research Objectives Analysis . . . 131
6.4 Limitations . . . 132

6.5 Future Research 132

6.5.1 Challenges and Directions of use of SyDPAR 132

6.5.2 Further Testing and Refinement of QMT09 133

List of Figures

1.1 Dynamic Hypothesis for Academic Quality Management in HE 11

1.2 Main Parameter Relationship Types 12

2.1 The EFQM Excellence Model (Source: Umashankar and Dutta, 2007) 22

2.2 Baldrige Education Criteria for Performance Excellence Framework: A Systems Perspective (Source: NIST, 2004) 23

2.3 A Three-Dimensional perspective of TQM (Source: Lau and Anderson, 1998) . . . 24

2.4 Comprehensive Framework for HE Quality Management(Source: Csizmadia, 2006) 25

2.5 Mapping of the Education Criteria onto the Performance Management Perspectives (Source: Shawyun, 2006) 27

2.6 Steps in System Dynamics Model Building (Source: Zagonel, 2002) 33

2.7 The Practice Perspective of Action Research (Adapted from: Cronholm and Goldkuhl, 2004) 39

2.8 The Action Research Cycle(Source: Baskerville, 1999) 40

2.9 Global sector diagram for UNIGAME (Barlas and Diker, 2000) 50

2.10 Quality assurance framework at the University of Louisville (Welsh and Dey, 2002) 51

3.1 The Conceptual SyDPAR's Modelling Architecture 65

4.1 Conceptual HE Quality Management System Structure 74

4.2 Publications by Selected Ugandan Universities 78

4.3 Distribution of Academic Staff by Qualification in Ugandan Tertiary Institutions (Source: NCHE, 2006) 79

5.1 The Preliminary Model 85

5.2 Research and Publications Sector's Influence Diagram 86

5.3 Dynamic Behaviour for Reference Modes 88

5.4 Basic Model Symbols 90

5.5 Finance and Strategic Planning Sector 92

5.6 Research and Publications' Stock and Flows 94

5.7 Students Sector's Stock and Flows 95

5.8 A Representative Stock and Flows for Government Sector 96

5.9 Educational Resources Sector's Stock and Flows 97

5.10 Academic Staff Sector's Stock and Flows 98

5.11 Teaching and Learning Sector's Stock and Flows 99

5.12 Example of Calibrated Behaviours 102

5.13 A structure for the growth of research and development in a university (Source: Vahdatzad and Mojtahedzadeh, 2000) 104

5.14 Actual Students Enrolment and Selectivity Trends 107

5.15 Staff Establishment Trends 108

5.16 Trends of Available Funds 109

5.17 The User Interface for QMT09 110

5.18 Dynamic behaviour of the main institutional quality indicators 111

5.19 An estimation of quality of students' outcomes 113

5.20 Available income and expenditure dynamics 114

5.21 Dynamics of staff capacity indicator and its basic dependencies 115

5.22 The Validated SyDPAR Modelling Architecture 119

6.1 Classification of Intervention Approaches in Higher Education Quality Issues . . . 122

List of Tables

2.1 Decision support systems/models for quality issues in higher education 49

3.1 Comparison of the Quality Management Approaches using Design Science Framework 63

3.2 Interview distribution: purpose and target universities 70

3.3 Survey distribution: sample size and percentage response 70

4.1 Interview responses analysis by universities 77

4.2 Public and Private Universities expenditure (NCHE, 2006) 80

5.1 Parameters and Assigned Values for Sectors 105

5.2 Comparative Analysis of QMT09's scope versus IUCEA Quality Checklists 117

5.3 Analysis of SyDPAR process design by theoretical research aims 120

6.1 Analysis of client involvement in modelling 125

6.2 Analysis of research objectives, descriptive approach and outcomes 131

LIST OF ACRONYMS

AR	Action Research
AHP	Analytic Hierarchy Process
BSC	Balanced Score Card
DSS	Decision Support System
ENQA	European Association for Quality Assurance in Higher Education
EURASE	European Association of Institutions in Higher Education
GP	Goal Programming
GMB	Group Model Building
HE	Higher Education
HEQC	Higher Education Quality Committee
HLM	Hierarchical Linear Modelling
IS	Information Systems
IUCEA	Inter University Council for East Africa
MCDM	Multi-Criteria Decision Making
PAR	Participatory Action Research
SD	System Dynamics
SyDPAR	System Dynamics and Participatory Action Research
SPC	Statistical Process Control
QMS	Quality Management System
QMT09	Quality Management Tool 2009
UML	Unified Modeling Language
UNESCO	United Nations Educational, Scientific and Cultural Organisation

Abstract

Quality management has become a central concern for managers of higher education institutions (HEIs) as it is arguably the cornerstone of success and eventual survival of these institutions. Previous research in higher educational quality, however, have mixed characteristics. In some cases, focussing on a narrow scope such as academic staff quality tantamount to addressing the main challenge (Vinnik and Scholl, 2005). Others have suggested that quality is too subtle to be measured meaningfully (Srikanthan and Dalrymple, 2007; Grandzol, 2005; Parker, 2002), while others claim that good policies on quality improvement in higher education are often not based on systematic engagement with simulation experiments but on use of intuition and experience (Grandzol, 2005; Barnabé, 2004). This thesis extends this discussion further by developing simulation models for institutional and program quality analysis that demystify these claims.

In adopting the system dynamics (SD) modelling and simulation technique in this research, attention to the modelling process was highly regarded. This follows insight formulated from many scholars in the field of SD that the modelling process is often more important than the resulting model (GröBler and Milling, 2009; Forrester, 1998). Hence, the integration of SD and participatory action research (PAR) in this thesis is meant to increase modelling process outcomes through a more rigorous modelling design architecture. The emerging integrated approach, also, referred to as SyDPAR was evaluated against rigour and relevance criteria for information systems methodologies, making the SyDPAR approach not only an original aspect but a useful outcome.

The SyDPAR approach recognises the contributions as well as benefits of clients/practitioners in participative modelling using three cycles, namely: problem articulation, modelling proficiency, and solution refinement. In addition, it provides a general modelling framework that extends participative modelling outcomes beyond the prevalent individual, group, and organisational outcomes, culminating into contributions to the SD knowledge base and system change by modellers and clients respectively. Fundamental to this thesis is the application of SyDPAR to higher education quality management problem area, leading to the development of a "quality management tool 2009" (QMT09). This tool is validated and verified using standard system dynamics tests and three sets of quality checklists.

Specifically, the contributions of this research and the thesis may be classified into four aspects: 1)

provision of guidelines for evaluation of participative modelling design effectiveness, 2) theoretical validation of the SyDPAR research process, 3) development of SyDPAR as a generic participative modelling design, and 4) development of decision support tool for higher education quality management. In terms of scientific rigour and relevance, the first two can be aptly categorised as theoretical and the rest practice oriented. Consequently, the dual imperatives of solving a real world problem while contributing to the knowledge base adopted by the researcher is fulfilled.

Chapter 1

INTRODUCTION

Research that aims at solution of practical problems is of increasing importance to information systems research (Chen and Hirschheim, 2004; Hevner *et al.*, 2004; Baskerville, 2001). In terms of system dynamics (SD) modelling, this kind of research approach is reflected by involving stakeholders/clients in model building, hence the name group model building (GMB) or participative modelling. The integration of SD and the participatory stream of action research (AR) in this thesis contributes to the design of a more rigorous participative modelling architecture which, contrary to existing designs, emphasises clients' contribution to- as well as benefits from- modelling involvement.

Over the years, SD model builders have designed more or less effective procedures to involve clients or management stakeholders in the process of model development (Vennix, 1996; Andersen, Richardson and Vennix, 1997; Rouwette, 2003). Indeed, as far back as 1980, system dynamicists have identified requirements for the design of participative modelling projects with great improvements (Stenberg, 1980). These requirements as summarised by Rouwette and Vennix (2006) include: suitability of system dynamics for client's problem; purpose of modelling effort; clarity of client's problem; number of participants and whom to involve in the modelling process; the phase in the model building process and type of task performed; time available from participants; costs involved in using alternative techniques. In addition, calls for more comprehensive organisational intervention techniques/architectures have been made (Luna-Reyes *et al.*, 2006; Zock, 2004). This emerging necessity originates in the insight formulated from many scholars in the field of system dynamics that often the modelling process is more important than the resulting model (GröBler and Milling 2009; Forrester, 1998).

In contrast, research into improvement of the design of SD modelling process has attracted little attention probably because system dynamicists find existing designs adequate. However, participative modelling which involves clients/participants without prior modelling knowledge requires methodological details that show clients' contributions to modelling. This raises interest in further exploring the relationship between clients' involvement in model building and modelling process outcomes. A starting point in this direction would be to review reasons for clients' involvement in order to derive the benefits from modelling participation as the measure of outcomes. Zagonel (2002) gives three reasons for involving clients in modelling. First, in the context of clients as identifiers of problem of interest, secondly, clients as sources of information required in the modelling effort, and finally, clients as implementers of modelling results. Rouwette and Vennix (2006) emphasise the latter as the most important adding that, although system dynamics models can be used productively to analyse strategic problems and come up with robust strategies this does not mean that the proposed strategies will be adopted by the organisation. The fourth and probably only reason that caters for clients' individual benefits from modelling participation is learning how the qualitative model of their issue can be translated into a formal model. The integration of SD and PAR in this thesis particularly addresses this fourth aim. Furthermore, this research investigates the relationship between client involvement and modelling outcomes by applying the integrated method to higher education (HE) quality management problem area.

Since participative modelling involves people with a wide variety of view-points (Vennix, 1996; Zock, 2004) concerns over commitment to modelling process, reaching consensus by the team, control of the team, and evaluation of outcomes of the intervention are challenging. These challenges can be mitigated if the modelling process as proposed in this thesis is designed with consideration of three issues:

1. The aim of research. Research aim should be stated upfront even if it represents only a broad theme for the study that requires refinement overtime.
2. Research process design. The research process is the sequence of steps by which research is conducted (Lau, 1999). Therefore methodological details such as: the role of the researcher/modeller and participant or stakeholder, the process of problem diagnosis, intervention planning, stakeholder management, and the extent of reflection and learning intended, must be explicit.

3. Criteria of evaluation of research impact. Two level evaluations may be needed in participative modelling: first, on the basis of research aim and secondly, on basis of intended learning by the participants and modellers.

1.1 Background

Participative SD modelling and expert SD modelling differ in some fundamental ways, namely: purpose of modelling endeavour, applicability of results from modelling and simulation projects, and parametisation (GröBler and Milling, 2009; Snabe and GröBler, 2006) yet existing modelling designs/architectures do not cater for these differences (Snabe, 2005). Furthermore, contributions of clients to modelling has been emphasised in most participative modelling studies (Luna-Reyes *et al.*, 2006; Rouwette and Vennix, 2006; Rouwette, Vennix, and Mullekom, 2002) but again not reflected in the design/architecture. These observations suggest the need to re-conceptualise and improve participative modelling process design.

Over the fifty years of SD application till today, practitioners as well as commentators from various disciplines have raised questions pertinent to SD theory and practice which are still largely unresolved. In the context of this thesis, only challenging questions on model conceptualisation and model building process are emphasised here, as a step towards delineating requirements for the design of a more rigorous modelling process.

Mass (1986) puts forth seven questions in the area of model conceptualisation in SD which have been only partially answered:

i. To what extent can models hope to capture in a realistic way, and without the indiscriminate use of switching functions, those structures that may be latent or inactive in historical behaviour but that could become important in the future or upon implementation of a new policy regime?

ii. System dynamics aims at realistic behavioural portrayal of the system being analyzed. But what are the specific constituent elements of such a behavioural portrayal? What heuristics are available to facilitate the structuring of quasi-rational behaviour, e.g., “satisfying” behaviour?

iii. How does, or should, a model structure evolve through iterative formulation, testing and analysis?

iv. How do we judge the adequacy of a model conceptualization?

v. What are the appropriate bases that establish the *a priori* objectives of a model?

vi. To what extent can a SD model of a given system be said to be unique? What would be the relationship between alternative models of the same system conceived by different SD analysts?

vii. How does the SD approach to model conceptualization differ from, draw upon, or relate to other methods?

With regard to modelling for organisational intervention, GröBler (2007) envisages eight questions that if addressed could raise significantly the impact of system dynamics in improving long-term organizational performance. Five of these questions that concern the design of the modelling process include:

- What organizational change methods can be usefully combined with system dynamics?
- How can system dynamics projects be embedded into more comprehensive organizational intervention architectures?
- Are there differences in principle in the organizational impact of expert modelling and participative modelling projects, viz. group model building?
- Are there characteristics inherent in the system dynamics methodology that hinder the full exploitation of results and recommendations within an organizational context (for instance, the focus on causal relationships instead of power structures or communication acts)?
- Is sustainable impact prohibited because system dynamics projects are too narrowly seen as one-time problem-solving activities?

Emerging from these questions is the need to re-conceptualise participative modelling process design in order to improve its effectiveness. Along this line, this thesis seeks to answer a research question at the interface of modelling design and outcomes in a manner that subsumes some of the preceeding questions. Details about this and other research questions investigated in this thesis are given in section 1.4.

In order to contribute to the design of a more rigorous participative modelling architecture this research integrates insights from action planning and action learning with the prevalent procedures for client involvement in participative modelling, culminating into an integrated approach also referred to as SyDPAR (from SD and PAR). A rigorous design implies the modelling architecture capable of producing strong results by emphasising the contributions of all parties (modellers and clients) involved in model building. In the context of SyDPAR, this is achieved through iterations in three cycles, namely: problem articulation, modelling proficiency, and solution refinement, as explicitly discussed in chaper 3. The relevance of SyDPAR is tested on HE quality management problem area, as a method suitable for solving un-structured, non-linear and dynamically complex problems in an environment of multiple stakeholders' views. More specifically, SyDPAR supports triangulation of hard scientific data with the existing knowledge of practitioners, such that the knowledge of general systems theory of the researchers/modellers intersect with practical theory of practitioners during the research process.

1.1.1 The Higher Education Quality Management Case

Researchers now regard quality as the single most important factor for long-term success and survival of HEIs (Umashankar and Dutta, 2007; Williams and Van Dyke, 2007; World Bank, 2000). At the same time, HE is perceived as a highly complex system, which is embedded within the broader cultural, political, and economic context. Each interdependent component of the HE quality system influences the other components in often unforeseeable and unpredictable ways. Hence, the quality of teaching, students' outcomes and research may be as much determined by factors external to the system as to those directly within the control of education planners and managers (Srikanthan and Dalrymple, 2007). New methods may be required to address the current quality management challenges only if they provide a guiding framework for realistic quality problem conceptualisation against which an intervention can be made. Such a framework should be anchored on problematic data as is the case with reference modes in system dynamics. With regard to this research, the latter insight served as a starting point.

Sources of Problems in Higher Education Quality Management Applications

Several Decision Support Systems for HE quality management issues are currently available with differentiated focus and capabilities. These have been developed using approaches and technologies such as: data warehousing (Vinnik and Scholl, 2005; Welsh and Dey, 2002), system dynamics (Barlas and Diker, 2000; Kennedy, 2002), hierarchical linear modelling (Try and Grögaard, 2003), multi-criteria decision making (Ho et al., 2006), goal programming (Ho, Higson and Dey, 2007), analytic hierarchy process (Badri and Abdulla, 2004; Grandzol, 2005), and data mining (Maltz *et al.*, 2007).

Specifically, the focus of these systems have been on various aspects of quality management including: strategic management (Barlars and Diker, 2000); performance assessment and outcomes assessment (Deniz and Ersan, 2001); quality measurement (Welsh and Dey, 2002); resource management (Vinnik and Scholl, 2005); and enrolment management (Maltz et al., 2007). However, other areas have not received as much attention. Little is known about quality improvement versus enrolment management, except for suggestions that institutions should integrate their quality improvement and enrolment management efforts with their mission, role and strategic directions (Schray, 2006; Welsh and Dey, 2002; Tavenas, 2004; Csizmadia, 2006). In other cases the problem scope is signifantly reduced to suit its method, for instance Vinnik and Scholl (2005) develop a Decision Support System (DSS) for managing student enrolment with available resources, but only focus on teaching staff resource, claiming that staff availability is by far the most crucial resource constraint, expensive and hardly adjustable in the short-term compared to other resources involved, such as facilities, budget, appliances, materials etc.

Srikanthan and Dalrymple (2007, p.186) suggest that a holistic model for quality management would be well served, “if one could develop an implementation methodology by only systemically monitoring quality improvement”. This however, would fall short of realisation in environments where demand and supply of education equilibrium is unattainable. For example, economic challenges especially in the developing countries have resulted into higher priority on higher education provision over quality improvement strategies.

Generally, funding requirements for research development, staff development, curriculum development, teaching resources, etc, exist in all HEIs. Ideally, actual allocation of funds should be based on funding demands, but this is usually not the case especially when income is insufficient. As such percentage rationing is used in favour of higher priority funding item. Consequently, attempting to increase percentage allocations to one item creates an equivalent percentage decrease on another or several other items combined, leading to no lasting solution. On the other hand, each item has a different scale of effect on quality, and therefore, effecting correct changes for desired outcomes is challenging. This study aims to address this challenge through adoption of the integrated research design in conceptualising, representing, and analysing policy directions for quality improvements while taking into consideration the inherent complexity and feedbacks within the quality system structure.

From the systemic perspective, the sources of HE quality problems can be generally considered to arise from:

1. The complexity of quality management problems, rendering their integration difficult and hence their cumulative effect may be inconsistent or highly varied. This arises from the nature of the factors that influence quality, transcending the qualitative-to-quantitative landscape (Barnabé, 2004; William and Van Dyke, 2007), i.e, some are qualitative in nature, while others are quantitative, and the rest are of the qualitative/quantitative mixed type.

2. The dynamics of quality management itself. This is challenging because HE changes are continuously unfolding, non-linear, full of unforeseen contingencies, and revised strategies (Parker, 2002; Kennedy, 2002). Huitema *et al.* (2002) use the term, “external dynamics” in higher education quality to explain the scenario whereby, tackling one problem (e.g., students’ capacity) exposes another (e.g. teaching quality).

3. Complexity of feedbacks in quality issues leading to adoption of methods that delineate a set of quality problems facets as more worthy of attention than others rather than all conceivable facets of quality problems.

4. The diverse perception of quality problems by different stakeholders leading to claims that render research on quality less attractive such as “quality is difficult to measure” (Parker, 2002; Srikanthan and Dalrymple, 2007); good policies on quality are based on personal knowledge rather than simulation experiments (Grandzol, 2005; Barnab´e, 2004).

HE quality management problems are thus inherently non-linear, un-structured, and dynamic. Consistent decision-making over such problem characteristics requires an approach that transends the qualitative-to-quantitative continuum. Existing methods address the facets of quality problems rather selectively, raising doubts as to whether any methods exist which address all conceivable facets of quality problems. Indeed, the facets of quality problems are linked with ontoepistemological dispositions, no single method (or no set of methods emanating from a single theoretical position) can address all facets of quality satisfactorily. On the other hand, system dynamics modelling has been increasingly used to develop both quantitative and qualitative models for the analysis of policy and managerial issues. By involving HE stakeholders in the modelling process using the SyDPAR architecture, this research demonstrates greater outcomes and insights from modelling right from problem definition, through system description, model equations developments, system simulation, to evaluation of alternative policies and choice of a better policy for implementation.

1.2 Problem Statement

The need to develop new innovative ways of increasing clients' involvement in modelling has been underscored by leading participative SD researchers (Rouwette and Hoppenbrouwers, 2008; Schwaninger and Grösser, 2008; Luna-Reyes *et al.*, 2006; Rouwette and Vennix, 2006; Scholl, 2004). This has been attributed to the abstract SD modelling architectures that do not explicitly reflect clients' contribution to modelling, neither their benefits from involvement in modelling (Scholl, 2004; Schwaninger and Grösser, 2008).

In order to contribute to the design of a more client centred participative modelling architecture, this research integrates insights from action planning and action learning with the prevalent procedures for client involvement in participative modelling. The relevance of the integrated approach is tested on HE quality management problem area, as a method suitable for solving un-structured, non-linear and dynamically complex problems in an environment of multiple stakeholders' views.

1.3 Aims and Objectives

This thesis integrates SD and PAR. A method produced in this way should be able to improve the participative modelling outcomes by increasing clients' involvement in modelling (Scholl, 2004). Thus, the aim of this research is to develop a more rigorous participative modelling architecture.

Rigorous in the sense that it produces strong results while maximising the contributions of both clients and modellers as well as their benefits from modelling involvement. The relevance of the new architecture in solving complex practical problems is tested on HE quality problem area.

1.3.1 Specific Objectives

The research aim is addressed through the following specific objectives:

i. Investigate the benefits of integration of SD and PAR.

ii. Develop a rigorous participative modelling process architecture by integrating SD and PAR.

iii. Develop an SD simulation model for HE quality management using the integrated approach.

iv. Validate the model using the standard SD tests and benchmarked quality checklists.

v. Validate the integrated approach as a method for solving complex dynamic problems in participatory settings.

1.4 Research Questions

Given the comprehensive nature of HE quality concerns and the multi-disciplinary character of this research, three complementary research questions are investigated. The first, addresses methodological issues in participative modelling using insights from integration of SD and PAR. The others provide empirical test for the assumptions in the first question.

i. How might SD and PAR integration be useful in designing more rigorous participative modelling projects?

ii. What factors influence HE quality and how are they related?

iii. What higher education quality management problems should be addressed by future DSS?

With these as our heuristic point of departure, this research accomplished two complementary outputs: 1) a rigorous design for participative modelling referred to as SyDPAR; 2) a quality management tool referred to as QMT09 as a landmark model against which future DSS on HE quality issues can be built.

1.5 Dynamic Hypothesis

A dynamic hypothesis is a theory about how structure and decision policies generate the observed behaviour (Oliva, 2003). This theory is conveyed by a model in which the causal link between structure (captured in terms of equations and parameters) and the simulated behavioural output arise from interaction of the equations and initial conditions. In presenting the dynamic hypothesis in this research, the problem of quality volatility in higher education is explained by a complex relationship involving but not restricted to: resources dynamics (planned resources versus actual resources), funding, quality of staff, quality of research, and quality of teaching. This relationship is represented in Figure 1.1 as a simplified theory for enquiry into HE quality improvement issues.

As shown in Figure 1.1, seven dominant feedback loops can be identified. Four of these loops are reinforcing loops and the rest balancing loops. A feedback loop is called positive, as indicated by Ri (i = 1, 2, -,-), if it contains an even number of negative causal links. Similarly, a feedback loop is called negative, as indicated by Bi, if it contains an odd number of negative causal links. Furthermore, a positive or reinforcing feedback loop, reinforces change with even more change whereas a negative or balancing feedback loop seeks a goal, i.e., if the current level of the variable of interest is above the goal, then the loop structure pushes its value down, while if the current level is below the goal, the loop structure pushes its value up.

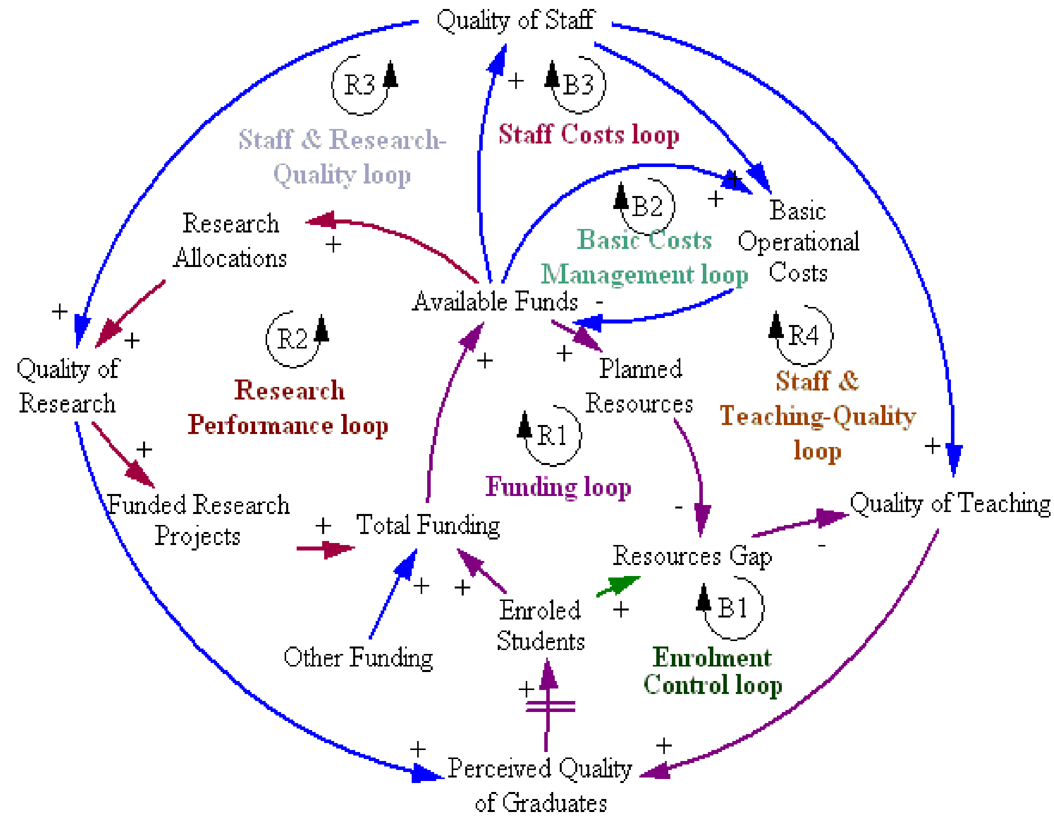


Figure 1.1: Dynamic Hypothesis for Academic Quality Management in HE

The dynamics in Figure 1.1 reflect two categories of feedback loops, namely:-

- Funding and performance loops (R2, R3, R4 and B1)

- Funding and costs management loops (R1, R2, B2, B3)

Enrolment and quality performance loops (R2, R3, R4 and B1) Both loops R2 and R3 associate quality of research with research allocations and quality of staff. Specifically, loop R2 articulates that: an increase in available funds increases research allocations in turn impacts on quality of research. Further increase in quality of research increases funded research projects which results into increases in total funding and ultimately available funds. The loops R3 and R4 are longer but their causal explanations are similar to R2. The theory depicted by B1 follows that an increase in quality of teaching increases perceived quality of programmes which over time attracts more enrolment. However, increase in enrolments reduces quality of teaching.

Funding and cost management loops (R1, B2 and B3)

The balancing effects of loops B2 and B3 show the effects of basic costs on available funds. Considering loop B3, an increase in available funds increases quality of staff. A subsequent increase in quality of staff increases basic operational costs which in turn decreases available funds. Loop R1 purely focuses on funding issues. It depicts that an increase in total funding increases available funds (after some cost deductions). Subsequently an increase in available funds over time increases enrolled students and when more students are enrolled then more total funding is achieved.

Dynamic behaviour resulting from feedback loop structures can be represented by at least three parameter relationships: linear relationship (y=mx+c), saturation relationship (y= a $\pm$e^{-bx}), and exponential relationship (y=ae^{bx} for exponential growth or y=ae^{-bx} for exponential decay). In each case, the letters other than x and y are constants. These relationships are given in Figure 1.2

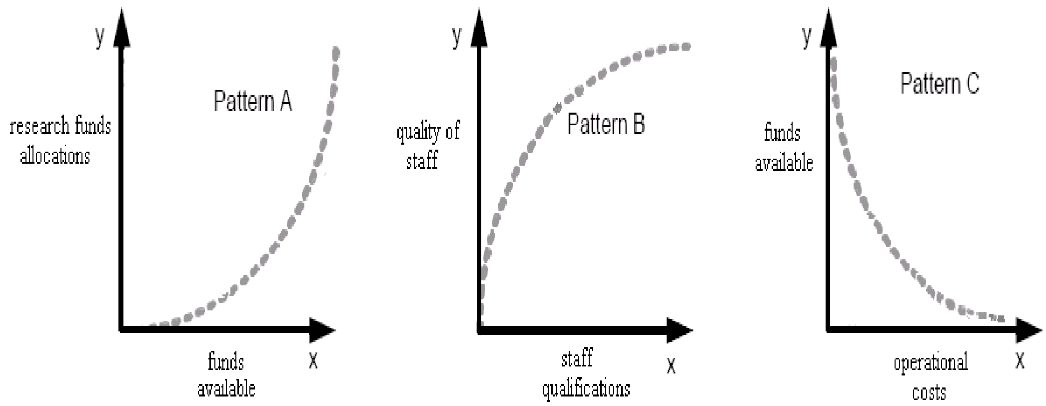


Figure 1.2: Main Parameter Relationship Types

Figure 1.2 above depicts "Pattern A" as an exponential growth generated by a reinforcing loop. "B" is a balancing pattern with goal seeking relationship, where an increase in parameter x (staff qualifications) gives proportionally larger response in parameter y (quality of staff). Furthermore, in real life "Pattern B" occurs when staff qualifications is a measure of the percentage of staff with a PhD such that as more staff acquire PhD qualifications the quality of staff tends towards saturation point. Similarly, "C" is a goal seeking behaviour generated by a balancing loop. There are of course other relationships such as S-shaped growth, boom and bust, and cyclicality (Warren, 2004) that depict more reinforcing and balancing complex behaviours.

1.6 Scope

The tool/model developed in this research is grounded on the settings of both public and private Ugandan universities. The causes of HE quality management problems were investigated and used to craft the model scope in nine sectors. These include: student, academic staff, teaching and learning, research and publication, finance and budgeting, educational resources, government, community, and institutional quality standards. Data for model validation and calibration were mainly obtained from Makerere University through participative engagement with stakeholders coordinated by the quality assurance directorate. Supplementary parameter verification data was collected from four leading Ugandan universities, including: the two oldest public universities (Makerere University and Mbarara University of Science and Technology) and two private universities (Uganda Christian University and Uganda Martyrs University).

1.7 Justification of the Research

In justifying this research, this thesis argues from three perspectives: importance of the problem; appropriateness of the methodology; and the research contribution.

First, the challenge involved in modelling quality is in defining the problem space (problem modelled) then mapping it with the solution space (model of the problem). This is confirmed by Parker (2002) who recognises that "university change will be continuously unfolding, nonlinear, dynamic process full of unforeseen contingencies, modified pathways and revised strategies". In this line, this thesis integrates SD and PAR on the premise of theoretical work that places SD and PAR in the context of complementary methods, such as that described by Scholl (2004), needs to be followed up by empirical research that puts underlying assumptions to the test. Since, as noted by Senge *et al*. (2000), "ideally, any model for management in any organisation can only succeed, if it represents the shared values of the stakeholders" (p.162-3), this integration facilitates participation of HE stakeholders and most importantly the decision makers throughout model development process. In doing so, this thesis maintains that, the hybrid approach (SyDPAR) improves the model conceptualisation process, translating into correct stock and flow diagrams, justifiable simulations, and ultimately ownership of the model by the decision makers or stakeholders (model users).

Second, the appropriateness of the methodology is grounded on three principles: the salience of issues studied, application of available knowledge and production of strong results by ensuring relevance of the solution to a specific environment. These principles are core to the integrated approach (SyDPAR) adopted in this research, as they are respectively addressed through: problem articulation cycle, modelling proficiency cycle, and solution refinement cycle. These cycles are explicitly discussed in chapter 3.

Thirdly, the overall contributions of this research are two fold: 1) methodological synthesis built upon the positivist and interpretivist tradition for solving complex dynamic problems in participatory settings through the integration of SD and PAR leading to the SyDPAR approach, and 2) application of SyDPAR in developing a decision support tool for higher education quality management, also referred to as "Quality Management Tool 2009 (QMT09)". The details of the contributions are given in chapter 6.

1.8 Theoretical Terms Used

The research uses terminology familiar to researchers and others involved in the study of decision support systems for quality management. Therefore, to put this research in context, the theoretical terms used are briefly described in this section. Since a term that is correctly defined renders it functional within a specific enquiry, the five terms here discussed are drawn from the title of this research.

Integration

The usefulness of integration of research methods in information systems (IS) research has been due to the complexity of phenomena which requires information from a great number of perspectives. Thus, some IS researchers maintain that the complexity of the majority of social interventions requires the use of a wide spectrum of qualitative and quantitative methods (Robey, 1996; Hevner *et al.*, 2004). The term integration in the context of this research broadly implies the combination of two methods, namely: SD and PAR. These approaches are envisaged to significantly inform each other as there is a great degree of similarity and overlap between them (Scholl, 2004).

Action Research

Action research (AR) is fundamentally a change-oriented approach in which the central assumption is that complex social processes can best be studied by introducing change into these processes and observing their effects (Baskerville, 2001). AR is arguably useful in bridging theory with practice, and hence allowing one to solve real-world problems while contributing to the generation of new knowledge (Lau, 1999). AR therefore offers the means of effecting change and generating knowledge about the change simultaneously. A notable stream of AR that involves direct participation of practitioners in a dynamic research process, while evaluating the effects of actions with regard to improving practice is PAR. Succinctly, Whyte (1991) defines PAR as research which involves all relevant parties in actively examining together current action (which they experience as problematic) in order to change and improve it.

System Dynamics

System dynamics (SD) is a computer-aided approach for analysing and solving complex problems through policy design and analysis. The problems addressed by SD are based on the premise that the structure of a system, that is, the way essential system components are connected, generates its behaviour (Sterman, 2000). If dynamic behaviour arises from feedback within the system, finding effective policy interventions requires understanding system structure. Once a model is built, it can be used to simulate the effect of proposed actions on the problem and the system as a whole. As Forrester (1994) notes, this kind of tool is necessary because, while people are good at observing the local structure of a system, they are not good at predicting how complex, interdependent systems will behave.

Higher Education

The term higher education in this study is restricted to education at degree level and above. This definition specifically excludes education at diploma level because of decreasing interest in diploma studies by the educational stakeholders (e.g. students, employers of graduates, government) at least in Ugandan case. Therefore, higher education courses are those leading to the award of a Bachelor's degree, post-graduate certificate, post-graduate diploma, Master's degree or Doctoral degree.

Quality Management

Quality management has been defined in various perspectives. From the industrial practice, ISO 9000 defines quality management as the "aspect of overall management function that determines and implements the quality policy, i.e., intentions and directions of the organisation". Similarly, Welsh and Dey (2002) define quality management from a technological perspective as a technology based approach for generating and formatting information for performance assessment that leads to improvement of quality. These two definitions present quality management concept as a means to an end and not the end itself. In the context of higher education, quality management is defined as the quality processes (control, assurance and improvement) by which an institution discharges its corporate responsibility for articulating, maintaining and enhancing academic standards of those activities for which it is responsible (HEQC, 1995).

Adding to these different but related facets of quality management concept, this research introduces a 'benchmark' perspective of quality management as the process/means by which an institution ensures that its core functions: education provision, research, and outreach services are satisfactory.

Integration of System Dynamics and Action Research with Application to Higher Education Quality Management

This research comprises two complementary components: 1) the integration of system dynamics and action research as a generic approach for participative modelling and 2) the development of a computer simulation model for higher education quality management using the integrated approach. While there is no panacea to complex and multi-faceted challenges of improving educational quality, this thesis's title suggests that the integrated approach developed and successfully applied in this research, provides a singular opportunity for management of quality of higher education system.

1.9 Thesis Organisation

The rest of the thesis comprises of five chapters.

Chapter Two performs a critical literature review by identifying the existing intervention approaches and their suitability to specific quality management challenges/problems. The depth of intervention approaches' analysis goes beyond mere review; thus it also attempts classify the nature of quality management problem against corresponding methodology.

Chapter Three outlines the research approach, starting with the the philosophical and theoretical foundations while pointing out the ontological and epistemological assumptions. Thereafter, the current approaches to quality management are evaluated. Subsequently, chapter three provides the methodology for this research.

Chapter Four presents the guiding conceptual framework and the resulting field research design including results of the field study.

Chapter Five addresses the application of the proposed SyDPAR approach to HE quality management. Specifically, chapter five discusses the model development including scope, assumptions, audience, structure, calibration, and validation.

Chapter Six discusses the findings, conclusions and limitations of this research. The areas for future research are also suggested in this chapter.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature review, analysis, and classification of HE quality management systems' research. With exception of the concluding section, the rest of the sections present the literature review in four main categories: 1. trends in HE quality management research in section 2.2; 2. approaches to HE quality management in section 2.3; 3. systems and technologies used in HE quality management in section 2.4, and 4. critical analysis of the causes of problems in HE quality management in section 2.5. Since the integration of SD and PAR is core to this thesis, SyDPAR is presented as one of the approaches for HE quality management including its theoretical basis and relevance.

2.2 Trends in HE Quality Management Research

The trends implied in this section include: perceptions of quality, the excellence models that have been adopted in HE quality studies, and the HE quality management frameworks as basis for the conceptual framework proposed in this research.

2.2.1 Quality Perceptions

Defining quality of higher education has proved to be a challenging task. Cheng (2003) suggests that education quality is a rather vague and controversial concept. At the broadest level, education quality can be viewed as a set of elements that constitute the input, process and output of the education system, and provides services that completely satisfy both internal and external strategic constituencies by meeting their explicit and implicit expectations (Cheng, 2003). If higher education is viewed as a system, then any quality management program must therefore assess inputs, process and outputs.

Contextual Perspective

Lindsay (1992) maintains that indeed, the notion of quality in higher education has no agreed technical meaning and its use usually involves a heavy contextual overlay of some political or educational position. For example, references to the quality of research, students' supervision, assessment, student intake, academic programs, teaching and learning, and program designs are not uncommon. Any attempt to define or attach meaning to the term is largely ignored and one is left to assume that it is 'high' quality that is being referred to as opposed to 'good' or 'poor' quality.

Stakeholders Perspective

From the stakeholders perspective, Harvey and Green (1993) highlight the importance and value of considering quality from a variety of stakeholder perspectives. The different HE stakeholders, i.e., government, quality agencies, universities, individual academics, students, employers, parents and the society, have the potential to think about quality in different ways. Similarly, five aspects of quality, including: exception, perfection, fitness for purpose, value for money, and transformation, are attributed to stakeholders perspective (Harvey and Green, 1993). Watty (2003) further elaborates on these aspects as follows:

- Exception: distinctive, embodied in excellence, passing a minimum set of standards;
- Perfection: zero defects, getting things right the first time (focus on process as opposed to

inputs and outputs);

- Fitness for purpose: relates quality to a purpose, defined by the provider;
- Value for money: a focus on efficiency and effectiveness, measuring outputs against inputs. A populist notion of quality (government);
- Transformation: a qualitative change; education is about doing something to the student as opposed to something for the consumer. Transformation includes concepts of enhancing and empowering: democratisation of the process, not just outcomes.

These aspects with exception of perfection have been generally accepted as a matrix for quality analysis. The key issue is the ability of the quality concept to facilitate the perspectives of a range of stakeholders who have differing conceptions of higher education. The concern is that there will be a direct relationship between the conception of higher education being taken, the definition of quality being used and the performance indicators chosen to measure quality. The challenge is to overcome these concerns and produce a performance evaluation framework that permits the equal expression of legitimate voices, though they may conflict or compete in some ways (Tam, 2001). Furthermore, Tam notes that these voices posses their own fully flaged imperatives of quality such as:

- Stakeholders' Driven Imperatives - the constituents of whom are students, parents, alumnus, employment market leading to the strategic and customer focus;
- Regulatory Driven Imperatives the constituents of whom are the government, and other academic institutions of higher learning leading to the curriculum, teaching, learning and research, and students development focus, and benchmarking;
- University Driven Imperatives the constituents of whom are the administrators, the support and service units, the faculty and personnel's focus.

Whether contextual or stakeholders perspective, HE in general aims to ensure quality of all its activities. Notably, the contextual view of quality of HE in terms of performance in research, students' supervision and assessment, teaching and learning, are all sustained by resources (students, staff, and finances). Similarly, the view of quality of education as a measure of satisfaction of its stakeholders is also underpinned by resources. Accordingly, Csizmadia's (2006) input-throughput-output model for HE quality is well served given that resources correspond with inputs, performances issues are throughputs and satisfaction issues as outputs. Therefore, quality should not be independently positioned in a contextual or stakeholders perspective but a combination of these.

2.2.2 Excellence Models

Excellence models emphasize the perfection aspect of quality, i.e., zero defects, getting things right the first time or focus on process as opposed to inputs and outputs. From the performance assessment literature, Conti (2003, as cited by Shawyun, 2006) identifies 5 key "excellence and improvement" models as:

1. ISO 9000 Standards
2. EFQM Excellence Model
3. Malcolm Baldridge Model
4. Deming Application Prize Model
5. Other TQM models, proposed by other organizations, authors, consultants specially conceived for organizational improvement.

Conti (2002) contends that models 2, 3 and 4 can be used for excellence recognition, "level of quality" recognition and organization improvement, whereas model 1 can be used for conformity and performance assessment. In a more recent study, Csizmadia (2006, p.72) cautions that the simplistic application of models from industry such as these excellence models in HE is unlikely to improve quality. With exception of the Deming Prize Model as its equivalence for educational issues are not yet well developed, a brief discussion on rest is given next.

ISO 9000 Standards

ISO 9000 is the generic reference for a family of standards on quality management. It comprises five parts, three of which are more relevant to education quality. These include: ISO 9000:2000, which covers quality management and quality assurance standards; ISO 9001:2000, which is the actual specification for a quality management system; and ISO 9004:2000, which is designed as a guide for those organisations that want further improvement of their quality system. Worthy of mention is that ISO 9001 is the only standard in these series for certification the other two are for guidance. Without going into details of each, only the more general standard (ISO 9000:2000) is discussed here.

ISO 9000:2000 provides four requirements for quality management systems of organizations:
(1) Quality management system - defines general and documentation requirements of this standard
(2) Management responsibility - defines management commitment, customer focus, quality policy, planning, responsibility, authority, and communication, and management review
(3) Resource management - deals with all resources within the organization in order to improve the quality. This section covers provision of resources, human resources, infrastructure of the organization and work environment.
(4) Product realization - defines planning, customer related processes, design and development, production and service provision, and control of measuring and monitoring devices.

While it may be logical to assert that ISO 9000 does nothing to ensure actual quality of products or services, but its registration merely indicates a 'system' which fulfills the often vague requirements of the standard, it has on the other hand, been estimated that only 30% of all applicants pass the on-site audit on the first attempt (Coppola, 1994). A valid limitation of ISO 9000 standard is the lack of self-assessment strategy which is considered important by most excellence models.

EFQM

The success of the Baldrige Model (USA) and the Deming prize (Japan) encouraged the formation of the European Foundation for Quality Management (EFQM) in 1988. The EFQM excellence model was introduced in 1991 with the European Quality Award being awarded for the first time in 1992. Although EFQM represents different organisational areas, it has over the years been mainly implemented by industrial organizations. These organizations have currently built up much experience in the issues to be addressed when aiming for successful implementation of the model. Till now it has been used in various industries such as schools, hospitals, police and public organizations (EFQM, 2002; Umashankar and Dutta, 2007).

The EFQM Excellence Model is a non-prescriptive framework based on 9 criteria. Five of these are 'Enablers' and four are 'Results'. The 'Enabler' criteria (leadership, people, policy & strategy, partnership and resources andprocesses) cover what an organization does, while the 'Results' criteria (people results, customer results, impact on society results and business results) cover what an organization achieves. ‘Results’ are caused by ‘Enablers’ and ‘Enablers’ are improved using feedback from ‘Results’. This is depicted by the arrows in EFQM Model as presented in Figure 2.1.

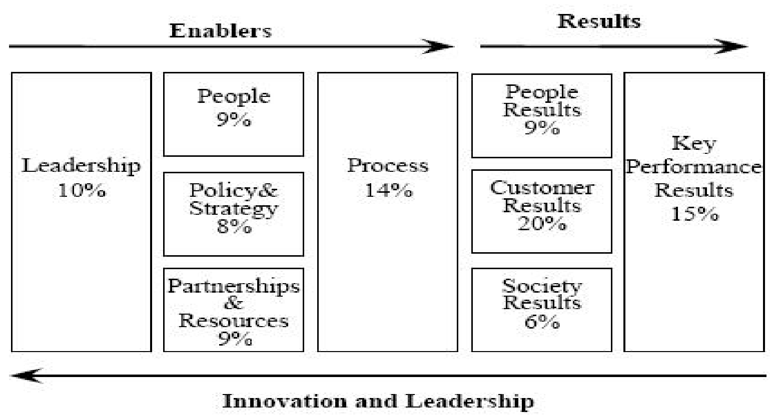


Figure 2.1: The EFQM Excellence Model (Source: Umashankar and Dutta, 2007)

The Model recognizes that there are many approaches to achieving sustainable excellence in all aspects of performance, basing on the premise that: excellent results with respect to performance, customers, people and society are achieved through leadership driving policy and strategy, that is delivered through people, partnerships and resources, and processes (EFQM, 2002; Umashankar and Dutta, 2007). Therefore, it may be assumed that the excellence of a higher education institution will depend primarily upon the processes that take place within its scope (namely teaching/learning, research, and financial management) and the results that, through the processes, it is able to achieve.

Malcolm Baldridge Model

Just like the other excellence models, the Malcolm Baldridge Model has been used in various sectors such as manufacturing industries, health care, companies, government agencies, education organisations, and others. Specific to the education sector, the 2004 Education Criteria for Performance Excellence was developed (NIST, 2004). This concept of excellence is used in NIST (2004) because: (1) it places the major focus on teaching and learning strategies; (2) it poses similar types of challenges for all organizations regardless of resources and incoming student preparation and abilities; (3) it is most likely to stimulate learning-related research and to offer a means to disseminate the results of such research; and (4) it offers the potential to create an expanding body of knowledge of successful teaching and learning practices in the widest range of organizations.

The Baldrige Criteria provide a systems perspective for managing your organization and its key processes to achieve performance excellence. The core values and concepts embodied in the seven Baldrige categories, include: a) Leadership, b) Strategic Planning, c) Student, Stakeholder, and Market Focus, d) Measurement, Analysis, and Knowledge Management, e) Faculty and Staff Focus, f) Process Management, g) Organizational Performance Results. These are illustrated in the Baldrige framework in Figure 2.2.

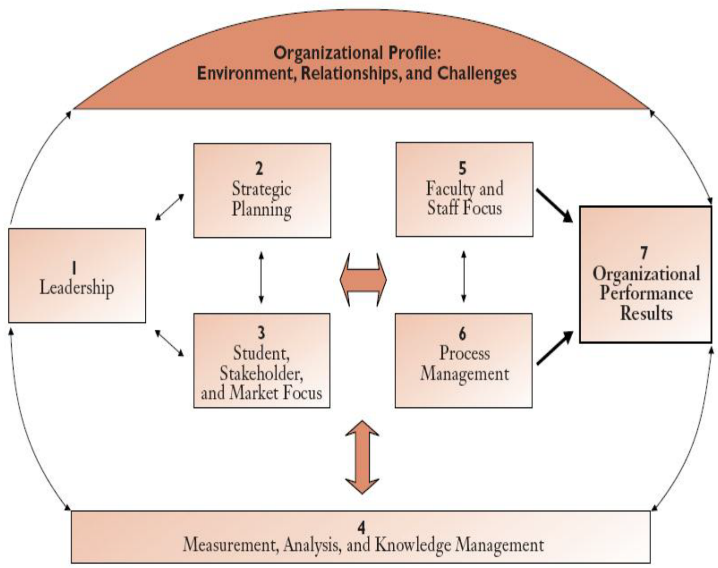


Figure 2.2: Baldrige Education Criteria for Performance Excellence Framework: A Systems Perspective (Source: NIST, 2004)

A systems perspective includes the senior leaders' focus on strategic directions and on students and stakeholders. It means that the senior leaders monitor, respond to, and manage performance based on organizational results. A systems perspective also includes using measures, indicators, and organizational knowledge to build key strategies. It means linking these strategies with key processes and aligning resources to improve overall performance and satisfy students and stakeholders. Thus, a systems perspective means managing the whole organization, as well as its components, to achieve success. For example, the organizational performance category focuses on areas such as: (1) student learning results, (2) student- and stakeholder-focused results, (3) budgetary, financial, and market results, (4) faculty and staff results, (5) organizational effectiveness results, including key, internal operational performance measures, and (6) governance and social responsibility results.

TQM

The TQM 'movement' has been very broad and covered many approaches and models, hence, it is not possible to describe *the* TQM approach (Csizmadia, 2006). Following a review of literature on excellence models, Csizmadia (2006) reports that quality: 1) is directed at customer satisfaction, 2) should meet set requirements, 3) applies to every product (physical product, information product and service product), 4) is a profitable long-term investment, 5) requires changing an organization's culture, 6) requires top management leadership, 7) is everybody's job, 8) equates to "good business practice and system", 9) requires a focus on people, 10) is achieved through process improvement, 11) is improvement is forever and 12) is a fundamental long-term goal of the organization. In order to traverse these perspectives, the development of a seamless "total", "quality" and "management" big picture integration that identifies the cause-effect system to measure and manage the quality of the institution was inevitable. Figure 2.3 gives one of such TQM frameworks.

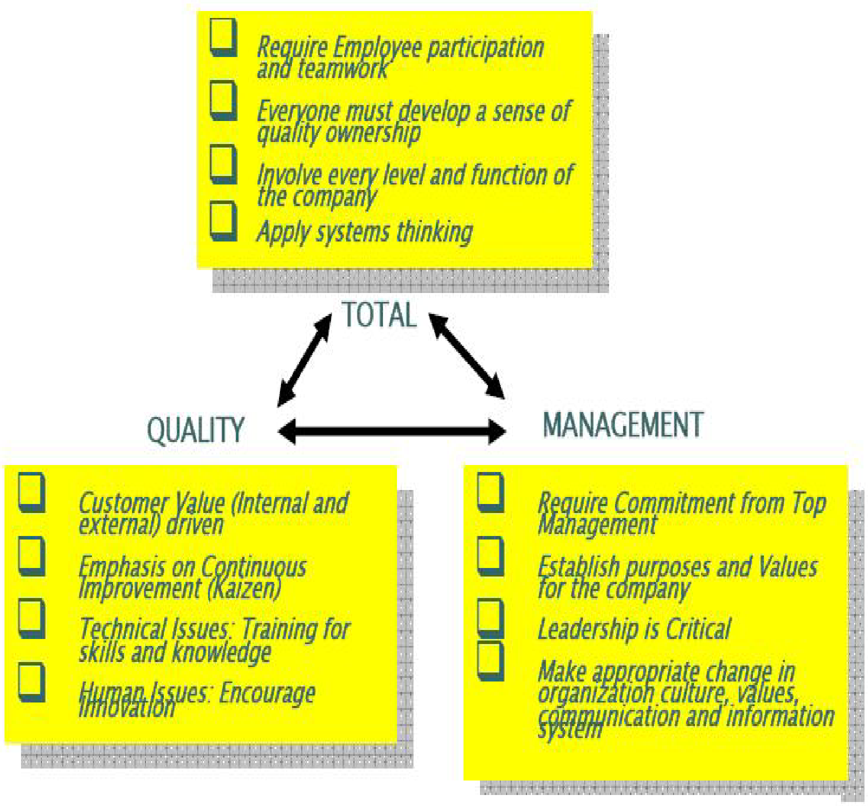


Figure 2.3: A Three-Dimensional perspective of TQM (Source: Lau and Anderson, 1998)

The TQM model as depicted in Figure 2.3 emphasises: the identification and improvement of critical processes, satisfaction of stakeholders' needs, data gathering and analysis, improvement of the work environment, contact and communication among staff in different but related functions, increased knowledge of what the organisations are about, and prevention of mistakes and errors to minimise costs rather than being dependent on inspection activity and corrective actions. The latter emphasis may not be feasible in highly complex systems like HE.

2.2.3 Quality Management Frameworks

A number of quality management frameworks have been proposed in the literature. Only the recent ones are discussed here as these largely extend the previous ones.

The Comprehensive Quality Management Framework

Csizmadia (2006) developes a comprehensive framework for quality management based on input-throughput-output model grounded in the nature of academic organisations. In presenting the comprehensive framework, Csizmadia (2006) perceives higher education institutions as part of an abstract system in which their fitting to external expectations would influence their success and eventual survival. Therefore, the nature of the relationships between the higher education institutions and their environment (stakeholders, government, etc.), and in its concern for unique internal processes, is pertinent to this framework. Figure 2.4 gives the input-throughput-output model for addressing quality in a comprehensive way in which education and its support processes are directly connected.

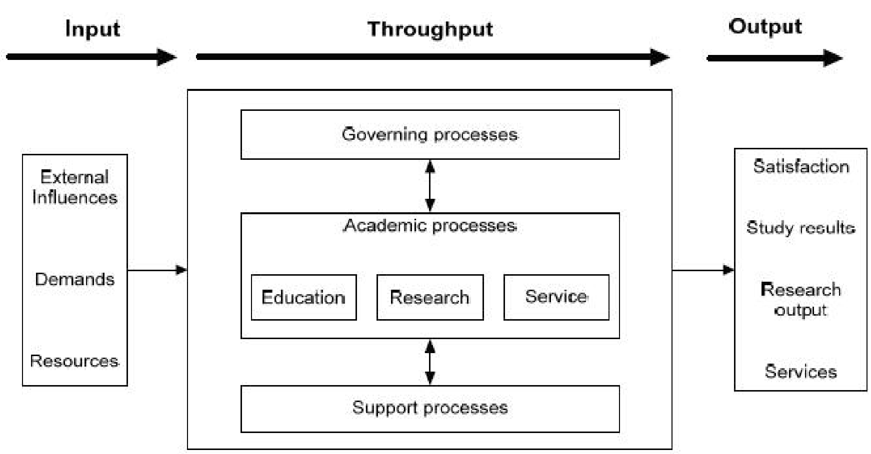


Figure 2.4: Comprehensive Framework for HE Quality Management(Source: Csizmadia, 2006)

As depicted in Figure 2.4, the inputs include: external influences (e.g., governmental expectations, requirements of accreditation agencies), demands (expectations of students, academics, employers, alumni, and the society), and resources (students, staff, and financial). The complete discussion on the comprehensive framework can be found in Csizmadia's (2006) PhD thesis. However, its relevance to this thesis is in explicitly showing the systemic nature of HE in which both its environment and its unique internal processes influence its outcomes and hence quality. More specifically, the conceptual framework developed and presented in this thesis (Figure 4.1) extends elements of the comprehensive framework into a systems structure with multiple feedbacks.

The Holistic Implementation Framework for Quality Management System

van Waveren (2004) proposes an implementation framework for a quality management system based on the 1S0 9000:2000 series of quality management system standards. that can be utilised by an academic department to standardise on quality requirements and the management of these requirements. The framework is arguably applicable to an academic department incorporating both academic, service and support functions.
The main reasons for this decision to focus on IS0 9000:2000 according to van Waveren (2004) are three fold:

- There is a large overlap in quality management activities and requirements between the different business excellence models and the IS0 9000:2000 series of standards;
- The IS0 9000:2000 series is an internationally recognised standard and is a process based standard, developed for a wide range of organisational types.
- The IS0 9000:2000 series, embraces all activities in an organisation that serve the satisfaction of customers.

In consideration of the above, to be able to implement an appropriate quality management system (QMS) in the academic department, a three dimensional implementation framework is envisaged. The framework encompasses the mapping of a QMS requirements on the core and supporting processes while considering all the different stakeholders and customers of each process step. The conceptual representation of the framework is not given in this section, however, the insights from it, namely, quality management systems requirements have been adapted (not adopted) in this research in understanding general elements that constitute any quality management system.

Quality Management, Information and Planning System-QMIPS

QMIPS is a generic framework for quality management arising from holistic integration of the TQM, performance management models, strategic management models and the balanced scorecard (Shawyun, 2006). The QMIPS has five perspectives covering Strategic, Financial, Stakeholders, Process and Learning and Growth perspectives and 9 sets of Key Performance Indicators (KPI). The key determinants in the quality process perspective in QMIPS are: 1) operation management (KPI 2 of teaching-learning, KPI 3 of student activities, KPI 4 of research; 2) Stakeholders management (KPI 9 of quality assurance and performance results; 3) innovation management; and 4) regulatory and social management (KPI 5 of academic services). The strategic perspective (KPI 1 of Vision, Mission and Strategic Plans), financial perspective (KPI 8 of Finance and Budgeting) and learning and growth perspective (KPI 7 of Administration) are comprehensively covered and enhances the alliance of quality management as framed within the strategic implementation framework of the integrated QMIPS.

The consolidated QMIPS is shown in Figure 2.5 in which the 9 sets of KPIs are mapped onto the balanced scorecard model to identify the KPI specific to the perspective, so that the KPIs are the de facto measures for that perspective. As such, the KPI specific to the perspective are enshrined as part of the processes or activities, other needs identified and measured.

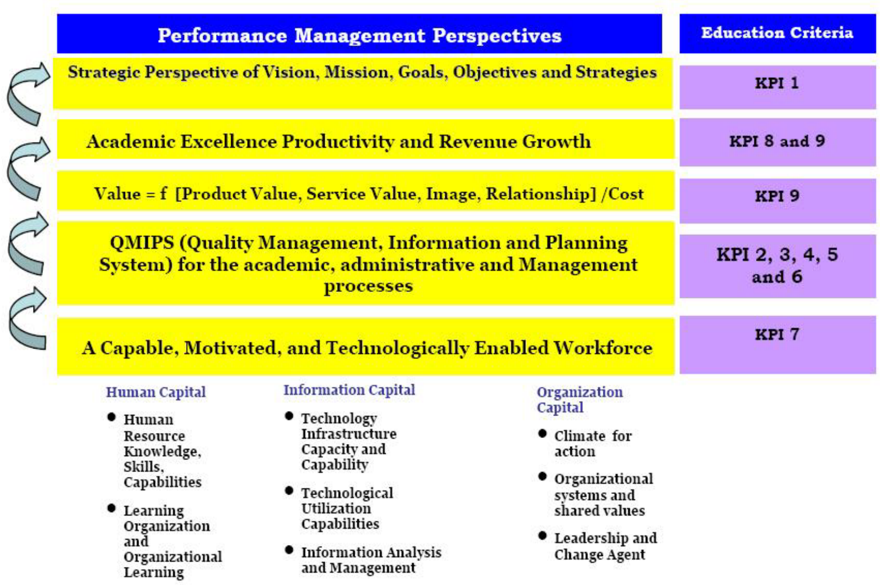


Figure 2.5: Mapping of the Education Criteria onto the Performance Management Perspectives (Source: Shawyun, 2006)

The entire scope of QMIPS in terms of its five perspectives and 9 sets of KPI provide a robust and generic model that incorporates quality management issues from a system's perspective and hence core to the development of quality management conceptual framework in this thesis. In addition, the human capital, information capital, and organisation capital provide insight into the focus of quality management frameworks.

Generic Model for Quality Management in Education-QME

Srikanthan and Dalrymple (2007) note that it is difficult to apply quality management models to teaching and learning, because the quality management models are measurement focussed yet the core processes of learning are too subtle to be measured meaningfully. Nevertheless, Srikanthan and Dalrymple (2007) suggest specific issues of consideration for models of quality management as follows:

- The product control is crucial for quality management: teaching in higher education is too varied in its products, site delivered, delivery modes, processes and personnel to be controlled;
- Customer focus is the key tenet of quality management models: in higher education the identification of the customers is a critical problem. The customers can variously be students, employers, government etc;
- Managerial responsibility for quality;
- The empowerment of staff for quality improvement;
- Setting of standards that reflect customer requirements; and
- Avoidance of error and minimising variation.

Given the above perspectives, Srikanthan and Dalrymple (2007) maintain that a generic model for quality in higher education would have to be more complex, to address service and pedagogical aspects of quality uniquely. In such a composite model, quality management addressing the service areas, should be meshed seamlessly with the model addressing the core areas of teaching and learning. Such a synthesis is presented as the key features of a generic model addressing the QualityManagement in Education (QME), including:

- a clear focus on "transformation" of the learners;
- a synergistic collaboration at the learning interface; and
- there is a clear role for commitment at all levels supported by senior management.

The insight from QME suggests that educational programmes should be continually designed and redesigned based on stakeholder needs as well as organisational knowledge and expertise. As such, the process of development of quality management tools are as important as the ensuing tools. We discuss this further in section 5.3.

2.3 Current Approaches to Quality Management in HE

Various approaches have been used in HE quality research. The prominent ones include: statistical analyses (e.g., Abdullah, 2006), multi-criteria decision making (analytic hierarchy process (AHP), e.g., Grandzol, 2005 and goal programming (GP), e.g., Ho et al., 2006), data management (data warehousing and data mining, e.g., Maltz et al., 2007; Vinnik and Scholl, 2005), system dynamics modelling and simulation (Barlas and Diker, 2000), hierarchical linear modelling (Try and Grógaard, 2003), and participatory action research (Fletcher and Zuber-Skerritt, 2008). Discussing these approaches according to the nature of HE problems solved as in the following sections, is well suited for facilitating the understanding necessaty for comparative analysis of their effectiveness.

2.3.1 System Dynamics Modelling

System dynamics is a computer based modelling approach for analysing and solving complex problems through policy design and analysis. The problems addressed by SD are based on the premise that the structure of a system, that is, the way essential system components are connected, generates its behavior (Sterman, 2000). If dynamic behaviour arises from feedback within the system, finding effective policy interventions requires understanding system structure. Once a model is built, it can be used to simulate the effect of proposed actions on the problem and the system as a whole. As Forrester (1998) notes, this kind of tool (SD model) is necessary because, while people are good at observing the local structure of a system, they are not good at predicting how complex, interdependent systems will behave.

Kennedy (2002) provides a comprehensive taxonomy of publications describing various system dynamics models on higher education issues. These include topics such as: external forces, corporate governance, planning, resources and budgeting, human resource management, teaching quality, teaching practice, micro worlds, and enrolment demand. Without intention to ignite debate on qualitative versus quantitative system dynamics models, starting with Kennedy's taxonomy, it seems necessary to further categorise these publications into quantitative (involving simulations) and qualitative system dynamics. Doing so clarifies on previous trends of research as the basis for further work.

The potential value of SD modelling in addressing higher education quality issues is in its ability to:

- Model feedbacks or interactive views in dynamic systems like higher education
- Incorporate non-linear relationships inherent in higher educational quality issues
- Address complexity situations while experimenting their behaviour over time
- Accommodate soft factors such as effectiveness of students projects supervision, staff competence, quality of staff, quality of research, and quality of teaching that underpin higher education quality issues
- Model time delays that underpin certain policies on quality, e.g., time to recruit new staff, durations of study programmes, staff on training, executing research projects, and investment in new students capacity.

Features of SD Methodology

Six features of SD have been identified by Schwaniger (2006). These are further discussed here.

- Focus on feedback-driven, mainly internally generated dynamics: The systems modelled are networks of closed loops of information. However, they are not limited to the representation of 'closed systems', in that (a) flows can originate from outside the systems boundaries, (b) exogenous factors or systems can be incorporated into any model as parameters or special modules and (c) new information can be accommodated via changes to a model.

- High degree of operationality: SD relies on formal modelling. This fosters disciplined thinking; assumptions underlying equations and quantifications to be clarified. Feedback loops and delays are visualized and formalized; therewith the causal logic inherent in a model is made more transparent and better discussable than in most other methodologies. Also, the achievable level of realism is higher than, for example, in econometric models.

- Far-reaching possibilities for the combination of qualitative and quantitative aspects of modelling and simulation: The focus is not on point-precise prediction, but on the generation of insights into the patterns of behaviour generated by the systems under study.

- High level of generality and scale robustness: The representation of dynamical systems in terms of stocks and flows is a generic form, which is adequate for an enormous spectrum of potential applications. This spectrum is both broad as to the potential subjects under study, and deep as to the possible degrees of resolution and detail.

- Availability of powerful application software: The packages (Stella/Ithink, Powersim, VENSIM and MyStrategy) are easy to handle and give access to a high variety of mathematical functions. Part of this applications array offers optimization procedures and validation tools. Also, some support for collaborative modelling and the communication with databases is provided.

- Potential synergies: Combination with many other tools and methodologies is possible, both conceptually and technically.

Given the diversity of SD strengths, an equivalent application area of SD as already highlighted exists. The emerging trend of mixing other methods with SD further confirm the superiority of SD features. Examples of the latter include: dynamic synthesis methodology- involving case study and SD (Williams, 2002, 2004), soft system dynamics methodology- involving soft systems methodology and SD (Paucar-Caceres and Rodriguez-Ulloawe, 2007), managing from clarity (Ritchie-Dunham and Rabbino, 2001), group model building- modelling with clients (Vennix, 1996, 1999; Andersen *et al.,* 2007), action research-SD integration (Scholl, 2004), collaborative systems modelling-GMB integration (Rouwette and Hoppenbrouwers, 2008), object role modelling-SD integration (Tulinayo *et al.*, 2008).

The SD Intervention Process

SD is a systemic approach based on feedback thinking or rational cause-effect relationships. According to Forrester (1998), SD modelling can be effective because it builds on the reliable part of our understanding of systems while compensating for the unreliable part. The modelling process separates consideration of underlying assumptions (structure, policies, and parameters) from the implied behavior and contrary to its advantage, SD models have little impact unless they change the way people perceive a situation. Forrester (1998) further argues that, a model must help to organise information in a more understandable way by linking the past to the present and showing how present conditions arose, then extending the present into persuasive alternative futures under a variety of scenarios determined by policy alternatives.

Since its inception, SD has emphasized the importance of clarity of purpose for any intervention, i.e., a defined problem, issue or undesirable behaviour to be corrected (Forrester, 1961). The problem behaviour is usually described in a reference mode, and the purpose of the intervention is to identify how structure and decision policies generate the identified reference mode so that solutions can be generated and implemented. SD practitioners build and depend on formal simulation models to overcome the cognitive limitations to grasp the detailed complexity of the problem situation, and to make reliable behavioural inferences. Generation of problem solutions relies on using these models for policy testing (Forrester, 1961), and what-if scenarios.

Regardless of the intervention situation, the main steps of modelling process itself remain the same. Accross the literature, stages (or steps) of model development in SD range from four to seven. As a matter of preference, seven steps given by Zagonel (2002) as shown in Figure 2.6 is discussed here.

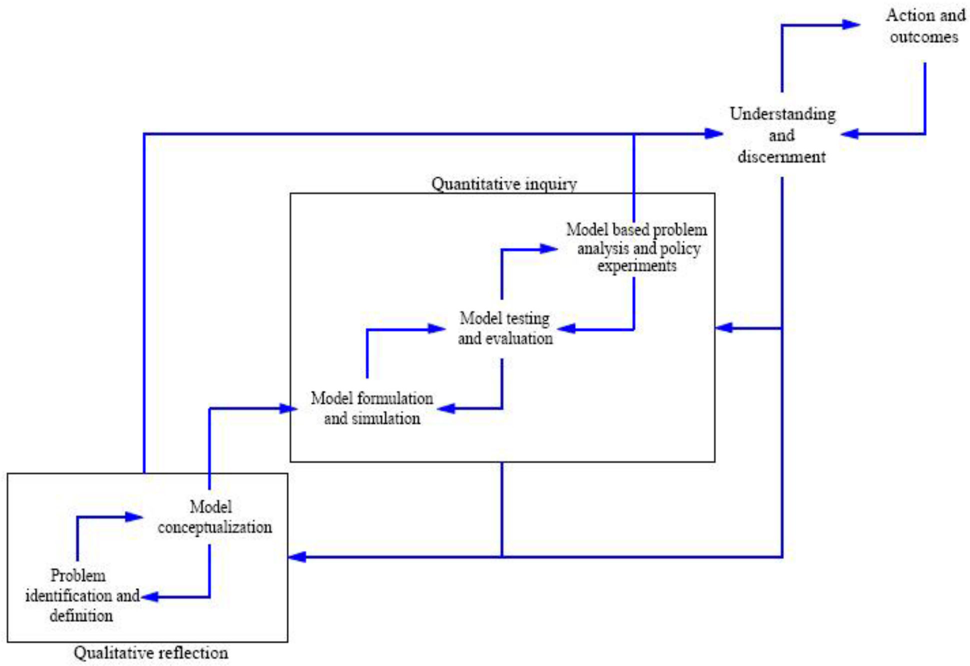


Figure 2.6: Steps in System Dynamics Model Building (Source: Zagonel, 2002)

Figure 2.6 depicts the phases of the method as a sequence of iterative steps, as in climbing up and down a ladder. The first two steps have to do with a qualitative reflection involving problem definition and model conceptualization. The next three steps relate to a quantitative inquiry based upon model formulation and simulation, model testing and evaluation, and model based problem analysis and policy experimentation. The iteration happens both within each cluster of steps, and across clusters, as desired or needed. At any point in the process, there exists some degree of understanding and discernment regarding the problem and the system under study.

Zagonel assumes that as one climbs toward the higher steps, from qualitative analysis to quantitative inquiry, and from formulation to testing, to model based analysis, the level of understanding and discernment improves and gains accuracy. At some point in this process, if the model building effort is to be successful, the insights generated will result in decisions and actions in the form of new policy implementation. Those, in turn, will lead to new outcomes.

Irrespective of the modelling steps involved, SD interventions can only be as good as the conceptualised model that is at the interface between problem definition and model formulation/simulation, thus careful consideration must go into model conceptualisation. Issues such as: views of reality, model scope and level of aggregation, and dynamic hypothesis and its validation, must be made explicit.

2.3.2 Data Mining

Data mining is the process of identifying valid, novel, potentially useful, and ultimately comprehensible understandable patterns or models in data to make crucial business decisions (Kuonen, 2004). In a similar perspective, Rubenking (2001) defines data mining as the process of automatically extracting useful information and relationships from immense quantities of data, while Luan (2001) explains that data mining doesnt involve looking for specific information, neither does it require starting from a question or a hypothesis, but data mining simply seeks patterns that are already present in the data.

The relevance of data mining field of study is in bridging the gap between information and the knowledge that ensues. In real life, data leads to information, which then leads to knowledge, which in turn leads to decisions then action. The biggest challenge therein according to Kuonen (2004) is how to get from data to knowledge. The solution is data mining, least "you drawn in information and remain starved of knowledge". With data mining, Kuonen (2004) adds, companies can analyze customers' past behaviours in order to make strategic decisions about the future.

Recent applications of data mining in HE focus generally on enrolment management, while addressing topics such as: admission yields (Maltz *et al.*, 2007), student retention and degree completion time (Deniz *et al.*, 2002). Specifically, the questions explored include: discovering which inquiries are most likely to turn into actual applications; predicting enrollment to specific courses to help determine a programs success rate; identifying and targeting students who are at risk of attrition; and achieving and maintaining optimum graduation rates, recruitment, and retention rates.

2.3.3 Analytic Hierarchy Process

The analytic hierarchy process (AHP) has been applied as a multiple attribute decision making technique to several decision problems in HE since its inception by Saaty in 1980. AHP is especially suitable for complex decisions which involve the comparison of decision elements which are difficult to quantify. It is based on the assumption that when faced with a complex decision the natural human reaction is to cluster the decision elements according to their common characteristics. It involves building a hierarchy (Ranking) of decision elements and then making comparisons between each possible pair in each cluster (as a matrix). This gives a weighting for each element within a cluster (or level of the hierarchy) and also a consistency ratio (useful for checking the consistency of the data). In short, the AHP consists of three main operations including hierarchy construction, priority analysis, and consistency verification (Anderson *et al.,* 2005 as cited by Ho *et al.,* 2006).

AHP has been applied to several decision problems in HE as a multiple attribute decision making techniques including: resource allocation (Ho *et al.*, 2006), budget allocations (Arbel, 1983), faculty promotions and section process (Grandzol, 2005). A complete review on use of AHP in HE decision areas can be found in Grandzol (2005) and Ho *et al.* (2006). In the context of this thesis, AHP is useful in setting priorities for budget allocations prior to running the simulations so that real-life decisions on allocation of funds are depicted in the simulations.

2.3.4 Goal Programming

Goal programming (GP) is a special extension of linear programming. This method is regarded as the most practical multi-objective decision-making (MODM) technique, since it is frequently used to solve the higher education decision problems (Ho *et al.*, 2006). GP takes multiple goals with varying priorities into consideration at the same time and therefore differs from conventional linear programming method where the objective function is undimensional (either maximize profits/effectiveness or minimise costs/sacrifices). The goals as well as their priority level (i.e. P_1; P_2; . . . ; P_n) are identified by the decision makers such that $P_1 > P_2 > P_3 > .... P_n$. The goals with a higher priority level are considered first. Once they have been satisfied with no further improvement, the next most important goals are then considered.

In GP, instead of trying to maximise or minimise the objective criterion directly, the deviations between goals and what can be achieved within a given set of constraints are to be minimised. Hence deviational variables take a new significance in GP, as they are represented in two dimensions, i.e., both positive and negative deviations from each goal. The objective function then becomes minimisation of these deviations based on preemptive priority attached to them. The value of a GP therefore is a solution of problems involving multiple, conflicting goals according to defined priority structure. The general GP model for which Z is the objective function can be mathematically expressed as:

Minimize $Z = \sum_{i=1}^{m} (d_i^+ + d_i^-)$

subject to Ax - Id$^+$ + Id$^-$ = b, for x, d$^+$, d$^-\geq$ 0,

where m goals are expressed by an m component column vector b (b_1, b_2, ...b_n), A is an m x n matrix which expresses the relationship between goals and subgoals, x represents variables involved in the subgoals (x_1, x_2, ...x_n), d$^+$ and d$^-$ are m component vectors for variables representing deviations from goals and I is identity matrix in m dimensions. The decision maker must analyse each one of the m goals considered in the model bearing in mind that for each goal, there are three possible alternatives of incorporating deviation variables in the objective function, as shown in the following:

1. if over-achievement of a goal is regarded as unsatisfactory, then only d $^+$ is included in the objective function; or
2. if under-achievement of a goal is regarded as unsatisfactory, then only d $^-$ i is included in the objective function; or
3. if both over- and under-achievement of a goal are not desirable, then both d $^+$ and d$^-$ are included in the objective function.

In summary, after formulating a GP model for a particular decision problem, commercial packages like LINDO and CPLEX can be used to solve the model to optimality. In cases where the model only consists of two decision variables, even the simple graphical method can be adopted (Ho et al., 2006). In the context of this thesis, the graphical GP concepts provided insights on development of a predictive sub-model for estimating the optimal student numbers.

2.3.5 Hierarchical Linear Modelling

Hierarchical Linear Modelling (HLM) is a technique for modelling multilevel data when observations at lower levels are nested within observations at higher level. The relevance of HLM in higher education quality research is in generating a hierarchy of structured data in order to improve the insights from analysis. Hwang (2002) emphasises that the use of massive large-scale secondary data in higher education research, without consideration of the inherent hierarchical data structures involved may lead to inaccurate or misleading conclusions. He backs up this argument with a satisfaction survey of 1,187 students in which the multilevel modelling adopted revealed the difference in satisfaction rating by the different student clusters. Other applications of HLM in higher education quality studies can be found in: DeMars (2002) in the study of programme effectiveness in universities; Try and Grögaard (2003) in measuring the relationship between resources and outcomes in Norwaygian higher education.

2.3.6 Balanced Scorecard

Traditionally, most organizations look into their corporate performance by reviewing their financial aspects. However, financial measures alone are not a balanced view of the critical success factors of any organisation, mainly because financial measurements tend to measure the past, without strict consideration as to why it has happened. Against this background, Kaplan and Norton (1996) developed the Balanced Scorecard (BSC) in the early 1990s. In their view, "the BSC translates an organization's mission and strategy into a comprehensive set of performance measures and provides the framework for strategic measurement and management".

The BSC according to Umashankar and Dutta (2007) is based on four key perspectives:

i. Financial goals - How will we look to our stakeholders?

ii. Customer perspective - How must we look to our customers?

iii. Internal processes - What internal processes must we excel at?

iv. Learning and growth - How can the organization learn and improve?

These perspectives provide an inter-connected view necessary for quality management studies.

Balanced Scorecard Applications in Higher Education

It is evident from the literature that the BSC has been widely adopted in the business sector but less in the education sector. Nevertheless, Umashankar and Dutta (2007) in their presentation of a BSC model for Indian higher education programs/institutions, call for the adoption BSC in educational institutions for reinforcement of the importance of managing rather than just monitoring performance. Papenhausen and Einstein (2006) lay out a comprehensive and content-specific BSC for a business school as a whole. In addition, they suggest that in an environment that demands increasing accountability from business schools, the BSC offers a promising and valuable tool for implementing a strategic performance management system. In the context of this research, the four perspectives of BSC (financial goals, customer focus, internal processes, and learning and growth) provided insight to the understanding of the main factors that influence HE quality.

Participatory Action Research

The dual aim of the PAR approach is to address a problem or a problem situation and to develop practical and theoretical generalisations/learning (Lau, 1999). The PAR approach supports the argument that when theory and practice are interconnected, then solving real world problems while contributing to new knowledge can be achieved concurrently. This is possible because PAR involves practitioners as both subjects and co-researchers. In the same spirit, Kock and Lau (2001) explicitly note: "*whatever the case, the IS action researcher serves two different 'masters', namely the research client and the research community as a whole. The needs of these two masters are usually entirely different and sometimes conflict with each other*", and therefore, PAR should have little distinction between the two parties by offering the potential of reducing the conflict of 'serving two masters'.

The increased practitioner participation is a major distinguishing characteristic in PAR but at the same time raises contention of who is in charge of the research. By adopting the practice perspective of AR (Cronholm and Goldkuhl, 2004) in PAR (see Figure 2.7), the authority of researchers and practitioners are clear. As depicted by Figure 2.7, the researcher is always "in charge" of the theoretical research practice while the business practitioners are "in charge" of the regular business practice. In the business change practice/empirical research practice, the researchers are "in charge" of the empirical data collection part and the business practitioners are "in charge" of the business changes.

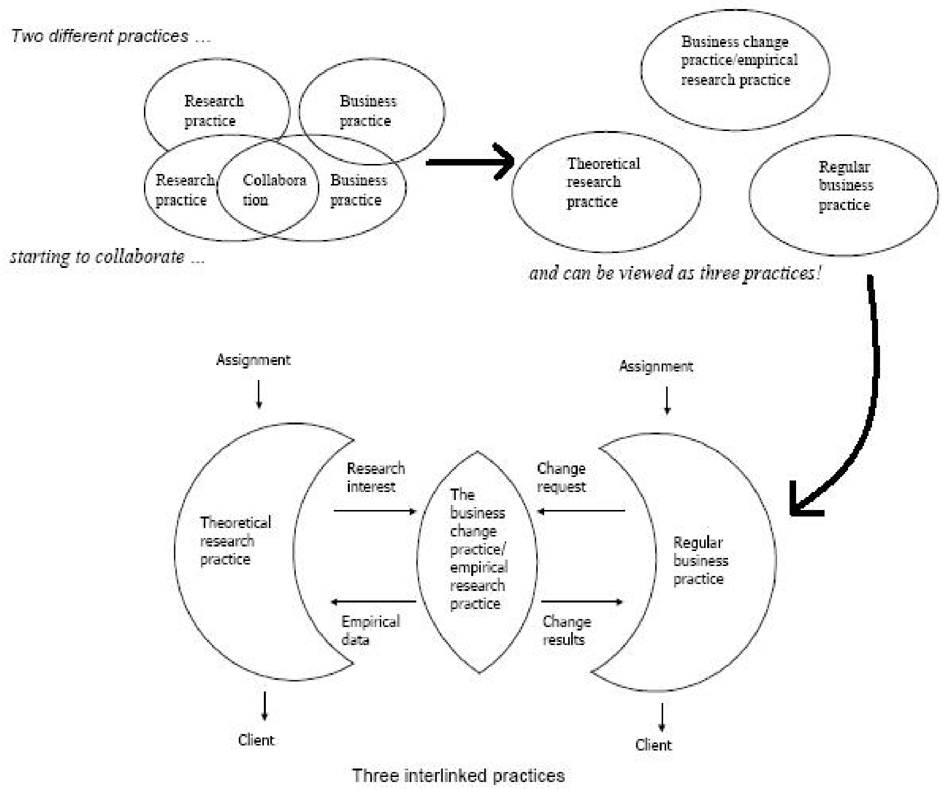


Figure 2.7: The Practice Perspective of Action Research (Adapted from: Cronholm and Goldkuhl, 2004)

When action research is performed, the interaction between research and business practice initiates collaboration. Cronholm and Goldkuhl (2004) claim that this collaboration makes it possible to talk about a third practice, which in itself is the intersection of the two practices. Noteworthy to reiterate, in PAR, researchers and practitioners bring their own distinctive sets of theoretical knowledge into the action research process. Action researchers bring their knowledge of action research and general information systems theories, while practitioners bring situated, practical theory into the action research process. As a result, control over the social setting is realigned, allowing for free self-reorganisation rather than be artificially determined by the external researchers (Baskerville, 1999).

PAR Intervention Process

A number of models are available in the literature about AR and hence PAR process. Most of them regard the process as non-linear, appreciating that people are unpredictable, and that their actions often do not follow a straightforward trajectory. Susman and Evered(1978) give a five phase cyclic

AR process involving:

1. identification of area of practice and problem to be investigated;
2. designing a solution strategy or considering alternative courses of action;
3. implementing the strategy or selecting a course of action;
4. evaluating the solution or consequences of an action;
5. change practice in light of the evaluation.

The prevalent AR process in IS begins with specification of the client-system infrastructure. The client-system infrastructure clarifies on issues of: research agreement, level of commitment, and roles/responsibilities (Baskerville, 1999; Davison et al., 2004). The client-sytem infrastructure therefore, addresses two core concepts in PAR. First, it provides the authority, or sanctions, under which the researchers and host practitioners may specify actions, as well as suitability of PAR to the organisational situation (client or host organization). Secondly, it defines the responsibilities of the client and the researchers to one another, i.e., roles/responsibilities of researchers as experts or facilitators and the client organisational members as participative/collaborative. A key aspect of the infrastructure is the collaborative nature of the undertaking. The researchers work closely with practitioners who are located within the client-system and who provide the subject system knowledge and insight necessary to understand the anomalies being studied. The representative AR process with the infrastructure espoused is given in Figure 2.8. With issues of client-system

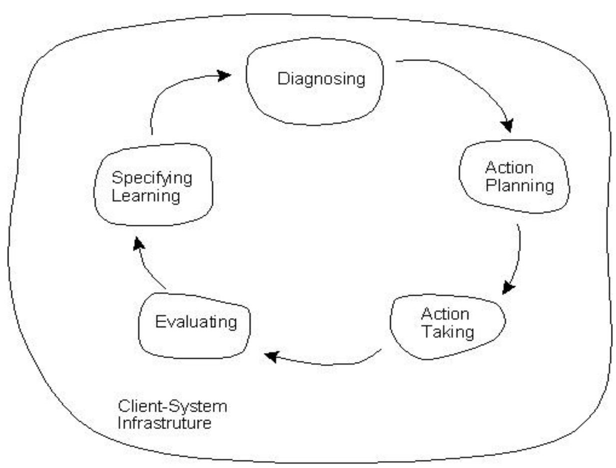


Figure 2.8: The Action Research Cycle(Source: Baskerville, 1999)

infrastructure resolved, the problem is identified and data is collected for a more detailed diagnosis. This is followed by a collective postulation of several possible solutions, from which a single plan of action emerges and is implemented. Data on the results of the intervention are collected and analyzed, and the findings are interpreted in light of how successful the action has been. At this point, the problem is re-assessed and the process begins another cycle. This process continues until the problem is resolved.

Ultimately, the AR cycle when adopted in PAR intervention can be repeated depending outcomes of step 5. It is thus possible to imagine a series of cycles (spiral of cycles), where one issue forms the basis of another and, as one question is addressed, the answer to it generates new questions (Baskerville, 1999; Davison et al., 2004; Scholl, 2004).

2.3.7 Participatory Action Research and System Dynamics

The field of IS is enhrently multi-methodological. As such a wide variety of ontological assumptions and epistemological principles are acceptable, but the norm is to distinguish between positivist and interpretative positions. HE quality management problems have both a strong social/qualitative and quantitative inclination, yet available intervention methods are either qualitative or Mathematical (quantitative). To resolve this conflict, this research adopts both the predominantly qualitative (PAR) and predominantly quantitative (SD) approaches. By using these approaches in an integrated environment, this research concurs with other researchers who acknowledge and advocate for methodological complementarism (Scholl, 2004; Schwaninger, 2006; Rouwette and Hoppenbrouwers, 2008; Tulinayo et al., 2008). More specifically, Schwaninger (2006) has succinctly argued that there is a potential complementarity between different methods, and, one may add methods, models, even if they come from distinct paradigms.

The rest of the analysis is organised under four themes: a) common grounds and differences between SD and PAR; b) limitations of SD and PAR; c) providing the case for the integration; and d) discussing the outcome of the integration.

a) common grounds and differences between SD and PAR

i) Similarities

The similarities given here are largely extracted from Scholl (2004), recogonising the cyclic nature of both PAR and SD research processes as already discussed.

1. Both research approaches start with the statement of a problem, in which the problem is diagnosed or posed and theoretically embedded in a context of existing knowledge.

2. Desired outcomes are formulated following successful problem diagnosis with emphasis on improvement of situation in PAR, and reference modes in SD.

3. While action is planned and taken within an organizational setting in PAR, in the SD cycle a dynamic hypothesis on the basis of a conceptualized feedback structure is developed, and then a model is formulated and tested. Policy formulations and recommendation for action and change complete the SD cycle.

4. The evaluation in the SD cycle pertains to identifying high leverage points in the model, e.g., for changing the dominant feedback loops by redesigning the stock and flow structure, changing the flow and quality of information available at key decision points, or fundamentally reinventing the decision processes. Similarly, the evaluation of AR intervention takes the form of learning through reflection, involving collaborative reflection on outcomes, project success descriptions, and implications for theory and practice.

ii) Differences

Two main differences between SD and PAR can be identified, these include:

- As opposed to the PAR cycle, the action of applying recommended policy changes and, hence, the ultimate test of the SD models utility in practice, are not included in the SD cycle (Scholl, 2004).

- From the basic foundation context, PAR is anchored on subjective epistemology while SD is associated with moderately objective epistemology.

b) Limitations of SD and PAR

i) Limitations of SD

Althogh SD is growing at an impressive exponential rate due to its unique ability to represent the real world and accept the complexity, nonlinearity, and feedback loop structures that are inherent in social and physical systems, the method faces several difficult steps in moving from problem to solution hamper system dynamics. First, and probably most elusive as reported by Forrester (1994), little guidance exists for converting a real-life situation into a simulation model, adding that at later stages, many SD projects have fallen short of their potential because of failure to gain the understanding and support necessary for implementation. He suggests that systems thinking and soft operations research may help organize and guide group processes that must occur when system dynamics interfaces with people in the actual systems.

Checkland (1981, pp. 138) argues that hard systems thinking and soft systems thinking as two quite different ways of undertaking an inquiry using systems principles and further demonstrates that in hard systems thinking of which SD may be appropriately placed, there is a desired state, S_1, and a present state S_0, and alternative ways of getting from S_0 to S_1. 'Problem solving', according to this view consists of defining S_0 and S_1 and selecting the best means of reducing the difference between them. Checkland (1981)concludes that hard methodologies are goal-centred or goal-oriented in that they assume that there is clear agreement among stakeholders over the goal state S_1 and that the current state S_0 is also known. Lane and Oliva (1998) recognise this significant weakness and argue that the use of mathematically based techniques in planning movement from S_0 to S_1 should be augmented with 'soft methodologies' so that the nature of the two states can be investigated.

Apart from the limitations of SD as a method, the phenomenon of SD models on organisational issues having low impact despite passing validity tests has been the hallmark of involvement of practitioners in modelling or group model building - GMB (Rouwette and Hoppenbrouwers, 2008; Rouwette *et al.,* 2002). At the same time, GMB also faces the same challenge, namely, the practitioner commitment to action and change beyond the intervention is sometimes weak (Scholl, 2004). In other words, though the SD researcher may perceive the emerged model as a correct and flawless representation of the "real world" according to accepted external criteria, and even though the practitioners confirm a high degree of learning and insights gained, no change action is taken, and the intervention leads to no further consequences (Scholl, 2004).

i) Limitations of PAR

As with all research methods, AR is not without its valid limitations. The limitations of AR and hence PAR as contained in Rose's (2000) PhD thesis include:

- goal dilemmas between the practical problems at hand and the research endeavour;
- value dilemmas between roles as consultant and researcher, such as clients belief in quick actions (quick wins) versus researchers belief in careful abstract reflection before action;
- difficulties establishing rigour and objectivity according to conventional positivist natural science traditions;
- pre-occupation with organizational problem solving at the expense of transferable theoretical understandings;
- lack of epistemological clarity in theory testing and development.

iii) Complementarity Overcomes Limitations

Even though SD and PAR belong to two different research continnums, they have a strong common denominator. The strength of SD as a theory building approach complements PAR's weakness in theory development. An SD model is a theory of the problem which is specifically represented as a dynamic hypothesis. Goal dilemmas in PAR are overcome in SD as the fundamental aim of SD is solving a specific problem or rather "model a problem, not a system". Whereas both SD and PAR consider problem diagnosis as their first phase, the gap between practical problems and research endeavour arises in PAR and not SD because standard measures of model validation and verification exist in SD methodology to ensure that the problem modelled and model of problem are the same.

In contrast, the limitations of SD can be mitigated by integrating PAR concepts into SD. In particular, the issue of low model impact (no action taken) even when practitioners are involved, can be overcome through increased practitioners' involvement in the modelling process. 'Action' results from practitioners' commitment to act which is preceded by ownership of and involvement in the process (Scholl, 2004). In other words understanding the modelling process by practitioners in regard to their contribution to modelling and benefits from involvement leads to action. This has been found worthwhile in PAR's three practices where practitioners' participation is increased through clearly defining roles and contributions of practitioners and researchers (Cronholm and Goldkuhl, 2004). In this context, this thesis maintains that including insights from PAR into SD could usefully strengthen the modelling process design by addressing issues that increase practitioners' understanding of modelling process and reasons for their involvement as well as their responsibilities, as subsequently discussed.

c) The Case for Integration of SD and PAR

By all measures, the question as to whether SD and PAR can benefit from each other when combined has been meticulously addressed by Scholl (2004). In order to extend this idea, the theoretical basis for this integration and practical benefits are further explored henceforth.

i)Theoretical Basis

Although Eden (1990, p. 91) remarks that "when different methods reflect different 'theories-in-use', it is unlikely that they will sit happily together in practice", SD which is largely positivist has learnt from the interpretivist tradition following limitations in which positivist modellers have built 'objective' models of an organisational issue which remained unused by organisational managers (Schwaninger and Grösser, 2008; GröBler, 2007). In fact, lately bridges are being built between the positivist and the interpretivist paradigms through SD integration with other qualitative methods, e.g, SD and case study (Williams, 2002, 2004), SD and soft systems methodology (Paucar-Caceres and Rodriguez-Ulloawe, 2007), SD and AR (Scholl, 2004), collaborative systems modelling and GMB (Rouwette and Hoppenbrouwers, 2008), and object role modelling and SD (Tulinayo et al., 2008).

Following an analysis of trends in model building designs, Schwaninger and Grösser (2008) envisage the emergence new age modelling for which the roles of modellers and model users converge and models are developed at conversational pace. This is particularly achieved in SyDPAR's "solution refinement cycle" as discussed in chapter 3.

The integration of SD and PAR is meant to usefully extend/improve the participative SD intervention process by emphasising clients contributions to modelling and benefits from modelling involvement. The criterion for success is therefore the extent to which the integrated design provides answers to the following design questions:

- Can the modelling process design effectively balance the goals of fundamental modelling understanding with consideration of usefulness of the resulting models?
- How should participative modelling be rigorously designed?
- How does modelling design influence outcomes?
- What is the significance of inclusion of clients' contributions to- and benefits from- modelling in the actual design?

The answers to these questions can be deduced from the subsequent discussion on model building process versus participant involvement as well as from analysis of SyDPAR effectiveness in chapter 3 (section 3.4).

ii) Model Building Process versus Participant Involvement

The system dynamics modelling process in general involves four to seven phases. Luna-Reyes and Andersen (2003) have made a conceptual summary of these processes across five selected representatives of the classical literature into four iterative phases. These include: 1) problem definition and system conceptualisation, 2) model formulation, 3) model testing, 4) policy formulation and model use. Snabe and GröBler (2006) add that these phases are concordant with participative modelling. However, the rationale in integrating PAR concepts into SD is in extending the SD modelling process to ensure contributions of clients/stakeholders in model development are reflected in the modelling design itself. As such, the methodological details are clearly articulated, making it easier for modellers and participants to represent the external policy environment investigated while contributing to the knowledge base. In addition, the integrated design should ensure that the modelling process outcomes provide benchmarks for which intended learning by participants are evaluated. Since in participative modelling intervention, the modeller serves two different "masters", namely; the solution beneficiaries or clients and the research community as a whole, the integrated modelling architecture should provide a platform for achieving this dual goal.

The phases of model building that are supported by direct client involvement in participative system dynamics modelling have been explicitly discussed by Rouwette (2003). This thesis extends Rouwette's (2003) discussion by proposing that client participation in modelling can be enhanced through detailed modelling architecture/design in which the purpose and benefits of modelling are tied to the phases of modelling process and not as a final outcome of modelling. Doing so facilitates the clients to realisation that the final model may ensue from a number of iterative modules (evolving models) and so does modelling proficiency. This view is supported by Scholl (2004) who, through exploring the benefits of integrating PAR and SD concluded that practitioners or clients can benefit in various ways from SD researchers as peers in the project team, in the sense that: "practitioners would learn from SD researchers how to express aspects of the problem in feedback structures and modelling terms. The SD researchers would be "sounding boards" rather than expert facilitators. As modelling proficiency among practitioners increases, the SD researcher's educator role decreases, and the project progresses towards action planning and action taking. The SD model would not act as an embodiment of an overarching and imposed theoretical framework but naturally evolve with the skills and the insights from action planning and action taking. Rather than being perceived as intended correct representations of the "real-world" problem, the evolving models would likewise play the role of sounding boards with great utility for learning and insight".

Forrester (1994, p.253) notes that defining the problem and conceptualising the system is not only the most critical part of the modelling process, it is also the most difficult one. Indeed failure to define the problem may lead to what Luna-Reyes and Andersen (2003) call the "gap between problem modelled and the model of the problem". While these challenges are arguably overcome in participative modelling (Vennix, 1996; Zagonel, 2002; Luna-Reyes, 2006) on the premise that problem owners in this case clients are involved in modelling, the other issues in managing client groups, e.g., group facilitation skills and attitudes, overlapping client schedules and hence low commitment, may prevent active involvement of clients throughout the modelling process. By espousing the problem articulation cycle and modelling proficiency cycle in the current modelling process design (refer to part d, following), the management of clients is approached through emphasis that both modellers and clients are contributors as well as apprentices, i.e., in the problem articulation cycle, clients are mainly contributors while modellers are more of apprentices, yet the reverse is depicted in the modelling proficiency cycle.

d) Outcome of the Integration: SyDPAR

The SyDPAR approach is a modelling process design resulting from the integration SD and PAR. The case for this integration was the need for a comprehensive participative modelling design where activities and outcomes of each phase reflect purpose and benefits of both modellers and clients/participants involved in participative modelling. The six phases of SyDPAR design comprise of a new phase called action planning, derived from PAR process against which the emphasis of clients' contribution in participative modelling is articulated. The interplay of the six phases during modelling results into three cycles namely; problem articulation (PA) cycle, modelling proficiency (MP) cycle, and solution refinement (SR) cycle, all of which address the diversity and legitimacy of contributions by all parties involved in modelling.

The design of modelling as a series of iterative steps with process outcomes arising from cycles of 'PA', 'MP', and 'SR' as opposed to the prevalent designs in which modelling evolves as a series of iterative steps (Richardson and Pugh, 1981; Sterman, 2000; Zagonel, 2002; Luna-Reyes and Andersen, 2003) is necessary since the former affirmatively shows that roles of clients and modellers vary as modelling progresses from one cycle to another. In practice, modellers maintain the role of facilitators throughout these cycles except for "PA" cycle where they double as apprentices of the problem situation. On the other hand, client roles and reasons for client involvement in a modelling project are more or less the same. The three reasons for client involvement, i.e., identification of the problem, providers of information, and implementers of modelling results, are catered for in the "PA" and "SR" cycles. A fourth and probably only reason that caters for client's individual benefit from modelling participation is addressed in the "MP" cycle for which clients are perceived as apprentices of model development under guidance of modellers.

2.4 The State-of-Practice of Higher Education Quality Management Tools

The use of DSS in academic decision-making date as far back as the 1960's (Levine, 1968). This section focuses on the recent ones (2000 to 2009) as reviewed from the literature. Table 2.1 gives a summary analysis of existing decision support systems/tools, their development approach and focus in this time frame.

With reference to the focus of this thesis as delineated by quality and enrolment management, and following from Table 2.1, three DSS, namely UNIGAME, QMS2000, and QMT09 are further elaborated.

Name of DSS or Model	Author(s)	Methodology/ technology	Area of application
UNIGAME	Barlas & Diker, 2000	SD modelling	Strategic management
PADSS	Deniz and Ersan, 2001	Data mining	Performance assessment
QMS2000	Welsh and Dey, 2002	Data warehousing	Quality management
DEWAS	Deniz, Uyguroglu & Yavuz, 2002	Database	Departmental workload administration
UNICAP	Vinnik and Scholl, 2005	Data warehousing	Resource and capacity management
	Ho et al., 2007	Integrated AHP and Goal programming	Resource allocation
	Maltz et al., 2007	Data mining	Enrollment management
QMT09	Oyo et al., forthcoming	SyDPAR	Funding, quality, and enrollment management
UNIGAME - University Simulation Game, UNICAP - University Capacity Planning QMS2000 - Quality Management System 2000, QMT09 - Quality Management Tool 2009 PADSS - Performance-based Academic Decision-Support System DEWAS - Departmental Workload Administration System			

Table 2.1: Decision support systems/models for quality issues in higher education

2.4.1 UNIGAME

UNIGAME, is a dynamic simulation game or model for strategic University management that was developed by Barlas and Diker (2000). This model focuses specifically on long-term, dynamic and strategic management problems, such as growing student-faculty ratios, poor teaching quality and low research productivity. It yields numerous performance measures about the fundamental activities in a university: teaching, research and professional project activities. The simulation model is built using system dynamics methodology and validated/verified by standard tests, using data from Bogazici University, Istanbul, Turkey. The gaming interface is built using VENSIM software. Accordingly, Barlas and Diker (2000) claim that the research results obtained by using UNIGAME promises not only a useful technology to support strategic decision making, but also a laboratory for theoretical research on how to best deal with strategic university management problem. They proposed the diagram in Figure 2.9, as the global sector diagram upon which UNIGAME was developed.

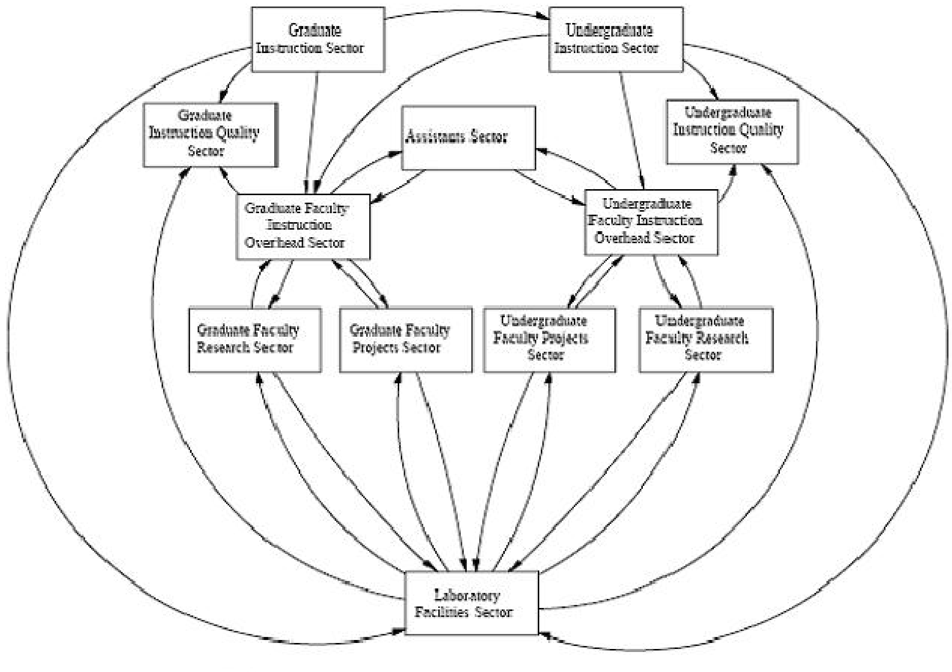


Figure 2.9: Global sector diagram for UNIGAME (Barlas and Diker, 2000)

The twelve sectors in Figure 2.9 reflect three interrelated areas, namely: graduate instructions and research, undergraduate instruction, and resources. A core sector that should have been explicitly addressed is funding, which is rather subsumed in three identified areas, hence casting doubt on the granularity and scope of UNIGAME with regard to strategic university management. Nevertheless, UNIGAME provides an important foundation when building SD models for HE management issues. In particular, the insights from UNIGAME: causality, stocks and flows, contributed to 'theoretical' structure validation for the QMT09 model developed in this research.

2.4.2 Quality Measurement System (QMS2000)

QMS2000 was developed by the University of Louisville in partnership with Dey Systems, a Louisville technology company using data warehousing technology. QMS2000 is a relational, interactive information system that includes data from students, alumni, faculty, staff, and employer satisfaction surveys that are linked to corresponding databases at the university. QMS2000 is on-line, operating in a networked; client-server environment that permits licensed users access to designated components of the system at any time from designated desktops at the university. The data and reports for QMS2000 are integrated into accreditation, strategic planning, budgeting, outcomes assessment and program review processes at the university. Figure 2.10 shows the quality framework against which QMS2000 was developed.

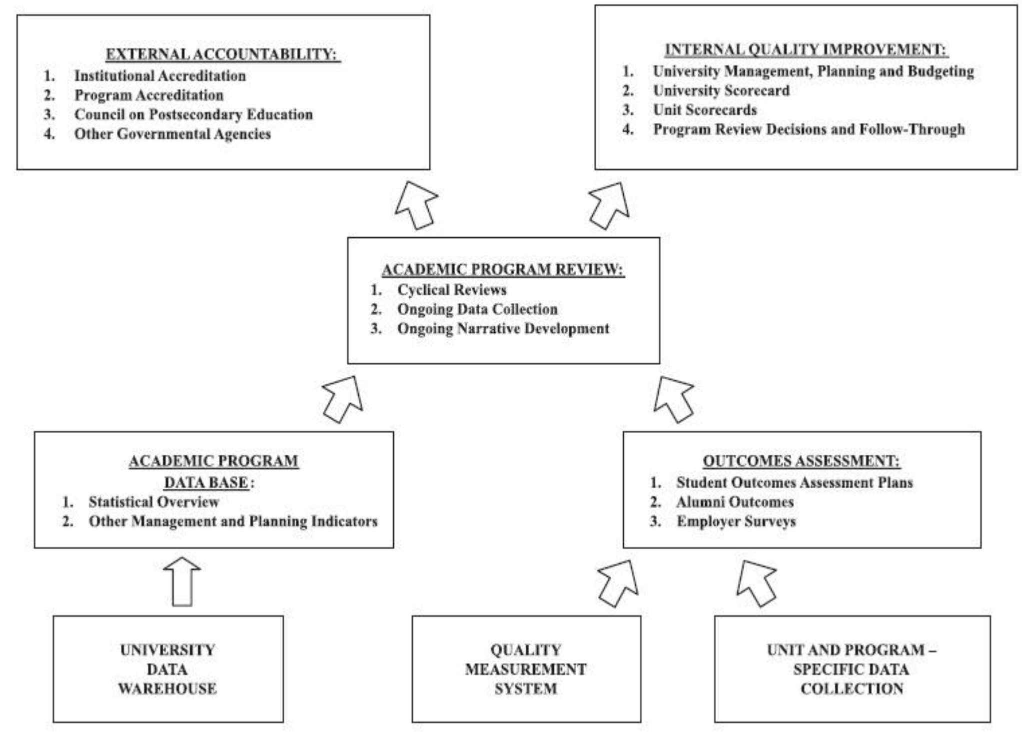


Figure 2.10: Quality assurance framework at the University of Louisville (Welsh and Dey, 2002)

2.5 Critique of Causes of Problems in HE Quality Management

The general causes of HE quality problems as highlighted in chapter 1 include:

1. The complexity of quality problems due to a large number of influencing factors transcending the qualitative to quantitative landscape. These problems are therefore difficult to address in totality using one method.

2. The dynamics of quality issues. This arises due to the nature of quality problems, i.e., the problems do not have an exhaustively describable set of potential solutions. This is because a potential solution reveals new information about the problem, requiring a new solution and hence a continuous process of problem conceptualisation. In this context, Huitema *et al.* (2002) use the term, “external dynamics” in higher education quality to explain the scenario

whereby, tackling one problem (e.g., increasing students' capacity) exposes another (e.g. teaching quality).

3. Complexity of feedbacks in quality issues leading to adoption of methods that delineate a set of quality problems facets as more worthy of attention than others rather than all conceivable facets of quality problems.

4. The diverse perceptions of quality problems by different stakeholders leading to claims that render research on quality less attractive such as "quality is difficult to measure" (Parker, 2002; Srikanthan and Dalrymple, 2007); good policies on quality are based on personal knowledge rather than simulation experiments (Grandzol, 2005; Barnab´e, 2004).

In light of these causes, the use of multiple feedbacks is inevitable when addressing HE problems. This way, the aim of feedbacks is depicted by two fundamental outputs: a representative problem structure and a conceptual framework showing all the conceivable influencing factors as feedback loops. Such a representation takes care of the qualitative and quantitative facets of quality simultaneously, demystifying the notion that a set of quality problems facets as more worthy of attention than others.

2.6 Conclusion

The primary strength of this review is the comprehensive, yet focused, literature search as demonstrated by the five dimensions covered. First, trends in quality management research including perceptions of quality and existing excellence models were meticulously discussed. Secondly, the HE quality management frameworks were explored, delineating gaps that should be addressed. Third, the current approaches for quality management were discussed, highlighting the need to extension through integration of SD and PAR. Fourth, the technologies used in developing quality management DSS were highlighted and lastly a critique of causes of problems in HE quality management was made as basis for the proposed methodology in the next chapter.

Chapter 3

Methodology

3.1 Introduction

This chapter presents the research approach adopted. First, the philosophical and theoretical foundations are discussed, and then, the current approaches/methods for HE quality management are compared using a matrix developed from Design Science Framework. Following this comparison, methodological gaps are delineated and a method is proposed and discussed. Subsequently, a field study design is presented. Finally, the chapter ends with a conclusion.

3.2 Philosophical and Theoretical Foundations

3.2.1 Philosophical Underpinnings

A critical consideration of any research is the underlying assumptions guiding its research design. These assumptions provide a coherent philosophical and methodological system for the conduct of scientific research including a commensurate theory of validation (Chen and Hirschheim, 2004). The most pertinent philosophical assumptions are those that relate to paradigms. A paradigm may be regarded as a set of basic philosophical assumptions about the nature of the world (ontology), how we can understand it (epistemology), and how we can improve our understanding of the world (methodology). A paradigm therefore represents shared philosophical understandings, terminology, rules and research approaches adopted by a particular community that continuously evolve as they are negotiated and debated within the communities (Morgan, 2007).

Orlikowski and Baroudi (1991) suggest three underlying paradigms: positivist, interpretive, and critical thinking as guiding Information Systems (IS) research.

- Positivist investigations seek to explain and predict by looking for regularities and causal relationships between variables. They are primarily concerned with formulation of hypotheses, not how a phenomenon occurred, and are often associated with quantitative analysis for testing the hypotheses. IS research methodology is dominated by this stance. Laboratory experiments, numerical methods or mathematical modelling, and survey methods are examples of positivist methods.

- Interpretivist studies seek a deeper understanding of phenomena within its context, which may be used to inform other contexts. They acknowledge multiple interpretations of the world and the inevitable influence of the researcher. This view has been relatively espoused in IS research, see, Myers and Avison (2002), Nandhakumar and Avison (1999).

- Critical thinking approaches are interventions orientated and associated with participant and action research, with clear objectives to change practice and make social critique. Critical thinking researchers assume that social reality is intrinsically constituted and that it is produced and reproduced by people. The emancipatory action research is a representative critical thinking method.

One of the realities in studying HE quality systems resides in the fact that they are characterised by both hard and soft issues. As such the positivist and/or interpretive perspectives may not be as much informative as the combination of these perspectives. For this reason, this research is informed by the systems paradigm, which has specifically been used when dealing with hard and soft research issues. When dealing with problems in a complex organisational world such as HE quality, mathematical methods that operate at a high level of abstraction may not be entirely useful, since these models are forced to analyse a narrow slice of reality, as that is the only way to construct a model suitable for mathematical analysis. In contrast, the foundations of the system paradigm is to grasp reality in so far as possible, not just a thin slice of it. The systems paradigm is largely concerned with the whole picture, the emergent properties and other relationships between parts of the whole (Lane and Oliva, 1998). The earliest adoption of the systems perspective resulted from the realisation that scientific methodologies sometimes failed because they did not take into account the interactions which take place when a problem involves multiple stakeholders with independent views of the system.

There are two main ways of viewing a system, the soft systems approach and hard systems approach. Hard systems approaches involve computer simulations, e.g., system dynamics, and the techniques used in operations research. Hard systems look at the "how?" meaning, how to best achieve and test the selected option of development and analysis. Hard systems approaches are useful for problems that can justifiably be quantified. However, they cannot easily take into account unquantifiable variables (opinions, culture, politics, etc) for which soft systems approaches are applicable. Furthermore, Checkland (1981) maintains that problem solving may involve choosing alternative ways to move a present state S_0 to a desired state, S_1. The hard systems thinking perspective involves defining S_0 and S_1 and selecting the best means of reducing the difference between them. However, as the complexity of the problem solved increases, the certainty with which these states are defined diminishes.

From a synthesis of discussions on the systems philosophical perspectives by Checkland (1981), Ackoff (1999), and Lane and Oliva (1998), this research deduced that the development of a decision support tool for quality management in an action oriented environment of higher education could not be done without engaging HE management with the needed domain knowledge or mental models. The research therefore adopted the SD philosophy of modelling with clients or simply group model building (GMB) which addresses problems involving multiple stakeholders with independent views of the system, where there is strong inter-personal disagreement in the client group regarding the problem and/or regarding policies that govern system behaviour (Vennix, 1999; Zagonel, 2002).

System Dynamics is yet another lens of conducting multi-disciplinary research involving both 'hard' and 'soft' systems in complex environments. It has been used to perform research into IS, organisational, and social phenomena (Forrester, 1961; Luna-Reyes and Anderson, 2003; Warren, 2004; Rouwette and Vennix, 2006). Such wide scope is possible because SD though mainly quantitative, traverses the qualitative approach.

In advancing the SD paradigm debate, Meadows (1989) asserts that "the SD paradigm assumes that the world is composed of closed, feedback-dominated, non-linear, time delayed systems and thus the method must be most applicable to systems that do indeed possess these characteristics. In general, such systems will be characterized by distinctive dynamic patterns, long time horizons, and broad interdisciplinary boundaries". In other words, certain ontological and epistemological principles underpin formal modelling leading to realistic representation and simulation of the system.

Ontological Principles

The basic ontological assumptions of SD is found in Meadows (1989): "that things are interconnected in complex patterns, that the world is made up of rates, levels and feedback loops, that information flows are intrinsically different from physical flows, that nonlinearities and delays are important elements in systems, (and) that behaviour arises out of system structure". In an earlier proposition, Forrester (1961, p.60) argues that, "all constants and variables of a system dynamics model can and should be counterparts of corresponding quantities and concepts in the actual system". Other ontological propositions such as: system dynamics modelling as representation of reality versus modelling as a tool for negotiating a social order (Zagonel, 2002), support the adoption of more moderate views, namely that systems, stocks, flows, and so on, may sometimes really exist, and may sometimes be interesting devises to structure, describe and make sense of perceptions of complex real-world issues in the world around us.

Considering that SD models are rational structures that generate a formal behaviour which must fit the empirical behaviour of the system being modeled, for a model to be accepted as valid, in the first place, it is necessary that the hypotheses used to build the model should be compatible with available scientific or heuristic knowledge. Secondly, these hypotheses should be captured adequately with the representational tools of SD language, and all this information must be processed properly to obtain conclusions that will fit the empirical behaviour. These propositions have direct epistemological equivalences. This is the subject of next discussion.

Epistemological Principles

SD inquiry stems from an epistemology that is built around the centrality of mental models as cognitive schemes or structures (Forrester, 1970). Due to the 'bounded rationality' concept, i.e., limitations in memory and cognitive skills when humans attempt to infer the dynamics of mental models involving feedback, humans fail to work out the consequences of their assumptions in a complete and logical way. In consequence, decisions that are made daily are incomplete ‘mental simulation’ of very complex ideas about social systems (Lane and Oliva, 1998). Indeed, as Forrester (1970, p. 213) puts it, “the human mind is not adapted to sensing correctly the consequences of a mental model”. However, such dilemma can be resolved by using a modelling framework that coincides with that of the real system such that there can be a natural flow of real-world information into the model. As such, the level-rate-feedback structure in system dynamics is indeed the fundamental and universal structure of real social and physical systems (Forrester, 1994).

Vázquez, Liz, and Aracil (1996) suggest three main kinds of knowledge involved in SD model building:

- Structural knowledge: this sometimes comes from the available theoretical knowledge, and is expressed with the help of scientific concepts. The only source of structural knowledge is the mental models which subjects/experts have about the system to be modelled. Hence, structural knowledge is expressed only in intuitive terms and in ordinary language (Forrester, 1998).

- Quantitative knowledge: this is reflected in reference modes, temporal series, empirical behaviours as well as knowledge concerning the initial conditions in which the real system is placed. In other words, the empirical knowledge that is available with regard to the variations of the relevant magnitudes of the system over time and the particular values of these magnitudes in a given situation.

- Operational knowledge: the specific SD skills and practical knowledge that the modeller uses when integrating the other two kinds of knowledge in order to represent the SD model. The SD model simulates the dynamic behaviour of the modelled system and assumes that it contains a certain structure. It is intended that the SD model will be able to guide policy actions of the real system.

Vázquez et al. (1996) claim that it is essential to have these three kinds of knowledge coherently included in the SD models, since, while empirical behaviours give the quantitative data and anchor in reality, mental models give information which is not so much quantitative but structural. Therefore, mental models can be said to be strongly interactive and to have a very rich and relevant representational content regarding the system structure.

3.2.2 Theoretical Underpinning

A theory is a coherent descriptive structure and explanation of observed or experienced phenomena (Lane, 1999). It is a structured, explanatory, abstract and coherent set of interconnected statements about a reality (Schwaninger and Grösser, 2008). The purpose of theory in applied disciplines is therefore to explain the meaning, nature and challenges of a phenomenon, often experienced but not explained in the world in which we live so that we may use that knowledge and understanding to act in more informed and effective ways (Lynham, 2002).

Lane (1999) suggests using different theories and concepts that relate to the specific problem to be solved. In the same line, Robey (1996) argues *...theoretical foundations for research and specific research methods are justified by research aims or purposes. They should not be chosen because they conform to a dominant paradigm or because the researcher believes in their intrinsic values. Rather, theories and methods are justified on pragmatic grounds as appropriate tools for accomplishing research aims.*

Given the dual goal and multi-disciplinary nature of this research as highlighted in chapter 1, no single theoretical foundation would be suitable, yet at the same time it would be absurd to claim that the research is not informed by any theory. Hence, two theories were arguably found relevant: a technology driven theory for guiding SD model building and validation (critical rationalist theory of science), and organizational decision choice theory for guiding decision making on HE quality issues (Garbage Can Model of Organizational Choice). Whereas the complementarity of these theories have not been researched, they soundly underlie the two sides of the current research.

Critical Rationalist Theory of Science

SD modelling is often colloquially referred to as 'theory building' approach (Schwaninger and Grösser, 2008; Kopainsky and Luna-Reyes, 2008). The knowledge of SD model building in this research is underpinned by the critical rationalist theory of science (Popper, 2002). According to this theory, a hypothesis is tested and if falsified, then it is refuted. If, however, the attempt of falsification is not successful, then it can be temporarily maintained. The critical rationalist stance adopted is consistent with Schwaninger and Grösser (2008, p.450) proposition that "theory building in the human and social sciences is not primarily meant to be an exercise of underpinning hypothesis, nor anything like ‘proving’ their truth. It is a process by which assumptions and systems of hypotheses, are specified, and then are submitted to tests. These tests are essentially endeavours of falsification”.

SD simulation models generally embody propositions that are empirically testable. These include underlying mathematical equations, formal structures and behavioural assumptions. These tests enable researchers to check how well their assumptions match available data about the overall system behaviour (Lakatos, 1974). In the spirit of the critical rationalist theory of science, model calibration and model validation tests are reported in section 5.5 and section 5.6 respectively.

Garbage Can Model of Organisational Choice

The Garbage Can Model of Organisational Choice (GCM) is a description of an organisational decision process involving: participants, choice opportunities, solutions and problems. The organization is seen as a container where the members involved in the decision process interact to generate decisions. Within the broadly defined field of organization theory Fioretti and Lomi (2008) maintain that the best example of thinking about organisational decision processes is represented by the GCM as originally proposed in 1972 .

According to the theory, garbage can-like decision situations are induced by the simultaneous presence of three factors. The first factor is problematic preferences, a term that Cohen, March and Olsen (1972) introduced to capture the general tendency of decision-makers to discover their preferences through action rather than acting on the basis of pre-defined and unchanging preferences. Second, unclear technology: organisation processes are not understood by its members, operates on the basis of simple trial-and-error procedures, and learns from the accidents of past experience. Third, fluid participation: participants vary in the amount of time and effort they devote to different domains; involvement varies from one time to another. As a result, the boundaries of the organisation are uncertain and changing; the audiences and decision makers for any particular kind of choice change capriciously.

Cohen et al. (1972) define an organisation as a collection of choices looking for problems, issues and feelings looking for decision situations in which they might be aired, solutions looking for issues to which they might be the answer, and decision-makers looking for work. To understand processes within organisations, one can view a choice opportunity as a garbage can into which various kinds of problems and solutions are dumped by participants as they are generated. The mix of garbage in a single can depends on the mix of cans available, on the labels attached to the alternative cans, on what garbage is currently being produced, and on the speed with which garbage is collected and removed from the scene.

Garbage Can-like Decision Processes in HE

The relevance of the GCM is demonstrated by the considerable research that it has inspired, a large section of which falls under higher education organisations. In the seminal work, Cohen et al. (1972) emphasize that one class of organisation which faces decision situations involving unclear goals, unclear technology, and fluid participants is the modern college or university. A decision in GCM is the result of several relatively independent streams within an organisation, namely: problems, solutions, participants, and choice opportunities. In other studies, through Martin's (1980, as cited by Fioretti and Lomi, 2008) work on psychological research process, the GCM became influential in psychology.

The existing work under the GCM umbrella is supported by the basic idea that GCM does enable choices to be made and problems resolved, even when the organisation is plagued with goal ambiguity and conflict, with poorly understood problems that wander in and out of the system, with a variable environment, and with decision makers who may have other things on their mind (Fioretti and Lomi, 2008; Cohen et al., 1972). Therefore, management choices, e.g., quality improvement policies, implemented as a result of computer simulations may be justified provided organisational structures associated with such simulations represent a real HE system. Most importantly, involving practitioners in building decision support models leads to consensus over decision policies arising (Rouwette and Venix, 2006; Rouwette et al., 2002; Zagonel, 2002). This seems to be the point of convergence between GCM and participative SD modelling's underlying principles.

Within organisation theory the garbage can model represents a pioneering attempt to view organisations as decentralised systems with a relatively complicated interplay in generation of problems, engagement of personnel in the production of solutions, and the resulting opportunities for choice. The modelling and simulation process presented in this thesis implies - for example - that the participants involved in modelling contibute to - and benefit - from modelling at varying degrees. This is particularly visible as modelling proceeds from problem identification cycle to modelling proficiency. In this respect, the design of the modelling process and the resulting model itself are fully consistent with the spirit of the GCM.

3.3 Evaluation of the Current Methods

A method according to March and Smith (1995) is a set of steps or guidelines used to perfom a task. HE quality management encompasses a very large number of decisions in the areas of: students' entry qualifications, teaching quality, staff quality, staff retention, students' projects supervision and assessments, curriculum reviews, resource allocation, policy execution, and funding and budgeting, to consider the major ones. A combination of these presents a complex challenge that may not be resolved by one method. In fact, previous methods (refer to chapter 2, section 2.3) have generally been successful in addressing a narrow scope of quality management challenges. The evaluation of current methods therefore constitutes an important part of this chapter.

Evaluation of methods according to March and Smith (1995) concerns "operationality (the ability to perform the intended task), efficiency, generality and ease of use". In light of this, the design science framework which emphasises rigour and relevance of interventions (March and Smith, 1995; Hevner *et al.,* 2004) is adopted in this research for evaluating the effectiveness of existing methods in addressing HE quality management problems.

The Design Science Framework

Hevner *et al.* (2004) present their information systems research framework: the design science framework, for addressing novel organisational problems. In this framework, IS research is influenced by the "Environment of use" (people, organizations, and technology), as well as by a "Knowledge Base of theoretical components" consisting of "Foundations" and "Methodologies". To build IS relevant to an environment, applicable knowledge from the Knowledge Base must be applied in the building of artifacts that are part of the IS. These artifacts, put to use, must then be evaluated according to the utility criterion of how well they meet the business needs of the users. If the intervention has proven to be successful, the knowledge that a particular foundational/methodological component was useful in the design of an artifact in a particular context can be added to the knowledge base. In the view of Hevner *et al.* (2004), by focussing on the relations between behavioral and design processes as informed by both the environment and the knowledge base, the design science framework can help researchers develop new representations of IS problems, solutions, and solution processes. This research therefore finds Hevner *et al.*'s

(2004) framework suitable for evaluation of current methods for HE quality management partticularly because it provides checks and balances on how knowledge is generated, used, tested, and modified in the course of IS research project. This is possible by focussing on the central theme in the research process, including: artefact development, evaluation techniques, methodology (data analysis and validation), technology, roles and characteristics of people, and organisational structure and processes.

Application of Design Science Framework in Evaluating the Current Methods

Inspired by the previous discussion of the design science framework, seven methods are compared using the design research strategy as given in Table 3.1.

Research Strategy		Data Mining	PAR	SD	BSC	GP	HLM	AHP
Build/ Develop	Theories	√	√	√				
	Artefact			√		√		√
Justify/ Evaluate	Analytical	√	√				√	
	Case study	√	√	√	√	√	√	√
	Experimental			√				
	Field study	√	√		√			√
	Simulation	√		√				
Methodology	Data analysis	√		√			√	√
	Measures	√		√	√	√		
	Validation criteria	√		√	√	√		√
Technology	Infrastructure							
	Applications			√				
	Development capabilities	√		√	√	√		√
People	Roles		√					
	Capabilities		√		√			
	Characteristics		√		√			
Organisation	Strategies	√	√	√	√			
	Processes	√	√	√	√			√
	Structure and culture		√	√	√			√

Table 3.1: Comparison of the Quality Management Approaches using Design Science Framework

Subjective analysis of the comparison in Table 3.1 shows that the SD approach has greater potential in the context of design science in addressing HE quality problems over other approaches in the literature. Integration of PAR and SD would even increase SD's potential in the areas of field studies and involvement of people in modelling. This integration therefore is further explored and presented in the subsequent section.

3.4 Proposed Methodology

The proposed methodology is a combination of SD and PAR resulting into SyDPAR. Since the theoretical case for the integration of SD and PAR has already been discussed (see section 2.3.7), this section proceeds to present the SyDPAR architecture.

3.4.1 The SyDPAR Modelling Architecture

The process of building system dynamics models ranges from linear iterative phases to the circular phases. However, while all these process designs are well known and explicit to system dynamics modellers, they are not comprehensive for participative SD modelling involving clients/practitioners without prior modelling knowledge. While the six phases of SyDPAR's architecture are comparable with those of the prevalent SD literature except for the action planning phase, the difference this phase makes by emphasising clients' contributions and benefits from modelling involvement is indisputably significant and useful. In this respect, the interplay of SyDPAR's six phases during modelling results into three cycles namely; problem articulation cycle, modelling proficiency cycle, and solution refinement cycle, all of which address the diversity and legitimacy of contributions by both modellers and clients.

The SyDPAR's architecture is underpinned by the following characteristics:

- Explicit outcome(s) for every phase
- Evaluation at every phase as basis for advancement to the next phase
- Explicit cycles/loops during modelling. The dynamics of mandatory and optional steps during modelling results into these loops.
- Differential roles of the team are tied both to every phase and to the individual member of the team such that control over the team and respective stages is concurrent
- Modelling exercise ends with implementation of recommended policies

Therefore, prior to modelling intervention, the team comprising of modellers and practitioners/participants must clearly understand the modelling process. In other words, the modeller's prime task as a facilitator and process coach is to ensure that the modelling process is not only followed during the intervention, but understood by the team right from the start. This task is simplified by SyDPAR's architecture in Figure 3.1.

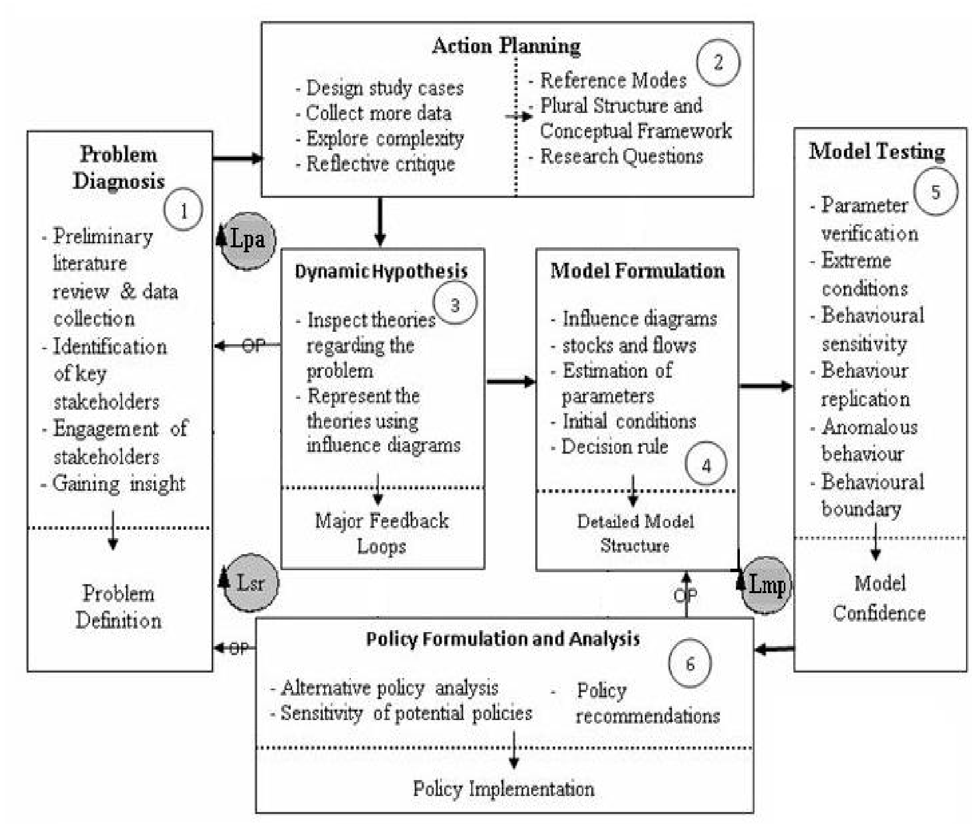


Figure 3.1: The Conceptual SyDPAR's Modelling Architecture

Arrows within each phase, depict the relationship between the activities and the expected outcome of that phase. Arrows labelled "op" imply optional dependency, i.e., a fall back to a previous phase for improvement of outcomes in the phase(s) concerned. The "op" arrows as shown in Figure 3.1, are used to complete three cycles: the first is "problem articulation cycle"- involving phases 1-3 and labelled $\mathrm{L}pa$, the second is the "modelling proficiency cycle"- corresponding with phases 4-6 and labelled $\mathrm{L}mp$, and last is "solution refinement cycle"- that connects phases 6-1 and labelled $\mathrm{L}sr$, resulting into a new modelling cycle. The stepwise details of Figure 3.1 are discussed next.

Step one: problem diagnosis

In this phase, the researcher must become aware of the real-world problem, one that provides scope for the elucidation of research themes or ideas. Underpinning this initial identification the researcher endeavours to find out more about the nature of the problem and the problem context, who the problem owners are, key stakeholders in the problem solving process, historical, cultural, and political components of relevance, and so on. In collaboration with the stakeholders, the problem is defined, setting the research process to the next phase. Most importantly in this phase, the stakeholder's perception of what constitutes the problem as well as the causes of the problem is asserted.

GOAL: ensure that problem is defined more accurately and thoroughly bearing in mind that a problem well stated is more or less a problem half solved. In addition, phase one explicitly connects to the second phase since the setting of research objectives and framing the intervention in phase two cannot be done independent of problem formulation.

Step two: action planning

In this phase, the research team develops a problem solving strategy after designing study cases, collecting more data, and exploring problem complexity. The outcomes from this stage are reference modes, research questions and detailed documentation of research process (or system description) also known as "plural structure", and the conceptual framework. In developing/refining research objectives, consensus is sought on the basis of all parties (modellers and participants) accepting the legitimacy of the other's contributions. Only then will the action planned or rather specific objectives of the intervention encompass both the modelling exercise and how competency levels of participants in dealing with their practical problems should be addressed.

GOAL: develop a detailed system/model boundary. Specify criteria for evaluating results of modelling exercise including benefits or changes in mental models of participants involved.

Step three: dynamic hypothesis

This phase together with the first two phases constitute the problem articulation cycle: for example, identification of problem stakeholders and problem definition in step one, leads to the design of study cases, eliciting of reference modes, and the model conceptual framework in step two, which underpins the development of dynamic hypothesis in step three. Depending on the nature of the problem, rather than move to step four from step three, a fall back to step one, hence the problem articulation cycle, may be preferred until consensus is reached on the problem to solve. The messier the problem, the higher the iterations of problem articulation cycle. The keyword "articulation" is aptly used to imply that: a complete diagnosed problem relies on stakeholder-provided data on the problem (reference modes) and the research team's ability to represent the problem structurally (dynamic hypothesis).

GOAL: show the sections of the system's structure or major feedback loops that are responsible for dynamic behaviour of the whole system.

Step four: model formulation

The insights from step three and step two are used in model formulation in this phase. The outcome

of this phase therefore, is a detailed model structure. The model structure comprises of influence diagrams that capture relationships between different elements of the system, and stocks and flows diagram for quantitative representation of these relationships. The actual model building is accomplished in this phase and hence stakeholders' contributions are minimal but their involvement is relevant, and must be considered a priori (cf., second step). In order to reconcile scepticism regarding capacity of rational reasoning and learning in human beings when dealing with complex systems (Sterman, 2002) with claims that model building concepts can be easily grasped by stakeholders without prior related skills (Luna-Reyes *et al.*, 2006), "modelling proficiency cycle" is envisaged. In this case, a module that is easier to follow by un-experienced stakeholders is built, tested and simulated in the first iteration, then a larger model is developed in the second iteration, and process repeated until the final model is built.
GOAL: detailed model is built and adopted by the modelling team. It is certainly crucial that communication between the researcher(s) and the stakeholders is maximised so that stakeholders maintain a good momentum to sail through the last stages of modelling.

Step five: model testing

Model testing does not require technical knowledge of SD provided the stakeholders are encouraged to learn new but simple validation concepts. Both model structure and model behaviour tests are done in this stage in comparison with reference modes in stage 2. Success in testing of the model creates confidence in the model.
GOAL: analyse simulation results against reference data as basis of gaining confidence in the model built.

Step six: policy formulation and analysis

Phase 6 requires more emphasis by stakeholders especially those at the forefront of policy implementation. Although the researcher monitors policy analysis stage, actual policy changes in real life are effected by the stakeholders. If satisfactory outcomes are realised in this stage then the modelling process is considered successful otherwise, the research team refocus on the problem, amend the action plan and make additional changes to the problem context in a new modelling cycle also referred to as solution refinement cycle.
GOAL: policy implementation including a continuous evaluation of whether the need for further policy changes is still existent.

3.5 Field Studies

This research follows a participative modelling design. Performing a field study in such a design defeats the very foundation of participative modelling for which clients/participants provide data and information needed for model building. The field studies were nevertheless necessary particularly in generating data for facilitating better understanding of the problem which culminated in a preliminary model. The preliminary model was then refined into the final model also referred to as 'QMT09' through a series of iterations of participative engagement with HE management stakeholders .

3.5.1 Stakeholders

The history of HEIs from their traditional perception as "ivory towers", namely elite institutions characterised by complete and undisputed intellectual and behavioural autonomy, to the current perception as customer-oriented and revenue-seeking enterprises, has created a range of stakeholders. The broad HE stakeholders therefore include: academics, government, labour market, alumini, students, parents, and accreditation agencies. In the context of this research, three stakeholders categories are considered:

a) Senior academic staff from two oldest Ugandan public and two oldest private universities as experts on HE quality problematic issues

b) Selected senior academic/management staff of Makerere University as participants in model building

c) Quality Assurance departments of Makarere University and the Inter-University Council for East Africa as users of QMT09

3.5.2 Data Collection

Stakeholders or clients are involved in participative modelling for three main reasons: as identifiers of problem of interest, as sources of information required in the modelling effort, and as implementers of modelling results. Although the involvement of stakeholders in itself guarantees provision of the required data, the development of the preliminary model as basis for participative engagement would not be possible without having a better understanding of quality problems. For this reason, the second research question (what factors influence HE quality and how are there related?) was formulated. In order to answer this question, interviews with senior academic and management staff from four Ugandan universities were conducted in December 2006. Due to scarcity of certain required data which in some cases was incomplete or invalid, another set of data was collected in the latter stages of modelling, in which the questionnaire survey of academic staff in the same universities was conducted in the period of December 2007 to Feburuary 2008, to delineate the percieved research and publications influence on quality. The subsequent discussions therefore focus on these two data collection aspects.

Interviews

While the quality influencing factors may differ in context of developing and developed world, they are reasonably consistent in their effects on quality. In order to focus on a specific context, the wealth of knowledge in the minds of HE stakeholders must be tapped. For this reason, twenty two in-depth interviews with academic department heads and non-academic/administrative units' heads from four leading Ugandan universities, were conducted. The institutions included: Makerere University (Mak), Uganda Martyrs University (UMU), Uganda Christian University (UCU) and Mbarara University of Science and Technology (MUST). The interview distribution is given in Table 3.2.

<table>
<tr><th colspan="4">Data categories and institutions</th></tr>
<tr><th>Target group</th><th>University</th><th>Number interviewd</th><th>Purpose</th></tr>
<tr><td rowspan="4">Departmental heads (academic& administrative)</td><td>(UMU)</td><td>5</td><td rowspan="4">To elicit the quality management challenges through interactive discussions</td></tr>
<tr><td>(UCU)</td><td>5</td></tr>
<tr><td>(Mak)</td><td>7</td></tr>
<tr><td>(MUST)</td><td>5</td></tr>
</table>

Table 3.2: Interview distribution: purpose and target universities

Twenty two interviews were distributed in terms of three academics and two administrative units (Academic registrar and planning department) for every university except Makerere University which had an additional two administrative units that directly interface with quality concerns (quality assurance directorate and graduate school). Furthermore, the three academics interviewed in each of the universities corresponded with faculties/departments of science, business and education as these academic units exist in all the target universities.

Questionnaire Survey

The questionnaire survey was conducted during the last modelling sessions when it emerged that research information (trends in grants, publications, and graduate training throughput) was either unavailable or incomplete.

Selection of academic units for the study

In establishing the sample space, initial insight from the interviews showed that all the four universities have equivalent faculties or academic units in science, business and education. Therefore, only these three categories of faculties were considered in the survey. The resulting distribution is given in Table 3.3.

Institution	Total units/faculties established	Units Surveyed	Population	Survey Response	% Response
MUST	5	3	61	57	93%
UCU	6	3	56	46	82%
UMU	5	3	51	44	86%
Mak	19	3	93	69	74%

Table 3.3: Survey distribution: sample size and percentage response

According to Krejcie and Morgan's (1970) table for determining samples sizes for finite population (refer to appendix D), the percentage responses in Table 3.3 are justified.

3.6 Conclusion

The need for client centred participative modelling design is core to this research. This has been addressed by the SyDPAR solution process presented in this chapter. A field study design has also been presented in this chapter as a necessary step in discovering HE quality problems prior to engaging HE stakeholders in participative model building. What remains is applying SyDPAR in actual model developement. This is explicitly treated in chapter 5.

Chapter 4

Research Issues and Field Study Findings

4.1 Introduction

This chapter presents the research issues including the conceptual HE quality management system structure and findings from the field study. First, the research issues underpinning HE quality problem area are discussed in section 4.2. This is followed by a presentation of the findings of the field study in section 4.3. Finally, a concluding discussion is given.

4.2 Research Issues

An application for quality management in this research denotes a system dynamics simulation model for institutional and program quality analysis. The recent studies have shown that quality management is an extremely important topic in HE research (Telford and Masson, 2005; Csizmadia, 2006; Shawyun, 2006; Umashankar and Dutta, 2007) and at the same time, have pointed out areas that still need to be addressed. In particular, research on quality improvement amidst other dynamics in education settings, such as: rising enrolment, funding inadequacy, low staff qualifications, low research productivity, resources and infrastructure constraints, has been characterised by narrow scope, disguised in some cases as addressing the main challenges (Ho *et al.*, 2006; Temponi, 2005; Vinnik and Scholl, 2005), rather than the entire spectrum of challenges. As such, these studies have not succeeded in providing lasting solution to quality improvement concerns. In addition, available studies on enrolment are silent on the relationship between enrolment and quality (Maltz *et al.*, 2007), yet enrolment dynamics has been found to be the main challenge to quality improvement especially in the developing world (Materu, 2007; NCHE, 2006; Das, 2006; World Bank, 2000). Enrolment dynamics, here, refers to deficits or excesses in actual enrolment as well as variations in enrolment distribution in terms of undergraduate and graduate students.

Other studies have, however, made refutable claims:

- that quality is too subtle to be meaningfully measured (Srikanthan and Dalrymple, 2007).
- that the factors that influence quality have different scales of effect on quality, i.e., quality of academic staff is the main challenge (Vinnik and Scholl, 2005; Grandzole, 2005).

In light of these claims, the use of multiple feedbacks is inevitable when addressing HE problems. This way, the aim of feedbacks is depicted by two fundamental outputs: a representative problem structure and a conceptual system structure showing all the conceivable influencing factors as feedback loops. Such a representation takes care of the qualitative and quantitative facets of quality simultaneously, demystifying the notion that a set of quality problems facets as more worthy of attention than others.

4.2.1 The Conceptual HE Quality Management System Structure

In view of the quality management frameworks discussed in chapter two and the focus of quality management tools discussed in the same chapter, eleven sub-systems or sectors neccesary for establishing institutional quality standards that are concordant with improvements in teaching and learning, research and publication, resource allocation, and funding, were identified. The underlying causality of each sector is purposely omitted at this stage to allow assessment of its consistance with organisational structures of both public and private universities, at least from the Ugandan context.

In explaining these sub-systems/sectors, it is convenient to start with the "administration and quality management" sub-system. This sector is responsible for admission of students, evaluation of teaching, learning and research effectiveness, and review of institutional quality standards. It is therefore linked to six other sectors (institutional quality standards, teaching and learning, community, students, finance and budgeting, and educational resources) as shown in Figure 4.1. The dynamics of admitted students or rather students on programmes are addressed in the student sector. Depending on the study programme, a student takes one to five years in this sector unless dismissed. The student sector similarly influences five sectors, e.g., institutional funds depend on students' fees, research depends on graduate students' thesis publication index, academic staff are employed on basis of available or projected students' enrolment, teaching depends on students to staff ratio, and the community assesses institutional quality standards basing the quality of graduates.

To avoid ambiguity of the word "educational resource", this sector includes resources such as: library, infrastructure, utilities, equipment, and other teaching aids. In terms of modelling, these may be replicated in the sectors linked to "educational resource" sector.

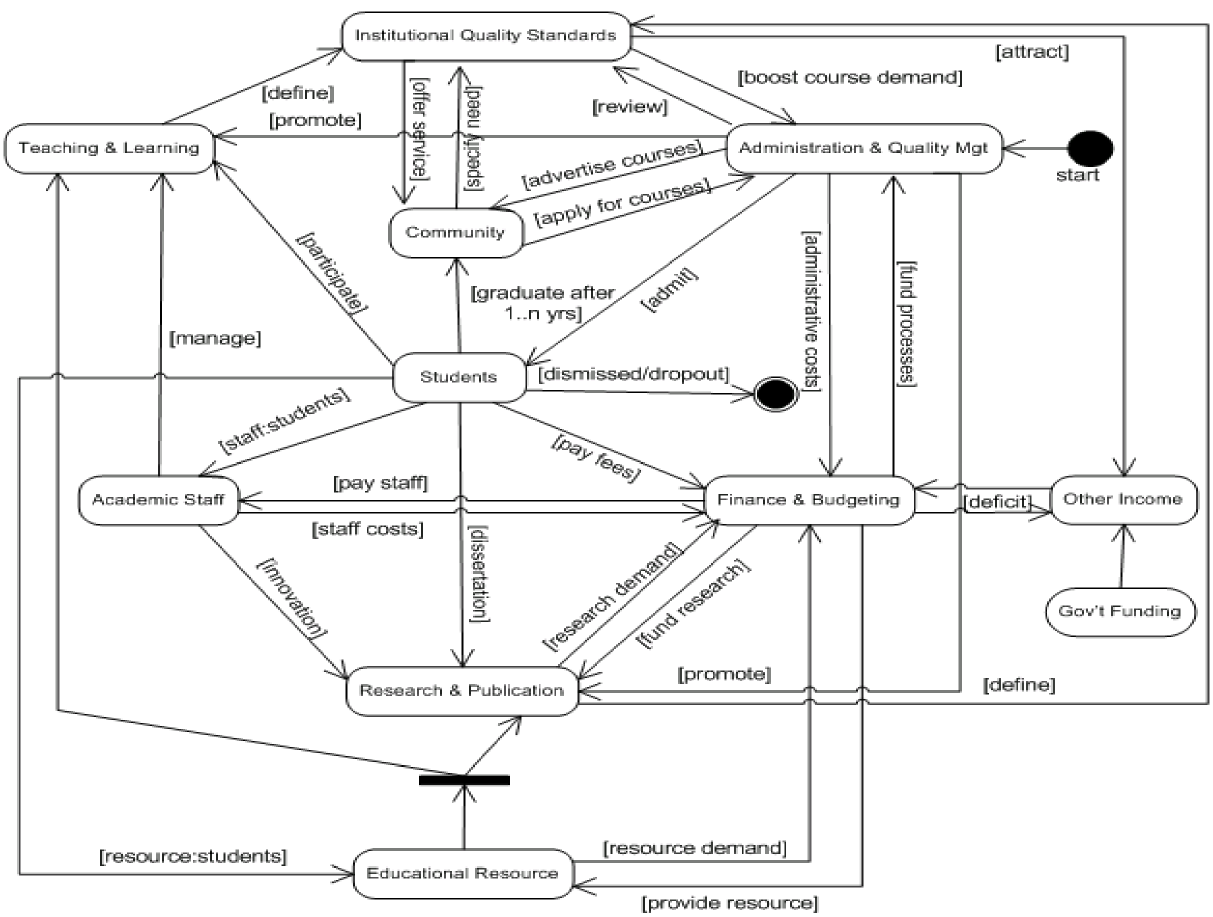


Figure 4.1: Conceptual HE Quality Management System Structure

The appropriateness of these sub-systems or sectors lies in the feedback loops representing real life academic evironment. To a system dynamicist, Figure 4.1 is a good starting point to collect necessary data and develop reference modes, explore causality in form of causal loop diagrams (CLDs) for each sector, then develop stock and flows diagrams and finally perform simulation experiments. These steps are discussed in the next chapter.

Granularity and Scope of the HE Quality Management System Structure

Each sector in Figure 4.1 implies its own unique set of factors that influence higher education quality. The overall effect on quality is achieved both by accurancy of causality and mathematical representation of this causality. To achieve a comprehensive system structure, the identification of the sub-systems as well as their integration into the overall system is important, thus eliminating blind spots and other weaknesses that would result from ignoring parts that form the whole. Ultimately, the features of the framework in Figure 4.1 in addressing quality management in higher education can be summarised by the following points:

- A clear focus on designing a quality management system, taking into consideration all the sub-systems;
- Replication of the relationships between the sub-systems as they exist in a higher education institutional setting;
- A clear emphasis on the role of funding on quality, including mechanisms of funding sustainability outside tuition fees collection;
- Consideration of the interests of various stakeholders including students, academic staff, institutional managers, government and the community;
- The effectiveness of teaching/learning is dependent on teachers (qualifications, teaching load, experience), learners (prior knowledge, motivation) and academic environment (class size, staff to student ratios, and teaching resources);
- Graduate training is necessary for increasing research publications throughput;
- The class of undergraduate degree reflects quality of undergraduates;

- The focus is on quality of an academic unit since within the same institution, different academic units can have different quality of outcomes;

- Required educational resources are acquired based on established demands thereby providing means of determing resource gaps;

- Information systems are necessary in supporting the different quality management processes;

- Quality problem representation transcends a mere feedback system by demonstrating higher education as a system with multiple feedback structures.

4.3 Field Study Findings

The findings presented in this section originate from the interviews and questionnaire survey described in chapter 3.

4.3.1 Nature of HE Quality Problems

In eliciting problems in HE quality management, the academics and administrative heads were asked to explain the existing problems with appropriate examples. As a means of validating the responses, only problems mentioned by at least two respondents have been considered. The analysis in Table 4.1 shows the depth of problems as experienced by the universities.

Identified Problem	Distribution by universities			
	Mak	MUST	UCU	UMU
Rising students' enrolment without regard to absorption capacity	***	***	*	*
Irregular staff training and development support from the universities	**	**	***	***
Hidden budget priorities, e.g., budgeted funds for conference staff participation are rarely allocated when the need arises	**	**	**	**
Over reliance on part-time staff for teaching, leading to reduced staff to student ratios and hence mismatch between staff capacity and enrolled students	***	***	*	*
Inadequate public funding compounded by the politics of fees, donor policies and insufficient national income	**	**	***	***
Low research productivity escalated by a vacuum of national research funding mechanism	**	**	**	**
Poor supervision of students' dissertations and projects due to poorly qualified academic staff and high teaching load	*	*	*	*
Large class sizes	**	*	*	*
Lack of feedbacks on evaluation of teaching and learning	**	**	**	**
Prevalence of undergraduate training due to human resources challenges in running graduate programmes	-	**	**	**
Difficulty in measuring quality due to subject/human factors that influence quality	**	**	**	**
Weak external regulation. Universities in some cases operate below minimum standards, e.g., a Masters graduate teaching on a Masters programme	**	**	**	**
Disappearing emphasis of staff appraisals by university management leading to decreasing and in some cases no follow-up mechanism on performance (competence) of employed staff	*	*	*	-
Low staff retention rates especially in science departments	*	**	**	**
Data problems relating to availability, accuracy and completeness, e.g., students' to material resources ratio was overall either unavailable or incomplete	**	**	*	*
-: not applicable; * weak problem; ** average problem; *** strong problem				

Table 4.1: Interview responses analysis by universities

The distribution of problems in Table 4.1 indicate that HE problems are more or less the same accross the public and private universities. Slight disparities however, exist on issues of rising enrolment and rising part-time staff which are more prevalent in public universities compared to private universities. Furthermore, apart from Makerere University, graduate training pauses a great challenge to the rest of the universities.

On the basis of these problematic issues, the factors that influence quality were deduced and reflected in the preliminary model in Figure 5.1.

4.3.2 Research Publication Trends in HE

Out of 216 academic staff respondents to the questionnaires, 44 percent submitted at least one publication (conference paper, journal, book chapter or book) in the period 2004-2007. Narrowing down to the individual universities changes the general picture significantly as depicted in Figure 4.2. For instance out of 69 academic staff of Makerere, 65 percent had at least one publication in the same period. While these findings may not represent the actual publications throughput, they can be used as threshold for future publications analysis. Figure 4.2 summarises publications on a per university basis.

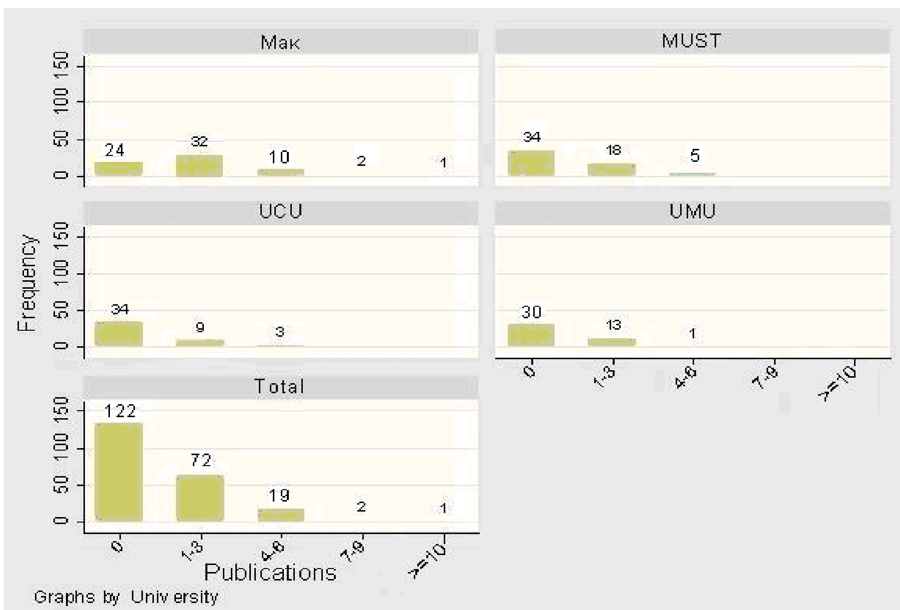


Figure 4.2: Publications by Selected Ugandan Universities

Judging by the publications grouping in Figure 4.2, it is clear that a large section of academic staff in leading Ugandan universities do not consistently publish. Three reasons may be advanced for this: first, low funding of research as already discussed. Secondly, low percentage of qualified researchers or staff with PhD qualification. Lastly, inadequate graduate training. In terms of qualifications of the surveyed academic staff, 13.5% hold PhD, 67% hold Masters and 19.5% have a Bachelors. These outcomes are comparable with staff numbers by qualifications in the Ugandan university settings for which the highest ratio hold Master's degree as shown in Figure 4.3.

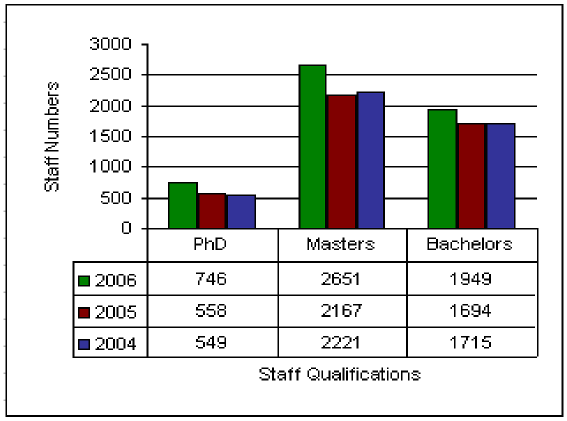


Figure 4.3: Distribution of Academic Staff by Qualification in Ugandan Tertiary Institutions (Source: NCHE, 2006)

Since tertiary institutions span beyond universities, the equivalent staff distribution for universities with reference to Figure 4.3 for staff with PhD and Masters qualifications are respectively in the range of 92%-93% and 80%-81% in the same period (NCHE, 2006). Considering the large numbers of staff with Master's and Bachelor's qualifications (refer to Figure 4.3), a simplistic proposal would be to increase staff development funding. However, attempting to increase percentage allocations to one item, in this case staff development, creates an equivalent percentage decrease on another or several other items combined, leading to no lasting solution. Only the study of these dynamics as a feedback system may lead to correct solutions.

4.4 Conclusion

The common denominator from analysis of both the interviews and questionnaire survey is quality volatility as a result of excessive enrolment growth amidst financial uncertainities. Emerging from the interactions with senior academic staff was that expenditures on HE activities are allegedly in terms of demand projections on priority areas, and yet actual allocations do not reflect such projections. Although statistical data indicate steady rising enrolments, funding allocations to infrastructure, furniture, and equipment all combined are only about 4% in public universities and 20% in the private ones. Reports from other authentic Ugandan sources indicate that only about 15% of academic staff hold a PhD and yet funding allocations to staff development is less than 3% (NCHE, 2006). With a clear indication of funding priorities as given in Table 4.2, the magnitude of funding inadequacy is revealed, but with no clear means of overcoming the shortfall.

Expenditure Item	Expenditure Allocation (%)	
	Public Universities	Private Universities
Books	0.1	2.4
Equipment	0.6	2.8
Furniture	0.6	2.3
Infrastructure	2.2	16.5
Material supplies	16.5	6.3
Research	1.1	0.4
Staff development	1.6	2.2
Staff emolument	58.5	50.2
Students accommodation	8.9	5.5
Students welfare	3.8	1.5
Utilities	5.6	4.7
Vehicles	0.7	3.8
Other academic costs	-	1.7
Total	100.0	100.0

Table 4.2: Public and Private Universities expenditure (NCHE, 2006)

As shown in Table 4.2, attempting to increase percentage allocations to one item creates an equivalent percentage decrease on another or several other items combined, leading to no lasting solution. On the other hand, each item has a different scale of effect on quality, and therefore, effecting correct changes for desired outcomes is challenging. These conflicting choices only depict one of the several perspectives that make HE quality management problematic. It establishes a precedent for creation of new approaches or rather extending existing approaches such that the facets of quality (complexity, non-linearity, soft and hard co-existance of influencing factors) can be fully addressed. Attention will be given to such a new approach in the next chapter.

Chapter 5

Application of SyDPAR to HE Quality Management

5.1 Introduction

This chapter presents the details of the research process by adopting the SyDPAR methodological framework proposed in chapter 3. The claimed effectiveness of the SyDPAR solution process is further justified in this chapter by discussing the modeling process outcomes. In order to achieve this objective, this chapter is organised as follows: first, the model's design is given, starting with underpinning research questions. Thereafter, stepwise model development process and outcomes following the SyDPAR solution process (refer to Figure 3.1) is presented, followed by the dicussions on the simulation results from the quality management tool (QMT09) developed. These discussions are extended to include model validation (structural and behavioural validation). The chapter closes with an analysis of the effectiveness of QMT09 in light of the three Inter-University Council of East Africa (IUCEA)'s quality checklists.

5.2 Quality Management System Overview

5.2.1 Scope of the Model

The model developed in this research is grounded on the settings of both public and private Ugandan universities . It is established that an academic unit or faculty's functions are generally defined by the following characteristics:

- Offering both undergraduate and graduate programmes, but in a manner that the graduate programmes are dynamically initiated when the desired ratios of staff with PhD are achieved;
- Generating income from internal activities like short courses training, consultancy and/or hire of premises on addition to tuition from students;
- Prospecting for funding to support staff training and research projects execution;
- Having full-time academic staff in the categories of teaching assistants to professors, whereby, subsequent full time staff recruitment ratios, follow a pattern that depends on graduate students' graduation rates;
- Operating under a fixed strategically planned students capacity but with provisions for growth or fall in actual capacity depending on the dynamics of the factors that influence capacity growth;

5.2.2 Assumptions

The model developed is underpinned by the following assumptions:

1. A minimum number of publication(s) is mandatory for graduate/research students (Masters and PhD) prior to their graduation. According to Badri and Abdulla (2004), a PhD or Master's thesis publication index is an indication of student's outcomes quality . A publication is a journal or its equivalent;
2. Research allocation is less than 10% of the total tuition from student (cf. Table 4.2). Since research is one of the core activities, this percentage is insufficient. Therefore research only thrieves when supported by other channels;
3. Faculty's academic staff with a PhD qualification together with research students constitute research groups. Every research group in turn manages at least one research project over a defined period of time, and the maximum number of research groups within a faculty depends on existing areas of specialisation;

4. A retake stock contains students who fail to graduate according to the stipulated study program durations. As a conveyor, this stock holds students for an extra period of one year;

5. The attrition at admission is 21% for graduate students and 14% for undergraduate students. (cf. the 2006 QA report for Makerere University);

6. Part-time staff are recruited when teaching hours exceed the total load of full-time staff.

Other assumptions are subsumed in the discussion of stokes and flows in the later sections of this chapter.

5.2.3 Audience, Purpose and Use

The model developed has general relevance to decision making on quality issues in HEIs. This withstanding the fact that there is a great variation in HEIs both between countries and within any country. Further still, a variation in quality practices and outcomes exist within academic units of the same institution. To maintain relevance of the model to these different but related levels or audiences, the appropriate parameter values must be run in the model. In this respect, three audiences have been identified as fitting within the framework of the model developed.

1. An institution's QA Department seeking internal quality analysis of its academic units.
   A comparative analysis of simulation results for different scenarios e.g. academic units with undergraduate training only, those without other internal sources of income, those with small numbers of private students, those without external donor support, those with high student to staff ratios, etcetera would reveal unique performance outcomes as behavioural trends for different academic units of the same institution.

2. External QA agencies seeking institutional quality analysis of its member institutions.
   At this level, the QA agency uses its standard parameters for generating a base run against which actual parameter values from its member institutions are compared and improvement strategies tested.

3. Academics and senior management staff seeking to evaluate the effectiveness of contraversial policies that affect institutional and program quality.

5.2.4 Time Horizon

The selection of a time horizon depends on the problem solved. In selecting the simulation time in this research, the period 2000 to 2012 was chosen on two grounds. First, because the historical data was available in the period 2000-2007 and thus a further projection for 5years was deemed concordat with strategic planning time frame of most instituitional quality assurance departments. Secondly, policies and structures within HE settings may change due to external forces in the HE environment and hence shorter simulation time horizon produces a more realistic projection of the system modelled.

5.3 Model Development

The model development process followed the SyDPAR architecture. The core modelling team (the researcher and his supervisor) interacted with the client team (stakeholders described in section 3.5.1) in several group model-building sessions. Before the first session, the perceived problem had been crafted as a preliminary model following interview results presented in chapter four as well as literature review, and guided by the conceptual framework in Figure 4.1. In the first session therefore, the preliminary model was discussed and historical data required for modelling sought. In the second session, the group efforts were devoted to establishing reference modes for six variables basing on historical data for the past eight years. These included: -Admission selectivity, enrolment numbers, graduation rates, staff distribution including qualifications, funding for all categories (public, private, and donor), rate of growth of universities in Uganda. This data was harmonised with data from NCHE and reference modes in Figure 5.3 sketched. Conceptualisation of the dynamic hypothesis was the main activity of the third session.

The fourth and subsequent sessions centered on enrichment of the preliminary model. The preliminary model as a set of influence diagrams emerging from the conceptual framework (see Figure 4.1) is henceforth given in Figure 5.1.

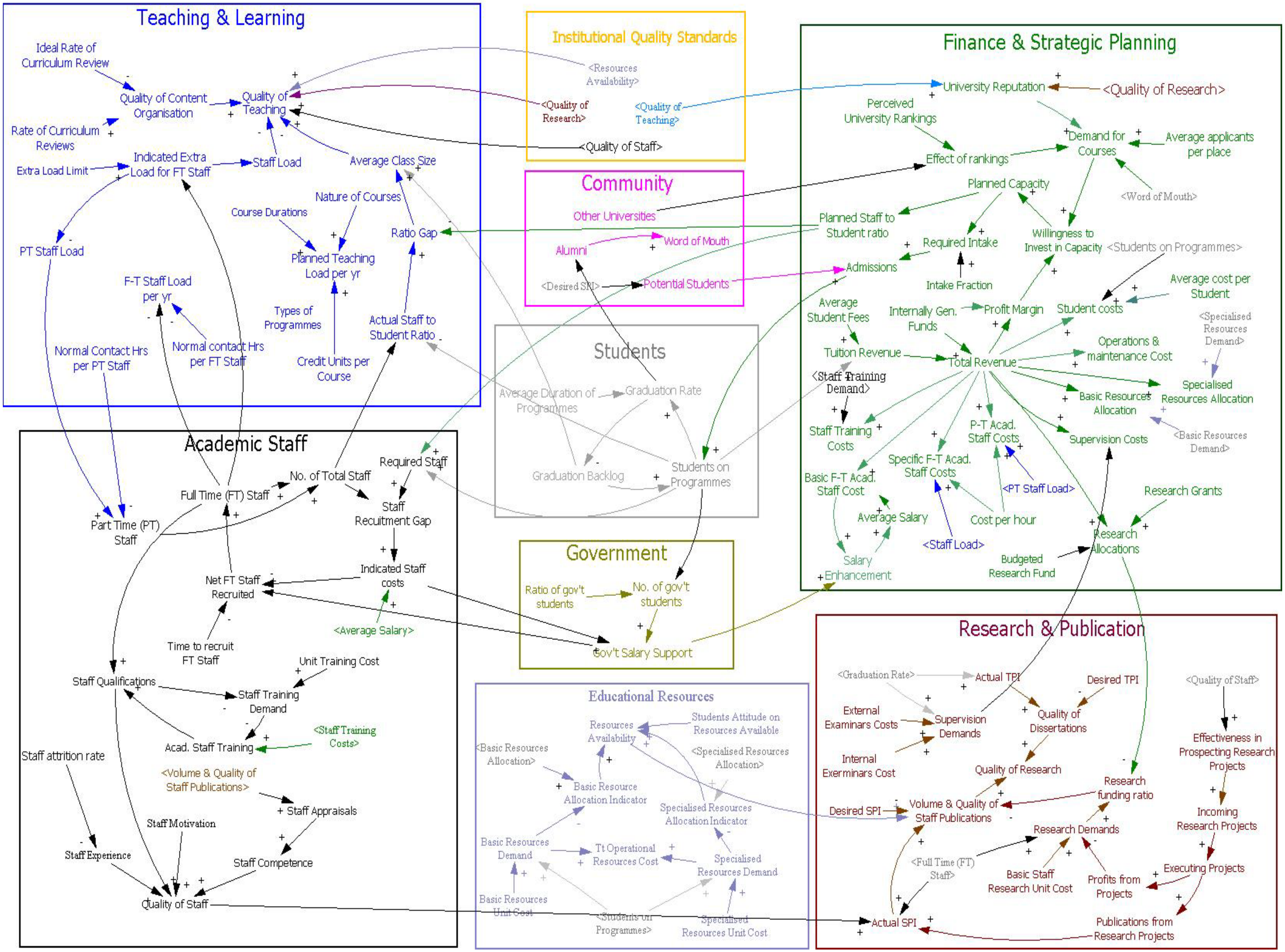


Figure 5.1: The Preliminary Model

The practice of model based research involves defining a reasonable model boundary or conceptual framework and refining the boundary during model building but without deviation from the real system structure (Sterman, 2000). This was the case in this research as it emerged following interviews' results that three sectors: 'finance and budgeting', 'administration and quality management', and 'other income' (refer to Figure 4.1) could be merged into 'finance and strategic planning' sector as given in the preliminary model in Figure 5.1. This is consistent with HE system structure for which changes in funding arise from the university's strategic direction. In the same spirit, 'institutional quality standards' sector was renamed 'outcomes quality' to reflect the contextual perspective of quality as discussed in chapter 2. Subsequent enrichment of the preliminary model involved extension of the model's influence diagram for each sector at a time, leading to evolving influence diagrams of increasing complexity. An example of the extended research and publications sector's influence diagram is given in Figure 5.2.

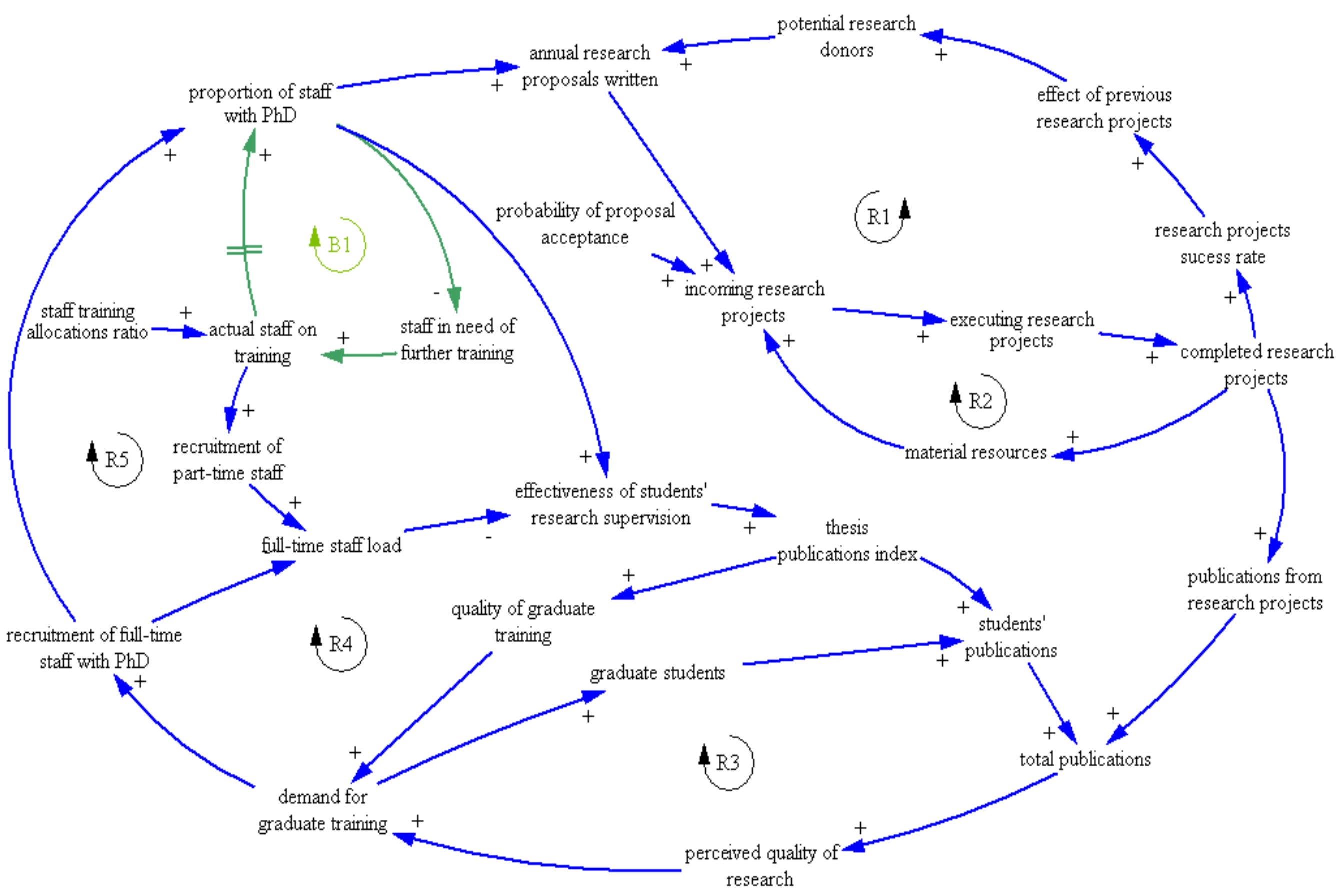


Figure 5.2: Research and Publications Sector's Influence Diagram

At least six feedback loops can be identified in Figure 5.2. Each of these loops represents a cause-effect perspective of the research productivity problem space. In this respect, the reinforcing loop R1 shows the process of research projects executed from inception through completion and the effects of research projects success rate. Similarly, R2 depicts effects of material resources gained from previous executed research on future research prospecting. Loop R3 delineates the effects of graduate training on perceived quality of research and subsequently demand for graduate training. Loop R4 depicts the influence of staff recruitment on staff load, students' supervision effectiveness which in turn affects students' thesis publication index, total publications, perceived quality of research and ultimately demand for graduate training. Last but not least, loop R5, also the longest loop can be similarly explained.

The transition from the enriched influence diagrams to the stocks and flows diagrams was done with less clients'/stakeholders participation as the mathematical formulations and additional complexity given the size of the model was beyond the expertise and/or commitment of most of the stakeholders. This observation is consistent with 'fluid participation' concept of the garbage can model. The stakeholders were however, re-engaged in evaluating the simulation results. In these evaluation sessions, stakeholders were 'walked through' the simulation results in detail in order to ensure both the model's face validity and the acceptance of the simulations by the stakeholders was a deductive exercise. Furthermore, quality checklists from Inter University Council for East Africa were used as benchmarks for evaluating the relevance of the model in addressing specific quality issues. Results of this evaluation are presented in section 5.7.2.

5.3.1 Dynamic Patterns in HE Quality

System dynamics emphasises the importance of clarity of purpose for any intervention, i.e., a defined problem, issue or undesirable behaviour to be corrected (Forrester, 1961). The problem behaviour is usually described in a reference mode, and the purpose of the intervention is to identify how the structure and decision policies generate the identified reference mode so that solutions can be generated and implemented.

Real data on problematic issues in the Ugandan universities was used to construct graphs of historical behaviour or reference modes. At national level, data was obtained from National Council for Higher Education reports on HE delivery (NCHE, 2006; Kasozi, 2006, 2003). Additional data was obtained from Makerere University (the pioneer university). Makerere is preferred because of availability of relevant data both from policy documents (Wabwire, 2007; Makerere quality assurance framework, 2006: Musisi and Muwanga, 2003) and specialised information systems such as: academic records system (ARIS), financial records system (FINIS), human resource records system (HURIS), and Library records system (MakLIBIS).

The reference modes in Figure 5.3a to Figure 5.3c show behaviours of problematic issues underpinning HE quality including: (a) growth in potential students versus growth of universities and ensuing university's absorption capacity (Figure 5.3a), (b) trends in staff qualifications as an indicator of staff development and staff quality (Figure 5.3b), and (c) funding trends and impact on quality (Figure 5.3c). Figure 5.3a depicts that the growth in universities correspond with de-

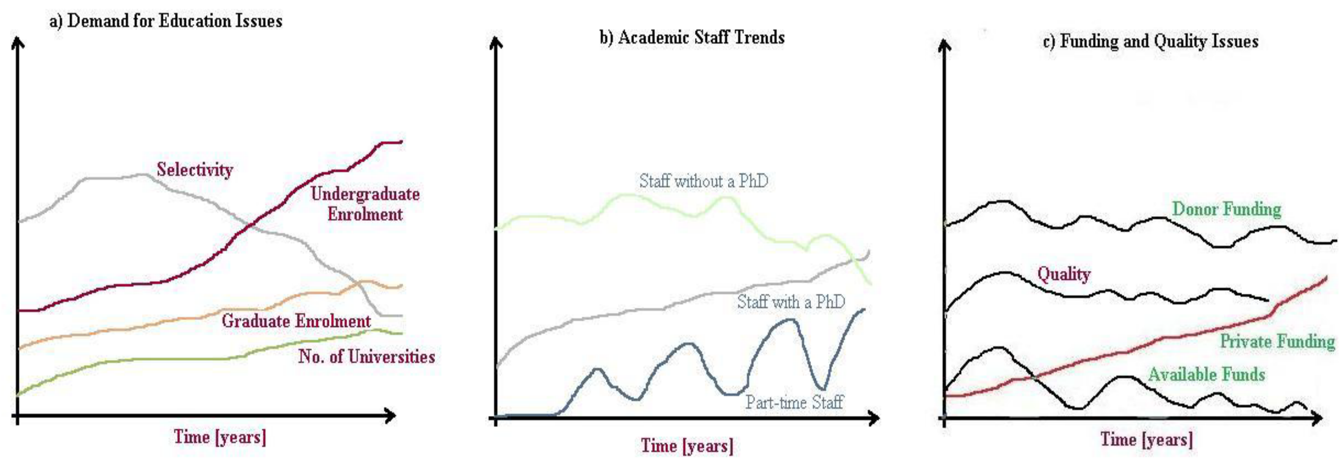


Figure 5.3: Dynamic Behaviour for Reference Modes

mand for new places as indicated by rising student enrolment. Considering selectivity (the ratio of number of applicants and number of admitted students), for Makerere University this ratio is generally falling over time, impling on the one hand that demand for admission is continuously increasing. On the other hand, it implies that demand for university training is not uniform in all Ugandan universities, i.e., some universities are more prefered by the potential students. Moving on to Figure 5.3b, the number of academic staff with a PhD increases steadily as those without a PhD falls, depicting a university with good staff development commitment. Certainly the number of part-time staff is volatile as these are only employed when the available teaching load exceeds full-time staff capacity. Finally, Figure 5.3c shows the dynamics of funding issues and the impact on quality. Private funding corresponds with rising student enrolment in Figure 5.3a. The available funds depicts the existing balance after the normal university's expenditures.

5.3.2 Model Control Statements

Prior to performing simulation experiments, some pointers of acceptable modelling standards must be considered. These generally constitute the model control statements. The following control statements were used in the development of the model:

- Units check - The built-in units feature was used to check all equations for consistency of units, i.e, to make sure the left and right side of all equations have the same units. Checking models for dimensional consistency before running the simulation is the basic validation test.
- Naming variables - A general element naming convention has been proposed by Ventana, the makers of Vensim Modelling Software. The first letter of Stock names are capitalized, constants are all capitals, and names of all other variables, including flows are all lower case. The word ”rate” is reserved for flows.
- Stock values - These cannot be negative and thus were set to have a minimum value of zero. The only model elements with direct connections to stocks are flows. No constants or auxiliary variables were directly entered in the stock equation, except for the initial values of the stock.
- Flow connections - A flow only increases or decreases a stock; it cannot be used as a source of information in a model as it cannot be measured. A flow unattached to a stock serves no purpose in the model, as it does not affect anything.
- Constants embedded in equations - Constants were explicitly modelled as individual elements and not embedded in equations. This facilitates future changes without changing any equations in the model.

5.4 Model Structure

The structure of an SD model is a loop diagram, consisting of positive and negative feedback loops. The model structures presented so far conform to the influence diagrams type of model structures and are used for information representation of problem/system modelled. The other type of model structures are the stock and flows diagrams that transform the influence diagrams into meaningful representation of the actual system modelled by estimating model parameters from historical data, laws of physics or common sense. The rest of this section is devoted to the stocks and flows diagrams.

5.4.1 Stocks and Flows Diagrams

A couple of SD software tools are available for modelling. In this study, the Stella Version 8.1.1 Modelling Software was used for simulation experiments. The description of the basic symbols of this Software is given in Table 5.4.

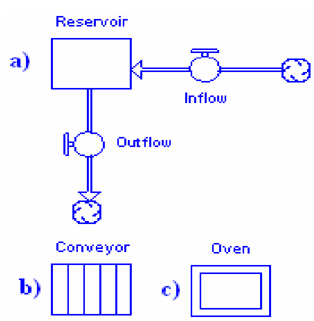
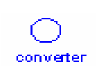
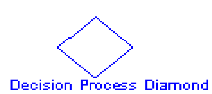
Symbol and Name	Function
	Stock variables represent the fundamental accumulations over time. Every stock passively accumulates through its inflows minus its outflows at each DT. The STELLA software uses specific symbols for specific stocks. Its default stock type is the Reservoir (labeled a). Others include: Conveyor (labeled b) and Oven (labeled c). A Conveyor (just like a conveyor belt) keeps materials, e.g., students for a period of time before they get off, allowing more inflow of new materials at each DT. The oven differs slightly by the fact that new materials cannot flow in unless materials in the oven have been unloaded over a defined period of time.
	The converter is an intermediary variable that takes input data and manipulates (or converts) it into an output signal.
	It represents the decision process such as if and if-else statements within a model. The ultimate goal is to ensure that both the inputs and the outputs associated with a decision process are clear, thereby maintaining a bi-focal perspective of the macro- and micro-structure as needed.

Figure 5.4: Basic Model Symbols

Finance and Strategic Planning Sector

This sector demonstrates the major determinants that underpin growth or decline in the strategic students' capacity, and dynamics in tuition revenue collections and allocations to overlapping funding needs. The sector links with the other six sectors as issues of funding and strategic planned students' capacity are core to any university's operational structure. Specifically, this sector depicts that revenue from tuition supports several activities including: full-time staff salaries for private universities, extra load allowances for full-time academic staff (denoted by specific FT Staff Extra Load Costs), part-time staff allowances (denoted by PT Staff Costs), staff training/development, student costs (includes costs for basic academic resources per student), and other funding needs (included all other categories of faculty expenditure). The rest of the outflows from tuition revenue stock are shown in Figure 5.5.

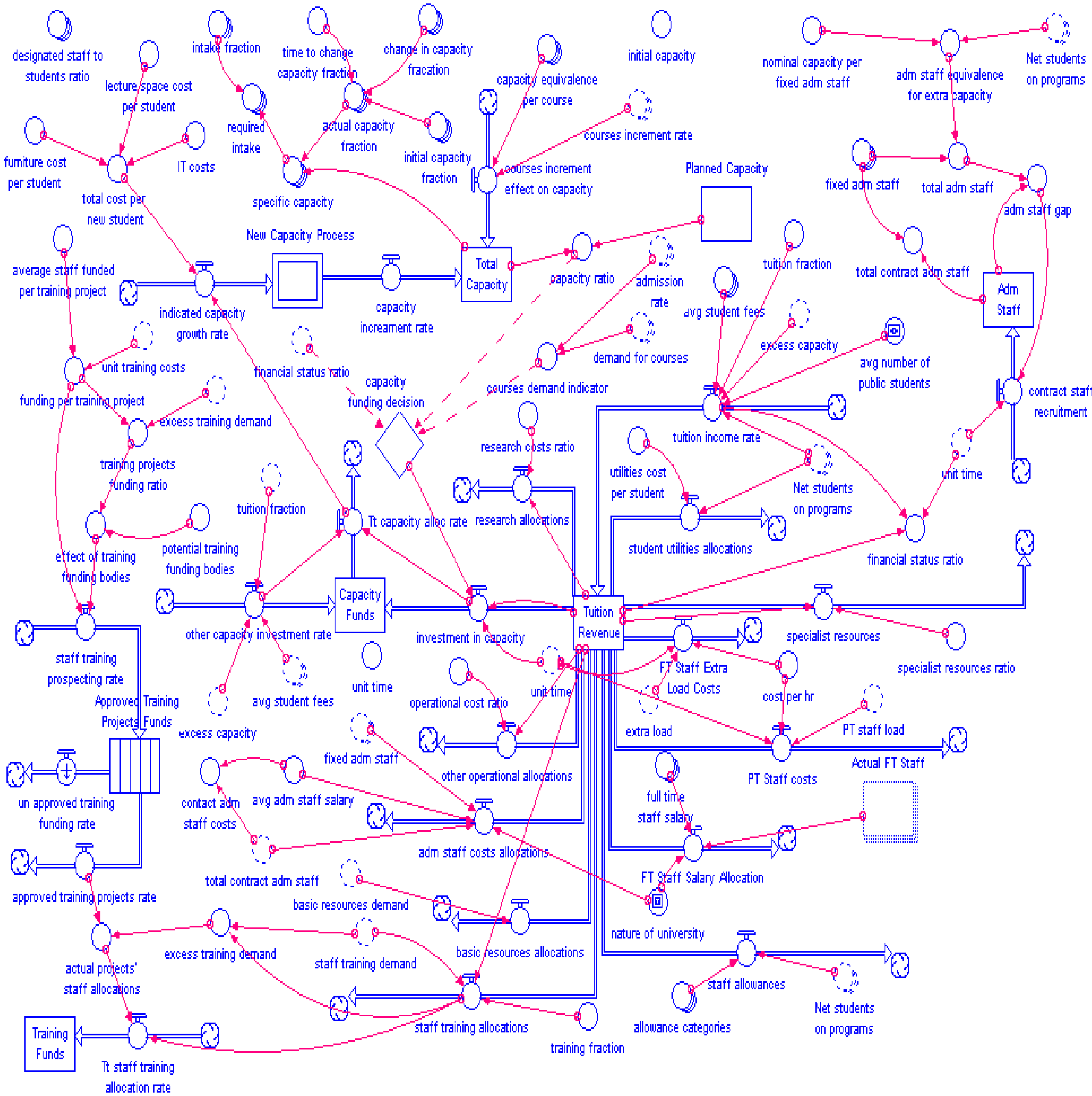


Figure 5.5: Finance and Strategic Planning Sector

Since full-time staff salaries in public universities are not paid from tuition revenue, and for the sake of keeping the tool generic so that it is applicable to both public and private universities, the “nature of university constant” is used to switch between these cases. This constant is modelled as ‘on’ and ‘off’ or ‘[0]’ (for public universities) and ‘[1]’ (for private universities) when determining the full-time staffs salary allocation out-flow (denoted by FT staff salary allocation).

Research and Publications Sector

Generally, research indicators include: staff publications, PhD completions, PhD thesis publication index and Masters Thesis publication index, research income, prestigious awards, and research-based infrastructure (Williams and Van Dyke, 2007; Badri and Abdulla, 2004; Kennedy and Clare, 1999). These indicators are modelled with regard to their influence on quality and quantity of research.

In terms of research quantity, the main indicators are "stocks" for PhD completions, faculty publications, research resources capacity or research based income. Conversely, quality relates to publications per PhD and Masters Thesis (Badri and Abdulla, 2004), and publications per faculty staff (Williams and Van Dyke, 2007). Besides these quantitative measures, universities have an obligation to do the research necessary to identify their legitimate strengths and distinctive advantages for reputation purposes. Furthermore and as indicated in Figure 5.6, "research students' publications" stock is accumulated by "students' publications" rate. This rate is obtained as the product of "indicated publications per thesis" and "research students' graduation rate".

$$IP = \overline{M}(SCP, RA) * UQP \qquad \text{(Eq. 5.1)}$$

Where

IP= indicated publications per thesis

$\overline{M}$= mean

SCP= staff commitment to supervision

RA= resource availability

UQP= upper quartile publications per thesis

The upper quartile publications are determined from historical publications trends of research students. It is assumed that a university sets a minimum number of publications (journal or its equivalent) as graduation requirements for the research degrees. Following from equation Eq. 5.1 and since upper quartile publications are considered as "ideal publications per thesis" (refer to Figure 5.6), indicated publications per thesis equals ideal publications per thesis. Furthermore, "expected students' publications" is derived from ideal publications per thesis, and subsequently "quality of students' thesis" computed as the ratio between "research students' publications" and "expected students' publications". Similar arguments are used to determine staff publications indicator in Figure 5.6. In the same line, SPI is an acronym for staff publications index. Regarding SPI, a publication can be a research book, journal, book chapter, or a refereed conference paper.

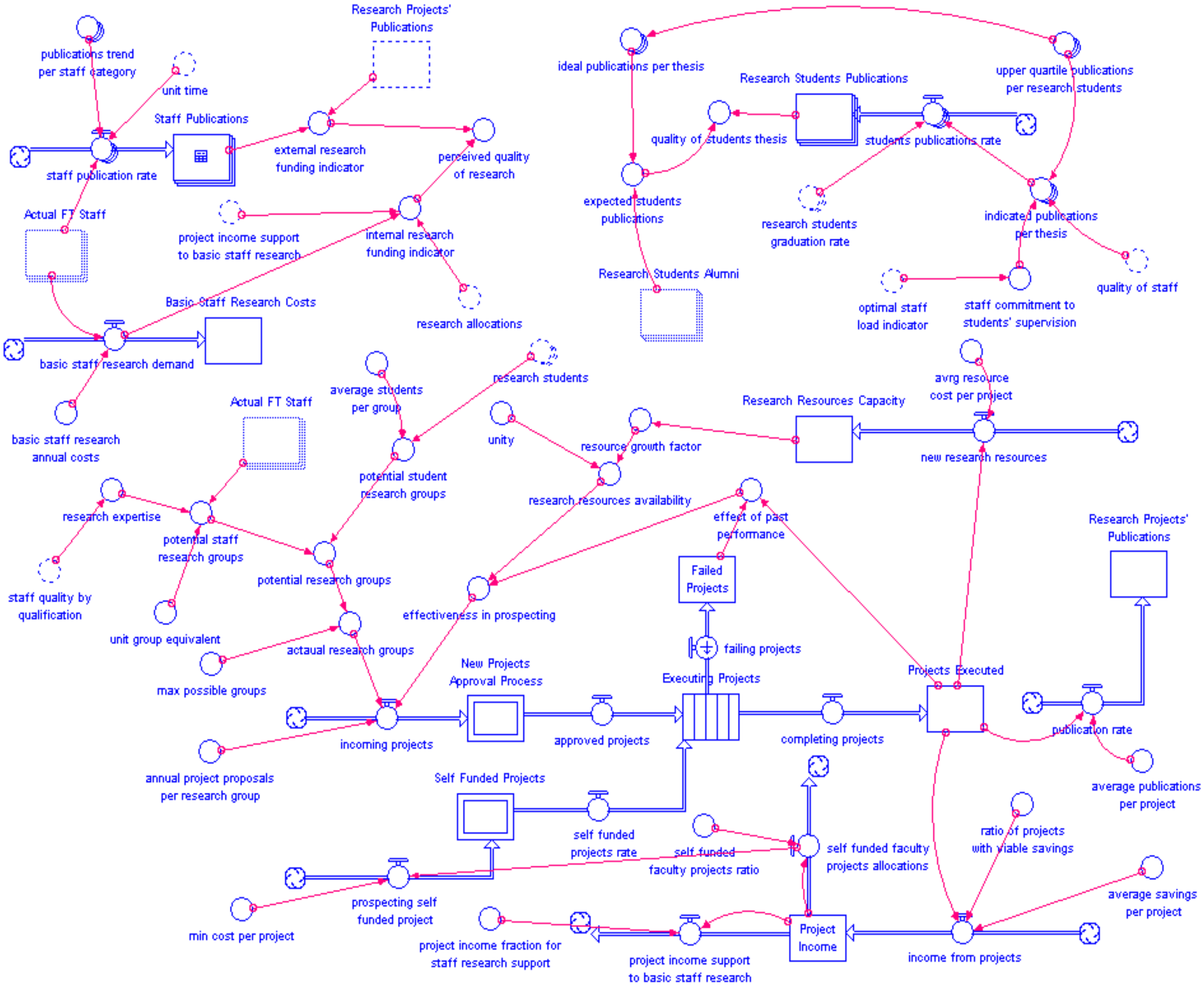


Figure 5.6: Research and Publications' Stock and Flows

Another set of interrelated stocks and flows in this sector correspond with funded research projects. These transcend incoming projects rate, to executed projects stock through executing projects stock. Starting from executed projects stock, research resources capacity stock is derived. Subsequently, research growth factor is computed.

$$Research\ Growth\ Factor = \frac{INIT(ResearchResourcesCapacity)}{ResearchResourcesCapacity} \qquad \text{(Eq. 5.2)}$$

Consider the result of equation Eq. 5.2 to be β, and since "Research Resources Capacity" is a stock that accumulates with number of projects executed, then β decreases over time. Research resource availability which is determined from β as $e^{-\beta}$, undergoes exponential growth in the range [0, 1]. The "research project publications" stock and "projects income" stock are similarly derived from "projects executed" stock.

Student Sector

This sector consists of five major stocks namely, potential applicants, admitted students, students on programmes, graduating students and students on retake. Potential applicants stock is accumulated by "demand for courses" rate. This rate is influenced by four factors including: required intake, initial applicants per place, university reputation, and market share. The "students on programmes" conveyor keeps students for specific periods depending on their programme of study. Undergraduate students take three years, Post Graduate Diploma (PGD) take one year, Masters take two years, and PhD take three years, while in this conveyor. At the end of these periods, students flow into "graduating students" stock, from which, the fraction that fails to graduate because of retakes (papers that must be redone) remain in the system through the "students on retake" conveyor, and graduate a year later. The screenshot of the students sector is given in Figure 5.7.

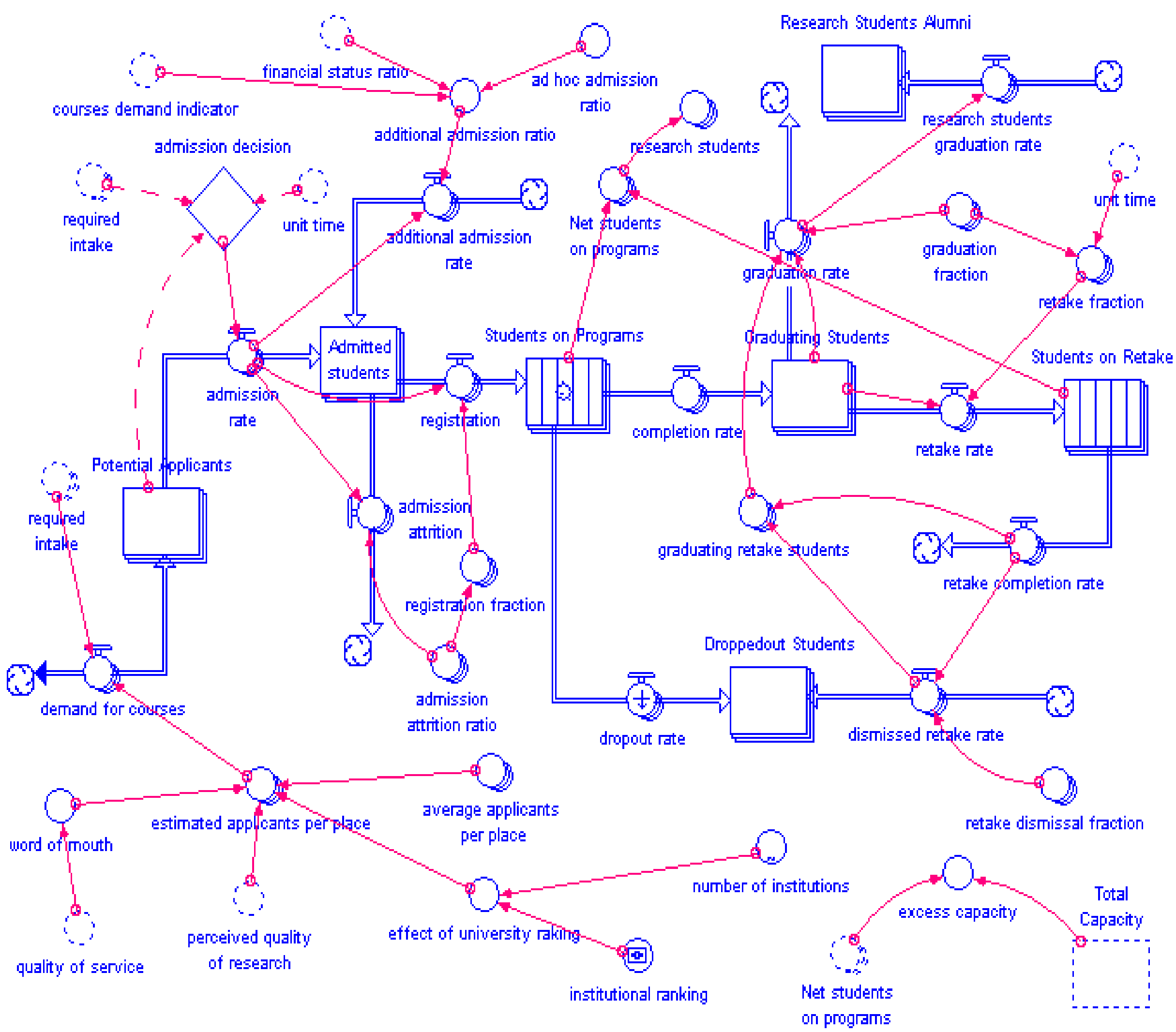


Figure 5.7: Students Sector's Stock and Flows

Government

The role of government with regard to the current model is provision of funds for recruitment of full time academic and administrative staff, and sponsorship of government students. Each of these, however, is modelled in a separate sector where their relationship with other variables exist. In this respect, the full time staff recruitment is modelled under the academic staff sector, while administrative staff (as a human resource) is modelled in the resources sector, and government students' sponsorship in the funding and strategic planning sector. For the purpose of illustration, Figure 5.8 shows the stock and flows for full time academic staff recruitment as extracted from the academic staff sector.

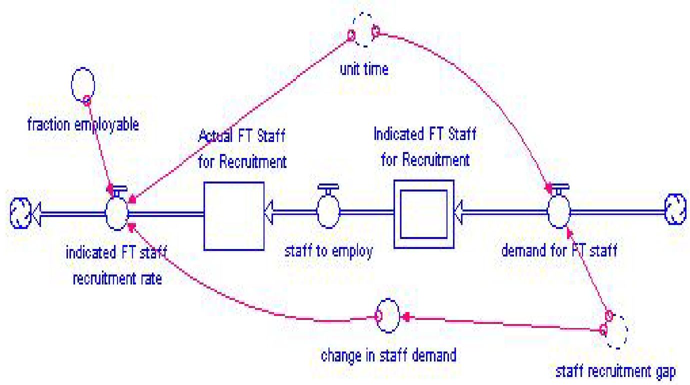


Figure 5.8: A Representative Stock and Flows for Government Sector

As shown in Figure 5.8, the time delay of recruiting full time academic staff is modelled using an "oven".

Educational Resources Sector

Educational resources are part of the indicators for teaching and research in higher education (Gornitzka and Maasen, 2000; Athiyaman, 1999). In modelling this sector, the assumption that a licensed university begins operation with adequate resources for the initial planned students capacity is made. Resources gap, however, may arise when operational resources demands outweigh resources allocations hence affecting quality of teaching delivery and research. A major component of operational resources are the basic resources. These are equivalent to running costs for the cross cutting resources like computers and computer networks, Internet accessibility and speed, journal subscription, and library books. The specialist resources for science based academic units form the second type of operational resources but are not emphasised in the current model. The screenshot of the resources sector is given in Figure 5.9.

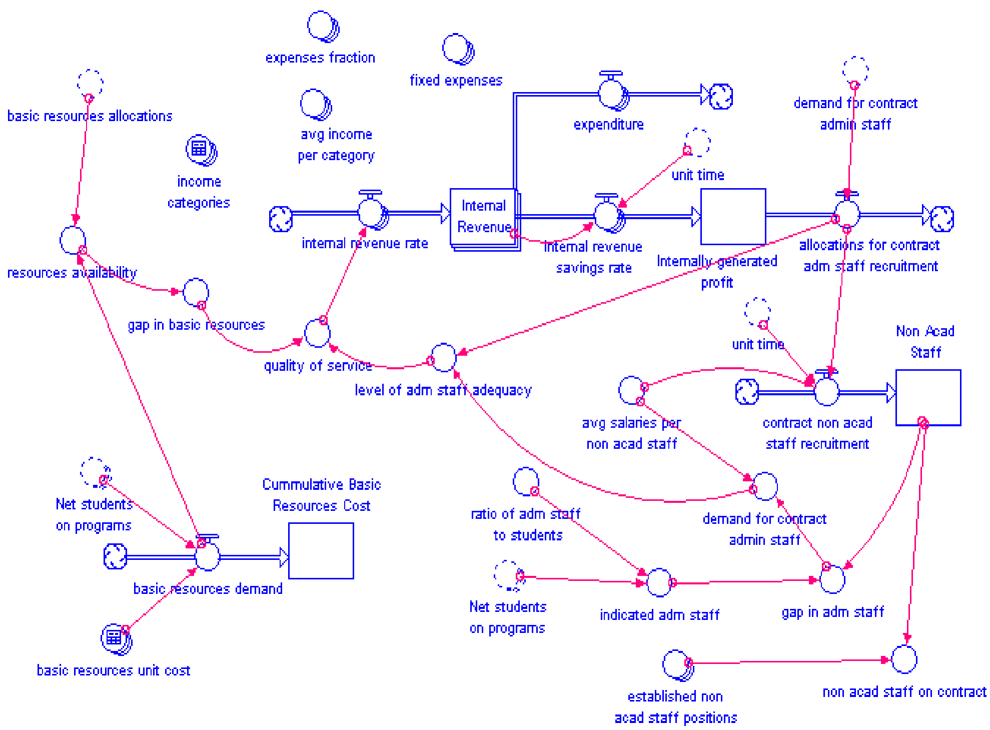


Figure 5.9: Educational Resources Sector's Stock and Flows

Academic Staff Sector

This sector includes stocks for full time academic staff and part time staff. The full time staff stock is further broken down into other stocks to track training progress of staff members without PhD qualifications (teaching assistant and assistant lecturers). Staff training is in two forms: first, through demand for training versus availability of training funds, and secondly, through executing faculty research projects. In the first scenario, all staff requiring PhD training or Masters training are considered while in the second scenario, only PhD training is catered for. This is based on the assumption that each funded research project run by a faculty has provision for a PhD training position of which staff members have top priority.

The status of staff degree as an indicator of quality of staff (ideal minimum required qualification is PhD) is computed as a ratio of staff with PhD or its equivalent qualifications to the total staff capacity. Other indicators for quality of staff include staff competency and staff experience as shown in the screenshot (Figure 5.10).

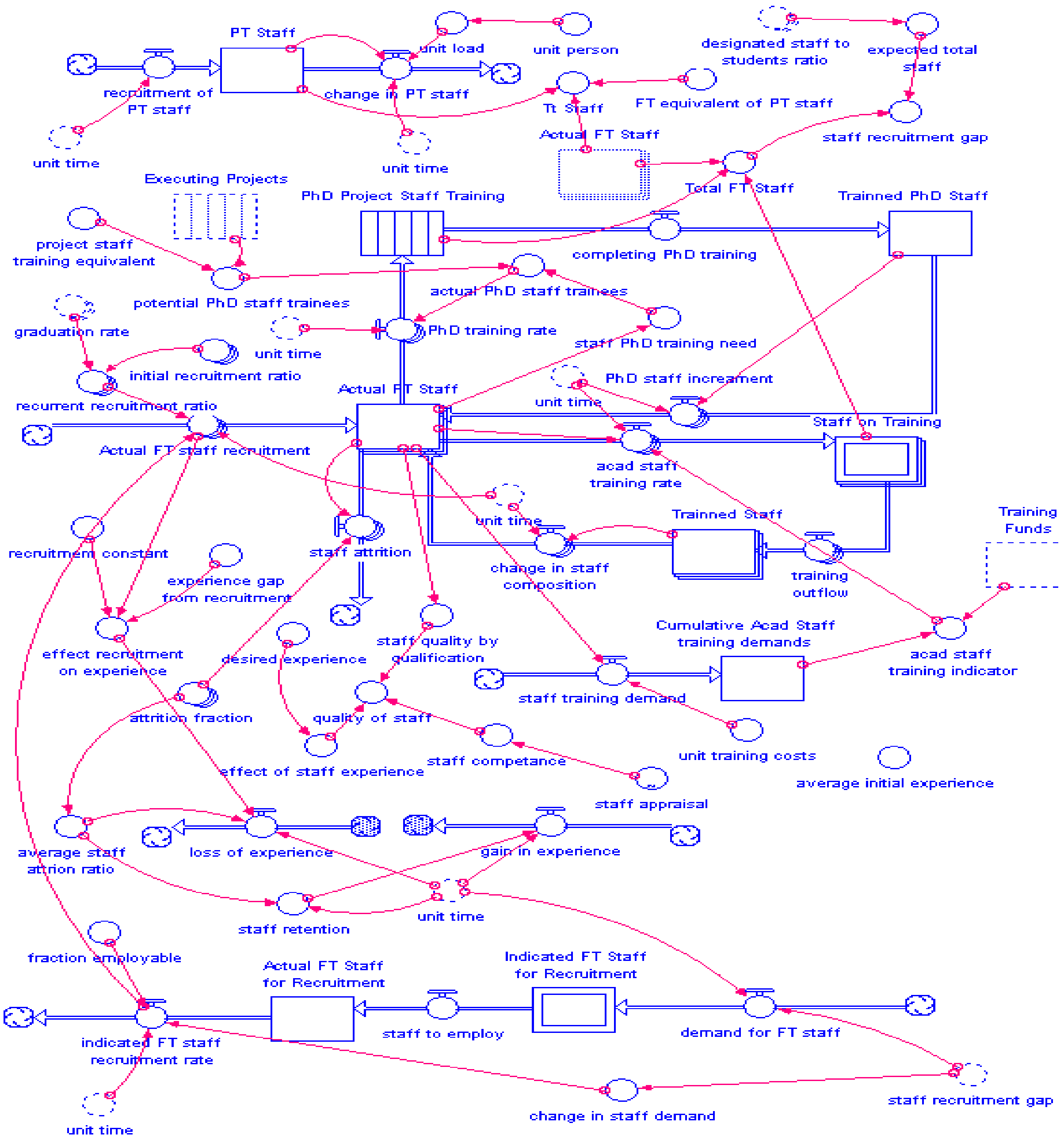


Figure 5.10: Academic Staff Sector's Stock and Flows

Teaching and Learning Sector

Quality of teaching is derived from quality of staff, resources availability (Gornitzka and Maasen, 2000), class size (Krueger, 2003; Athiyaman, 1999), and students rating of teaching. This sector contains mainly computations for teaching load distributions between full time and part time academic staff. The assumption here is that part time academic staff are only employed when the full time staff have been allocated teaching hours corresponding to their maximum load (nominal load + extra load). Two stocks in this sector have been modelled; one for monitoring changes in current courses and the other for class size. As for the former, it is observed that faculties with increasing students capacity also increase courses they offer. Since courses change (increase) in a non continuous form, this trend could best be modelled using a delay process (an "oven"), whereby the oven's inflow rate arises from the difference between maximum planned courses and current courses. The overall details of the teaching sector is given in screenshot in Figure 5.11

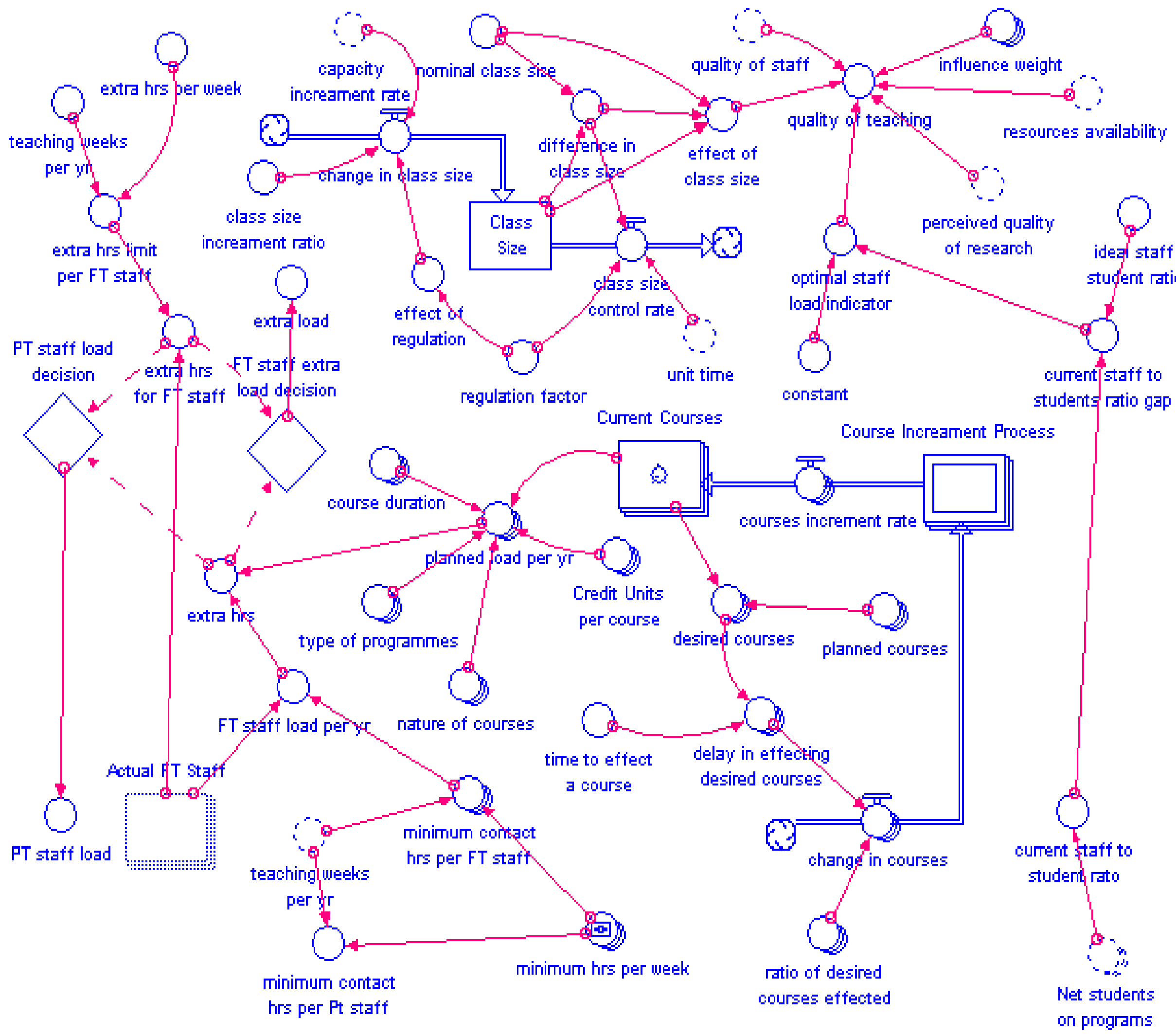


Figure 5.11: Teaching and Learning Sector's Stock and Flows

Quality of teaching is influenced by five factors: quality of staff, resources availability, optimal staff load indicator, optimal class size indicator, and quality of research. These influence factors are measurable in the scale [0,1], and if their influencing effect varies on a weighted scale of highest to moderate influence, then the overall effect on quality of teaching is the product of influence factor value and its influence weight divided by sum of influence weight. If the quality of teaching is denoted by (say) Q_{Tij}; for which F_i is the influence factor and W_j the influence weight; then Q_{Tij} is given by:

$$Q_{Tij} = \frac{\sum_{i,j=1}^{n} F_i W_j}{\sum_{j=1}^{n} W_j} \qquad \text{(Eq. 5.3)}$$

In the interest of clarity, the 'optimal staff load indicator' is the ideal staff load arising from staff to students ratio dynamics. Since part-time staff are employed on the basis of available teaching load and not the designated staff to students ratio, the overall staff to students' ratio decreases as part-time staff increases in response to increasing student enrolment amidst the delay in full-time staff recruitment. Let σ be the 'designated staff to students ratio' and μ the current staff to students' ratio gap, then 'optimal staff load indicator'(L_{so}) is given by:

$$L_{so} = e^{-10\mu} \qquad \text{(Eq. 5.4)}$$

For $0 \leq |\mu| \leq \sigma$. Therefore, the output values from equation Eq. 5.4 lie in the range [0, 1].

Community Sector

The community sector investigates the effect of university ranking and alumni survey or 'word of mouth' on demand for university training. Due to data deficiencies on alumni surveys, word of mouth effect is estimated from level of generation of other income, e.g., from: short courses, hire of premises, services to the private sector, and consultancy. As just noted, the variables corresponding to the community sector affect demand for courses which in turn affects students' admission rate. These variables are thus modelled in the students sector. What is interesting to discuss at this point is the equation for 'effect of university ranking' variable. In this respect, the effect of university ranking (R_e) for which r is the university rank, is given in equation Eq. 5.4.

$$R_e = \frac{u + 1 - r}{u} \qquad \text{(Eq. 5.5)}$$

For u = number of universities and r= (1, 2, ..., u). The value for r is assigned by the decision maker since the Ugandan universities ranking are not yet available.

Institutional Quality Standards Sector

The contextual perspective of quality as discussed in section 2.2 is used in defining variables for institutional quality standards sector. These include: quality of research, quality of staff, quality of teaching, quality of undergraduate and graduate students' achievements, resources availability, and availability of funds. Each of these variables is modelled in a primary sector and replicated in this sector for the purpose of representing the fundamental outcomes of the model as a whole. Just as for the community sector as described in the previous sub-section, there is no need to discuss these variables again here.

5.5 Model Calibration

Oliva (2003) defines model calibration as the process of estimating the model parameters to obtain a match between observed and simulated behaviour. Calibration explicitly attempts to link structure to behaviour, making it a more stringent test for a dynamic hypothesis. As such, a calibration test increases confidence in the dynamic hypothesis as the observed behaviour justifies the structure. Conversely, if the structure fails to match the observed behaviour, then the dynamic hypothesis can be rejected. The dynamic hypothesis in this research is presented in chapter 1 - Figure 1.1 and the inferred parameter relationships are subsequently shown in Figure 1.2. For ease of comparison, Figure 5.12 shows the parameter relationships overlying the simulated behaviours.

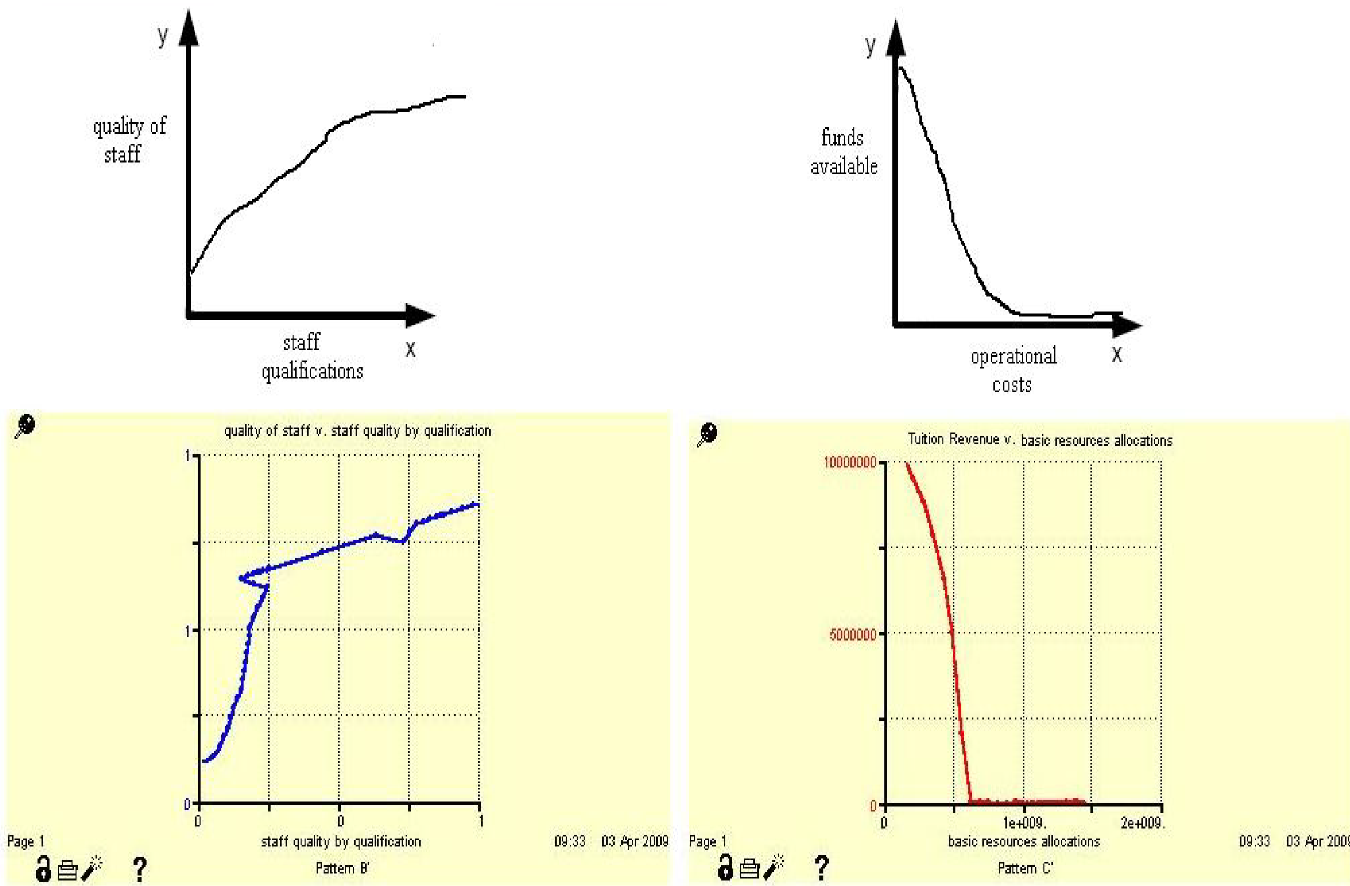


Figure 5.12: Example of Calibrated Behaviours

As demonstrated by Figure 5.12, there is a close match between the calibrated behaviours labelled pattern B' and parttern C' and their overarching hypothesized parameter relationships. In simulation science, this means that the estimated parameters match the observable structure of the system and hence the dynamic hypothesis proposed in chapter one is confirmed. Since a scientific hypothesis that survives experimental testing becomes a scientific theory, this research ably claims that the dynamic hypothesis proposed is indeed a theory for HE quality management.

5.6 Model Validation

The model developed is validated using both the standard system dynamics tests (Forrester and Senge, 1980; Barlas, 1989; Barlas, 1996) and empirical tests. The subsequent discussions explore these tests in detail starting with the two groups of standard system dynamics tests, namely: the structural validation and behavioural validation tests.

5.6.1 Structural Validation

Structure tests assess the validity of the model structure by comparison with knowledge about the real system. It involves taking each relationship (mathematical equations inclusive) and comparing it with available knowledge about the real system. The inclusion of the stakeholders' team in the modelling phase was a procedural measure for improving the validity of the model. Indeed, inductive validation of propositions about causal relationships and assumptions about parameter values was possible through team engagement. The structure tests performed in this research include: structure and parameter confirmation, extreme conditions, boundary adequacy, and dimensional consistency.

Structure Confirmation

The structure confirmation test is of fundamental importance in the overall validation process as it tests whether the model structure is consistent with relevant descriptive knowledge of the system being modeled. Since model building in this research was participative, shared understanding of factors that influence quality emerged from discussions starting with the preliminary model as already discussed in section 5.3. In these discussions, sketches were drawn by hand on whiteboard before transformed into computer causal loop diagram (such as Figure 5.2 in section 5.3). These procedures were important in establishing the credibility of the model structure as well as a feeling of ownership of the model among the participants (cf. Rouwette and Vennix, 2006; Vennix, 1996). Other functional relationships were drawn from the literature whereby in some cases, the whole structure was adopted while in other cases only structural formation was adopted. In fact, the stock and flows of research and publications sector was build by extending Vahdatzad and Mojtahedzadeh's (2000) structure in Figure 5.13 in line with the sector's influence diagram (Figure 5.2).

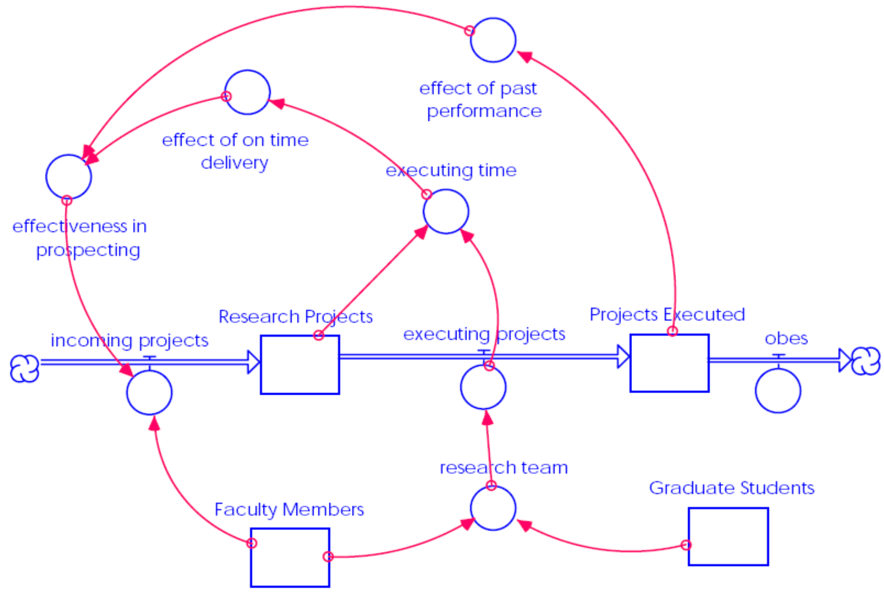


Figure 5.13: A structure for the growth of research and development in a university (Source: Vahdatzad and Mojtahedzadeh, 2000)

The practice of adopting structures from the literature as just described served as 'theoretical' structure confirmation test (Barlas, 1996; Forrester and Senge, 1980), and was significant in offsetting 'fluid participation' of stakeholders as reported in section 5.3.

Parameter Confirmation

Parameter confirmation determines whether the parameters in the model are consistent with relevant descriptive and numerical knowledge of the system. Parameter values used were from numerical data of Makarere University and other published sources (NCHE, 2006; Kasozi, 2006, 2003). For clarity, Table 5.1 gives some of the parameters and their values.

Parameter categories for selected sectors		
Model Sector	Selected parameters	Assigned values
Student	Duration of study programs (years)	PhD-3, Undergraduate-3, Masters -2
	Graduation ratio (per year)	PhD-0.5, Masters-0.6, Undergraduate-0.9
	Average applicants per place (Unitless)	PhD-1, Masters-1, Undergraduate- 3
Academic staff	Desired staff recruitment ratio (Unitless)	PhD holders-0.75, Masters' holders-0.25
	Average time to recruit full-time staff (years)	4
Teaching	Staff to student ratio (Unitless)	PhD-1:5, Bachelors-1:20, Masters-1:10
	Minimum teaching load (hours/week)	PhD holders-6, others- 10
	Class size (persons)	50
Research and Publications	Average publications trend (papers/year)	PhD holders- 0.9, Masters holders- 0.4
	Average publications per research student (papers/person)	PhD students-3, Masters-1
	Basic staff research support (Shillings/person/yr)	8,000,000
Resources	Basic resources unit cost (Shillings/person/yr)	PhD-600,000, Masters-500,000, undergraduate-450,000

Table 5.1: Parameters and Assigned Values for Sectors

Boundary Adequacy

Boundary adequacy ensures that important concepts and structures for addressing the policy issue are endogenous to the model. In the current model, all major aggregates in all model's sectors are generated endogenously. Only two variables: staff competency and number of universities are exogenous. Historical data on each of these are available from 2000 to 2007; the future values are determined by linear extrapolation.

Extreme Conditions

The extreme conditions test enhances model validity by analysing model behaviour beyond the initial boundary. In this respect, conditions tested (though not discussed further) include:

- No admissions as well as abnormally high admissions
- High versus low staff to student ratios
- Very low versus very high tuition fees

- Extremely high graduate training versus no graduate training
- Maximum staff retention rate versus zero staff retention rate

The dimensional consistency check was done using the inbuilt function within the modelling software. Without the model passing this test, the simulation runs presented in the subsequent sections would not be possible.

5.6.2 Behavioural Validation

The main behavioural tests done include: behaviour replication, anomalous behaviour, behaviour sensitivity, behavioural boundary, and family member test. Only behaviour replication will be discussed at this point since it links the simulated output generated by the interaction of the equations and initial conditions with the model structure itself.

Behavioural Replication

In comparison with the reference modes in Figure 5.3, three simulated behaviour patterns including: student enrolment trends, staff by qualifications trends, and trends of available funds, are discussed here.

a) Student Enrolment Trends

The dynamics of enrolment has been elaborated in the students sector. In the context of behavioural replication tests, the simulated behaviour for undergraduate and Masters enrolment in Figure 5.14 are comparable with reference modes in Figure 5.3a. As depicted by Figure 5.14, enrolment trends of undergraduate is steeper than Masters over the simulation period due to 90% to 6% enrolment distribution for undergraduate and Masters in most Ugandan universities.

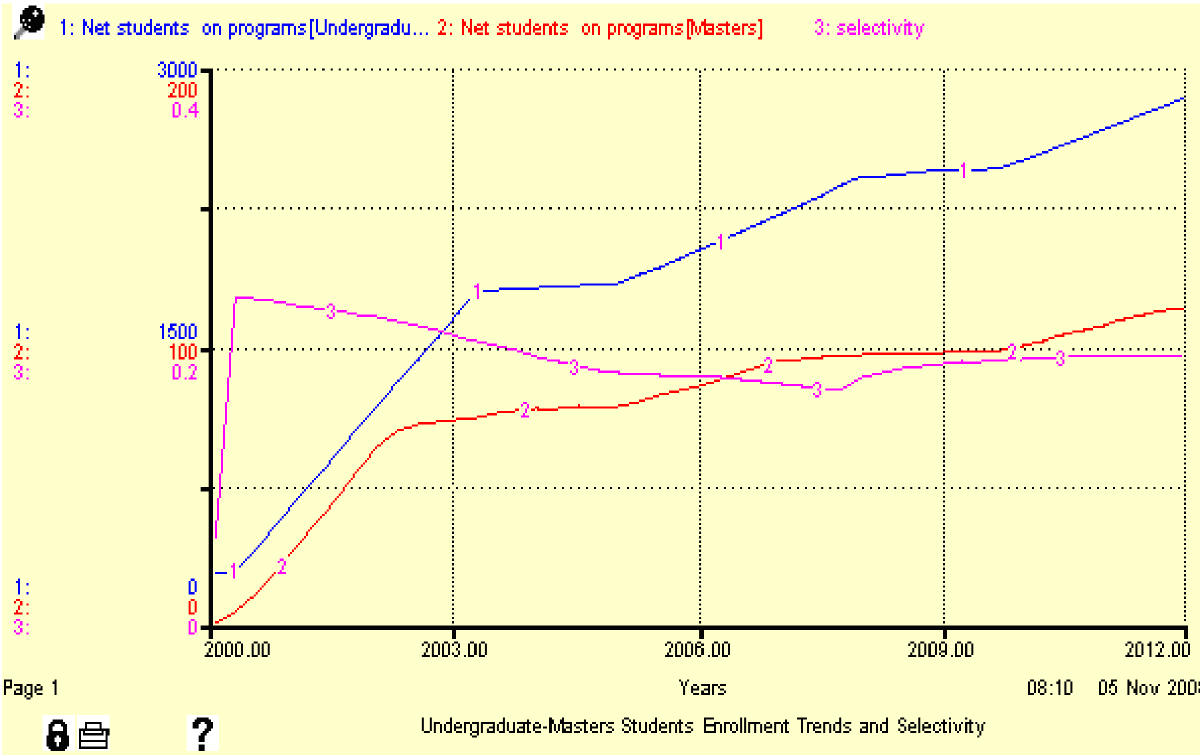


Figure 5.14: Actual Students Enrolment and Selectivity Trends

The selectivity (ratio of admitted students to potential students' applicants) behaviour in Figure 5.14 reflects that suggested in reference mode (Figure 5.3a) until 2008. The slight rise in selectivity after 2008 contrary to slight fall in the reference mode is negligible since enrolment trends were not affected. However, the rise in selectivity would eventually affect future enrolment if it persistently becomes steeper.

b) Staff establishment

Staff establishment is influenced by several factors including recruitment policies (how fast recruitment is done, e.g., four months, one year or 4years, when the need arises), staff development policies, level of students enrolment, and nature of graduate training. The resultant effect of these factors creates avenue for part-time staff and full-time staff recruitment choices. Full-time staff are recruited based on established ratios of staff in the categories of teaching assistants to professors. As depicted by Figure 5.15, full-time staff with a PhD (lecturer) follows stable growth which is comparable with reference mode (Figure 5.3b- Staff with a PhD graph). This behavioural trend is supported by two factors in the model, first, the fact that assistant lecturers who complete training become lecturers, and secondly, the number of lecturers grows due to recruitment of new full-time staff (cf. Figure 5.21). Similarly, the behaviours of 'Ass Lecturer' and 'Teaching Ass' graphs in

Figure 5.15 are comparable with their corresponding reference modes in Figure 5.3b.

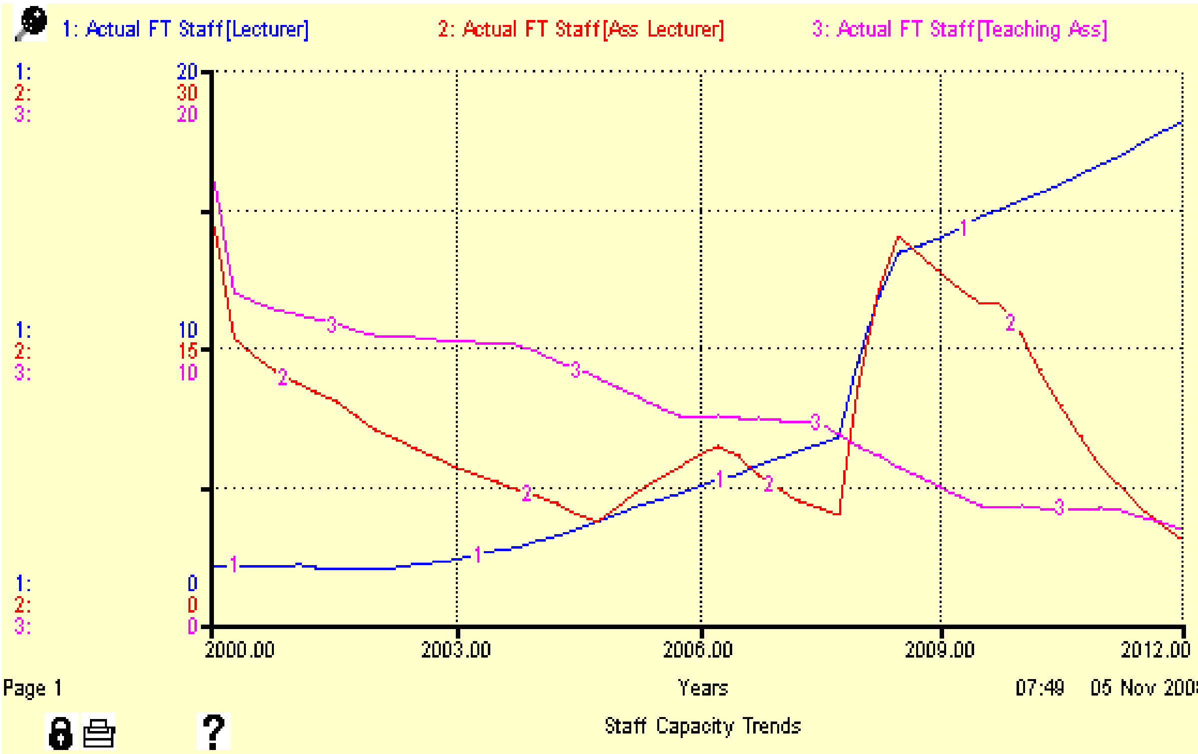


Figure 5.15: Staff Establishment Trends

The 'Ass. Lecturer' and 'Teaching Ass.' graphs in Figure 5.15 depict a generally falling trend because they correspond to the category of staff that are liable to further training and hence change in status, e.g, assistant lecturer (Ass. Lecturer) become lecturers after training. In contrast, while 'Teaching Ass.' graph has a steady fall, the 'Ass. Lecturer' graph rises instantaneously in the sixth and eighth year. The rise in the sixth year corresponds with change of status from teaching assistant to assistant lecturer after training, while that in the eighth year is due to recruitment of new staff (cf. Figure 5.21).

c) Available Funds

The norm of funding constraints in universities is worldwide. The simulated behaviour in Figure 5.16 depicts an unstable behaviour for available funds, reflecting that demands for funding allocations outweigh actual funding in the case of Ugandan universities. This is a good much of the reference behaviour of the same in Figure 5.3c.

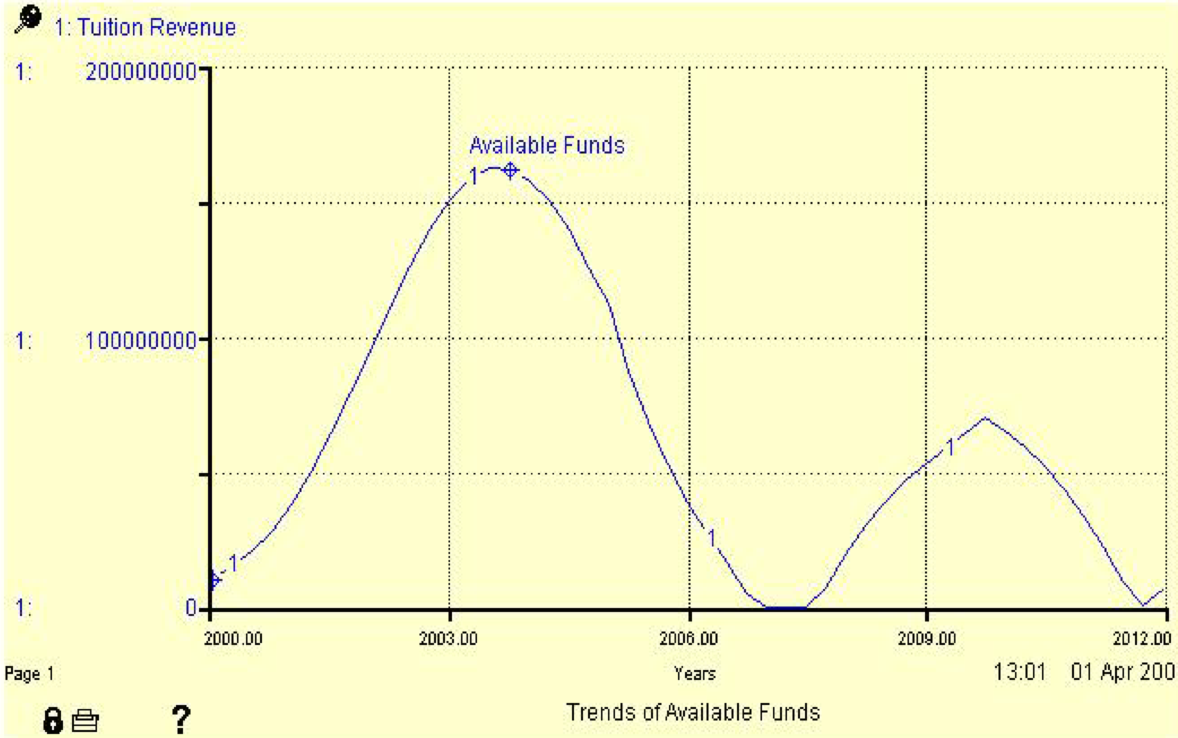


Figure 5.16: Trends of Available Funds

5.7 Evaluation of QMT09

The effectiveness of QMT09 can be seen from two perspectives: first, as a useful tool for policy analysis of HE quality issues, and secondly, as a tool that meets the criteria of standard quality checklists. Before we present these two perspectives, an overview of QMT09 is well served at this point. Given the large size of the resulting model, it was necessary to develop a simple yet complete interface for the model. In doing so, the design principles for good user interface (Meadows, 1989; Barlas and Diker, 2000) were adhered to. Following the standard design principles in addition to experience of the modellers, the user interface in Figure 5.17 was developed.

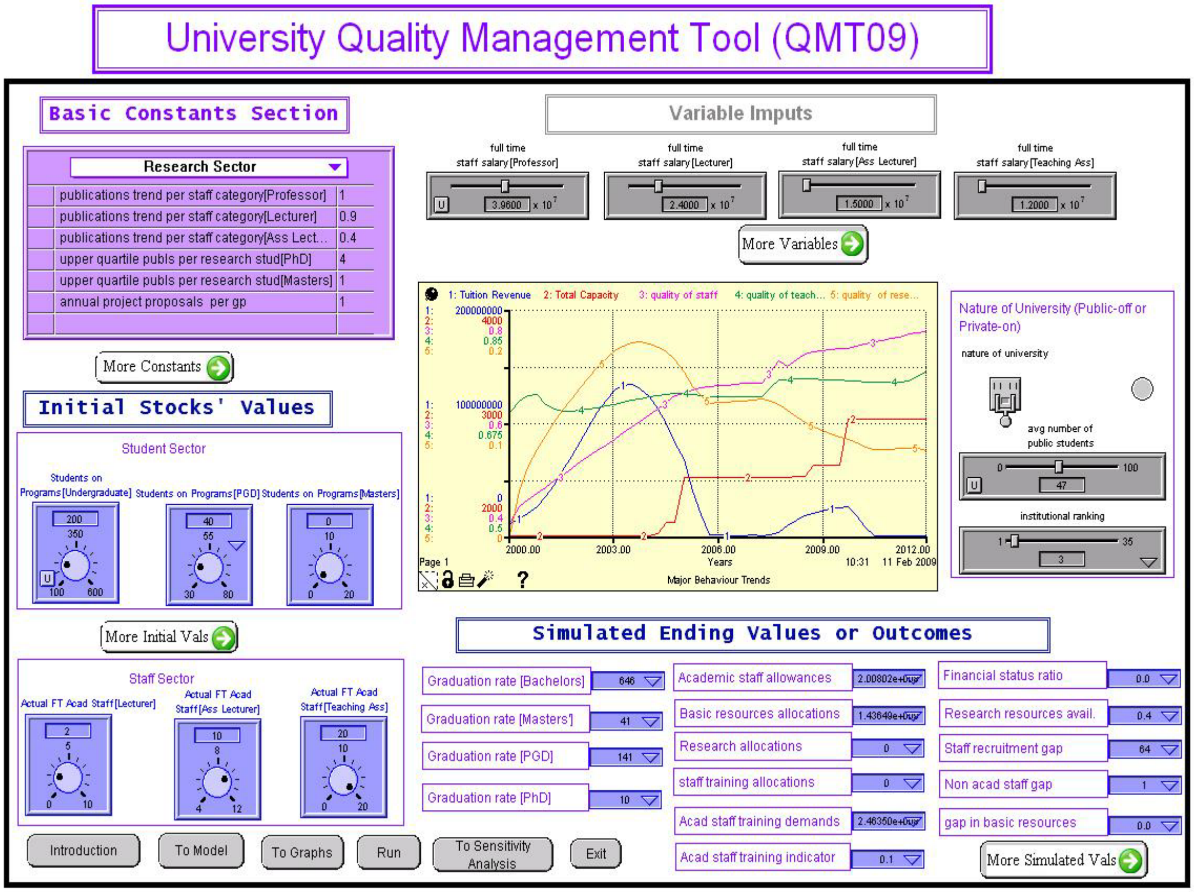


Figure 5.17: The User Interface for QMT09

5.7.1 Policy Analysis

Exploring the effects of policy changes and experimenting with alternative policy formulations is not feasible in the real world except through computer simulations. In this respect, the tool (simulation model) developed in this research, integrates the main sectors that underlie quality management in HE thereby offering ways to test policies on quality improvement. However, recognising the need for action and having the expertise to implement effective action plans are different matters. It is probably safe to say that QMT09 addresses the former, leaving the latter to policy makers as they adopt the tool. Three fundamental policy experimentations are discussed as follows:

Enhancing Quality of Outcomes

Quality of outcomes is studied at two levels: institutional performance and student outcomes.

Institutional Quality Performance (staff, teaching, and research)

The cardinal functions of any university are teaching and research. Quantitative measures for quality of teaching and research have over the years been hotly debated although without convergence of ideas (Srikanthan and Dalrymple, 2007; William and Van Dyke, 2007; Strong and Eftekhar, 1998). This research suggests new measures for these variables (see, e.g., equation Eq. 5.3). Following from equation Eq. 5.3, quality of teaching is influenced by five factors of which behaviours for quality of staff, optimal staff load indicator and quality of research are given in Figure 5.18. As observed in Figure 5.18, the behaviour of quality of teaching follows a different trend from all its influencing factors. In fact, quality of teaching results from the unified effect of its five influencing factors and therefore, improving quality of teaching implies avoiding volatility of its influencing factors.

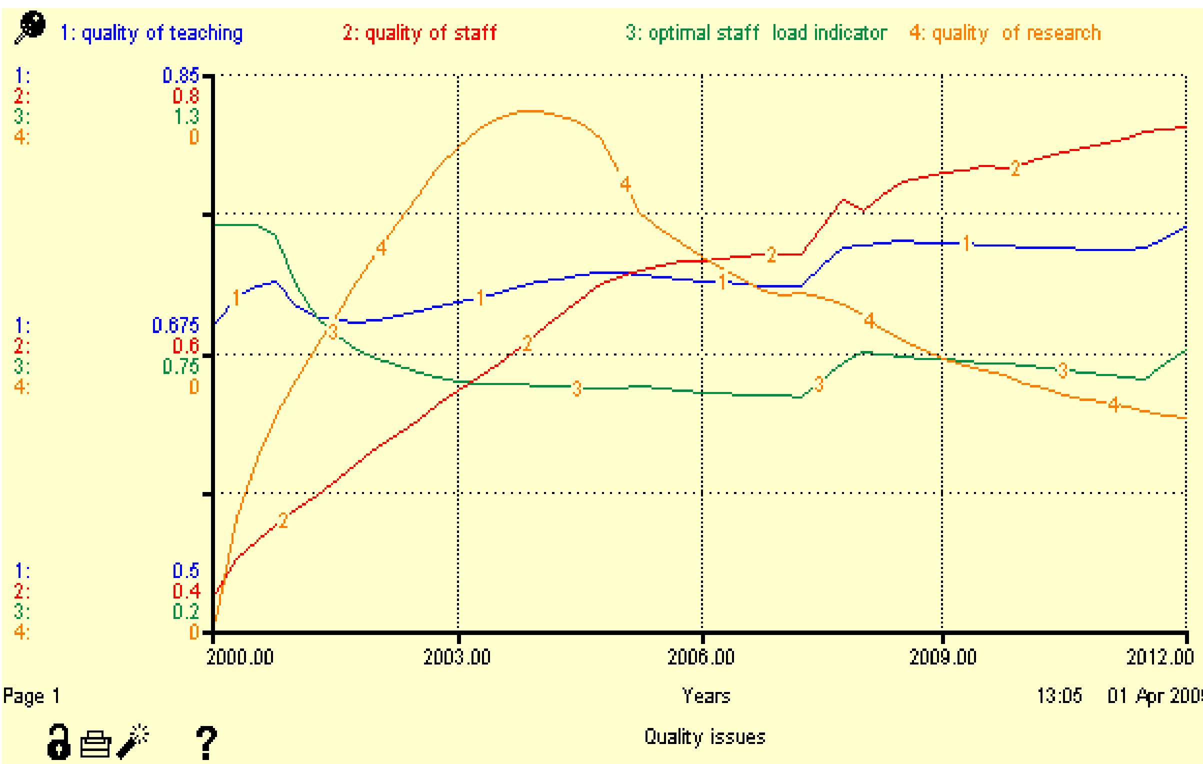


Figure 5.18: Dynamic behaviour of the main institutional quality indicators

As opposed to teaching demands which are addressed through unit costs, research allocations and hence outcomes depends on availability of tuition revenue in addition to funded projects. Consequently, for research to thrive, it must be funded through a separate channel and only supplemented by percentage allocations from available revenue. In so doing, efforts to introduce structural change and improve the quality of teaching cannot detract from the efforts to strengthen research and publication. Ultimately, academic units can improve quality across basic areas by seeking optimal behaviour. The soundness of model equations as reflected by logical behaviour outcomes in Figure 5.18 provide confidence that model parameters can be dynamically varied to produce required optimal behaviour.

Quality of Students Outcomes

Quantifying students outcomes has equally previously been attempted but with less consensus. This research contributes to this debate by exploring quality of students' outcomes in the categories of graduate and undergraduate outcomes. In this regard, graduate quality is approximated from students' thesis publications index (Badri and Abdulla), while undergraduate quality is obtained as the product of 'observed undergraduate quality' (say Q_u) and unified effect of quality of research, quality of teaching, and resources availability. Q_u is computed from the available percentage grading of undergraduate scores as follows:

$$Q_u = P_u(1 + P_p) + \frac{P_l}{1 + P_l} \qquad \text{(Eq. 5.6)}$$

Where:

Q_u is the indicated quality of undergraduate

P_u is percentage of students with first class and second upper degree

P_l is percentage of students with second lower degree

P_p is percentage of students with pass degree

The simulation behaviour of students' outcomes are given in Figure 5.19 next page.

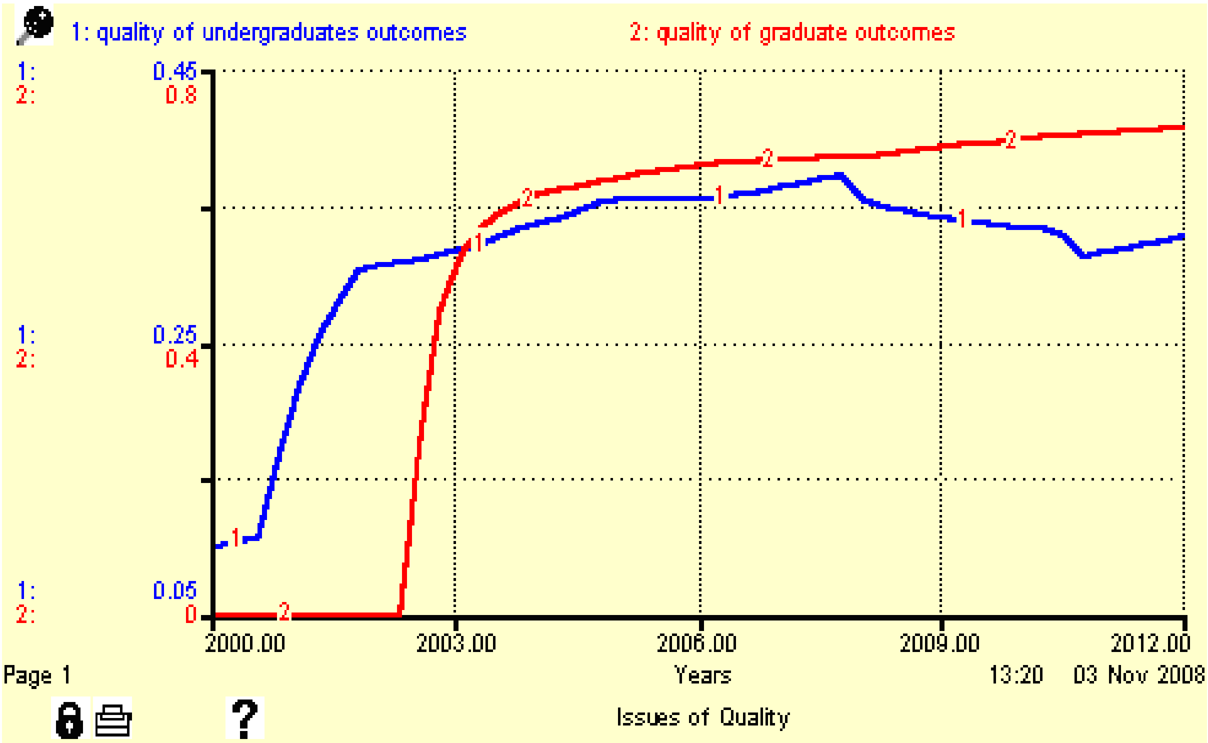


Figure 5.19: An estimation of quality of students' outcomes

As observed in Figure 5.19, the quality of graduate outcomes before 2002 is nil as no graduate students will have graduated yet. Notice that the behaviour in Figure 5.19 is one scenario where undergraduates are inputs for graduate training and the behaviour could have been different if initial values of graduate trainees were changed. Since the overall behaviour outcomes for undergraduate and graduate students are fairly stable at respective values of 0.44 and 0.76 despite dynamic behavioural changes of their influencing factors; then their underpinning formulas are logically sound.

Improving quality of students' outcomes can be effected through several policy options. For example, by raising the ratio of graduate students' admission while keeping other parameters constant, several positive indicators ensure. These include: improved research output in terms of publications both from students research areas and students' participation in faculty projects, higher quality of staff recruited as a result of available stock of desired qualified persons (cf. Figure 5.18), increased availability of funds (since tuition fees for graduate training are higher), and ultimately quality of students' outcomes improves.

Seeking Improvements in Allocations of available Funds

Prioritisation of available funds is a major problem in the Ugandan universities. Due to high demand for HE training, budget allocations on paper do not match the outcomes as allocations for expansion implicitly have top priority. Figure 5.20 compares allocations by demand projections (resource allocations and staff allowances) with allocations as ratio of available funds (staff training allocations). It is observed that allocation of funds on the basis of demand projections directly addresses funding needs while allocations as ratio of available funds has volatile effects, i.e., irrespective of demand, it rises when funds are available and falls when funding falls.

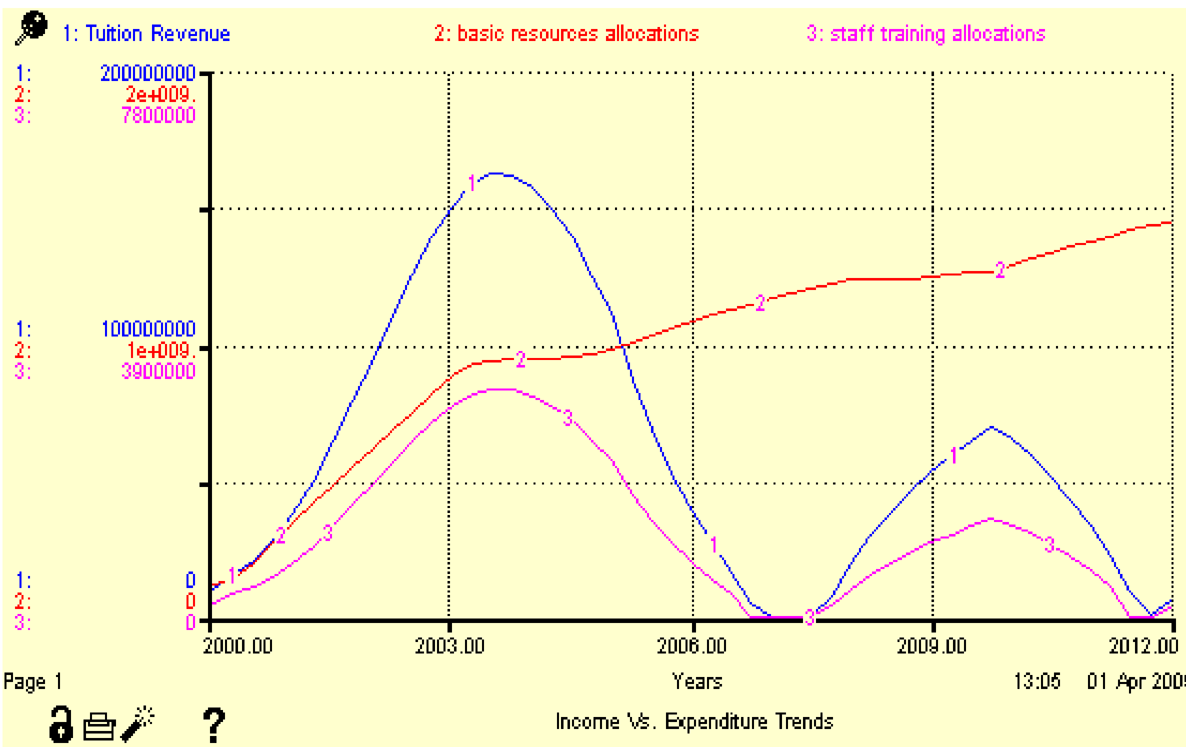


Figure 5.20: Available income and expenditure dynamics

It is clear from Figure 5.20 that strategic capacity of an institution to fund its activities should be guided by demand projections of these activities and not by percentage rationing. Under ideal scenario, unit costs should rhyme with tuition charged so that demand for funding institutional activities is sustained by income. However, seeking affordable education without compromising quality may require subsidising unit costs through diversifying the financial base. This can be achieved through a culture of engaging in research with, e.g., the private sector such that resources generated/acquired can subsidise related service areas and ultimately reduce unit costs.

Achieving Optimal Academic Staff Numbers

The interplay between part-time and full-time staff as elaborated in the teaching sector creates a gap between the desired and the actual staff to students' ratios. This gap arises because of policies aimed at reducing expenditure on staff emoluments. As such, recruitment of part-time staff which is on the basis of available teaching load rather than the established staff to student ratios alongside fewer full-time academic staff is favoured. As a result, effective teaching, evaluation of students performance, and students' research projects supervision are compromised. While it is not possible to accurately measure attributes in the latter statement, focusing on specific indicators is a viable starting point. Equation Eq. 5.4 as given in the previous section suggests that this gap in staff numbers, also referred to as 'optimal staff load indicator in this paper, can be explored using an exponential function. The resulting behaviour of staff capacity indicator with its dependencies is shown in Figure 5.21.

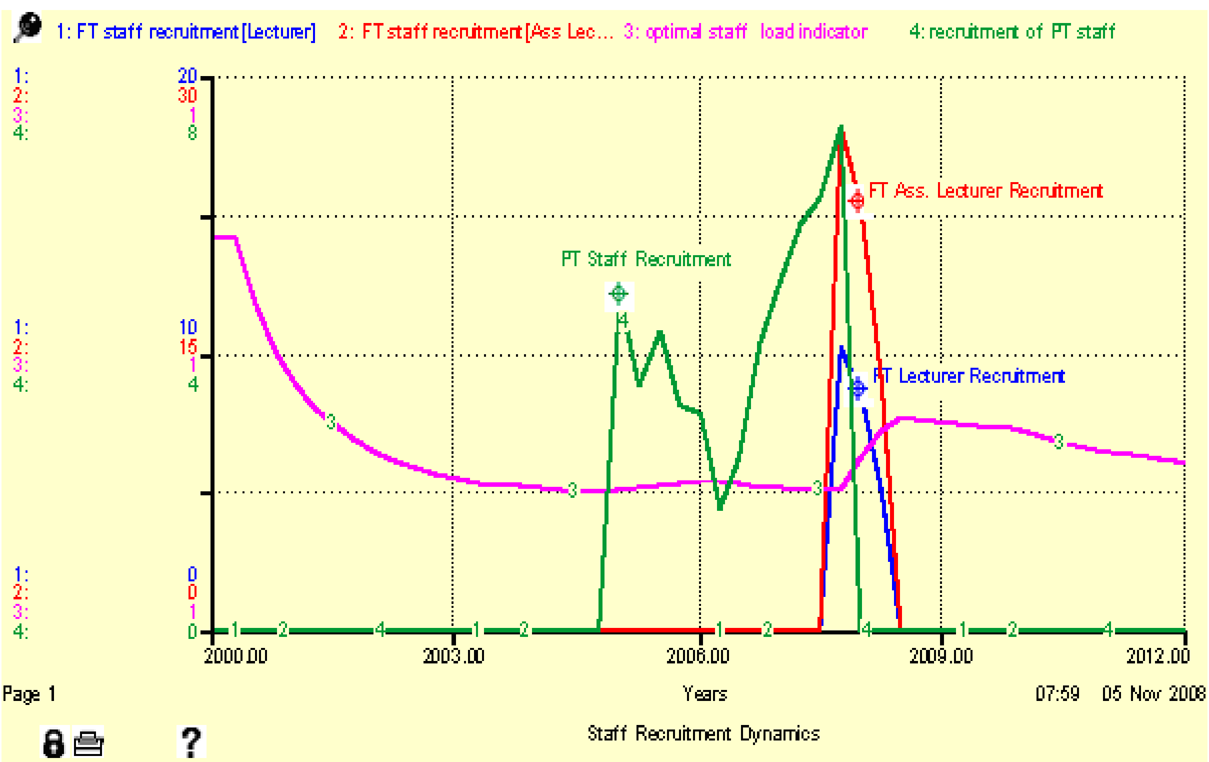


Figure 5.21: Dynamics of staff capacity indicator and its basic dependencies

It is observed that as enrolment of students rises (Figure 5.14) and a fraction of full-time staff without PhD qualification enrol for further training (Figure 3), new staff to match the increasing student numbers must be recruited. However, due to cost minimisation issues, part-time staff are employed resulting into gap in staff numbers as depicted by Figure 5.21 (PT staff recruitment graph). When new full-time academic staff are employed in the eighth year, subsequently part-time staff recruitment becomes zero and staff capacity indicator rises. The slight fall in staff capacity indicator after 2009 is due to further staff development (Figure 5.15) leading to overloading of available full-time staff, in this case without recruitment of part-time staff.

As just articulated, if ‘optimal staff load indicator’ is a good measure for optimal staff numbers given available students’ capacity, then paying attention to its dynamics enhances quality of service provision (teaching, students’ assessment and projects supervision) by a universitys academic unit. Although recruiting full-time staff boosts ’optimal staff load indicator’ and should yield optimal academic staff capacity, this only applies when the recruited staff all hold at least a PhD. On the other hand, if a fraction of the recruited full-time staff lack the minimum qualification of a PhD, subsequent pursuit for further training definitely lowers full-time staff numbers rendering optimal staff capacity unattainable even at ideal budgeted allocations.

5.7.2 Analysis QMT09 versus IUCEA Quality Checklists

The Inter-University Coucil for East Africa (IUCEA) has developed check lists for quality in three main stream HE quality areas, namely: quality of a program (IUCEA, 2008: Vol.1), quality of an institution (IUCEA, 2008: Vol.3), quality of internal quality assurance system (IUCEA, 2008: Vol.4). By contrasting QMT09 scope against these streams as contained in Table 5.2, it is observed that QMT09 satisfies all the three IUCEA check lists for quality. As such QMT09 is useable as a tool for: program quality analysis, institutional quality analysis as well as internal quality assurance system analysis. The quality checklists in ‘bold’ in Table 5.2 depict factors in the institutional quality queckList that replicate in quality of program and internal quality assurance system contexts. Detailed discussions on the actual model variables in the third column are avoided at this point as the same is given in the early sections of this chapter (e.g., Table 5.1).

The context of Quality of an Institution		
Quality checklist	**Corresponding QMT09 sectors**	**Actual variable(s) in QMT09**
Stakeholders requirements (government, labour market, students and parents, academic world)	Cross-cuts most sectors	Examples include: quality of staff, graduation rate, number of applicants per place, staff to students' ratio, etc
Adherence to mission statements	All sectors make QMT09 relevant to diverse quality goals	Diverse variables from different sectors apply
Policy planning	All sectors except quality of outcomes sector	Diverse variables from these sectors may be applicable
Governance structure	Not applicable (N/A)	N/A
Quality of academic staff	Academic staff sector	quality of academic staff
Quality of support staff	Resources sector	Quality of services provided
Funding	Funding sector	Tuition, grants, and internal income funding sources
Educational activities	Student, staff, and teaching sectors	Students' assessment of teaching, class size, staff qualifications
Quality of research	Research & publications sector	quality of research
Contribution to society	Research & publications sector	Self funded projects stock
Quality assurance	Quality of outcomes sector	All variables in this sector
Achievements	Quality of outcomes sector	All variables in this sector
Stakeholder satisfaction	Teaching and research sectors	Alumni and employer feedback
The context of Quality of Program		
Expected learning outcomes	Quality of outcomes sector	Average students' grades
Organisation of Program	Staff and teaching sectors	Quality of staff, courses stock
Student evaluation	Teaching sector	Students' assessment of teaching
Student support	Funding sector	Students' wellfare allocations
Facilities and infrastructure	Resources sector	Resources availability indicator
Staff development activities	Staff and funding sectors	Staff training indicator
Benchmarking	Cross-cuts most sectors	E.g., class size, staff:student ratio
Achievements/the graduates	Quality of outcomes sector	Average student outcomes
The context of Quality of Internal Quality Assurance System		
Monitoring	All sectors except quality of outcomes sector	Diverse variables from these sectors may be applicable
QA of facilities	Resources sector	Resources availability ratio
QA of student support	Resources sector	Quality of services' provision
Self assessment	Quality of outcomes sector	All variables in this sector
Information systems	N/A	N/A
Internal audit	Cross-cuts most sectors	Examples include: class size, demand for staff training versus allocations to staff training, etc

Table 5.2: Comparative Analysis of QMT09's scope versus IUCEA Quality Checklists

Judging by the overall presentation in Table 5.2, the effectiveness of QMT09 in addressing the three higher education quality contexts is further confirmed. It seems therefore, safe to state that QMT09 is not only a tool for testing quality improvement policies but also a theoretical framework for establishing structural boundaries on specific higher education quality concerns. This is because QMT09 is based on both data and theoretical statements about HE quality causal processes over time as identified by the stakeholders.

5.8 Validation of SyDPAR

The effectiveness of SyDPAR as an approach for solving dynamically complex problems has been tested through its application to the HE problem area. Most importantly, involving HE managers/stakeholders in the model building process was a vital element in confirming the hypothesis that SyDPAR is a client centred participative modelling approach. Indeed, the three reasons for client involvement which include: identification of problems, provision of information, and implementation of model results, are catered for in the "PA" and "SR" cycles. A fourth and probably only reason that caters for client's individual benefit from modelling participation is addressed in the "MP" cycle for which clients are perceived as apprentices of model development under guidance of modellers, i.e., clients learn how the qualitative model of their issue can be translated into a formal model. In addition, emerging from the stakeholders engagement was the need to include "information flow" in the architecture since the outcomes of an earlier phase influences several later phases, and not only the immediate sequenced phase. This is depicted by information flow arrows in the enriched conceptual SyDPAR architecture as shown in Figure 5.22.

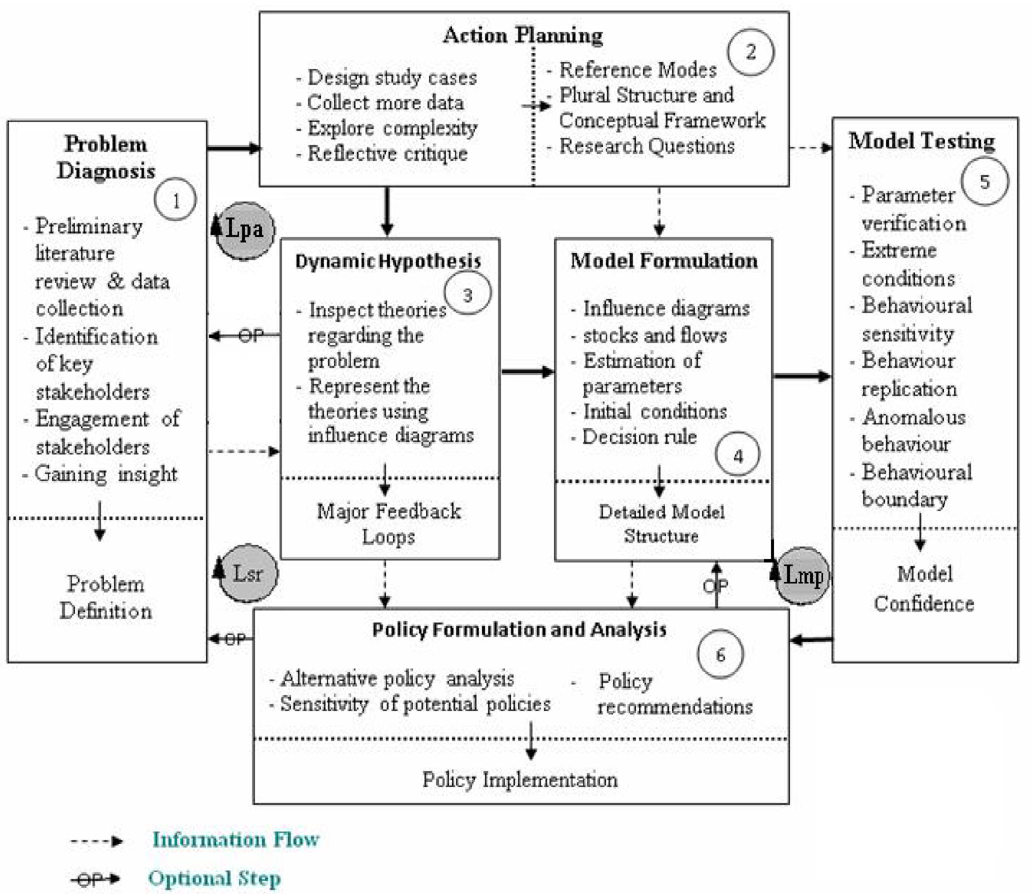


Figure 5.22: The Validated SyDPAR Modelling Architecture

5.8.1 Analysis of SyDPAR by Theoretical Research Aims

Following from the validated SyDPAR architecture (Figure 5.22), Table 5.3 provides a rigour-relevance analysis of SyDPAR accross seven basic research aims. These research aims were distilled from both SD literature (GröBler and Miling, 2009; Rouwette and Hoppenbrouwers, 2008; Sterman, 2002), and PAR literature (Cronholm and Goldkuhl, 2004; Rose, 2000).

Research Aims	**SyDPAR Design Perspective**
Problematisation (clarifying unclear situations)	explicitly addressed in step 1. If the problem is ill defined, then problem articulation (PA) cycle iterations are inevitable.
Data collection/analysis	addressed in step 2.
Detailed methodological description	complete illustrations of step1 to step 6 including the three dynamically emergent cycles.
Scientific rigour	production of strong results through iterations in 'PA', 'MP', and 'SR' cycles.
Validation of findings	arises from engagement with stakeholders especially during the problem articulation and modelling proficiency cycles.
Theory development	through the 'PA' cycle, the dynamic hypothesis is inductively developed from numerical, written, and verbal data. The hypothesis is tested by model validation techniques, leading to the overall theory supported by the simulation model.
Generalizability	relevance to different SD approaches including: expert modelling, GMB, learning support systems, modelling for learning, and targeted participative modelling.

Table 5.3: Analysis of SyDPAR process design by theoretical research aims

To ensure that practice and theorisation are concurrently addressed, the analysis in Table 5.3 is grounded on three drivers: the salience of issues studied (PA cycle), the application of available knowledge (MP cycle), and production of strong results by ensuring relevance of the solution to a specific environment (SR cycle). These principles are properly cultivated into the SyDPAR's solution process as a measure of rigour and relevance.

5.9 Conclusion

This chapter was devoted to testing the effectiveness of SyDPAR in addressing dynamic problems in HE quality management. The outcome of which was the model for HE quality management also referred to as QMT09. The guiding principle in applying SyDPAR that resulted into QMT09 was rigour-relevance or validity-utility. The empirical rigour and relevance of a model are closely related to problem identification and model conceptualisation (Kopainsky and Luna-Reyes, 2008). These two unique processes are reflected by problem articulation cycle within the SyDPAR stages and have been clearly discussed in the model development section of this chapter. Furthermore, the chapter presents results of model calibration and validation thereby strengthening the empirical rigour in the relationship between data and model structure. Generally, the analysis made in this chapter provides the basis for overall conclusions of this research as presented in the next chapter.

Chapter 6

Discussions and Conclusions

6.1 Introduction

This chapter presents the conclusions reached by the study at the end of the research cycle. This is presented first by giving the overall conclusions, then discussing contributions made by this research to the theory and practice of systems dynamics and higher education quality management systems. Further, the contributions in accordance with the the research objectives are presented. The chapter closes by presenting avenues for further research resulting from the findings and limitations of this study.

6.2 Discussion of Findings

This research started by highlighting the refutable claims in the recent previous research, including:

- That the factors that influence quality have different scales of effect on quality, e.g., quality of academic staff is the main challenge (Vinnik and Scholl, 2005)
- That quality is too subtle to be meaningfully measured (Srikanthan and Dalrymple, 2007)

The findings of this research are more or less new positions on these claims, as are subsequently highlighted. In addition, the research questions are examined in greater depth and then policy directions on HE quality issues are finally discussed.

6.2.1 Nature of Quality Problems

The advancement of research in quality management DSS requires good understanding of the nature of quality influencing factors and their effect on choice of intervention approach. This research has established that the methodological strength of an approach determines the focus of enquiry whether on qualitative factors, qualitative factors or the entire spectrum of qualitative-to-quantitative quality management issues. The contention of this research is not that the factors that influence quality have different scales of effect on quality but rather, that the different approaches to quality management have limited scope and hence range of problems they can address. As such, classifying quality management approaches according to the nature of problem solved is well served in articulating their effectiveness to the different problem space. Figure 6.1 is presented here for this purpose. It classifies six quantitative methods along the same continuum for structured to unstructured problem spaces. The other continuum looks at the nature of problems addressed ranging from static (linear) to dynamic. For clarity and ease of understanding, some studies are joined by lines within their methodological grouping, to illustrate the range of problems addressed by the same methodology.

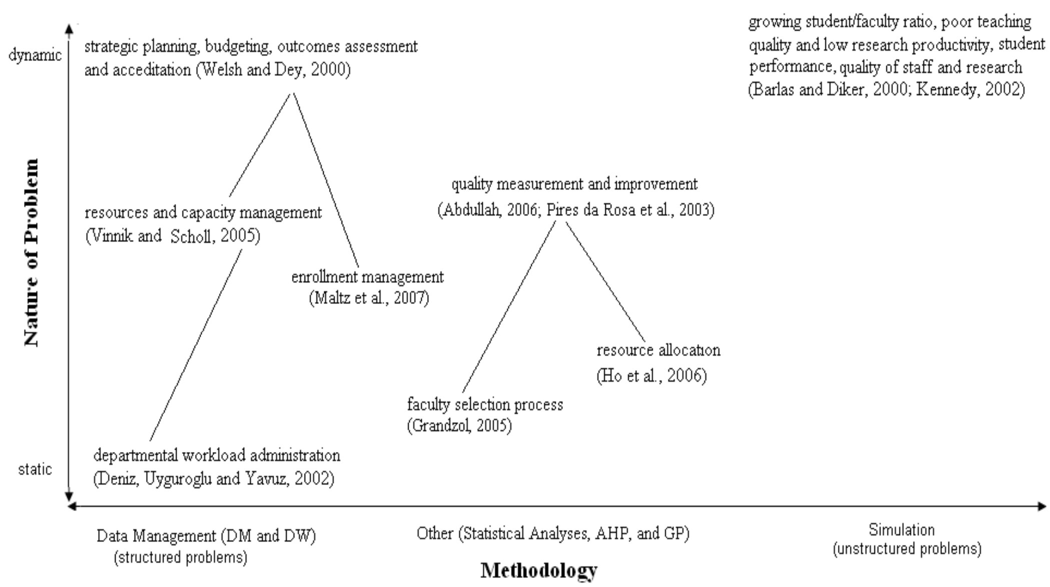


Figure 6.1: Classification of Intervention Approaches in Higher Education Quality Issues

The classification presented in Figure 6.1 provides the basis for debate over appropriateness of one methodology or intervention approach over another while encouraging adoption of relevant methodologies for different problem situations. For example, Abdullah (2006) uses statistical analysis to provide empirical evidence by comparing relative efficacy of three measurement instruments of service quality: the HEdPERF (Higher Education-Performance) scale, SERVPERF (Service Performance) and the moderating scale of HEdPERF-SERVPERF (Higher Education-Performance and Service Performance) scale within the higher education setting. Abdullah assesses the relative strengths and weaknesses of each instrument in order to determine the best measurement capabilities in terms of unidimensionality, and subsequently modified HEdPERF.

Comparative tests of the unidimensionality of the scales were conducted using goodness-of-fit indices from factor analysis to see if the one-factor model fit. Overall tests as highlighted by Abdullah (2006) indicate that the modified HEdPERF scale was superior to the SERVPERF and to the combined HEdPERF-SERVPERF scales in terms of: reliable estimations, greater criterion and construct validity, greater explained variance and better model fit. On the other hand, Grandzol (2005) uses AHP for setting priorities and selecting alternatives in recruiting faculty staff. Grandzol reiterates that hiring the wrong person may lead to dysfunctional departments, dissatisfied students, and, eventually, repeat efforts. In comparison, the latter fits its lower placement in Figure 6.1 compared to the former given its focus on the linear problem of faculty selection process.

Figure 6.1 clearly demonstrates that the simulation method or rather system dynamics modelling and simulation is useful in addressing dynamic and unstructured problem characteristics. Thus the contribution of this research partly is reflected in the design of participatory system dynamics modelling whereby the roles of clients or participants as contributors to modelling are reflected in the design itself.

6.2.2 Measurement of Quality

The qualitative and quantitative facets of quality have escalated mixed positions on whether quality can be meaningfully measured or not. This thesis is based on the view that quality can be measured. Certainly, the quantitative facets of quality are measurable in objective terms while the qualitative ones can only be represented by mathematical logic derived from data. The literature is not silent on quality measurement either. Al-Turki and Duffuaa (2003) suggest performance measures for academic departments in relation to teaching quality, research quality, and student outcomes quality. Vinnik and Scholl (2005) on their part, develop a mathematical formular for analysing the effects of resources on staff quality. Other researches have used a combination of statistical and mathematical approaches to measure different quality issues (Try and Grögaard, 2003; Ho *et al.,* 2006; Grandzol, 2005). Another category of researchers have relied on the vast volumes of data in HEIs to develop data warehouse from which decisions on quality issues are made (Welsh and Dey, 2002; Deniz and Ersan, 2001; Deniz *et al.,* 2002; Maltz, 2007).

The SD modelling approach adopted in this research is underpinned by differential equations and the task was to represent the quality system structure as rates of change that are supported by SD tools. While this was achieved as supported by the stocks and flows in chapter 5, measures for other factors were made using: data imported from Excel (e.g., appraisal data to establish staff competence), "if-then" statements e.g., for allocation of funds based on established demands and availability of funds, pulse function e.g., for periodic recruitment of new staff when needed basing on staff to students' ratio, and other mathematical formulae as shown in Appendix A.

By all standards, when it comes to measurements, no research can avoid mathematical representation and data inference. The degree of accurancy with which these measurements are made depends on the understanding of the software used by the researchers. A further enriching feature of SD tools is the ability to represent mental models of the stakeholders. This has even been strengthened by methods of analysing qualitative data in SD by Luna-Reyes aand Andersen (2003).

As for the design of this research, a preliminary model was first developed following the first field study. The subsequent engagement with HE management stakeholders in participative modelling sessions meant that data in support of the qualitative facets of quality was aggresively sought. The second field study during the later stages of modelling further provided data needed to ensure that measurements of the model variables were consistent with the educational settings. All these strategies culminated into model equations part of which have been elaborated in chapter 5 and the rest given in Appendix A.

6.2.3 Research Questions Analysis

The three research questions addressed in this thesis sought better methodological guidelines for involving clients and stakeholders and requirements of future DSS in dealing with quality problems. The analysis in chapters three to five implicitly provide answers to these questions. More specifically, the first question is partially answered in chapter 2, section 2.3.7 and chapter 3, section

3.4. The second question is answered in chapter four, section 4.4. Chapter 5, section 5.7.2 provides answers to the third question. Since the main objective of this research is strongly inclined to the first question, a further analysis is henceforth given.

SyDPAR has been developed as a client centred modelling architecture. As such, the three reasons for client involvement which include: identification of problems, provision of information, and implementation of model results, are catered for in the "PA" and "SR" cycles. A fourth and probably only reason that caters for client's individual benefit from modelling participation is addressed in the "MP" cycle for which clients are perceived as apprentices of model development under guidance of modellers, i.e., clients learn how the qualitative model of their issue can be translated into a formal model. In addition, as a rigorous participative modelling architecture in the context of client involvement, a further analysis is made in Table 6.1.

Indicators of modelling rigour	Modelling design considerations	
	The literature	Context of client involvement
Problem articulation cycle	suitability of SD for client's problem, purpose of modelling effort, clarity of client's problem (Rouwette and, Vennix, 2006), dealing with messy problems (Vennix, 1999)	clients as problem owners (identifiers of problem of interest, and providers of information required in the modelling effort)
Modelling proficiency cycle	Evolving models (Scholl, 2004; Galbraith, 1998), conversion of real life situation into simulation model (Forrester, 1994), models as "boundary-objects" as well as models as "micro-worlds" (Zagonel, 2002)	clients as apprentices of model development under guidance of modellers. Boundary objects reflect qualitative models, while micro-worlds are quantitative models
Solution refinement cycle	Model as a "micro-world" (Zagonel, 2002)	clients as implementers of modelling results, working closely with modellers towards achieving a better solution of the problem

Table 6.1: Analysis of client involvement in modelling

Table 6.1 suggests that a rigorous participative modelling design addresses both clients' contribution to- and benefits from- modelling simultaneously. In the 'PA' cycle, modelling is more and more seen as an aid in communication about the problem, which stimulates participants' learning about problem structure (Rouwette *et al.*, 2002). In the 'MP' cycle, modelling is viewed as building participants' proficiency in converting a real life situation into a simulation model. Lastly, in ‘SR’ cycle, modelling involves participants and modellers working closely to improve the system. Ultimately, the three ‘cycles’ view of modelling developed in this research seems applicable across all participative modelling projects be it qualitative versus quantitative or small versus large models.

6.2.4 Policy Directions for HE Quality Management

Two policy directions for quality management can be summarised from this research:
First, that quality cannot be maintained without controlling student enrolment growth. Although exponential growth in students’ numbers as discussed in this thesis is justifiable by the fact that Ugandan universities are generally inadequately funded and hence larger enrolments are needed to compensate funding gaps, significant rise in enrolment undermines any university’s capacity to maintain quality. A possible remedy to this conflict would be to reduce ‘tuition-based’ expenditures by creating separate channels of funding other non-teaching/learning activities such as: research, staff training, and infrastructure development. These channels would take the form of “other incomes” including: a) Prospecting research grants from government, donor institutions, and bilateral organisations; b) Strengthening internal funds generation through conducting short skills courses, consultancies, hire of premises, etc. Only then will universities be empowered to develop the culture of aggressive research prospecting while strengthening graduate training base, enrolling manageable students, and ultimately achieving the dual aim of teaching and research excellence.

Secondly, seeking optimal students’ enrolment for an increase in tuition fees cannot easily be implemented as it would inevitably invite resistance from most stakeholders, namely: students, parents, politicians, and the government. On the other hand, measuring the academic return on investment in terms of quality of outcomes as justification for an increase in tuition would instead attract these stakeholders’ support. This is safely achievable by adopting QMT09, since exploring the effects of policy changes and experimenting with alternative policy formulations is not feasible in the real world except through computer simulations.

Finally, the emerging policy directions discussed both here and in the policy analyis section of chapter 5 are founded on the SD modelling concept that structure generates behaviour. While this concept is not new as it has been repeatedly articulated by influencial authors (Sterman, 2000), the model developed in this research goes further by tapping into the power of participative modelling procedures of developing large models. In this respect, the procedure allowed for realistic and sufficient representation of a real HE quality management system, in which the constituent variables and their functional relationships, including the underlying assumptions, were formalized and hence made transparent.

6.3 Conclusions

6.3.1 Overall Conclusions

The research aimed to integrate SD and PAR in order to design more rigorous participative modelling projects by emphasising clients' contributions to modelling and benefits from modelling involvement in the modelling architecture itself. A decision support tool for HE quality management was subsequently developed as the measure of relevance of this integration. As such, two outstanding outcomes were achieved: 1) the integrated participative modelling approach, also referred to as SyDPAR; and 2)the decision support tool for HE quality management underpinned by feedbacks and differential equations, also referred to as QMT09.

6.3.2 Summary of Contributions

As described in chapter one, this research originates in observation that existing DSS on HE quality issues emphasise specific aspects of quality rather than the entire facets of quality problems. The main cause of this bias was found to be linked to the nature of quality itself (complex, dynamic, non-linear), and the inadequacy of most existing methods to provide equal means of addressing the qualitative and quantitative facets of quality including the human elements involved. Therefore, the problem addressed in this research had a dual character: practical (dealing with complex, dynamic, non-linear issues) and theoretical (lack of methodological guidelines for solving quality problems without compromising problem scope).

By adopting the SyDPAR approach, this research has aimed to address both theoretical and practical aspects of the reiterated problem. Consequently, the research has made contributions to theory and practice of participative modelling as well as higher education quality management systems research.

Contributions to Theory

1. Re-conceptualisation of Participative Modelling Design Effectiveness. Research into improvement of the design of system dynamics modelling process has attracted little attention probably because system dynamicists find existing designs adequate. However, participative modelling which involves clients/practitioners without prior modelling knowledge requires methodological details that show how a real-life situation translates into a simulation model. By providing a generic process design for participative modelling this research extends the view of participative modelling into that where practioners' contributions to- and benefits from- modelling involvement are reflected in the modelling process design itself. Furthermore, the changing roles of both the expert modeller and the practitioner or clients during modelling reflect the symbiotic dependence between these roles that accounts for the overall sucess of any participative modelling project. This contribution is detailed in section 2.3.7 and section 6.2.3

2. Feedback Systems Thinking for HE Quality Problem Representation. As presented in chapter one, higher education institutions' quality management related problems are rooted in the underlying dynamics, complexity and non-linearity of the system structure in educational settings. An attempt to address these problems before understanding their causes has often led to no lasting solution. Feedback systems thinking, however, has not yet been placed in main stream methods for HE quality studies as depicted in part by scarcity of publications using this approach in the HE body of literature. This study has gone beyond the typical state-of-the-art review and has placed feedback systems thinking among methods for HE quality problem conceptualisation/representation. This placement has provided insight into the rationale and relevance of feedbacks in HE quality research. This contribution is detailed in section 2.5

3. Theoretical Validation of SyDPAR. The Design Science IS research framework has been used to assess the rigour and relevance of SyDPAR as a participative modelling process tool, the analysis of which is contained in Table 5.3. Specifically, rigour results from reflection within the modelling design itself, the practioners' contributions to- and benefits from- involvement in a modelling project . This is highly linked to the view that participative modelling progresses through cycles of 'problem articulation', 'modelling profficiency', and 'solution refinement'. On the other hand, relevance seeks to evaluate the usefulness of SyDPAR in addressing complex problems. The results presented in this research attest to this usefulness. More specifically, this contribution is detailed in section 5.8.

Contributions to Practice

1. Generic Participative Modelling Design. The development of the SyDPAR as a participative modelling design has made a contribution towards the perceived lack of methodological guidilines for showing how a problem translates into a model while simultaneously emphasising practitioners contributions in modelling. By using this design, a practitioner/client possessing only the necessary domain knowledge finds his/her contribution reflected in the modelling process itself. In addition, the design gives activities and outcomes of every process thereby encouraging transition to the last stages on basis of explicit and acceptable outcomes of the previous phases. Ultimately, the cycles espoused in this process design demonstrates that new designs can achieve modelling of a thoroughness and usefulness far in excess of typical models found in academic publications.

SyDPAR occupies a niche defined by the answers it provides to the following modelling design questions:

- Can the modelling process design effectively balance the goals of fundamental modelling understanding with consideration of usefulness of the resulting models?
- How should participative modelling be rigorously designed?
- How does modelling design influence outcomes?
- What is the significance of inclusion of clients' contributions to- and benefits from- modelling in the actual design?

This contribution is detailed in section 3.4.

2. Decision Support Tool for Higher Education Quality Management. Quality management is the core higher education research since it encompasses the overall quality concerns (assurance and improvement). As a result, most studies have narrowed the scope, in some cases disguising as addressing important concepts rather than the entire spectrum of possibilities. The tool developed in this thesis attempts to address quality in its wider scope of quality concerns. In doing so, the contribution of this thesis is provision of a general theory of HE quality management system that integrates funding, enrolment and quality using feedbacks and validated in a simulation model underpinned by differential equations.

More visibly, the significnce of QMT09 is defined by the questions it addresses including:

- How can quality of staff, teaching, research and students' achievements be improved?
- What are the effects of increased tuition?
- What is the relationship between research throughput and learning achievements?
- When is it appropriate to increase graduate training?
- How does quality of admitted students affect quality of students achievements?
- How does the differences in admission rates and graduation rates affect the quality of institutional outcomes
- How do students and resources (academic staff, computers, books, lecture space, laboratories) ratios influence learning achievements?
- What is the relationship between the factors that underlie optimal students enrolment?
- How do student grades translate into quality of students outcomes?
- Can decreased teaching be substituted by an increase in infrastructure and other academic resources?

This contribution is detailed in section 5.3.

6.3.3 Contributions by Research Objectives Analysis

The specific contributions of this thesis are highly correlated with the specific objectives achieved. These achievements are discussed by analysing outcomes of every objective in light of underlying intervention approach as presented in Table 6.2.

Research Objective	**Descriptive Approach**	**Outcomes**
Investigate the benefits of integration of SD and PAR	Review of literature	Problem structure and model boundary
Develop an integrated SD and PAR modelling approach	Review of literature	SyDPAR architecture
Identify the factors that influence HE quality	- Interviews - Group discussions	Feedback structures of HE quality issues
Develop an SD model for HE quality management	System dynamics tools	Simulation results
Validate the model using both standard tests and benchmarked quality checklists	- Standard SD tests - Comparative analysis using quality checklists	- Behavioural and structural validation results - Empirical analysis results
Validate the integrated approach (SyDPAR)	- Theoretical validation - Empirical validation	- Rigour-relevance analysis - Clients' reflective critique

Table 6.2: Analysis of research objectives, descriptive approach and outcomes

As depicted in Table 6.2, the outcomes of this research can be summarised into three. First, the research develops an integrated methodological framework for participative modelling. Second, the research demonstrates the relevance of system thinking tools as used within this new methodological framework in representing complex quality management problems. In real life, these tools help academic managers and administrators in better identifying and understanding the basic cause-effect structure underlying their situations. Third and most significant, the research implements a dynamic model code named "QMT09" for HE quality management. QMT09 could assist academic administrators and managers in testing their quality management policies, thereby facilitating their actions on the basis of good preferences rather than use of trial-and-error procedures or learning from accidents of past experience.

6.4 Limitations

The tool presented in this thesis (QMT09) addresses the general HE quality management challenges in the Ugandan context in particular and the developing countries in general. The main limitation of this tool is exclusion of pre-higher education data and post higher education data which are important influencing factors on HE quality issues. The minimal or lack of emphasis of these boundary factors were inevitable due to the unavailabiliy of supporting data for meaningful inclusion.

6.5 Future Research

In light of the outcomes of this thesis, future research is required in two areas: i) extension of the application of SyDPAR to other participative modelling research projects and ii) further testing/refinement of QMT09.

6.5.1 Challenges and Directions of use of SyDPAR

The use of SyDPAR as a generic process design for participative modelling faces challenges that are also reflected in requirements for modelling design effectiveness. The three reasons for clients' involvement in participative modelling: clients as identifiers of problems of interest, clients as sources of information required in the modelling effort, and clients as implementers of modelling results, pause new challenges to participative modelling design. They espouse the view of clients' as contributors to modelling as well as beneficiaries from modelling involvement. These realities should be included in the modelling design. Thus, more model building projects using the SyDPAR strategy are needed in order to prove its usefulness and emphasize and refine the choices available to model builders for specific types of models (large vs. small or qualitative vs. quantitative). This study has provided a generic design for participative modelling, thus, the existing knowledge encapsulated in this and other areas subsumed by participative modelling can be reused and customised towards the creation of a formal methodology for participative system dynamics modelling.

6.5.2 Further Testing and Refinement of QMT09

The quality management tool (QMT09) developed in this study proves the feasibility of system dynamics modelling in addressing quality management concerns. However, the tool is by no means complete in addressing the entire quality management challenges. Further refinement can be achieved by its application to a significant number of higher education quality case studies. This may lead to changes in the focus of the tool and to the addition and/or modification of structure elements and selection of new policies to test. The tool in its current form emphasises institutional quality and programme quality issues but without consideration of all the factors involved (refer to Table 5.2 for details). Therefore extending its scope to accomodate the latter would be well served. Equally important would be to explore the effect of pre-university training on quality of university training as this was not included in the current tool/model given the lack of supporting data.

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Appendix A: MODEL EQUATIONS FROM STUDENT AND TEACHING SECTORS

Student Sector

```
Admitted students[PhD(t)=Admitted students[PhD(t-dt)+(admission rate[PhD]-admission attrition[PhD]-registration[PhD])*dt
INIT Admitted  students[PhD]=0
Document: The stock of PhD students admitted
Admitted students[Masters](t)=Admitted students[Masters](t-dt)+(admission rate[Masters]-admission attrition[Masters]-registration[Masters]*dt
INIT Admitted  students[Masters] = 0
Document: The stock of Masters students admitted
Admitted  students[PGD](t) = Admitted students[PGD](t-dt)+(admission rate[PGD] + additional admission rate[PGD] -
admission attrition[PGD] - registration[PGD]) * dt
INIT Admitted  students[PGD] = 0
Document: The stock of PGD students admitted
Admitted  students[Undergraduate](t) = Admitted  students[Undergraduate](t - dt) + (admission rate[Undergraduate] + additional admission
rate[Undergraduate] - admission attrition[Undergraduate]- registration[Undergraduate])* dt
INIT Admitted  students[Undergraduate] = 0
Document: The stock of Undergraduate students admitted

INFLOWS: Document: The admission rates are the numbers of PhD, Masters, PGD, and Undergraudate students admitted per year.

admission    rate[PhD] = actual  intake[PhD]
admission    rate[Masters] = actual  intake[Masters]
admission    rate[PGD] = actual  intake[PGD]
admission    rate[Undergraduate] = actual  intake[Undergraduate]
additional  admission  rate[PhD] = admission    rate[PhD]*(additional  admission  ratio-additional  admission  ratio)
additional  admission  rate[Masters] = admission    rate[Masters]*(additional  admission  ratio-additional  admission  ratio)
additional  admission  rate[PGD] = admission    rate[PGD]*(additional  admission  ratio-additional  admission  ratio)
additional  admission  rate[Undergraduate] = admission    rate[Undergraduate]*additional  admission  ratio

OUTFLOWS: Document: The admission attritions are the numbers of PhD, Masters, PGD, and Undergraudate students who are admitted but do not
report for studies. This is based on historical trends. For instance 21 percent of admitted graduate students do not take-up their courses.

admission    attrition[PhD] = admission    rate[PhD]*admission    attrition  ratio[PhD]
admission    attrition[Masters] = admission    rate[Masters]*admission    attrition  ratio[Masters]
admission    attrition[PGD] = admission    rate[PGD]*admission    attrition  ratio[PGD]
admission    attrition[Undergraduate] = admission    rate[Undergraduate]*admission    attrition  ratio[Undergraduate]
registration[PhD] = admission    rate[PhD]*registration  fraction[PhD]
registration[Masters] = admission    rate[Masters]*registration  fraction[Masters]
registration[PGD] = admission    rate[PGD]*registration  fraction[PGD]
registration[Undergraduate] = admission    rate[Undergraduate]*registration  fraction[Undergraduate]
Droppedout  Students[admission  category](t) = Droppedout  Students[admission  category](t - dt) + (dropout  rate[admission  category] +
dismissed  retake  rate[admission  category]) * dt
INIT Droppedout  Students[admission  category] = 0

OUTFLOWS:  Document: The dropout rates are the numbers of PhD, Masters, PGD, and Undergraudate students who leave their courses per year. These
rates are modelled as leakage outflows from a conveyor of students on programs. In practice, these rates are obtained from historical behaviour

dropout  rate[PhD] = LEAKAGE OUTFLOW
LEAKAGE FRACTION = 0.01
NO-LEAK ZONE = 1
dropout  rate[Masters] = LEAKAGE OUTFLOW
LEAKAGE FRACTION = 0.01
NO-LEAK ZONE = 1
dropout  rate[PGD] = LEAKAGE OUTFLOW
LEAKAGE FRACTION = 0.008
NO-LEAK ZONE = 0
dropout  rate[Undergraduate] = LEAKAGE OUTFLOW
LEAKAGE FRACTION = 0.008
NO-LEAK ZONE = 1

OUTFLOWS:  Document: The "dismissed retake" students are the category of students repeating courses beyound the normal study period but getting
dismissed per year because of further failures. These rates are a product of retake  completion  rate and retake dismissal fraction/ratio
dismissed  retake  rate[PhD] = retake  completion  rate[PhD]*retake  dismissal  fraction[PhD]
dismissed  retake  rate[Masters] = retake  completion  rate[Masters]*retake  dismissal  fraction[Masters]
dismissed  retake  rate[PGD] = retake  completion  rate[PGD]*retake  dismissal  fraction[PGD]
dismissed  retake  rate[Undergraduate] = retake  completion  rate[Undergraduate]*retake  dismissal  fraction[Undergraduate]

retake  dismissal  fraction[PhD] = 0.05
retake  dismissal  fraction[Masters] = 0.1
retake  dismissal  fraction[PGD] = 0.05
retake  dismissal  fraction[Undergraduate] = 0.1

OUTFLOWS: Document: The retake rates are the numbers of PhD, Masters, PGD, and Undergraudate students who fail to complete their studies in
the normal study period per year. These therefore extend their study period by a year or two.

retake  rate[PhD] = Graduating  Students[PhD]*retake  fraction[PhD]
retake  rate[Masters] = Graduating  Students[Masters]*retake  fraction[Masters]
retake  rate[PGD] = Graduating  Students[PGD]*retake  fraction[PGD]
retake  rate[Undergraduate] = Graduating  Students[Undergraduate]*retake  fraction[Undergraduate]

Document: The retake students stock is a conveyor that keeps PhD, Masters, PGD, and Undergraudate students who fail to graduate in normal
```

```
time for an extra year or two.

Retake Students [Masters](t) = Students  on  Retake[Masters](t - dt) + (retake  rate[Masters] - retake  completion  rate[Masters]) * dt
INIT Students  on  Retake[Masters] = 0
TRANSIT TIME = 1
INFLOW LIMIT = INF
CAPACITY = INF

Retake Students[PGD](t) = Students  on  Retake[PGD](t-dt) + (retake rate[PGD] - retake  completion  rate[PGD]) * dt
INIT Retake Students[PGD] = 0
TRANSIT TIME = 1
INFLOW LIMIT = INF
CAPACITY = INF

Retake Students[Undergraduate](t) = Students on Retake[Undergraduate](t-dt)+(retake rate[Undergraduate]-retake completion rate[Undergraduate])*dt
INIT Retake Students[Undergraduate] = 0
TRANSIT TIME = 1
INFLOW LIMIT = INF
CAPACITY = INF

Document: The graduation stock of students due for graduation with PhD, Masters, PGD, and/or Undergraudate degrees.

Graduating  Students[PhD](t) = Graduating  Students[PhD](t-dt)+(completion rate[PhD] - retake rate[PhD] - graduation rate[PhD])*dt
INIT Graduating  Students[PhD] = 0

Graduating  Students[Masters](t) = Graduating  Students[Masters](t - dt) + (completion  rate[Masters] - retake  rate[Masters] -
graduation  rate[Masters]) * dt
INIT Graduating  Students[Masters] = 0

Graduating  Students[PGD](t) = Graduating  Students[PGD](t - dt) + (completion  rate[PGD] - retake  rate[PGD] - graduation  rate[PGD]) * dt
INIT Graduating  Students[PGD] = 0

Graduating  Students[Undergraduate](t) = Graduating Students[Undergraduate](t-dt) + (completion rate[Undergraduate]-retake rate[Undergraduate]-
graduation  rate[Undergraduate]) * dt
INIT Graduating  Students[Undergraduate] = 0

OUTFLOWS: Document: The graduation rates are the numbers of students per year graduating with PhD, Masters, PGD, and/or Undergraudate degrees.

graduation  rate[PhD] = Graduating  Students[PhD]*graduation    fraction[PhD]+graduating  retake  students[PhD]
graduation  rate[Masters] = Graduating  Students[Masters]*graduation    fraction[Masters]+graduating  retake  students[Masters]
graduation  rate[PGD] = Graduating  Students[PGD]*graduation    fraction[PGD]+graduating  retake  students[PGD]
graduation  rate[Undergraduate] = Graduating  Students[Undergraduate]*graduation fraction[Undergraduate]+graduating retake students[Undergraduate]

Document: The graduation fraction is the percentage of PhD, Masters, PGD, and Undergraudate that graduate annually
graduation    fraction[PhD] = 0.4
graduation    fraction[Masters] = 0.8
graduation    fraction[PGD] = 0.9
graduation    fraction[Undergraduate] = 0.9

Document: The potential applicants are stocks of students from which PhD, Masters, PGD, and Undergraudate can be admitted
Potential  Applicants[PhD](t) = Potential  Applicants[PhD](t - dt) + (demand  for  courses[PhD] - admission    rate[PhD]) * dt
INIT Potential  Applicants[PhD] = 10

Potential  Applicants[Masters](t) = Potential  Applicants[Masters](t - dt) + (demand  for  courses[Masters] - admission    rate[Masters]) * dt
INIT Potential  Applicants[Masters] = 15

Potential  Applicants[PGD](t) = Potential  Applicants[PGD](t - dt) + (demand  for  courses[PGD] - admission    rate[PGD]) * dt
INIT Potential  Applicants[PGD] = 44

Potential  Applicants[Undergraduate](t) = Potential  Applicants[Undergraduate](t - dt) + (demand  for  courses[Undergraduate] - admission
rate[Undergraduate]) * dt
INIT Potential  Applicants[Undergraduate] = 200

INFLOWS: Document: The dropout rates are the numbers of PhD, Masters, PGD, and Undergraudate students who leave their courses per year.
These are also based on historical behaviour

demand  for  courses[PhD] = estimated  applicants  per  place[PhD]*required    intake[PhD]
demand  for  courses[Masters] = estimated  applicants  per  place[Masters]*required    intake[Masters]
demand  for  courses[PGD] = estimated  applicants  per  place[PGD]*required    intake[PGD]
demand  for  courses[Undergraduate] = estimated  applicants  per  place[Undergraduate]*required    intake[Undergraduate]

Document: The research students alumni are stocks of Masters and PhD holders
Research  Students  Alumni[PhD](t) = Research  Students  Alumni[PhD](t - dt) + (research  students  graduation  rate[PhD]) * dt
INIT Research  Students  Alumni[PhD] = 0

Research  Students  Alumni[Masters](t) = Research  Students  Alumni[Masters](t - dt) + (research  students  graduation  rate[Masters])*dt
INIT Research  Students  Alumni[Masters] = 0

INFLOWS: Document: The research students graduation rates constitute the numbers of Masters and PhD students graduation per year
research  students  graduation  rate[PhD] = graduation  rate[PhD]
research  students  graduation  rate[Masters] = graduation  rate[Masters]

Document: The students on programmes stock is a conveyor that keeps registered PhD, Masters, PGD, and Undergraudate students for a preset time
 or transit time (until they are due for graduation).

Students  on  Programs[PhD](t) = Students  on  Programs[PhD](t - dt) + (registration[PhD] - completion  rate[PhD] - dropout  rate[PhD])*dt
INIT Students  on  Programs[PhD] = 0
TRANSIT TIME = 3
INFLOW LIMIT = INF
CAPACITY = INF
Students  on  Programs[Masters](t) = Students  on  Programs[Masters](t - dt) + (registration[Masters] - completion  rate[Masters] - dropout
rate[Masters]) * dt
INIT Students  on  Programs[Masters] = 0
TRANSIT TIME = 2
INFLOW LIMIT = INF
```

```
CAPACITY = INF
Students  on  Programs[PGD](t) = Students  on  Programs[PGD](t - dt) + (registration[PGD] - completion  rate[PGD] - dropout  rate[PGD]) * dt
INIT Students  on  Programs[PGD] = 40
TRANSIT TIME = 1
INFLOW LIMIT = INF
CAPACITY = INF
Students  on  Programs[Undergraduate](t) = Students  on  Programs[Undergraduate](t - dt) + (registration[Undergraduate] -
completion  rate[Undergraduate] - dropout  rate[Undergraduate]) * dt
INIT Students  on  Programs[Undergraduate] = 400
TRANSIT TIME = 3
INFLOW LIMIT = INF
CAPACITY = INF

INFLOWS: Document: The registration rates are the numbers of PhD, Masters, PGD, and Undergraudate students who are admitted and report for studies.
The are based on known registration ratio/fraction from historical behaviour.

registration[PhD] = admission  rate[PhD]*registration  fraction[PhD]
registration[Masters] = admission    rate[Masters]*registration  fraction[Masters]
registration[PGD] = admission    rate[PGD]*registration  fraction[PGD]
registration[Undergraduate] = admission    rate[Undergraduate]*registration  fraction[Undergraduate]

Document: The applicants per place are the average numbers of potential applicants for PhD, Masters, PGD, and Undergraudate training
per available number of places. These values are obtained the known historical behaviour. The estimated applicants are computed from
average applicants per place
average  applicants per  place[PhD] = 1
average  applicants per  place[Masters] = 1
average  applicants per  place[PGD] = 1.5
average  applicants per  place[Undergraduate] = 1.5

estimated applicants per place[PhD] = (effect  of  university  raking+quality of research+word  of  mouth)*average  applicants per place[PhD]
estimated  applicants per place[Masters]=(effect of university raking+quality of research+word of mouth)*average applicants per place[Masters]
estimated  applicants  per  place[PGD] = (effect of  university raking+quality of research+word of mouth)*average applicants per lace[PGD]
estimated  applicants  per  place[Undergraduate] = (effect of university raking+quality of research+word of mouth)*average applicants per
place[Undergraduate]

Document: Institutional raking is a subjectively assigned value of percieved institutional rank on national rating. The effect of this
raking is mathematically computed from it as discussed in chapter five
effect of university  raking = ((number  of  institutions+1)-institutional  ranking)/number  of  institutions
institutional  ranking = 3
number  of  institutions = GRAPH(TIME{Unitless})
(2000, 10.0), (2001, 14.6), (2002, 15.9), (2003, 21.5), (2004, 23.0), (2005, 25.5), (2006, 27.8), (2007, 27.9), (2008, 27.8), (2009, 28.2),
(2010, 31.6), (2011, 31.1), (2012, 34.6)

Document: The net students are the total numbers of students persuing the PhD, Masters, PGD, and Undergraduate courses including those
repeating
Net  students    on  programs[PhD] = Students  on  Retake[PhD]+Students  on  Programs[PhD]
Net  students    on  programs[Masters] = Students  on  Retake[Masters]+Students  on  Programs[Masters]
Net  students    on  programs[PGD] = Students  on  Retake[PGD]+Students  on  Programs[PGD]
Net  students    on  programs[Undergraduate] = Students  on  Retake[Undergraduate]+Students  on  Programs[Undergraduate]

Document: The students intake is an admission decision that uses if-else statements to determine actual intake from estimated required
intake from a pool of potentially qualified students
actual  intake[PhD] = if(required    intake[PhD]<=(Potential  Applicants[PhD]*unit  time))then(required    intake[PhD])else(Potential
Applicants[PhD]*unit  time)
actual  intake[Masters] = if(required    intake[Masters]<=(Potential  Applicants[Masters]*unit  time))then(required    intake[Masters])
else(Potential  Applicants[Masters]*unit  time)
actual  intake[PGD] = if(required    intake[PGD]<=(Potential  Applicants[PGD]*unit  time))then(required    intake[PGD])else(Potential
Applicants[PGD]*unit  time)
actual  intake[Undergraduate] = if(required    intake[Undergraduate]<=(Potential  Applicants[Undergraduate]*unit  time))then(required
intake[Undergraduate])else(Potential  Applicants[Undergraduate]*unit  time)}
```

Teaching Sector

```
Class    Size(t) = Class    Size(t - dt) + (change  in  class  size - class  size    control  rate) * dt
INIT Class    Size = normal  class  size
Document: The average number of students taught per class session

INFLOWS:
change  in  class  size = capacity increament rate*MEAN(staff to students ratio gap,effect of class size regulation)
Document: The overall effect of factors that determine rate of increase in class size

OUTFLOWS:
class  size    control  rate = difference  in    class  size*unit  time*class  size  regulation  effectiveness
Document: The class size stock maintains a normal size when the regulation of class size is strong. The class size regulation effectiveness
is estimated from actual practice, e.g., an academic unit with 300 students per class session may divide these students into two or three
parallel sessions. In this case, the greater the divisions, the higher the class  size  regulation effectiveness.

class  size  regulation  effectiveness = 0.5
Document: Documented under class size control rate
difference in  class  size = Class    Size-normal  class  size
Document: This difference is used determining the value of class size control rate
effect of class size = if(Class    Size<=normal  class  size)then(normal  class  size/normal  class  size)else((normal class size/normal class
size)-(difference  in    class  size/Class    Size))
Document: Gives the effect of class size on quality of teaching

Document: The course increament process are stocks of the oven type that accumulate number of courses offered using parameters
from an institution's strategic plan document
Course  Increament  Process[PhD](t) = Course  Increament  Process[PhD](t - dt) + (change  in  courses[PhD] - courses  increment  rate[PhD]) * dt
INIT Course  Increament  Process[PhD] = 0
COOK TIME = 4
CAPACITY = 1
```

```
FILL TIME = INF

Course  Increament  Process[Masters](t) = Course  Increament  Process[Masters](t - dt) + (change  in  courses[Masters] - courses  increment
rate[Masters]) * dt
INIT Course  Increament  Process[Masters] = 0
COOK TIME = 4
CAPACITY = 1
FILL TIME = INF

Course  Increament  Process[PGD](t) = Course  Increament  Process[PGD](t - dt) + (change  in  courses[PGD] - courses  increment  rate[PGD])*dt
INIT Course  Increament  Process[PGD] = 0
COOK TIME = 4
CAPACITY = 1
FILL TIME = INF

Course  Increament  Process[Undergraduate](t) = Course Increament Process[Undergraduate](t - dt) + (change in courses[Undergraduate] -
courses  increment  rate[Undergraduate]) * dt
INIT Course  Increament  Process[Undergraduate] = 0
COOK TIME = 4
CAPACITY = 1
FILL TIME = INF

INFLOWS: Document: Provides the rate of increase in number of available courses
change  in  courses[PhD] = delay  in  starting    new  courses[PhD]*ratio  of  desired  courses  initiated[PhD]
change  in  courses[Masters] = delay  in  starting    new  courses[Masters]*ratio  of  desired  courses  initiated[Masters]
change  in  courses[PGD] = delay  in  starting    new  courses[PGD]*ratio  of  desired  courses  initiated[PGD]
change  in  courses[Undergraduate] = delay  in  starting    new  courses[Undergraduate]*ratio of desired  courses initiated[Undergraduate]

Document: The courses stock provide the actual estimated number of PhD, Masters, PGD, and Undergraduate courses
Current  Courses[PhD](t) = Current  Courses[PhD](t - dt) + (courses  increment  rate[PhD]) * dt
INIT Current  Courses[PhD] = initial  courses[PhD]

Current  Courses[Masters](t) = Current  Courses[Masters](t - dt) + (courses  increment  rate[Masters]) * dt
INIT Current  Courses[Masters] = initial  courses[Masters]

Current  Courses[PGD](t) = Current  Courses[PGD](t - dt) + (courses  increment  rate[PGD]) * dt
INIT Current  Courses[PGD] = initial  courses[PGD]

Current  Courses[Undergraduate](t) = Current  Courses[Undergraduate](t - dt) + (courses  increment  rate[Undergraduate]) * dt
INIT Current  Courses[Undergraduate] = initial  courses[Undergraduate]

Document: The course duration represents the number of years a particular course is taught and not necessarily studied.
It is used to compute the total number of teaching hours per year.
course  duration[PhD] = 1
course  duration[Masters] = 1.5
course  duration[PGD] = 1
course  duration[Undergraduate] = 3
Document: The credit units give the number of hours per semester per course category taught
Credit  Units    per  course[ThreeCU] = 45
Credit  Units    per  course[FourCU] = 60
Document: The ratio of available teaching staff to that of students
current staff  to student  ratio = Tt  Staff/(Net students on  programs[PhD]+Net students on  programs[Masters]+Net students on programs[PGD]+
Net  students    on  programs[Undergraduate])
Document: The difference between ideal staff tudent  ratio and current  staff  to student  ratio
current  staff  to  students  ratio  gap = if(ideal  staff student ratio>=current  staff  to student rato)then(ideal staff tudent  ratio-
current  staff  to student  rato)else(0)
Document: The time delay between when a new course is proposed and when it is approved then initiated. It is obtained
from historical behaviour.
delay  in  starting    new  courses[PhD] = DELAY(desired  courses[PhD],time  to  initiate  a  new  course[PhD])
delay  in  starting    new  courses[Masters] = DELAY(desired  courses[Masters],time  to  initiate a  new  course[Masters])
delay  in  starting    new  courses[PGD] = DELAY(desired  courses[PGD],time  to  initiate      a  new  course[PGD])
delay  in  starting    new  courses[Undergraduate] = DELAY(desired  courses[Undergraduate],time  to  initiate a  new  course[Undergraduate])
Document: The desired courses is the gap between planned courses and current courses
desired  courses[PhD] = planned  courses[PhD]-Current  Courses[PhD]
desired  courses[Masters] = planned  courses[Masters]-Current  Courses[Masters]
desired  courses[PGD] = planned  courses[PGD]-Current  Courses[PGD]
desired  courses[Undergraduate] = planned  courses[Undergraduate]-Current  Courses[Undergraduate]
Document: The planned courses are the number of courses envisaged in strategic document, some of which are proposed start in
the near future.
planned  courses[PhD] = 6
planned  courses[Masters] = 4
planned  courses[PGD] = 4
planned  courses[Undergraduate] = 6

extra  hrs = if((planned  load  per  yr[PhD]+planned  load  per  yr[Masters]+planned  load  per  yr[PGD]+planned load per yr[Undergraduate])>
FT  staff  load  per  yr)then((planned  load  per  yr[PhD]+planned  load  per  yr[Masters]+planned  load  per  yr[PGD]+planned load  per
yr[Undergraduate])-FT  staff  load  per  yr)else(0)
Document: Extra hours are the excess hours above the total normal teaching load of available full time staff
extra hrs  limit per FT staff = extra  hrs  per  week*teaching  weeks  per  yr
Document: The number of hours a full time staff can teach in excess of the normal load per week
extra  hrs for FT  staff = (Actual  FT  Acad  Staff[Professor]+Actual  FT  Acad  Staff[Sen  Lecturer]+Actual  FT  Acad  Staff[Lecturer]+
Actual  FT  Acad  Staff[Ass  Lecturer]+Actual  FT  Acad  Staff[Teaching  Ass])*extra  hrs  limit    per  FT  staff
extra hrs per week = 6
FT  staff  load  per  yr = Actual FT Acad  Staff[Professor]*minimum contact hrs per FT staff[Professor]+Actual FT Acad Staff[Sen  Lecturer]*
minimum  contact  hrs  per  FT  staff[Sen  Lecturer]+Actual  FT  Acad  Staff[Lecturer]*minimum  contact hrs  per FT staff[Lecturer]+
Actual  FT  Acad  Staff[Ass  Lecturer]*minimum  contact  hrs  per  FT  staff[Ass  Lecturer]+Actual  FT  Acad  Staff[Teaching  Ass]*
minimum contact  hrs  per  FT  staff[Teaching  Ass]

influence  weight[highest] = 1
influence  weight[high] = 75/100
influence  weight[average] = 50/100
influence  weight[low] = 25/100

initial  courses[PhD] = 0
initial  courses[Masters] = 0
```

```
initial  courses[PGD] = 1
initial  courses[Undergraduate] = 2

minimum  contact  hrs  per  FT  staff[Professor] = minimum  hrs  per  week[Professor]*teaching  weeks  per  yr
minimum  contact  hrs  per  FT  staff[Sen  Lecturer] = minimum  hrs  per  week[Sen  Lecturer]*teaching  weeks  per  yr
minimum  contact  hrs  per  FT  staff[Lecturer] = minimum  hrs  per  week[Lecturer]*teaching  weeks  per  yr
minimum  contact  hrs  per  FT  staff[Ass  Lecturer] = minimum  hrs  per  week[Ass  Lecturer]*teaching  weeks  per  yr
minimum  contact  hrs  per  FT  staff[Teaching  Ass] = minimum  hrs  per  week[Teaching  Ass]*teaching  weeks  per  yr
minimum  contact    hrs  per  Pt  staff = minimum  hrs  per  week[Teaching  Ass]*teaching  weeks  per  yr

minimum  hrs  per  week[Professor] = 8
minimum  hrs  per  week[Sen  Lecturer] = 8
minimum  hrs  per  week[Lecturer] = 8
minimum  hrs  per  week[Ass  Lecturer] = 10
minimum  hrs  per  week[Teaching  Ass] = 10
Document: The number of core and elective courses per semester for graduate and undergraduate programs
nature  of  courses[Elective  Undergrad] = 2
nature  of  courses[Core  Graduate] = 4
nature  of  courses[Elective  Graduate] = 1
nature  of  courses[Core  Undergrad] = 4
nominal  class  size = 50

optimal  staff    load  indicator = EXP(constant*current  staff  to  students  ratio  gap)
document: Optimal staff load indicator is the effect of staff load on quality of teaching.

planned  load  per  yr[PhD] = (nature  of  courses[Core  Graduate]*course duration[PhD]*Credit Units per  course[FourCU]*Current  Courses[PhD]*
type  of  programmes[Evening  Only])
planned  load  per  yr[Masters] = course  duration[Masters]*Credit  Units    per  course[FourCU]*nature  of  courses[Core  Graduate]*Current
Courses[Masters]*type  of  programmes[Evening  Only]
planned  load  per  yr[PGD] = course  duration[PGD]*Credit  Units per course[FourCU]*nature of courses[Core Graduate]*Current Courses[PGD]*
type  of  programmes[Evening  Only]
planned  load  per yr[Undergraduate] = (nature of  courses[Core  Undergrad]*course duration[Undergraduate]*Credit  Units per course[FourCU]*
Current  Courses[Undergraduate]*type of programmes[Day and Evening])+nature of courses[Elective  Undergrad]*course  duration[Undergraduate]*
Credit  Units    per  course[FourCU]*Current  Courses[Undergraduate]*type  of  programmes[Day and Evening]

PT  staff  load = impact  of  load  on  PT  staff
quality  of  teaching = (quality of staff*influence weight[highest]+optimal staff load indicator*influence  weight[high]+effect of  class
size*influence  weight[high]+resources  availability*influence  weight[average]+quality    of  research*influence  weight[high])/(influence
weight[highest]+influence  weight[high]+influence  weight[high]+influence  weight[average]+influence  weight[average])

ratio  of  desired  courses  initiated[PhD] = 1
ratio  of  desired  courses  initiated[Masters] = 0.5
ratio  of  desired  courses  initiated[PGD] = 1
ratio  of  desired  courses  initiated[Undergraduate] = 0.25

teaching  weeks  per  yr = 30

time  to  initiate a  new  course[PhD] = 4
time  to  initiate a  new  course[Masters] = 4
time  to  initiate  a  new  course[PGD] = 4
time  to  initiate  a  new  course[Undergraduate] = 4

type  of  programmes[Day  Only] = 1
type  of  programmes[Evening  Only] = 1
type  of  programmes[Day and Evening] = 2
```

Appendix B: Academic Staff Questionnaire Survey

The purpose of this questionnaire is to gather information necessary for analysing the requirements for the development of a computer simulation model for higher education quality management. The responses will be used as a basis for reference behavior (trends) against which the relevance of the simulated behavior will be determined. The questionnaires are in two fold: for the Faculty Administrators and Lecturers. Kindly ensure that you complete the most relevant copy. Please tick as required in the boxes and write in the spaces provided if specified. All answers will remain confidential and will be used for research purposes only.
The researcher will invite you to a presentation of the findings. For any queries concerning the questionnaire, please contact the researcher at, boyo@cit.mak.ac.ug

Thank you.
Kind regards from,

Benedict Oyo
Researcher

QUESTIONNAIRE: LECTURERS
Name of University..
Section A: General Information

1) What is your gender?
0 Male
0 Female

2) What is your age range?
0 Less than 20 years
0 20-30 years
0 31-40 years
0 41-50 years
0 Above 50 years

3) For how long have you taught at university level? (Choose one)
0 Less than 1 year
0 1-2 years
0 3-8 years
0 9-14 years
0 15-20 years
0 More than 20 years

4) In which category does your College/School/Faculty/Institute/
Department belong?
0 Medicine
0 Science/Technology/ICT
0 Education/Arts/Social Sciences/Law
0 Business
Other (Specify).......................................

5) What is your current title and/or qualification?
0 Professor
0 Associate Professor
0 PhD
0 MPhil
0 MSc/MA
0 BSc/BA
Other (Specify).................................

Section B: Teaching and Assessment

6) Please indicate your average teaching load as applicable in the table below

Year/Hours per week	below 5	from 5 to 8	from 9 to 12	from 13 to 16	above 16
2007					
2006					
2005					
2004					
2003					
2002					
2001					
2000					
1999					
1998					
1997					

7) What is the maximum teaching load range in hours per week that you would recommend for Lecturers of your qualification?

0 <5
0 5-8
0 9-12
0 13- 16
0 20

8) What is your competence in the following computer applications? (Please indicate 1 for very good, 2 for good, 3 for average, 4 for beginner, and 5 for never used)
0 Microsoft Word
0 Microsoft Excel
0 Microsoft PowerPoint
0 E-mail and online surfing

9) Apart from chalkboard and flipcharts, which of the following interactive teaching and learning approaches do you use? (Tick all that apply)

0 Overhead projector
0 E-learning
0 Smart interactive white boards
0 Field studies/industrial training
Other (Specify).......................

10) To what extent do you believe your academic unit/faculty has facilitated the teaching-learning approaches in Qn. 9?
0 Very well facilitated
0 Well facilitated
0 Averagely facilitated
0 Poorly facilitated
0 Not facilitated at all

11) In your opinion, does your university have the necessary IT infrastructure such as computers, computer hardware, printing and Internet services for lecturers? (Please explain)
....

Section C: Supervision

12) Please state the number of students you have supervised as specified in the table below

Year	Undergraduate	Postgraduate	Diploma	Masters PhD
2007				
2006				
2005				
2004				
2003				
2002				
2001				
2000				

Section D: Research Projects

13) Please indicate as specified in the table below, any three funded research projects you have done or been part of. Indicate in the publication column a tick (√) or dash (–) if your findings were published or not published respectively

Year/Period	Funding organization	Project aim	Your role	Publication

Section E: Research Publications

14) Please state the number of your publications in the categories specified in the table below

Year	Conference proceedings	Book chapters	Journals	Research Books
2007				
2006				
2005				
2004				
2003				
2002				
2001				
2000				

15) How do you rate the students co-authorship in your publications?

0 Very high
0 High
0 Average
0 Low
0 Zero

16) Does your faculty have a functional budget for international conference participation?
0 Yes
0 No

17) If yes in Q.16, what number of conferences is a full time staff entitled to?
....
....

Thank You.
For God and Our Country-Uganda

Appendix C: Interview Guide for University Administrators and Senior Academic Staff

PART I: University Administrators

1) Gender
0 Male
0 Female
2) Administrative position
0 University Secretary/Deputy
0 Academic Registrar/Deputy
0 Faculty Dean/Deputy
0 Institute Director/Deputy
0 Departmental Head/Deputy
0 Director of Planning and Development
0 Director for ICTs
0 Human Resource Manger/Deputy
0 University Librarian/Deputy
0 Director/Deputy for Graduate Studies
Other (Specify)......................
3) Experience
0 Less than 1 year
0 1-2 years
0 3-4 years
0 5-6 years
0 7-10 years
0 More than 10 years
4) Academic qualification/title?
0 Professor
0 Senior Lecturer
0 PhD
0 MSc/MA
0 BSc/BA
Other (Specify).................

5) Are you involved in teaching? What is your average teaching load per week?

6) Do you your students have access to:-
- Computers?
- Internet?
What is the average student to computer ratio?

7)Do you have a book bank in your academic unit? What is the average student to book ratio?

8) How is staff training/development in your academic unit financed? (Give all the details including number of current beneficiaries)

9) How does your unit finance its research?

10) On what basis do you recruit your academic staff? (explain each of the criteria for part-time and full time staff respectively)

11) Do you appraise your staff? How often? How does this data inform the decision process?

12) Please provide the academic staff retention and/or attrition statistics. What are the major reasons for staff attrition?

13) Do your students rate their lecturers? How do you utilize this data?

14) How are students' innovations monitored and/or supported?

15) Please provide statistics on students' admission trends, enrolment, graduation rates, and average class sizes

....Thank You...

PART II: Senior Academic Staff

1) Gender
0 Male
0 Female
2) Administrative position

0 Vice/Deputy Chancellor	0 University Secretary/Deputy
0 Academic Registrar/Deputy	0 Bursar/Deputy
0 Faculty Dean/Deputy	0 Human Resource Manger/Deputy
0 Institute Director/Deputy	0 University Librarian/Deputy
0 Departmental Head/Deputy	0 Director/Deputy for Graduate Studies
0 Director of Planning and Development	
0 Director for ICTs	Other (Specify)......................

3) Experience
0 Less than 1 year
0 1-2 years
0 3-4 years
0 5-6 years
0 7-10 years
0 More than 10 years
4) Academic qualification/title?
0 Professor
0 Senior Lecturer
0 PhD
0 MSc/MA
0 BSc/BA
Other (Specify).................

5) What is your teaching load per week?

6) On average, how many students per year do you supervise at:
Undergraduate ....
Post Grad Diploma......
Masters ....
PhD ....

7) A part from teaching private students if this is already applicable, how else does the academic unit you belong to generate funds?

8) Does your academic unit have research groups? How is research financed?

9) What kind of teaching resources does your unit have? Do you think these resources are satisfactory? (explain)

10) On average what is the class size in your unit?

11) Do you provide graduate training? What categories of graduate courses do you offer?

12) What is the publications throughput for your graduate students?

13) What is the distribution of staff by qualifications in the unit you belong to?

14) How are staff allowances (teaching/extra load, marking and supersion) paid? (explain whether and why they are prompt or delayed)

15) How often do you review the curriculum?

16) Explain the process of starting a new course, including the time delays involved from proposal stage to actual initiation

....Thank You...

Appendix D: Krejcie and Morgans (1970) Table for determining samples sizes (s) for finite population (N)-adopted from Gay and Airasian, 2003: 113

N	s	N	s	N	s	N	s	N	s
10	10	100	80	280	162	800	260	2800	338
15	14	110	86	290	165	850	265	3000	341
20	19	120	92	300	169	900	269	3500	346
25	24	130	97	320	175	950	274	4000	351
30	28	140	103	340	181	1000	278	4500	354
35	32	150	108	360	186	1100	285	5000	357
40	36	160	113	380	191	1200	291	6000	361
45	40	170	118	400	196	1300	297	7000	364
50	44	180	123	420	201	1400	302	8000	367
55	48	190	127	440	205	1500	306	9000	368
60	52	200	132	460	210	1600	310	10000	370
65	56	210	136	480	214	1700	313	15000	375
70	59	220	140	500	217	1800	317	20000	377
75	63	230	144	550	226	1900	320	30000	379
80	66	240	148	600	234	2000	322	40000	380
85	70	250	152	650	242	2200	327	50000	381
90	73	260	155	700	248	2400	331	75000	382
95	76	270	159	750	254	2600	335	100000	384