DEVELOPMENT OF A WHOLE-LIFE COST IMPLEMENTATION FRAMEWORK FOR THE NIGERIAN CONSTRUCTION INDUSTRY

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Declaration

I declare that the work in this thesis entitled “Development of a Whole-life Cost Implementation Framework for the Nigerian Construction Industry” has been performed by me in the Department of Building. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this Thesis was previously presented for another degree or diploma at this or any other Institution.

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Signature Date

Certification

This Thesis entitled DEVELOPMENT OF AWHOLE-LIFE COST IMPLEMENTATION FRAMEWORK FOR THE NIGERIAN CONSTRUCTION INDUSTRY by Aliyu Makarfi IBRAHIM meets the regulations governing the award of the degree of PhD. Construction Management of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Dedication

I dedicate this work to my late parents Hajiya Bilkisu Ibrahim, and Alhaji Ibrahim, Yahaya Makarfi. May Allah be merciful upon them and grant them Aljannah Fiddaus Amin.

Synopsis

Clients' demand should be the key driver for the supply of services, not the other way round. The consistent report of lack of demand for Whole Life Cost services by clients is a clear indication that the wrong driver is in control. It is imperative that existing whole- life cost models be adjusted to satisfy investor's core decision needs embedded in life-cycle options.

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List of Acronyms

AIRR -Adjusted Internal Rate of Return

ANN -Artificial Neural Network

ARC -Annual Running Cost

ARR -Accounting Rate of Return

ARSO -African Regional Organisation for Standardisation

ATC -Annual Total Cost

BCIS -Building Cost Information Service

BCR -Benefit to Cost Ratio

BIM -Building Information Modelling

BMI -Building Maintenance Information

BPP -Bureau for Public Procurement

BSRIA-Building Services Research and Information Association

CSI -Construction Specification Institute

DCF -Discounted Cash flow

DPB -Discounted Payback

DPWS -Department of Public Wok (Australia)

DTA -Decision Tree Analysis

EAC -Equivalent Annual Cost

ECBA -Economic Cost Benefit Analysis

EE -Embodied Energy

EI -Eco Indicator

ERR -Economic Rate of Return

ESL -Estimated Service Life

FEC -Federal Executive Council

FFA -Financial Feasibility Analysis

FMF -Fuzzy Membership Function

FST -Fuzzy Set Theory

ICRC -Infrastructure Concession Regulatory Commission

IPD -International Property Databank

IRR -Internal Rate of Return

ISO -International Organisation for Standardisation

ITOCC-International Total Occupancy Cost Code

LCC -Life Cycle Cost

LCCA -Life Cycle Cost Analysis

LCCM -Life Cycle Cost Management

LCCP -Life Cycle Cost Planning

MARR-Minimum Acceptable Rate of Return

MCM -Monte Carlo Method

MCS -Monte Carlo Simulation

MEC -Marginal Efficiency of Capital

MIRR -Modified Internal Rate of Return

MTTF -Mean Time To Failure

NCPP -National Council on Public Procurement

NDCF-Non Discounted Cash Flow

NP on PPP-National Policy on Public Private Partnership

NPV -Net Present Value

NRM -New Rules of Measurement

OBC -Outline Business Case

OSCON-Open System for Construction

PDF -Probability Density Function

PFI -Private Finance Initiative

PI -Profitability Index

PII -Partners In Innovation

PPM -Public Procurement Manual

PPP -Public Private Partnership

PPRGW-Public Procurement Regulation for Goods and Works

PV -Present Value

RADR -Risk Adjusted Discount Rate

RIBA -Royal Institute of British Architects

RICS -Royal Institution of Chattered Surveyors

RM -Risk Management

ROCE -Return On Capital Employed

RROC -Rate of Return Over Cost

RSL -Reference Service Life

SA -Sensitivity Analysis

SFCA -Standard Form of Cost Analysis

SFPOCA-Standard Form of Property Occupancy Cost Analysis

SIR -Savings to Investment Ratio

SMLCC-Standard Method of Life Cycle Costing

SON -Standards Organisation of Nigeria

SWOT -Strength Weaknesses Opportunities and Threats

TARIR-Time Adjustable Rate of Internal Return

TOR -Terms of Reference

TQM -Total Quality Management

VE -Value Engineering

VFM -Value for Money

WBS -Work Breakdown Structure

WLA -Whole Life Appraisal

WLC -Whole Life Cost

WLCC -Whole Life-Cycle Cost

YOI -Yield on Investment

ABSTRACT

Whole Life Cost (WLC) decision-making technique offers immense benefit to building investors as it captures not just the initial cost but also the maintenance, running and terminal costs of proposed buildings. Its application however is constrained by the absence of a standard implementation framework. This research effort was geared towards the development of an implementation framework that addresses; the legal requirement for WLC within the Nigerian construction industry; the limitations of existing frameworks; and major implementation challenges. First the legal requirement for WLC was articulated; the strength and weaknesses of existing frameworks was then assed based on some identified criteria; solutions to some of the critical implementation challenges were then identified through a mixture of theoretical survey, and structured interviews. The entire solution frame was then organised, integrated and harmonised into a framework structure. The framework was then improved by transforming it into programme flowcharts and interfaces to facilitate computer implementation. Result shows that substantial legislations, regulations and guidelines that facilitate the use of WLC are well established. Besides, none of the existing frameworks fully satisfy problem-solving, project life-cycle, and feedback requirement. A profiling of WLC Implementation challenges indicates that client's lack of demand/ understanding, data scarcity, process complexity, and high level of risk and uncertainty are the most severe. In an attempt to mitigate these limitations, a conceptual framework was proposed. The framework utilises a relational database, a model selection framework and two mathematical models: Modified traditional model which enables the identification of the best alternative based on payback period, net present/net future values, and break-even point and; an Options appraisal model which facilitates the evaluation of embedded WLC opportunities. The present value options appraisal model enables the

determination of the optimum investment time thereby improving the decision horizon from two-way to five-way. It also provides estimate of benefit to cost ratios, profitability index on both the net present values and option value. Test result indicates that the database is effective in terms of: storage and retrieval of multiple data types, preservation of data integrity, and ensuring user-friendliness. Furthermore, the test result confirms the efficacy and robustness of: the transformation and integration algorithms in converting one data type to another, and the modified WLC and the options appraisal models. It was recommended that building professionals and consultants be aware of the existence of legal provisions for WLC and also get prepared to take on the challenge placed upon them. They must understand that traditional procurement on the basis of initial cost alone is no more tenable and redirect their attention to the use of WLC as it gives the public better value for money and as such becomes imperative at especially the present times in which the country is experiencing recession. It is anticipated that the framework would improve the usability of WLC in the industry by providing both private and public sector with a robust analysis tool that would facilitate long term property investment decision making.

CHAPTERONE

1.0INTRODUCTION

1.1 Background of the Study

The economic evaluation of construction projects has been predominantly based on the initial capital cost. Cuellar-Franca and Azapagic (2013) discovered that, the initial cost of the UK housing stock constitute only about 35% of their cradle-to-grave cost. The remaining 65% is accounted for by the occupancy and disposal costs. This signifies that, by basing evaluation of building investments on initial cost only, the potential for cost savings at the operating stage is neglected thereby depriving clients Value For Money (VFM).

According to Owen and Merna (1997), the persistent need for infrastructural facilities, coupled with limited financial resources invoked the proliferation of new procurement methods in the form of Public Private Partnership (PPP). Some varieties of PPP scheme like Private Finance Initiative (PFI) and Build Operate and Transfer Options (BOT) require proposed projects to pass the VFM test. In conducting the VFM test the use of Whole Life Cost (WLC) cannot be avoided as forecast of both cost and income of an asset over its operating life are required.

Another essential development is the quest for sustainable building development. Economic sustainability requires that proposed construction ensures “fitness for purpose”, and efficient allocation of resources (elimination of under/over investment). Ellingham and Fawcett (2006) identified the provision of economic options as a key requirement of sustainability. These requirements are best evaluated using WLC appraisal. Dell’Isola and Kirk (2003) postulated that, the need for facilities to accommodate changes so as to guard against premature obsolescence, remain operationally effective, and maintain total quality management requirement also strengthen WLC agenda.

It is in line with the aforementioned necessities that most developed nations have mandated the use of WLC in the economic evaluation of proposed projects. Legislations mandating the use of WLC have been passed in the USA since mid-1970's (Dell'Isola and Kirk, 1981). In the UK, WLC became officially recognised in 1992 under BS 3845(1992). In contrast, WLC is rarely used in the developing countries like Nigeria due to a number of challenges, except in internationally financed projects like the World Bank assisted projects (Flanagan and Jewell, 2005). The challenges, like cost of implementation, process complexity etc. need to be overcome for a proper uptake of the service in the developing countries.

1.2 Statement of the Research Problem

The economic evaluation of proposed building projects in the Nigerian construction industry is traditionally based on initial capital cost instead of Whole Life Cost (WLC) which aggregates the initial, maintenance operating and terminal cost of proposed projects. This approach has the disadvantage of ignoring the operating, maintenance and disposal cost of proposed projects thereby placing significant financial burden on clients and users at a later stage of asset life. Recent developments like the quest for sustainable built environment, Public Private Partnering (PPP) and Build Operate and Transfer (BOT) options require proposed building projects to satisfy the Value for Money (VFM) test over their operating life (Dell'Isola and Kirk, 2003). This requirement clearly indicates the need for a shift from traditional to WLC evaluation methods. On recognising this, the Nigerian legislative arm of the government passed the Infrastructure Concession Regulatory Commission and the Public Procurement ACTs in 2005 and 2007 respectively. Both ACTs clearly require the application of Value-For-Money (VFM) standards and principles in the procurement of public assets. Furthermore, the Federal Executive Council in April, 2009 approved a national policy

on Private Finance Initiative which requires public office holders to assess VFM in public procurement on the basis of WLC. This requirement is a challenge to professionals considering the difficulties associated with WLC exercise. These difficulties which includes; lack of awareness, cost of implementation, scarcity of reliable historical data, diverse methodologies, and limitations of existing frameworks greatly limits the application of WLC in especially the developing countries like Nigeria (Flanagan and Jewell, 2005; Kishk, Al-Hajj, Pollock, Aoud, Bakis, and Sun, 2003a; Dermot and Jason, 2017). This research effort hopes to overcome the aforementioned problems through the development of an Implementation framework for WLC costing in the Nigerian building industry.

1.3 Justification for the Study

The reason for the slow uptake of WLC in especially the developing countries has been attributed to so many factors. These factors include: dispersed legal requirement; data scarcity; cost of implementation; multiplicity of data formats/models; complexity of the process; and lack of demand/awareness by the client amongst others (Ashworth, 1993; Seeley, 1996; Flanagan and Jewell, 2005; Olubodun, Kangwa, Oladapo, and Thompson, 2010; Opoku, 2013; Higham, Fortune, and James, 2015; Dermot and Jason, 2017). Solution to these problems has been the concern of many researchers since the early 1990s. Surprisingly, these problems keep on reverberating to the present as reported by Opoku (2013) and more recently by Dermot and Jason (2017). If these problems are successfully mitigated, WLC technique will offer great benefit to building Clients. Besides, the solution frame to these problems would then serve as a basis for the development of an implementation framework.

The development of an implementation framework for WLC would facilitate the identification, characterization and integration of the requirements for WLC analysis within the Nigerian construction industry. Such a framework would assist in identifying and integrating; the legal requirement for the application of WLC; the activities involved in WLC analysis; the sequence of WLC operations; WLC data collection, analysis and presentation format, and risk analysis framework.

It is anticipated that, the availability of the framework would encourage the use of WLC within the industry thereby: assist in cutting down maintenance and operating costs of proposed projects thus freeing resources for other investments; push forward the sustainability agenda in the built environment by minimizing over/under design through sound WLC practice; assist both the public and private sector clients in the preparation of technical/financial plans on maintenance and renovations of building assets; help to ensure that buildings do not get obsolescent prematurely through the evaluation of their physical, economic, functional and legal life; encourage innovation in the design, construction and management of building assets as professionals are forced to consider the performance of proposed projects over their operating life; providing a basis for the development of an industry based WLC standard method of cost analysis; and forming the basis for the development of an industry based WLC data analysis tools.

1.4 Aim and Objectives

1.4.1 Aim

The aim of this research work is to develop a WLC implementation framework for the Nigerian construction industry with the view to improving the usability of WLC in economic evaluation of building projects.

1.4.2 Objectives

The objectives of this research are:

a) To articulate the legal requirements for the application of WLC.

b) To evaluate the limitations of existing WLC implementation frameworks

c) To determine the most significant implementation challenges for WLC

d) To proffer logical solutions to the implementation challenges. .

e) To integrate the solutions into a framework structure by observing the legal requirements for WLC.

f) To transform the framework structure into a programme flowchart and interfaces for subsequent implementation on a computer system.

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1.5 Scope of the Research

This study focused on the public sector of the Nigerian building industry, thus the developed framework relates principally to public investments. Moreover, the implementation and testing was limited only to database and mathematical models using data for residential buildings only.

1.6 Limitations

The underlying assumption of Black-Scholes model which considers income to be log-normally distributed over time may not perfectly fit the Nigerian property market, thus there may be the need to further assess the validity of the assumption. More so, producing the best design requires concerted effort in research, testing and improvement over time. While logical arguments were drawn based on which decisions were taken at every milestone, there is no doubt that better designs could be achieved through continuous evaluation and research effort.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 History of Whole Life Costing.

The most important developments in the evolution of Whole Life Costing happened in the United States of America (USA) and the United Kingdom (UK). Dell'Isola and Kirk (1981) reported that the concept of Life Cycle Costing (LCC) began in the United States of America in the early 1930s. The consideration of only the initial cost of assets during procurement was considered to be economically inefficient. This was born out of the concern that some equipment with lower initial cost consumes comparatively more resources during operation and maintenance. As a result, the then General Accounting Office supported the evaluation of bids on the bases of both initial costs and 8000 hours of operating and maintenance of tractor equipment. Furthermore, the aftermath of World War II pressed the need for substitutes in both construction materials and methods to aid efficient reconstruction effort. The desire to reconstruct as quickly as possible Vis-a-Vis the scarcity of resources led to the evolution of Value Engineering (VE). The concept of VE was considered to be broader than LCC as it considers both functional requirement and total cost of an asset (Seeley, 1996). Moreover, in 1965, a report by the then Logistics Management Institute concluded that, had bids were evaluated on the basis of LCC, department of defence would have enjoyed considerable savings and that contract awards would have been made to other than low bidders (Dell'Isola and Kirk, 1981). Following this report a series of three guidelines for LCC procurement were published in the US. These guidelines are; "Life Cycle Costing Procurement Guide (Interim)", "Life Cycle Costing in Equipment Procurement-Casebook", and Life Cycle Costing Guide for Systems Acquisitions (Interim)" (Dhillon, 1989). The Arab oil embargo of 1973 led to the energy crisis which

consequently led to the enactment of two important legislations in 1975; The Energy Policy and Conservation ACT and the Energy conservation and Production ACT. Both ACTs emphasized the need for long term analysis of costs during procurement. Dhillon (1989) pointed out that, as at 1974 many states in the US have recognized the importance of LCC and thus have passed legislations on the planning, design, construction and management of state buildings. Hoar (2007) confirmed that by the late 1970s LCC was actively encouraged by the US federal government because of the increasing concern on the cost-in-use of public assets.

In the United Kingdom (UK) and between 1951 and late 1960s the idea of Terotechnology emerged outside the construction industry. This was as a result of the continuous rise in waste generation and high cost of doing business. Furthermore, Boussabaine and Kirkham (2004) noted that, other manufacturing industries had observed that taking decisions on initial costs only could be misleading and that by spending more in initial capital costs, substantial future savings could be enjoyed when compared with cheaper alternatives. According to Seeley (1996), Terotechnology is a combination of management, financial and engineering practices applied to physical assets to ensure economic LCC. The concept did not enjoy much recognition in the construction industry due to lack of awareness, scarcity of data and lack of data collection mechanism (Boussabaine and Kirkham, 2004). In another development, stakeholders in construction saw the need to capture the costs incurred during the occupancy stages of buildings. This led to the development of "cost-in-use" studies which appeared in the construction industry during the early 1970s. Cost-in-use was mostly limited to the operating stages of an asset. Boussabaine and Kirkham (2004) opined that cost-in-use studies is mostly concerned with the running, operating and

maintenance cost of an asset. Seeley (1996) had highlighted in the past though, that the term gave a wrong impression of being limited to the cost of using a building whereas it was also used in the comparison of design alternatives on the basis of initial and operating costs. In 1983 Roger Flanagan and George Norman published a book titled "Life Cycle Costing for Construction" following a study financed by Education Trust of The Royal Institution of Chartered Surveyors (RICS). The publication demonstrated the practical application of LCC in the industry by addressing its key challenges (Hoar, 2007). By early 1990s, LCC in construction had been recognized at least by the public sector in the UK. This led to the publication of a UK standard on LCC under BS 3843 (1992). By the end of the 1990s another term Whole Life Cycle Costing (WLCC) or Whole Life Costing (WLC) emerged. Boussabaine and Kirkham (2004) stated that while LCC was concerned with period of economic interest of a building, WLCC was concerned with the life of a building from cradle to grave. Figure 2.1 shows the evolutionary time-line for WLCC in the UK.

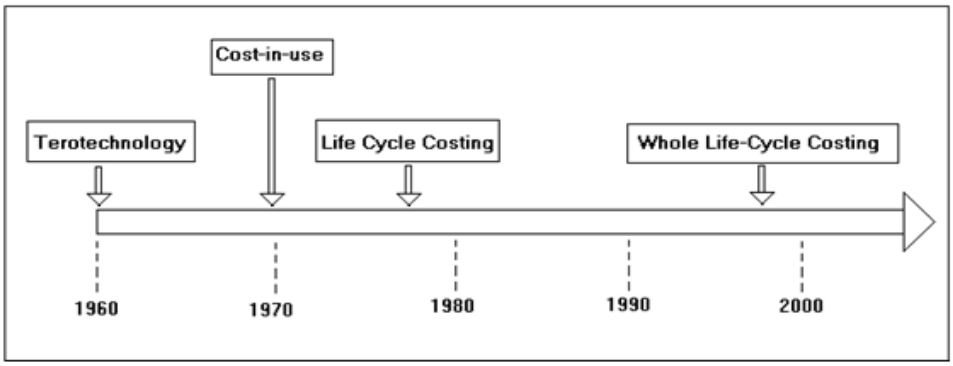


Figure 2. 1:The Evolution Time-line for Whole Life Cycle Costing(Source: Boussabaine and Kirkham, 2004)

Flanagan and Jewell (2005) identified another term called Whole Life Appraisal (WLA). They explained that WLA considers both cost and performance of assets as they argue that costs are influenced by the performance characteristics of plants and facilities, the standard of maintenance and the periods of occupancy and pattern of use.

They claimed that the term had been accepted globally. There is though little or no evidence to support the claim as most recent publication including the international standard on LCC i.e. ISO 15686-Part 5 (2008) did not recognise WLA.

In Nigeria references to WLC were made only recently in two separate documents titled "Procurement Procedures Manual for Public Procurement in Nigeria" and "National Policy on Private Finance Initiative" published by the Bureau for Public Procurement (BPP) and Infrastructure Concession Regulatory Commission(ICRC) respectively. The first document suggests the use of WLC in the procurement of plants and equipment where the difference in the cost of competing alternatives is not significant so that the ties could be broken. The second document places an onus on those responsible for government spending decisions to spend revenues wisely and obtain VFM in both relative and absolute terms and that the assessment of VFM should be based on Whole Life Cost (WLC) of an asset not just the initial cost. The application of WLC in the Nigerian construction industry though, is still at its infancy due to numerous challenges that need to be overcome (Ibrahim,Bala, and Ibrahim, 2008a).

2.2 Definitions of Cost-In-Use, LCC, WLC and WLA

As discussed in the previous section, the evolution of WLC and WLA gave rise to other parent terms like cost-in-use and LCC. These terms though different in both scope and meaning are closely related. The relationship sometime leads to confusion on the real difference between the three terms as they were at a time used inter-changeably. Seeley (1996) had reported the lack of clarity in the difference between cost-in-use and LCC while Boussabaine and Kirkham (2004) had through a survey concluded that the difference between LCC and WLC is subjectively tied to the experience, field of study,

and economic stand-point of respondent. Presently though, there seem to be a consensus on the chronological order of the terms. This order began with Cost-in-use, then transform into LCC, WLC and WLA. The divergent views in the meanings associated with the terms could be discerned in the definitions posited by different scholars. Cost-in-use as earlier stated was in some instances considered to be the cost of using a building. It captures the running, operating and maintenance cost of a building. In other circumstance it is considered to encompass the initial capital cost and terminal cost of a building in addition to the running operating and maintenance costs.Flanagan, Norman, and Furbur (1983), defined LCC as: *"an economic evaluation technique that concerns the assessment of the total cost of an asset over its operating life, including initial capital cost,maintenance cost, operating cost and the cost or benefit of the eventual disposalof the asset at the end of its life."*. El-Haram, Marenjak, and Horner (2002), defined WLC as": *"a technique for examining and determining all the costs- in monetary terms-direct and indirect, of designing, building and facility management (operating,maintenance, support and replacement) of a building throughout its entire service life including the disposal cost"*. Boussabaine and Kirkham (2004) opined that, there is a difference between LCC and WLC. They suggested that while LCC focus on period of economic interest, WLC is focused on the entire life of an asset. They thus defined WLCosting as: *".... a dynamic and on-going process which enables the stochastic assessment of theperformance of constructed facilities from feasibility to disposal. The WLC assessment process takes into account the characteristics of the constructed facility, reusability, sustainability, maintainability and obsolescence as well as the capital, maintenance, operational, finance, residual and disposal costs. The result of this stochastic assessment forms the basis for a series of economic and non-economic performance indicators relating to the various stakeholders' interest and objectives throughout the life-cycle of a project"*. The above definition has the advantage of being comprehensive and correctly describing WLCosting as a dynamic

activity throughout the life of an asset. It's main limitation however is that it fails to capture the possible benefits that may be derived from a project and proposes only stochastic risk assessment technique. These are clear limitations as WLC analysis captures both costs and benefits and also utilizes diverse risk analysis techniques (like artificial neural networks, genetic algorithms, sensitivity analysis etc.) depending on the nature and sources of data.Hoar (2007), defined the LCC of an asset as: "*the present value of the total cost of that asset over its operating life includinginitial capital cost, occupation cost, operating costs and the cost or benefit of the eventual disposal of the asset at the end of its life.".* Norman (2007) defined LCC as: *".....the total cost of the system or product under study over its complete life or duration of the period of study, whichever is the shorter".* He further defined LCC as: *"....the process of economic analysis that assesses the total cost of investment in and ownership and operation of the system or product to which the life cyclecosting analysis is being applied.".* All the above definitions demonstrate the confusion amongst professionals on the difference between WLC and LCC. In recognizing the confusion, the International Organisation for Standardisation published in 2008 ISO 15686: Service Life Planning. Part 5 of the standard- Life Cycle Costing, tried to differentiate between LCC and WLC. It defines LCC as: *"cost of an asset or its part throughout its life-cycle while fulfilling the performance requirement".*It further defines LCC as a:*"methodology for systematic economic evaluation of life-cycle cost over a period of analysis as defined in the agreed scope".*In contrast it defines WLC as: *"all significant and relevant initial and future cost and benefits of an asset,throughout its life-cycle, while fulfilling the performance requirement";*and WLCostingas:*"amethodology for systematic economic considerations of all whole-life costs and benefits over a period of analysis, as defined in the agreed scope".*These definitions have finally put to rest the confusion that has trailed the practice for so many decades.

2.3 Benefits and Uses of WLC.

The main benefits of WLC as outlined by many authors are; comparison of design alternatives, design optimisation, component performance evaluation and selection, costs forecasting and budgeting.

Flanagan and Jewell (2005) outlined the following as key benefits of WLA. comparison of designs;refinement of design details by comparing and selecting systems and components;planning and management of facilities throughout their service life;budgeting and scheduling of operations and maintenance activities realistically;An additional benefit outlined by Building Services Research and Information Association (BSRIA) (2008) is the ordering of independent projects to obtain maximum savings in operating, maintenance and repair cost.

Kishk et al (2003a) like Ferry and Flanagan (1991) divided the uses of WLC into two (2) broad groups exercised at different levels. At a lower level they say WLC is used as a decision making tool while it is used as a management system at higher level which is particularly useful at occupancy or operational stage of an asset. The types of decisions that could be taken at the lower levels are selecting from competing design or project alternatives, and selecting between two or more choices of components or materials. At the higher level they say, WLC is predominantly used to relate running cost and performance data thus making it useful in budgeting. Moreover, it serves as a useful tool in providing valuable information to designers who uses it as feedback information for design improvement.

ISO 15686-5:2008 has identified the circumstances under which WLCosting should be used and the decisions it facilitates. The circumstance includes the assessment of new

assets or major refurbishment and planning the future use of existing assets. It is also applied to a complete asset or to a specific assembly, component or system such as plant, road surface or a roofing assembly. The decisions that could be taken with aid of WLCosting as outlined in the standard are:evaluating different investment options;making choices between competing alternatives for the whole or part of a constructed asset at design and construction stages;making a choice between alternative components;comparing and/or benchmarking analysis of previous decisions at the levels of individual cost headings or at strategic levels;forecasting future cost for budgeting purposes or for the evaluation of the acceptability of an option on the basis of cost of ownership.

A survey conducted by Opoku (2013) in the UK revealed that the top benefits of using WLC are:Optimization of total cost of ownership;Assessment of future energy and running cost;comparison of options at building level;improved accuracy in the forecasting of future maintenance budget; and meeting durability standards.

In conclusion, the benefits expected from WLC assessment are summarized as follows: Selecting from competing investment options; Selecting from competing design alternatives; Selecting from choices of components at design, construction, and operating stages; Optimisation of design solutions or investment options through benchmarking; Forecasting future cost for budgetary purposes; Ordering of independent projects to obtain maximum savings in operating, maintenance and repair cost; Meeting regulatory standards.

2.4 The Legal requirement for WLC.

In view of the fact that WLC is still at its infancy in Nigeria, it should then be rationally expected that the legal requirement on the subject may be subtle and emanate from legislations on one hand and rules, regulations, and guidelines published by agencies they establish. Therefore, the following legislations were considered of interest:Public Procurement Act (2007); Infrastructure Concession Regulatory Commission Act (2005); Standards Organisation ofNigeria Act (1971); Privatization and Commercialization Act (1999); Fiscal Responsibility Act (2007)

2.4.1 Public Procurement Act 2007.

This Act was enacted on the 4Th day of June, 2007. The Act established the National Council on Public Procurement (NCPP) and the Bureau of Public procurement (BPP). These bodies have the statutory responsibility for "*monitoring and oversight of public procurement, harmonizing the existing government policies and practices by regulating, setting standards and developing the legal framework and professional capacity for public procurement in Nigeria*".

A reference to elements of WLC was made in the Act under section 32-"Evaluation of bids", subsections (4) and (5a) wherein it is stipulated that all relevant factors that will be considered during bid evaluation in addition to price, and the manner in which they will be used must be clearly stated. The section further outlines some of the factors that may be considered for the procurement of goods as: operating costs; efficiency; availability of services and spare parts; safety; and environmental benefits or loses by damages which are all aggregates of running costs

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The Act further stipulates the methods of disposal of public properties at the end of their life. Section 55 (Disposal of public property) clearly identifies the means of disposal of public assets. This includes: sale and rental; lease and hire purchase; licenses and tenancies; franchise and auction; transfer from one public department to another with or without financial adjustment; offer to public at an authorised variation. Section 56 (planning of disposals) further stated that, prior to the scheduling of any property for disposal; such a property must be valued by an independent and competent Evaluator.

Another relevant provision is for the procurement of consultancy services. The Act in section 44 requires procurement entities that wish to procure consultancy services to either request for expression of interest for pre-qualification or in the case of low value services where only domestic consultants would be interested, select not more than ten. The pre-qualified consultants are required to submit both technical and financial proposals simultaneously though in separate documents under section 48 (submission of proposals). Furthermore, the Act under section 49 (criteria for evaluation of the proposals) requires that, the criteria for the evaluation of the proposals be established and accorded relative weight for the purpose of evaluation of the effectiveness, price, ancillary or related costs of the proposals submitted by the consultants. Section 50 further requires that the Procuring Entity should select the successful proposal by choosing the proposal with the lowest evaluated price, or the best combined evaluation in terms of both the general criteria and quoted price. This provision is very important as it sets the legal ground for the comparison of design proposals based on both qualitative and quantitative evaluations.

The BPP has produced series of documents which serves as regulations and guidelines for public procurement. The publications considered relevant to WLC include;Procurement Procedures Manual (PPM); Public Procurement Regulations for Goods and Works (PPRGW)

2.4.1.1 Procurement Procedures Manual (PPM)

This document provides guidance or direction to all procuring entities on all matters relating to procurement. It is intended to give advice and assistance to procurement staff in carrying out their responsibilities. It is also a source of information on the tasks and element of the procurement process. Item 2.1 of the manual outline the "Principal Hallmark" of public procurement as; Economy; Efficiency; fairness; Reliability; Transparency and; Accountability and ethical standards. It explains Economy under items 2.1 as value for money to the purchaser. It further explains that, value may not be just a reflection of price but also quality especially for complex projects and that initial price may not equate to lowest cost over the operating life of goods procured. This is a salient call for the consideration of both quality and operating costs instead of just the initial price during procurement. Item 51.2 (Detailed bid evaluation Principles and Methodology) outlines the most frequently used bid evaluation criteria. Amongst these outline criteria are Operation Cost and Life Cycle Costs. sub-item (h) further defines LCC as "*...the assessment of the initial acquisition cost plus the follow-on ownership cost to determine the total cost during the life of a plant or equipment"* . In addition, it is stipulated that LCC is better used as a criterion for bids evaluation in the procurement of equipment in which the operating and maintenance costs are substantial so that minor differences in initial purchase price or competing bids can be overcome by the difference in follow-on costs.

The manual outlines the following as some of the elements to be considered in LCC assessments:Initial purchase price;Adjustment for extras, options, delivery, variations and deviations;Estimated Operational costs (fuel, labour etc); Estimated costs of spare parts and other consumables;Efficiency and productivity;Depreciation costs.Furthermore, the manual requires that future costs be discounted to the present using the Net Present Value (NPV) technique.

Item 77 (Selection and Employment of Consultants) detailed the procedure for the procurement of consulting services. The selection process consist of twelve sequential steps comprising of: the preparation or terms of reference (TOR); preparation of cost estimate and confirmation of available budgeted funds; choice of selection method; advertisement for expression of interest; short listing of consultants on the basis of the expression of interest received; preparation and issue of request for proposals (including letter or invitation and information for consultants); draft contract proposal submission in two separate envelops (technical and financial); Opening and Evaluation of technical proposals; opening and evaluation of financial proposals and ; combined evaluate based on the criterion identified in the RFP; negotiations and award.

What is of particular importance is that where design proposals are to be evaluated on the basis of LCC the platform for such an evaluation has already been established by section 77 through to 80 of the manual. For instance design consultants may be required to submit proposals based on specific requirements outlined in the ToR. The submitted proposals would then be evaluated based on outlined criteria (both Quantitative and qualitative) as specified in the RFP. The quantitative criteria may include initial cost, Operating, maintenance, and residual cost Income, and economic performance indicator. The qualitative criteria on the other hand may include

functionality, aesthetics, comfort, innovation etc. These criteria can then be combined to identify and select the best design proposal.

Items 89 to 90 under section 9 (Disposal of Public Property) explains the requirements and procedures for planning of disposal planning, selection of disposal method and documentation. Item 90 requires the Accounting Officer in charge of any public property slated for disposal to authorise the preparation of valuation report. Such a report should be prepared by an independent expert with the appropriate competence to carry out the valuation.

Item 91 stipulate the disposal methods that may used as: Trade-In; sales to other government agencies; Public Auctions; Sales by Sealed Bid; Negotiated sale and; Set Price. Item 92 demands the destruction or abandonment of public properly where it is unusable and determined to have no commercial value, or where it is established that the cost of sales far outweigh the expected returns.

2.4.1.2 Public Procurement Regulations for Goods and Works, 2007

This document aims to regulate the procurement process by identifying the various procurement activities, defining the roles and responsibilities of parties involved in the procurement chain, and stipulates how and when those activities should be exercised. The document under PART VI-Disposal of Public Property identifies the procedure through which a public asset should be slated for disposal and most importantly explains the various methods of disposal and when and how each should be used. The prevision under this section further elaborates items 90 to 92 of the PPM. The disposal methods are: Public Auction; Public Bidding; Sales to public officers; Trade-in; Transfer to another procuring entity; Destruction of assets. There are inconsistencies

between the disposal methods outlined in the PPM and those of PPR. Negotiated sales and set price are not captured in the PPR while sales to public officers and transfer to another procuring entity are not captured in the PPM.

2.4.2 Infrastructure Concession Regulatory Commission Act (2005)

This Act provides the legal framework for the participation of the private sector in financing the construction, development, operation, or maintenance of infrastructure or development projects of the Federal Government through concession or contractual arrangement. The Act also establishes the Infrastructure Concession Regulatory Commission (ICRC); a body charged with regulating, monitoring and supervising, infrastructure or development contracts. In line with provisions of the Act, ICRC was inaugurated on the 27Th of November, 2008. The Commission developed the national policy on PPP - which was approved by the Federal Executive Council (FEC) in April 2009. The policy aims to provide clear and consistent process and procedure guides for all aspect of PPP project development and implementation. The policy objectives of the FG as outlined in the policy intend to make infrastructural development a sustainable programme. Hence the objectives have been subdivided into three groups; economic, social and environmental.

The Economic objectives consist of the following amongst others:to ensure that all investment projects provide value for money (VFM) and the costs to government are affordable after allowing for economic growth;to increase the capacity and diversity of the private sector by providing opportunities for Nigerian and international investors and contractors in the provision of public infrastructure, encouraging efficiency, innovation, and flexibility;to ensure that the infrastructure projects are planned, prioritised, and managed to maximise economic returns and are delivered in a timely,

efficient, and cost effective manner;to manage the fiscal risks created under PPP contracts within the Government overall financial and budgetary framework.

The above objectives are very important in establishing the enabling environment for WLC application. First, the achievement of VFM requires the optimal combination of cost and quality over an assets life. By partnering with the private sector that is profit oriented under a competitive environment ensures that projects are properly planned and managed to maximize economic returns by ensuring efficiency, innovation, and cost effectiveness through careful risk evaluation.

Part 2 (VFM in public procurement by the FG) of the supplementary note to the policy requires the achievement of VFM in investment decisions to be based on both cost and quality. Such a decision should be based on both long-term affordability assessment having considered project risks and uncertainly. It is further required that the principle of VFM should be intrinsic to all PPP projects be it a freely provided or user-charge service. The note further emphasizes the need to consider economic, social and environmental benefits as well as WLC of services not just the initial cost in assessing VFM.

Section 2.1 (VFM) of the note places an onus on those responsible for government spending decisions to do so wisely so as to obtain VFM in both relative (where one of the options of meeting the purchasers needs provides greater benefits relative to cost than others) and absolute (the benefits of the purchase to the purchaser exceeds the cost) terms.

Section 2.1 further noted the difficulty associated with VFM assessment because of the scarcity of relevant data on costs and outcomes in options comparison, and the uncertainty associated with forecasting costs and assessing risks. It therefore suggests the use of expert opinions and advice on costs and risks in appraising project options and bid evaluation. In addition, the need for discounting when comparing options with different future profiles of costs and benefits was emphasized. The essence of the discounting is to demonstrate the need to receive benefits as early as possible and to incur cost later rather than sooner. It is further required that the discount rate should include the cost of financing investment through borrowing (risk-free rate), risk and uncertainty in project outcomes, and sometimes the effect of taxation. In addition the VFM analysis should take into account price inflation at both the general and section levels.

Moreover, VFM assessment could be done in real or nominal terms. The note requires analysts to be consistent so that either all values are expressed in real terms (i.e. net of general inflation) or in nominal terms (i.e. including an allowance for general inflation). Section 2.2 (Affordability) highlights that the use of historical budget allocations to test affordability will result in few PPP projects passing the affordability test because insufficient funding has historically been allocated to the maintenance of public infrastructure. Thus maintenance and financing costs of projects should be factored into the WLC of the project which would subsequently be paid to the private contractor.

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Section 2.6 (Discount rates) further describes discounting as the process of bringing future cash flow (both positive and negative) to a present value for the purpose of comparison. It further describes the sum of all the future cash flows as the net present

value of the investment. In addition it reiterates the importance of discounting in comparison of cash flows with different profiles over project life-cycle, and in the evaluation of bids which may have different profiles depending on the financing and indexation proposed by different bidders. It requires same discount rate to be used in project appraisal, the assessment of VFM of different procurement options, and bid evaluation.

Section 2.3(Risk) demands that risk be taken into account throughout project life-cycle and be factored into the project. Further, risk should be quantified in terms of its likely impact and probability of occurrence and where data is not available panel of experts should be use to systematically identify and then quantify the potential impact and likelihood of occurrence of different risks. Part 3 (Project risks and PPP with the Federal Government) categorises risks into six broad groups of; Demand and Revenue; Availability; Financial; Political and Contractual Risk; Changes in requirements and Residual risks. It further requires that these risks must be identified at different project stages and allocated between the contractor and the procuring authority. In addition, the quantification of risks should be based on relevant data where possible or be based on subjective assessment of both the impact and probability of occurrence (e.g. high, medium or low probability or impact). Other risks that should be borne by the contactor includes design and construction risk which may have an impact on quality of output.

Section 2.4 (project appraisal) defines project appraisal as "the process by which the need for further investment is identified, the objective of the investment project stated and various options for meeting this need determined to identify the preferred option." The preferred option is required to satisfy both VFM and affordability assessment. In addition, project appraisal should quantify both the cost and benefits over a projects

life-time. The quantification of the benefits should be based on monetary terms to aid the computation of the Net Present Value (NPV). However, benefits should be expressed in qualitative terms where they cannot be expressed in monetary terms.

There is always the need to look at a range of alternative solutions that could satisfy the project needs. In order to avoid over specifying project requirements a “Do-minimum” option should also be considered which represents the alternative with the minimum expenditure and risk profile but yet satisfy the project needs. Such a “Do minimum” option could be set as a “base case” against which other alternatives should be compared.

The ICRC also produced the PPP-toolkit which is a manual and a guide for the procurement and management of concession contracts. The kit describes VFM under section 1.2.2.4 as the option or bid that provides the highest ratio of net benefit to overall cost. This is suggestive of the use of benefit-to-cost ratio as the economic evaluation technique during comparison of options or bids.

Comparing this provision with section 2.6 of NP on PPP where the NPV is recommended for the evaluation of alternatives the use of portability index (which is a ration of NPV to cost) in economic evaluation is also valid.

Section 2.1 of the kit identifies four key stages of project life-cycle. These stages are: Project Development; Project Procurement; Project Implementation and; Project Maturity. Relating these stages to building through the RIBA 2013 plan;

Table 2. 1:Comparison of ICRC Project Life Cycle Phase and RIBA plan of work Stages

Stage	ICRC Stages	RIBA Project Life-cycle Stages
1	Project Development	Stage 0-Strategic Definition, Stage 1-Preparation and Brief, Stage 2 to 4-Design.
2	Procurement	Corresponds to design stages 2 to 4. Procurement for PPP usually occurs at early design stages.
3	Project Implementation	Stages 5-construction, stage 6-Hand over and close out and stage
4	Project maturity	7- In Use. To End-of-life

The Project Development phase corresponds to the initial stages where project brief and investment appraisals are performed, and preliminary designs are prepared in preparation for procurement stage. The level of design detailing required prior to contractor selection may vary from project to project depending on project complexity, and time available. Procurement could be achieved at any of the design stages. Where for instance the client is responsible for design, procurement may begin at later design stages, but where design proposals forms part of the contractors bid as in design and build, then the procurement will be achieved at early design stages. It is however best achieved at the early design stages to reduce cost of tendering for the contractors and fast track the procurement process. The Implementation phase represents the construction stage while the Project Maturity phase represents the operating and the end-of-life of the project (which could be physical, economical, legal or technological).

An important requirement of the project development stage is the preparation of outline Business case (OBC) by the procurement entity. The process specified in section 4.2 of the kit follows the following stages:

a) Strategic needs assessment;

b) Analysis of the service delivery option;

c) Technical analysis of option and outline design;

d) Preparation of risk matrix which identifies the entire project risks and allocates them to the party best able to manage them;
e) Financial modelling of the risk-adjusted project cost and revenues, including sensitivity and VFM analysis for government, in the form of a public sector comparator;
f) Project viability assessment for private investors using a shadow bid model incorporating financing costs and belt service cover ratios;
g) Economic cost benefit analysis;
h) Project implementation plan;
i) Compilation of the outline business case report.

The preparation of the financial model begins with the development of a Financial Feasibility Analysis (FFA). Section 4.2.4.1 (financial feasibility) identifies three cost centres that must be accounted for: capital costs, operating costs and maintenance costs. In addition, section 4.2.4.2 requires project revenues to be estimated and included in financial models. Other inputs of the financial models are: cost of finance, and assumptions on key economic variables. The financial viability of the project is then determined by computing the IRR of the project. Section 4.2.5 (Economic Cost Benefit Analysis) requires an Economic Cost Benefit Analysis (ECBA) to be included in any feasibility studies. Such an assessment should include:

a) The economic benefits from the project
b) The economic costs of the project
c) The balance of the two above expressed in Present Value (PV) terms based on either economic benefit or Economic Rate of Return (ERR).

The economic analysis however, captures other project impacts both positive and negative that may or may not be assessable monetarily. The obvious difference between

FFA and ECBA is that while the FFA is restricted to financial cost and revenues, the ECBA in addition captures the none-monitory costs and benefits.

Finally, Section 4.2.4.4 (Financial Sensitively) requires a sensitivity analysis to be conducted to assess the financial robustness of the project in response to changes in key uncontrollable variables.

2.4.3 Standards Organisation of Nigeria Act.

This Act was enacted by Act No. 56 of 1971. It comprises of three amendments: Act No. 20 of 1978, Act No.32 of 1984, and Act No. 18 of 1990. The Act establishes the Standards Organisation of Nigeria (SON) and the Standards Council of Nigeria. SON (2013) identified its aims and objective to include: "*preparation of standards relating to products, measurements, materials and processes among others and their promotion at the national, regional and international levels; certification of industrial products, assistance in the production of quality goods, improvement of measurement accuracies and circulation of information relating to standards*." In order to meet up with the socio-economic changes at both national and international levels, SON sought membership of International Organisations for Standardisation (ISO), African Regional Organisation for Standardisation (ARSO) and other relevant bodies to further Nigeria's interest in the field of standardisation. Therefore SON is effectively an affiliate of ISO (SON, 2013).

The International Organization for Standardisation in 2008 published ISO 15686: Buildings and constructed assets-service life planning which consists of the following parts:

Part 1: General Principles

Part 2: Service life Prediction Procedure.

Part 3: Performance audits and reviews

Part 4: Data structure

Part 5: Life-Cycle costing

Part 6: Procedures for considering environmental Impacts

Part 7: Performance evaluation for feedback of service life data from practice.

Part 8: Reference service life and service-life estimation

Part 9: Guidance on assessment of service-life data

Part10: Levels of functional requirements and levels of serviceability-Principles, measurement and use.

Part 5: Life-Cycle costing aims to achieve the following objectives:

to establish clear terminology and a common methodology for life-cycle costing (LCC);to enable the practical use of LCC so that it becomes widely used in the construction industry;to enable the application of LCC techniques and methodology for a wide range of procurement methods;to help improve decision-making and evaluation process at relevant stages of any project;to address concerns over uncertainties and risks and improve the confidence in LCC forecasting;to make the LCC and the underlying assumption more transparent and robust;to set out the guiding principles, instructions, and definitions for different forms of LCC and reporting;to provide the framework for consistent LCC predictions and performance assessment, which facilitates more robust levels of comparative analysis and cost benchmarking;to provide a common basis for setting LCC targets during design and construction, against which actual cost performance can be tracked and assessed over the asset life span;to provide guidance on when to undertake LCC, to what level and what cost headings are appropriate for consideration;to help unlock the real value of effectively doing LCC in construction by using service-life planning;to clarify the difference between life-cycle costing and whole-life costing (WLC);to provide a generic menu of costs for

LCC/WLC compatible with and customizable for specific national or international cost codes and data-structure conventions;to provide cross-references to guidance on associated activities within the other parts of ISO 15686.

The International standard ISO 15686-part 5: 2008 however, does not aim to replace national or local rules, regulations and practices. Its intention is that “more detailed guidance and cost structures applicable to national conditions are used to develop the cost plans which can be mapped to the ISO cost structure". It is in line with this position that the British Standards Institution published the Standardized Method of Life Cycle Costing (SMLCC) for construction procurement. The document was meant to be a supplement to ISO15686 Part 5: 2008. The objectives of SMLCC as outlined in the documents are to provide:

i. A UK standard cost data structure for LCC which aligns with ISO15686 and with BCIS Standard Form of Capital Cost Analysis (SFCA) and industry recognized occupancy cost codes;
ii. Life-Cycle costing practitioners with standardized method of applying LCC applicable to the UK construction industry and to the key stages of the procurement process;
iii. Process mapping the life cycle costing stages to help structure how to plan, generate, interpret and present the result for a variety of different purposes and levels of life cycle cost planning;
iv. Instruction on how to define the client’s specific requirements for LCC and the required outputs and forms- and to decide on which method of economic evaluation to apply;

v. Simplification and demystification- by providing practical guidance, instructions and definitions, together with informative worked examples on how to undertake life cycle costing (for construction); and

vi. An industry accepted methodology, to facilitate a more accurate, consistent and robust application of LCC estimation and option appraisals- thereby creating a more effective and robust bases for life cycle cost analysis and benchmarking.

The UK practice is supported by extensive and comprehensive databanks in which historical records in specific formats are kept. Examples are the BCIS and BMI databanks in which capital cost based on elemental format, and occupancy costs data are kept respectively. Since the use of such data for Nigerian practice is not practicable due to environmental and developmental differences, the use of SMLCC is negated in that regard. The elemental break down and occupancy cost codes may be useful in practice as building performance is better understood if studied on elemental basis. Additionally, a useful information provided by SMLCC is the process map of the key stages at which LCC is typically undertaken. The map relates decision stages with RIBA plan of work-which represents the project life cycle and the tasks to be performed by the cost analyst.

2.4.4 Public Enterprises (Privatisation and Commercialisation) Act.

This Act was enacted by Act No. 28 of 1999. An act ".....to provide for privatisation and commercialisation of certain public enterprises and to establish the national council on privatisation and the Bureaus of Public Enterprises…." The Act is particularly important where the decision to sale public property is taken at the end of its life. This is usual where a building becomes obsolete while physically sound. The Act under section 2 requires privatisation to be done either through public issue, private placement, willing seller and buyer basis or any other means as may be determined by the National Council on privatisation. The Public Procurement Act (2005) however, has extensively further discussed various disbursement options and procedures. The Public Enterprises Act however, is particularly useful in determining proportions of FG shares in the case of partial privatization and modalities for public and private offers.

2.4.5 Fiscal Responsibilities Act, 2007.

This Act was enacted on the 30th day of July 2007. It is “An Act to provide for prudent management of the Nations resources, ensure long-term macro-economic stability of the national economy, secure greater accountability and transparency in fiscal operation within the medium term fiscal policy framework, and the establishment of the Fiscal Responsibility Commission to ensure the promotion and enforcement of the nation's economic objectives; and for related matters”.

The Act requires the Federal Government (FG) in consultation with States Government to prepare annually and submit to the National Assembly a Medium-Term Expenditure Framework for their consideration and approval. Section 11(Medium term expenditure) sub sec.3 to outlines the constituent of the framework to include; a macro-economic, framework; a fiscal strategy paper; an expenditure and revenue framework; a consolidated debt statement and; a description of the nature and fiscal significance of

contingent liabilities, quasi-fiscal activities and measures required to offset the crystallisation of such liabilities. Section 11 subsection 3 (c) specifically requires the projections of revenues and expenditure to be based on reliable and consistent data from:

i. National Planning Commission
ii. Joint Planning Commission.
iii. National Commission on Developmental Planning
iv. National Economic Commission
v. National Assembly
vi. Central Bank of Nigeria
vii. National Bureau of Statistics
viii. Revenue Mobilization Allocation and Fiscal Commission
ix. Any other relevant statutory body as the minister may determine.

This provision is very important as it clearly identified the recognized and approved sources of data for economic assessments and evaluations concerning the public sector.

2.5 Impediments to the Application of WLC

The uptake of WLCosting has been very slow since its inception around the 1960's. The slow uptake has been attributed to a number of factors. These factors are discussed in detail in the following subsections.

2.5.1 WLC Implementation cost and scarcity of historical data.

The cost of WLC analysis has been largely attributed to the cost of data collection. Ferry and Flanagan (1991) reported that the costs of data collection are enormous and time consuming. The problem is particularly magnified where WLC models requiring large data samples are used. Bull (1993) asserted that there is the lack of appropriate,

relevant and reliable historical cost information and data. He stated further that, where the data is available, they are usually so contradictory in their nature. According to Ashworth (1996), historic data will never provide us with precise solution and high quality judgment will always be required. In view of the data availability/scarcity problem, many writers (Clement and Winkler, 1999; Sobanjo, 1999) advocates for the use of subjective assessment where cost and performance data would be elicited from experts. Kishk and Alhajj (1999) argued however that, unless a method for modelling human judgment is built, the problem of personal bias would arise.

In another development, El-haram et al (2002) attributed the data scarcity/availability problem to lack of industry standards. They postulated that, although a number of data collection structures like UNIFORMAT, Building Maintenance Information (BMI) and Building Cost Information Service (BCIS) have been proposed they are not universally accepted. Bakis (2003) also share a similar view as he suggested the need to develop an acceptable data collection framework.

Alhajj, Pollock, Aoud, Sun,and Bakis (2001) noted that WLC implementation has been trapped in a vicious circle containing a series of causes and consequences. They asserted that, the lack of sufficient and appropriate data leads to lack of confidence in WLC evaluation process thus hindering the obtainment of feedback information on building performance. They explained that, this vicious circle must be broken if the application of WLC is to be improved.

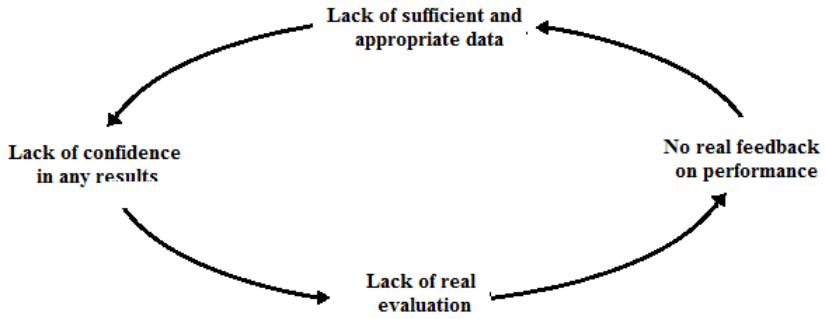


Figure 2. 2:The vicious circle of WLC Implementation (Source: Al-Hajj et al, 2001)

Another data related problem resides with the limitations of existing databases. These databases which are supposedly designed to provide a system that simplifies WLC data storage and retrieval are inconsistent. Al-Hajj et al (2001) described them as "constructed" rather than "historical-based". They argued that the databases are based on "expert opinion", trades publication data, and manufacturers' data. They further noted that background information and measures of uncertainty are often lost during data storage as the context information on the data is often not recorded. This is particularly a problem as data relating to a proposed project is often generated from multiple sources. Moreover, the accuracy of existing databases is questionable as close to 38% difference in estimate was observed between two commercially available cost databases. Part of the problem they say was that cost per unit area was used as a normalisation factor without considering hours of use and occupancy profile.

In Nigeria, WLC data scarcity has been reported by Ibrahim, Bala, Ibrahim, and Ibrahim (2010). They noted the complete absence of published data relating to operating and maintenance cost, life expectancy of building components, cost indices and location adjustment factors. In addition, they asserted that a standard datacollection, analysis and presentation framework is not available in the industry.

This is a serious handicap to the development of database that would facilitate WLC data storage and retrieval.

Sobanjo (1999) and Kishk and Al-Hajj (1999) suggested the use of Fuzzy Set Theory (FST) as a means of modelling subjective assessment in cost modelling. Since then, concerted effort has been made by researchers (Kishk and Al-Hajj 2000a, 2000b, 2000c, 2002a, 2002; Kishk, 2002; Kishk, 2004; Wang et al, 2004) to explore the application of FST to model subjectivity in LCC computations. This led to the development of series of algorithms and models to handle expert judgement. For instance, Wang (2011) developed a fuzzy multi-criteria decision-making model that eases the ranking of design alternatives while Mohammad and Osama (2013) developed a fuzzy-based WLC decision-making model under subjectivity.

In another stride, El-haram et al (2002) developed a generic framework for collecting WLC data for the UK building industry. They first proposed WLC breakdown structure that consists of five levels of data. These are: project level, phase level, category level, element level and task level. The project level represents the highest level of the structure and it relates to the different types of buildings like residential, commercial, industrial etc. Each building passes through 3-phases over its life-cycle: capital (design and build); facility management; and disposal. Level2 which is the phase level is comprised of the cost categories. These cost categories are broken down to cost elements. The elements at level4 consist of elemental costs. Level5 is the task level which is the final and lowest level of the structure. A task is a combination of so many activities. Figure 2.3 shows the proposed cost break down structure. The adoption of the framework would provide the opportunity to generate alternatives by considering various what-if scenarios; reuse data generated from previous projects thereby reducing

design and bidding times; encourage the use WLC and other techniques thereby helping in the design and construction of buildings with lower WLC. Despite these promises, the framework has a major limitation of not conforming to international standard; specifically, ISO1568-5:2008. It falls short of the standard both in terms of definition and classification. For instance, under the international standard, WLC captures both costs and benefits over an asset's life. The proposed structure however, did not consider expected incomes and revenues. More so, financial cost, overhead cost, management and land acquisition cost are classified under non-construction costs while project impact on environment and social wellbeing of others is under externalities based on the standard. Such limitation should be expected though, since the structure was proposed in 2002 while the standard was published in 2008.

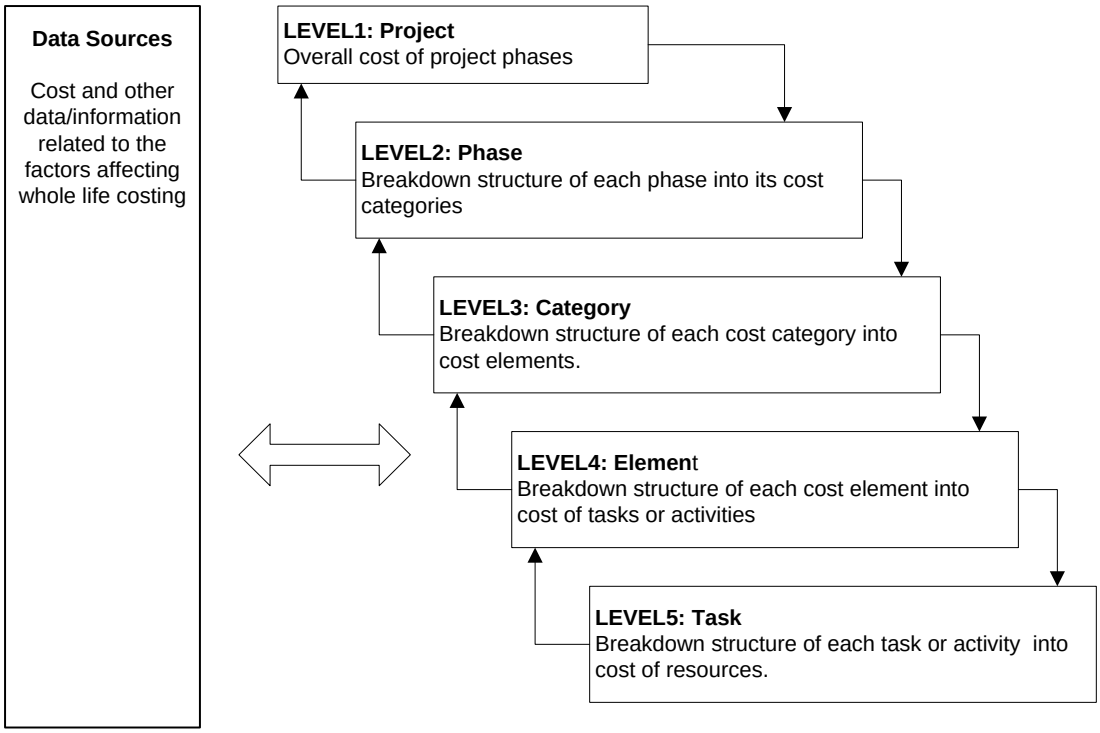


Figure 2. 3: Levels of WLC Data Structure (Source: El-Haram et al, 2002)

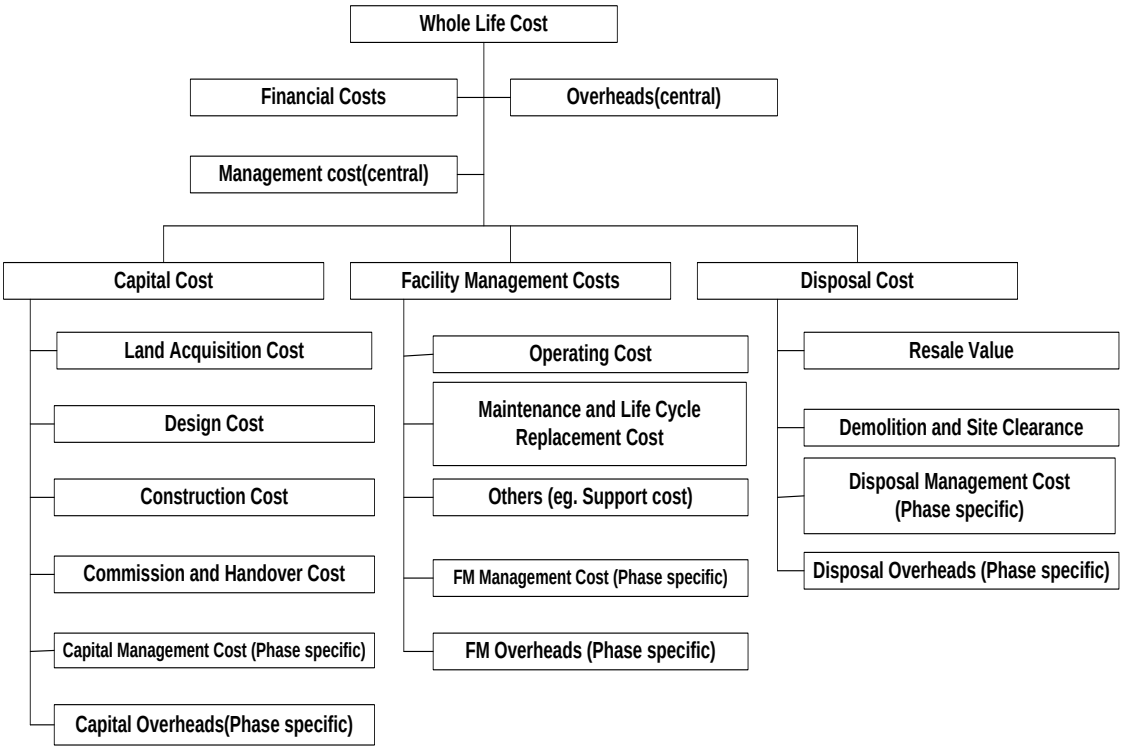


Figure 2. 4: Cost Breakdown Structure of Cost of Project (Source: El-Haram et al, 2002)

In an attempt to address the limitation of existing WLC databases on the other hand, Kishk, Al-Hajj, Pollock, Aoud, and Bakis, (2002b) and Kishk, Al-Hajj, and Pollock (2003b) designed and developed two databases intended for use at the design stage of a project life-cycle. The databases which they called resource and project database were integrated into Open System for Construction (OSCON) design platform developed at the University of Salford to aid decision-making during option evaluation and selection at design stage. The purpose of the resource database is to accommodate all necessary information on various options for every element in the Work Breakdown Structure (WBS). The project database enables the identification, retrieval and storage of data for specified building objects within OSCON design platform. The resource database however, is of more interest to this study as it stores performance data on building elements collected from different sources. It is obvious from the design that, the database was developed with the clear intention to preserve data integrity. It facilitates the storage of background data for elemental costs thus keeping performance data in

context. In trying to achieve this however, a compromise was made where large data items on same elements with similar characteristics is available. Under this circumstance, the data sets are refined so that only their range median, and standard deviation are stored while the raw data is discarded. It may be argued that, the refinement frees up computer memory thereby realizing cost savings. The implication of losing the original data set must however be examined. Considering the numerous data analysis techniques in use and their data requirement, it is expedient that the raw data be kept intact so that transformation between data types is possible. For instance transforming the data into probability density function or fuzzy membership function can be made for use in stochastic and fuzzy models.

2.5.2 Lack of awareness

Many writes like Ashworth (1993), Kishk et al (2003a), Norman (2007), Hoar (2007), Moir and Bowles (2010), Higham, Fortune, and James (2015) have reported on lack of awareness on the part of the client as a drawback in the application of WLC. The level of awareness on the importance of WLC differs between the public and the private sectors. While the public sectors of countries like UK, US, Sweden, Canada, Australia amongst others have identified its value and have taken steps to ensure its use in their respective construction industries, the private sectors are sceptical. This may not be unconnected with the fact that while the public sector tries to demonstrate accountability and whence mandate WLC analysis to achieve value for money, the private sector is predominantly profit driven and only invest in ventures that are demonstrably rewarding. This reluctance on the part of the private sector client is according to Norman (2007), due to poor understanding of the concept. In order to mitigate the problem, Bull (1993) suggested that professionals must educate and convince their clients on the benefits of WLC. In addition, they must be able to

demonstrate to the clients the significance associated with costs throughout the life of a building. Higham et al (2015) noted however that professionals themselves have not fully embraced the concept. Goh and Sun(2016) noted however that, there is growing interest in the use of WLC as it is finding an increasing application in the sustainable design and development of green buildings. In another report by Swaffield and McDonald (2008) contractor's Quantity Surveyors in the UK generally applies WLC concepts during the procurement of materials and components to be used in especially PFI projects.

Substantial advocacy progress has been made in the public sector of most developed countries. The UK government for instance demands that "*all procurement must be made solely on the basis of value for money in terms of the optimum combination of whole life cost and quality to meet the user's requirement*" (OGC, 2003). Kirkham, Alisa,Silva, Grindley, and Brondsted (2004) asserted that, this view was fully supported by the UK's National Audit Office policy which led to the publication of their joint guide "*Getting value for money from procurements- How auditors can help".* Consequently, WLC was considered an integral part of procurement decision-making process in the UK.

In the US, legislations requiring the use of WLC have been in existence since the mid 1970's. Presently, most states in the USA require the use of WLC for public procurements (Norman, 2007). The European Union (EU) in 2004 saw the need for a common European WLC methodology. They initiated a research in 2006 which led to the development of an EU wide WLC methodology and WLC application guide in 2007. A promotional campaign aimed at promoting the use of the EU LCC

methodology/guidance and stimulating an exchange of experience and information related to WLC between member states was launched in 2009 (Langdon, 2010). Other countries like Canada, Australia and New Zealand have also made significant progress in the application of WLC in public procurements.

In Nigeria, the legislative arm of the government passed the Infrastructure Concession Regulatory Commission and the Public Procurement ACTs in 2005 and 2007 respectively. Both ACTs clearly requires the application of Value-For-Money (VFM) standards and principles in the procurement of public assets. Furthermore, the federal executive council in April, 2009 approved a national policy on Private Finance Initiative which contains a supplementary note titled "Value-For-Money in public procurement by the Federal Government". The note places an onus on those responsible for government spending decisions to spend revenues wisely and obtain VFM in both relative and absolute terms and that the assessment of VFM should be based on Whole Life Cost (WLC) of an asset not just the initial cost. This requirement clearly poses a challenge to professionals giving the plethora of difficulties associated the WLC exercise.

It is pertinent to note that, despite the effort from various quarters to standardize WLC process and procedure, device innovative risk analysis tools, mathematical models, database and state-of-the-art applications, all in an attempt to improve WLC result accuracy and reliability, client's in especially the private sector do not commission projects on WLC bases. Opoku (2013), like Higham et al (2015) concluded that clients' refusal to commission projects on the basis of WLC remains the topmost drawback in the use of the technique. This is particularly worrying as clients' demand is supposed to

be the key driver of WLC services. Could it be that professional in the industry had been negligent all along by focusing on WLC processes rather than product? Could it be that professionals have been forcefully pushing down the throat of their clients a product they don't need yet complaining that they don't consume? These are valid questions that need answers because the vicious circle that Kishk et al (2003a) desire to be broken confirms that professionals are more bothered about data scarcity instead of demand for the service. This vicious circle could be explained by the clients' attitude. First, clients do not understand the concept as a means of value addition so they do not demand for the evaluation. This lack of demand means that practical WLC evaluation would be rare. The rarity of evaluations also results in shortage of empirical feedback information on cost and performance which means that, a basis for comparison and whence cost control is missing leading to lack of sufficient and appropriate data. Scarcity of reliable data of course reduces confidence on the part of the professional who then find it very difficult to justify results for the client. It is this circle as shown on Figure 2.5 that needs to be broken not the former.

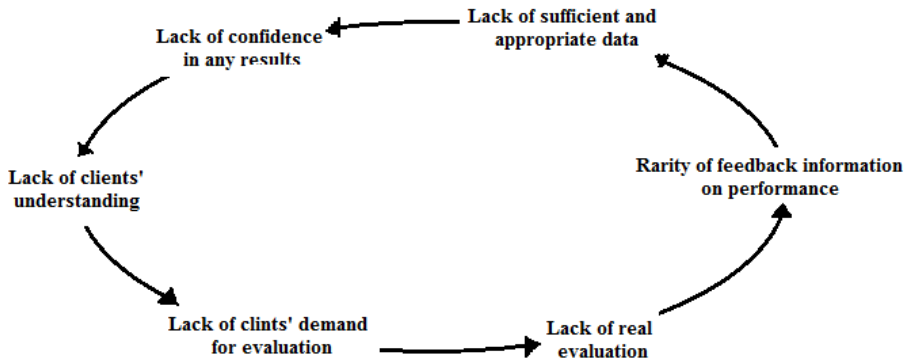


Figure 2. 5: Vicious circle of WLC Implementation based on Client's Lack of Demand for Evaluation.

A further examination of the situation reveals also that clients in their own way, consciously or unconsciously apply WLC concepts in their investment decisions.

For instance, clients are prepared to pay more for energy saving lamps in anticipation forfuture reduction in energy cost (BSRIA, 2008). Moreover, building owners often deck the roofs of their buildings in anticipation for a possible future vertical expansion. Also buildings are often constructed with soft partitions or in some cases without partition walls in anticipation for possible future change in demand. These are all WLC concepts considered by clients based on intuition. Surprisingly, not much effort has been channelled by professionals towards assisting clients in taking informed decisions regarding their strategic investment concerns. A research funded by Partners in Innovation (PII) and conducted in 2002 sought to explore the use of financial management techniques in the evaluation of WLC of proposed projects. Findings of the research suggested the use of "options thinking" or “life-cycle options” in WLC assessments. Ellingham and Fawcett (2005) concluded that for buildings to be economically sustainable we must not only embed options in design but rather learn to evaluate them. They identified five options:

i. Option to develop;
ii. Option to reconfigure;
iii. Option to switch use;
iv. Option to expand; and
v. Option for new technology.

Fawcett (2011) emphasised that, there is a responsibility on professionals to ensure that, built environment can easily accommodate change and growth. Predicting future change and growth with certainty he maintains is impossible to achieve. For this reason he noted, flexibility should be embedded in the design of the built environment. Current WLC tools cannot be deployed to evaluate the adequacy and value of an embedded flexibility in a building design. This calls for the development of special models that

can achieve such task. These models use financial management techniques as a basis for evaluating real options.

Though the rationale behind "option thinking" is to make investment in buildings economically sustainable, it is indeed a sound idea as it addresses the kinds of strategic investment decisions usually taken by especially the private clients. By deploying the financial management techniques advocated in options analysis, building investors would be served with a product that addresses their strategic investment needs which in return would improve the demand of WLC services by the clients.

2.5.3 Complexity of the Process

The preparation of a typical WLC estimate is usually a complex task. Bakis, Kagiouglou, Aoud, Amaratunga, Kishk, Al-Hajj (2003) highlighted that the exercise is too complex to be applied manually especially at the detail design stage. They noted that the analyst has to estimate the WLC of different options for each building element. In addition, he has to consider various cost and performance data for each building element. The computed cost must then be discounted, added up, and then projected over the buildings life cycle. The analyst finally conducts risk analysis to ascertain the validity and reliability of the results obtained and also facilitate the decision-making process. While the risk analysis requires the use of complex techniques like, sensitivity analysis, Monte Carlo simulations, Confidence Index approach, to mention but a few, decision-making requires the assessment of not only the cost factors but also quality factors like aesthetics, functionality, eco-friendliness, fire/thermal resistance, etc. (Kishk and Pollock, 2004). Development in software computing has however drastically reduced the WLC process complexity. Kishk et al (2003a) asserted that, existing WLC software has improved the computational efficiency and reduced process

complexity thereby allowing the analyst to focus on results interpretation and decision-making.

2.5.4 Limitations of existing WLC Implementation Methodologies

The absence of a standard WLC implementation methodology plunges the practice in to disarray by promoting lack of conformity in; variables to be considered, implementation procedure, economic performance measure, models to be employed risk analysis technique, and presentation format. Though numerous methodologies exist, they are diverse and do not provide uniform basis for WLC evaluation (Kelly, 2008). These methodologies need to be evaluated in order to establish their efficacy in satisfying WLC requirement. In doing so, the requirements that these methodologies should satisfy must first be articulated from literature.

One of the principal uses of WLC evaluation is to aid decision-making. There is an overwhelming consensus amongst researchers and authors on WLCosting being a tool that enables analyst to make informed decision on choices between competing alternatives (Dell'Isola and Kirk, 1981; Griffin, 1993; Kishk et al, 2003a; Flanagan and Jewell, 2005 etc.). This implies that the sequence of any WLC methodology must reasonably follow the decision-making process. Taking the issue a step further, it is logical to infer that WLC methodology should also conform to the problem solving process. This is a valid presumption giving the relationship between decision-making and problem solving process. In fact since WLC activities span through the entire life of an asset, the entire cycle is better viewed as a problem solving process. This would facilitate a holistic approach to WLC rather than the traditional fragmented process. Figure 2.6 below shows the relationship between problem solving and decision-making

process on one hand, and life-cycle stages of a building on the other. The first three stages of the decision-making process are collectively referred to as problem structuring, while the last two stages are referred to as problem analysis.

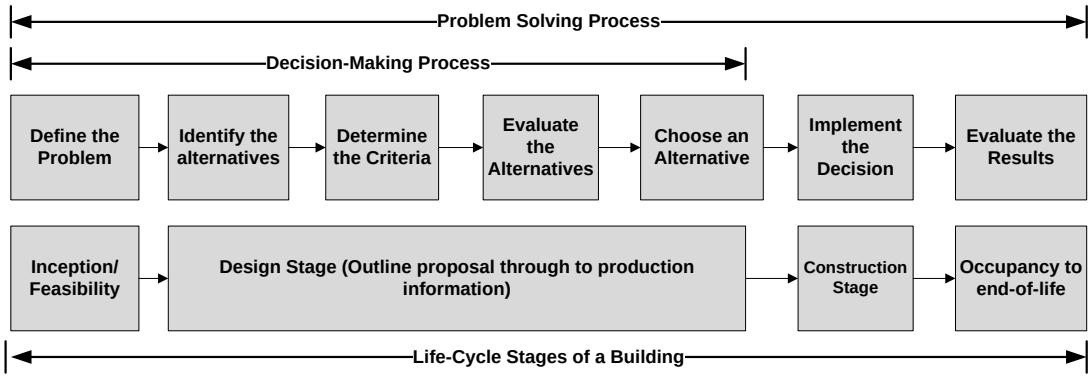


Figure 2. 6: Relationship between Life-Cycle Stages of a Building and Decision-Making and Problem Solving Processes

Secondly, it has been well established in literature that, WLC is a continuous activity throughout the life-cycle of a building (Flanagan and Norman, 1983; Dell'Isola and Kirk, 1991; Ashworth, 1993; Garnett and Owen, 1995; Kishk et al, 2003a, Boussabaine and Kirkham, 2005, Norman, 2007 etc.). This is an important condition because so many parameters vary with life-cycle stages. It has been demonstrated for instance that:

the potential for cost savings and cost of WLC implementation vary with life-cycle stages (Dell'Isola and Kirk, 1981). Figure 2.7 and 2.8 shows this relationship;

the nature impact and level of risk varies with life-cycle stages (Boussabaine and Kirkham, 2004);The types of decisions required vary at different stages of building life-cycle (Griffin, 1993; Kishk et al, 2003a; Boussabaine and Kirkham, 2004);

Data certainty and reliability varies with life-cycle stages (Kishk et al 2003a, Ibrahim, 2008a);the type of model to be employed is dependent on the objectives of the assessment which in turn varies with life-cycle stages (Boussabaine and Kirkham, 2004).

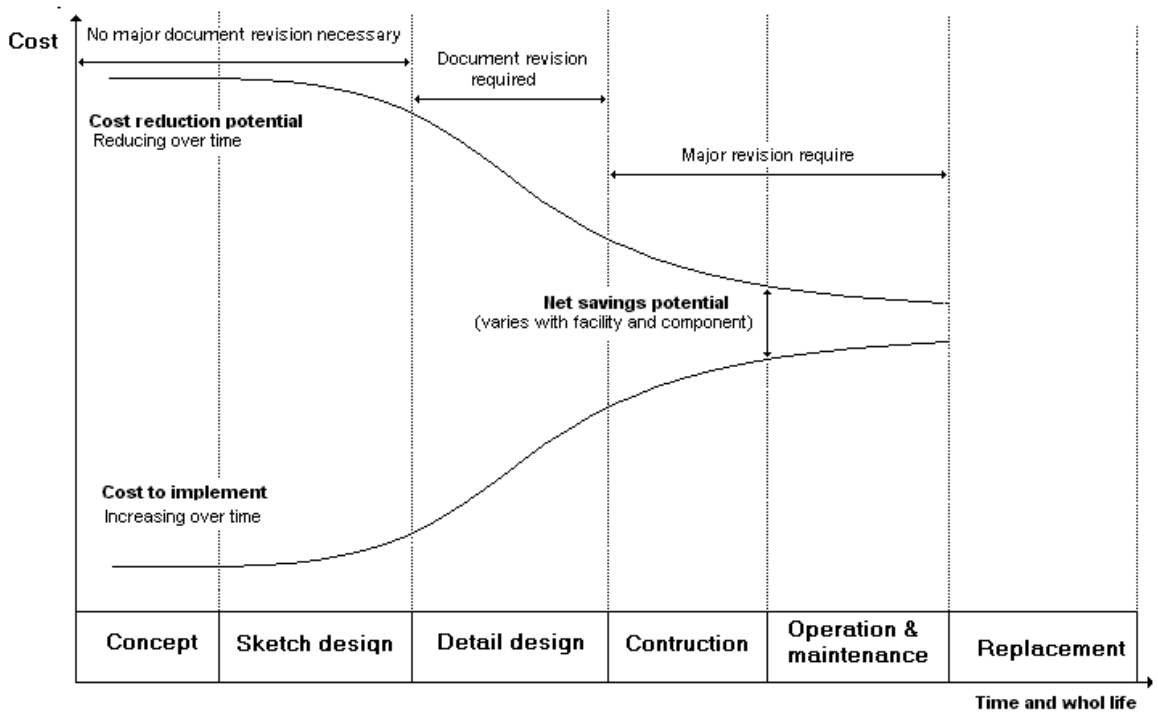


Figure 2. 7: Potential for cost Savings at Different Stages of Project Life-cycle (Source: Dell'Isola and Kirk,1981)

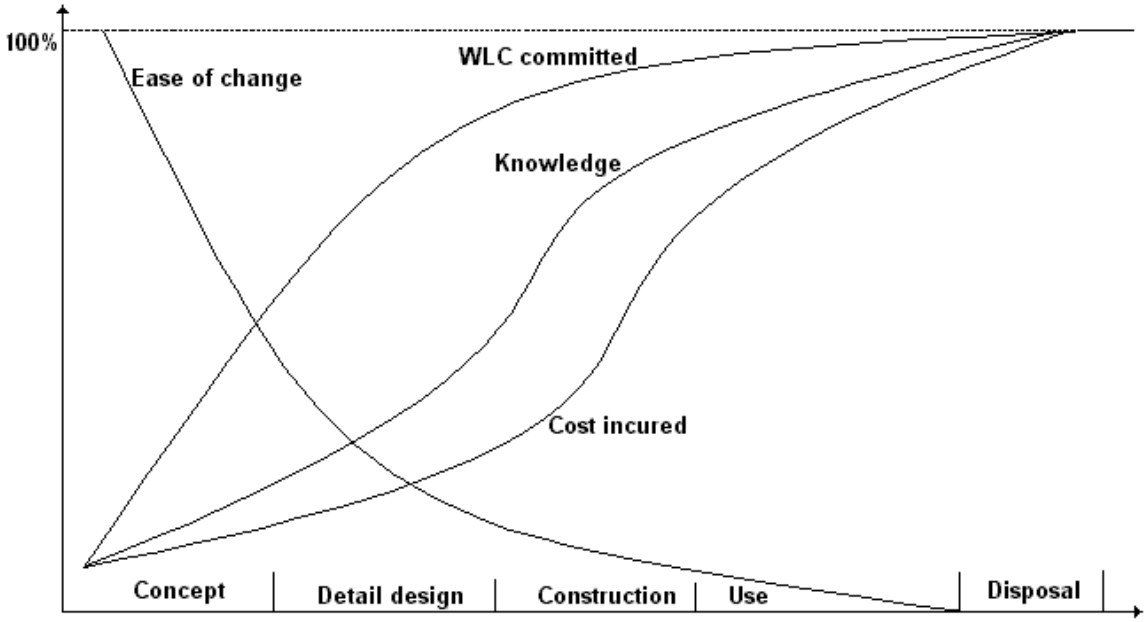


Figure 2. 8: WLC Committed, Cost Incurred, Knowledge and Ease of Change. (Source: Fabricky and Blanckard, 1991)

Thirdly, the desire to make forecasts over long periods of time coupled with the dearth of reliable historical data necessitates the evaluation of sensitive and risky variables. Risk and uncertainty analysis is necessary in WLC evaluation due to certain uncontrollable factors analyst must include in their analysis. These factors includes; technological changes; changes in fashion, cost and value changes; policy and decision changes and result accuracy (Ashworth, 1993). A reliable WLC methodology must therefore stress the need for risk and uncertainty analysis.

Lastly, WLC methodology should also stress the relationship between the stages. This should be achieved through the identification of activity and information flow. This eases the identification of possible activity recycling or feedback. It has been recognized that WLC cost activities are both sequential and iterative. Norman (2007) stipulated that, the entire process must be viewed as consisting of discrete and sequential steps with possible iterations where necessary. In addition, information generated at previous stages is usually refined on the basis of new information derived from subsequent stages. Data generated at later stages of an asset life could be useful in taking similar investment decisions or deciding on whether to redesign, retrofit, abandon or demolish a building at the end of its life. Where decision to retrofit or redesign is taken, cost and performance data generated over the assets life will be invaluable in the WLC management of the new building.

2.5.4.1 7-Step Implementation Model by Ferry and Flanagan (1991)

The model shown on Figure 2.9 presents the WLC implementation process in a simple and sequential manner. The model is suitable for options evaluation. It perfectly follows decision-making procedure. Stages 1 to 3 of the model represent problem structuring, while stages 4 to 7 represent problem analysis. The model also demonstrates the need for uncertainty/risk analysis.The major limitations of the model are that; it did not align the stages with life-cycle stages of a facility; it fails to capture the need for process iteration and feed-back of information from operating/end-of-life stages to the design stage; it also fails to extend the activities beyond decision-making to cover the entire problem solving process.

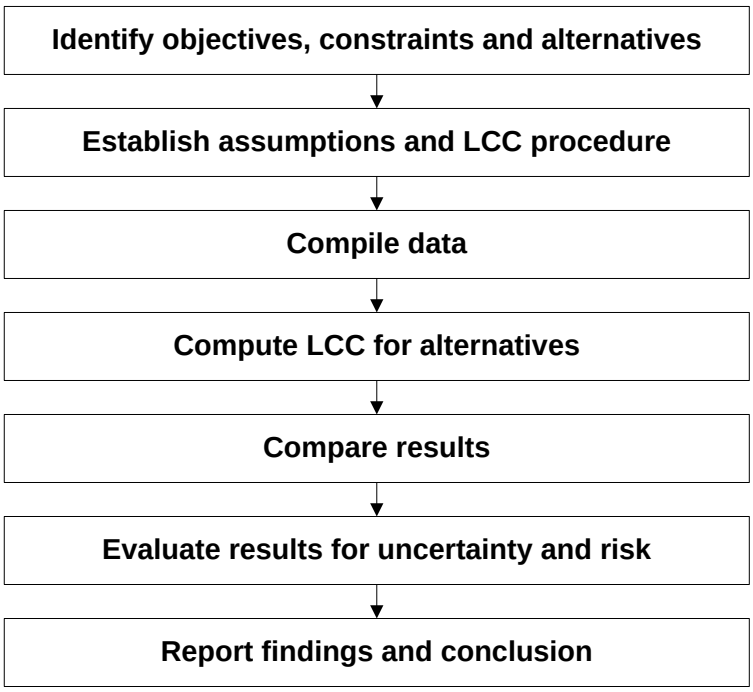


Figure 2. 9: 7-Step Implementation Model by Ferry and Flanagan (1991)

2.5.4.2 LCC Implementation Logic by Dell'Isola and Kirk (1995)

This implementation procedure is a simple representation of LCC process in an iterative manner. While it is suitable for comparison of design alternatives, it also

follows the decision-making stages. Stages 1 to 3 represent problem structuring while stages 5 to 6 represent problem analysis. A key advantage of this procedure is that it identifies the need for iteration where the result of the analysis is not conclusive.

The shortcomings of this procedure are; it did not align LCC activities with project life-cycle stages; it fails to identify the need for uncertainty/ risk analysis; it did not capture the need for feedback of information from post-occupancy stages to the early design stage; and its activities did not extend beyond the decision-making stages.

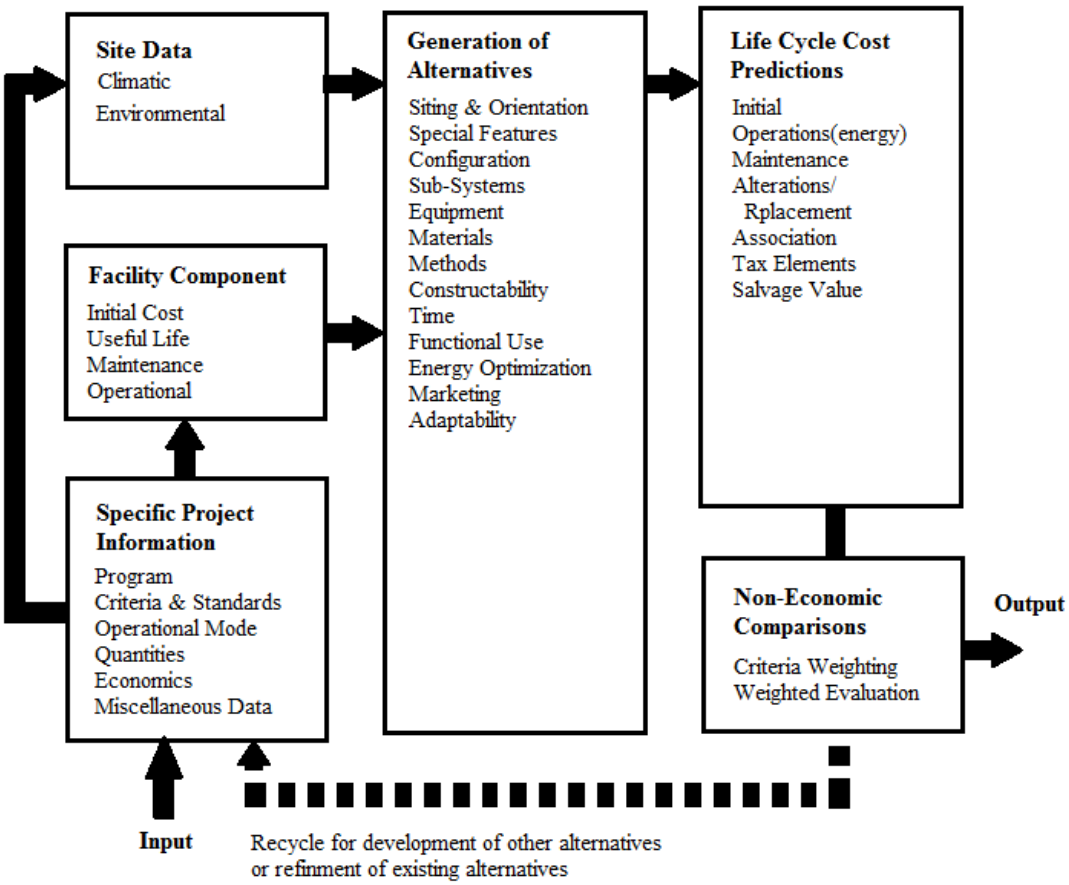


Figure 2. 10: LCC Implementation Logic by Dell'Isola and Kirk (1995)

2.5.4.3 Framework for WLC in the National Health Service Estate, UK by Boussabaine and Kirkham (2000)

The framework was designed to aid investment decision-making in UK hospital estates. A major goal of the framework was to profile the WLC of facilities at different cost centres or produce an overall WLC scenario. This profiling enabled the planning budgeting, and comparison of WLC at elemental, system and facility levels. The framework facilitates data collection and analysis to produce risk profiles for different cost centres which then serves as feedback information for investment decision-making at both design and operating stages of the buildings. It first suggest the identification of building characteristics, followed by the conduct of condition survey and service-life survey to profile the elemental service life and risk distribution for subsequent use in the profiling of various cost centres (like operational cost, maintenance cost, finance cost, residual cost and capital cost). The final output is a profile of key performance indicators and WLC.

Two major limitations of the framework are that: it is not suitable for options evaluation and does not align with decision-making and problem solving processes. Moreover, the framework activities are not in line with project life-cycle stages.

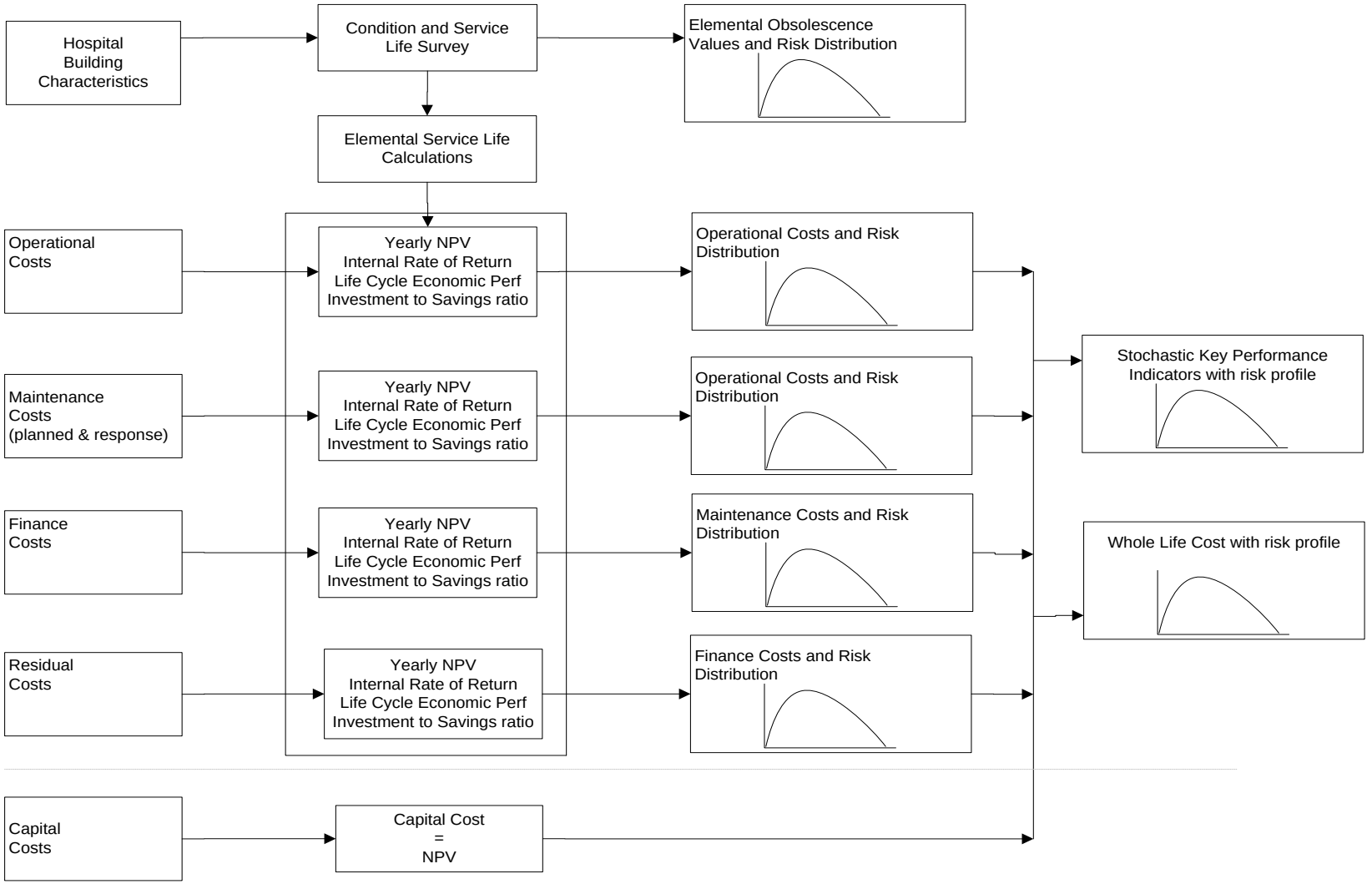


Figure 2. 11: Framework for WLCosting by Boussabaine and Kirkham, 2000

2.5.4.4 Framework for Implementing WLC by Al-Hajj et al (2001)

This framework was primarily designed to overcome WLC data scarcity and also the limitations of existing databases. It employs the use of two databases; the resource database and project database. The resource database accommodates information on various element options while the project database is integrated within the OSCON (Open System for Construction) design platform and houses data items necessary for WLCosting. The overall aim was to provide an avenue for designers to make informed decisions on possible alternatives that meet specified performance criteria at sub-elemental, elemental, systems and facilities level. In subsequent research efforts (Kishk et al,2002a; Kishk et al, 2002b; Kishk et al, 2003b), an IT application that supports the systematic data collection of the running costs of occupied buildings and provides the necessary linkage between the occupancy and design stages was developed based on the framework. The advantages of the framework are that it recognizes the need for the feedback of information to the design stages and iteration of the processes which is achieved through the resource database in conjunction with the design platform; it's five steps coincides with decision-making stages; it also stress the need for risk and uncertainty analysis through the profiling of various cost centres.

The main limitations of the framework however are that; it restricts its usability to designers (Architects to be precise) thereby ignoring the inputs of other professionals; it's usability at the inception and feasibility stages is doubtful as it was to essentially support the design process.

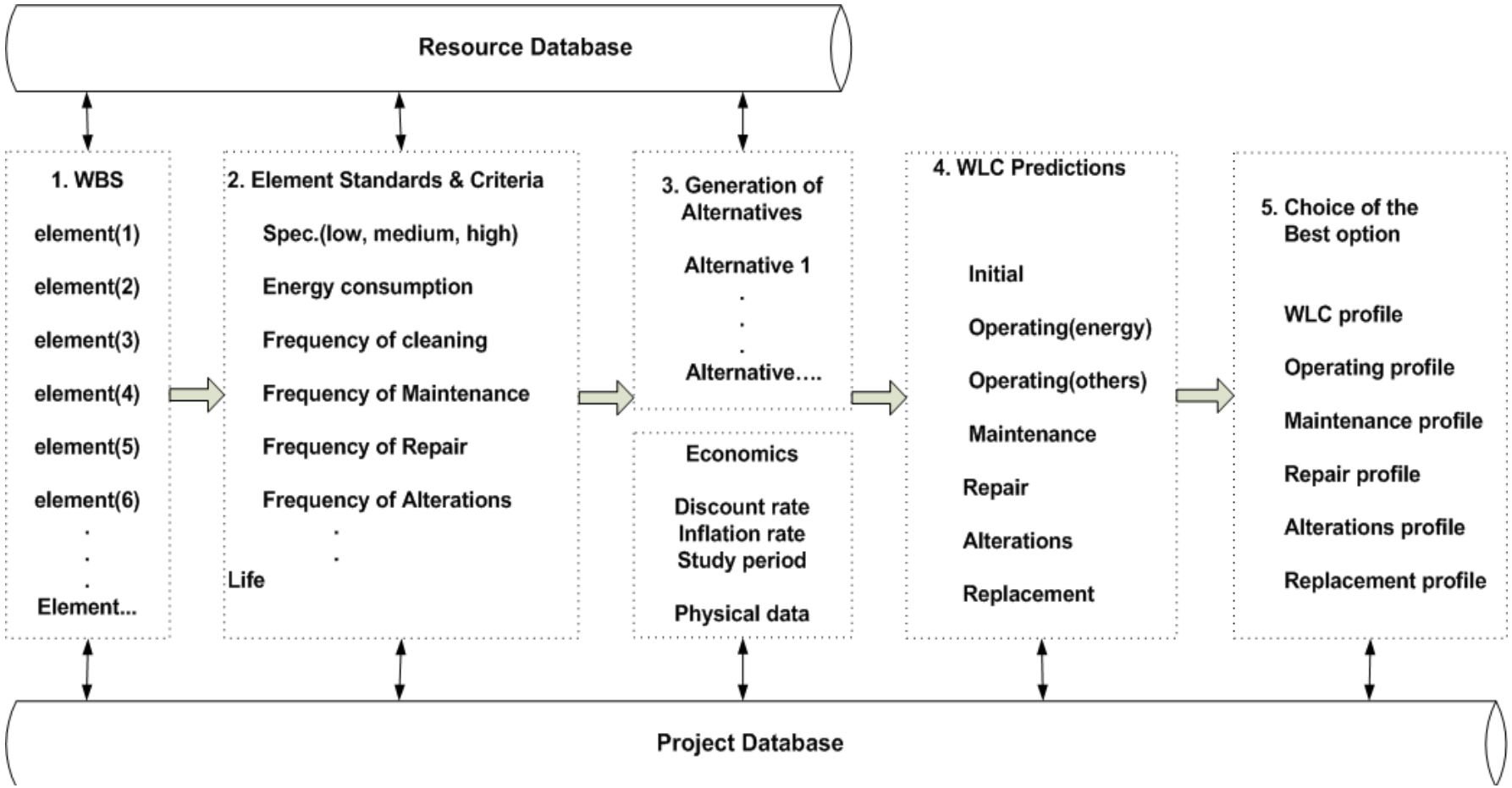


Figure 2. 12: Framework for Implementing WLC by Al-hajj et al (2001)

2.5.4.5 WLC Framework to Achieve Best Value by Kishk and Pollock (2004)

This framework is subsequent to an integrated approach to WLCosting proposed by Kishk, Al-Hajj, and Pollock(2002). The framework divides WLC decision-making process into phases. Each phase is expected to produce a well-defined set of criteria and alternatives. The framework is suitable for use in the evaluation and selection of the best alternative based on both WLC and performance. The various phases of the model correspond to the decision-making process. The framework supports risk and uncertainty analysis through confidence measure. In addition, it identifies the need for iteration based on three possible scenarios:where decision is partially conclusive (i.e. 2 or 3 alternatives outrank host of others;where decision is not conclusive and there is the possibility of refining existing alternatives or development of new alternatives;where decision is not conclusive, and further refinement of existing alternatives or development of new alternatives is not possible but the development of new evaluation criteria is possible;

The limitations of the framework are that; it does not extend its functionality to post design stages thereby under stressing the need for feedback of data and information to inception stage of project life-cycle.

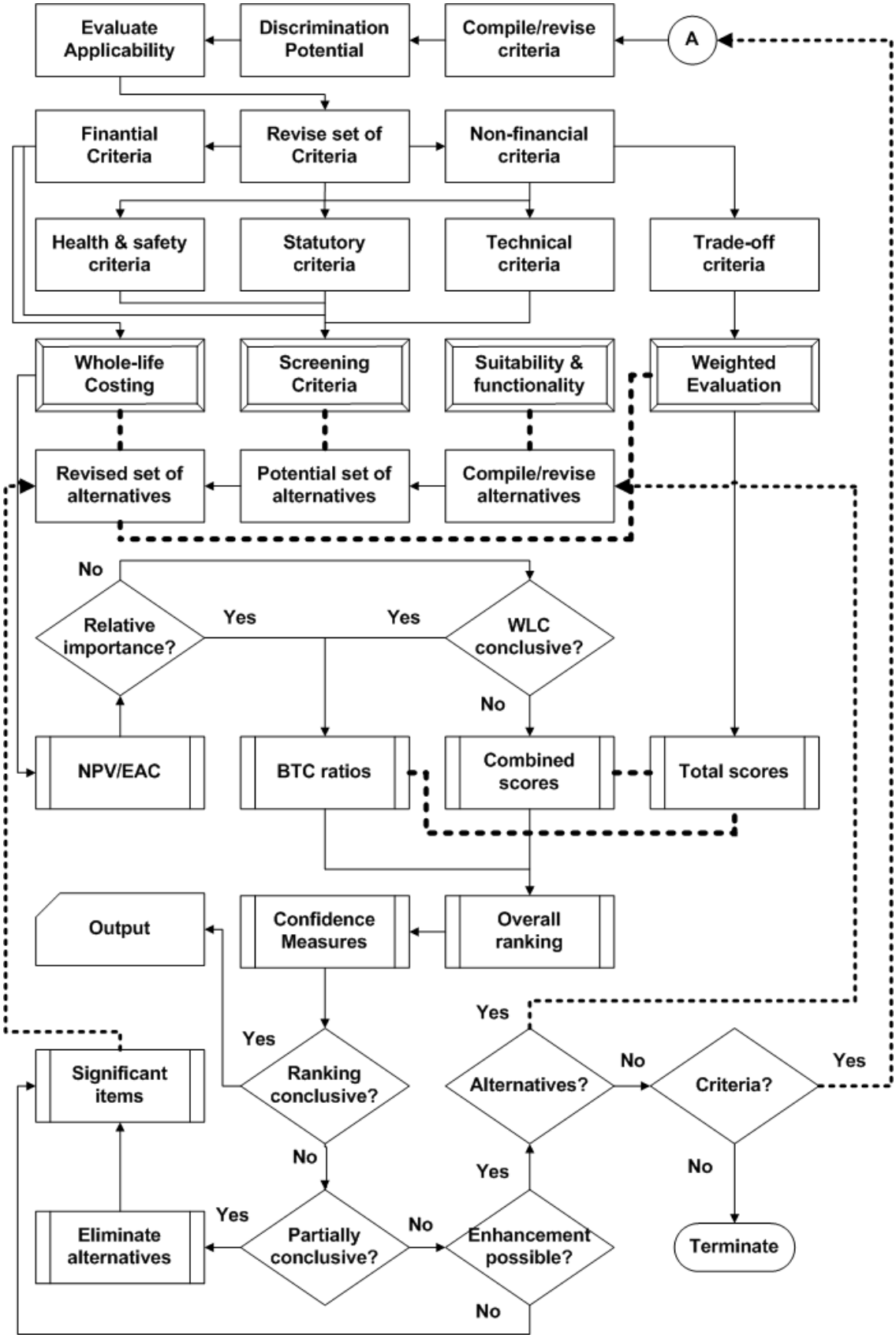


Figure 2. 13: WLCosting Framework to achieve best value by Kishk and Pollock, 2004.

2.5.4.6 An Integrated Framework for WLC Budget Estimation by Boussabaine and Kirkham (2004).

The framework consists of nine sequential steps which collectively tallies with the decision-making process. A glaring feature of this framework is it's circular nature which suggest iteration of WLC decision process. It helps an analyst to decide on whether to proceed with an investment plan or abandon at each phase of design through to construction in addition to its usability in budgeting and benchmarking WLC centres. The framework underscores the necessity for risk assessment at four important stages of: developing assumptions; data collection; risk allocation; reviews and updates/client objectives.

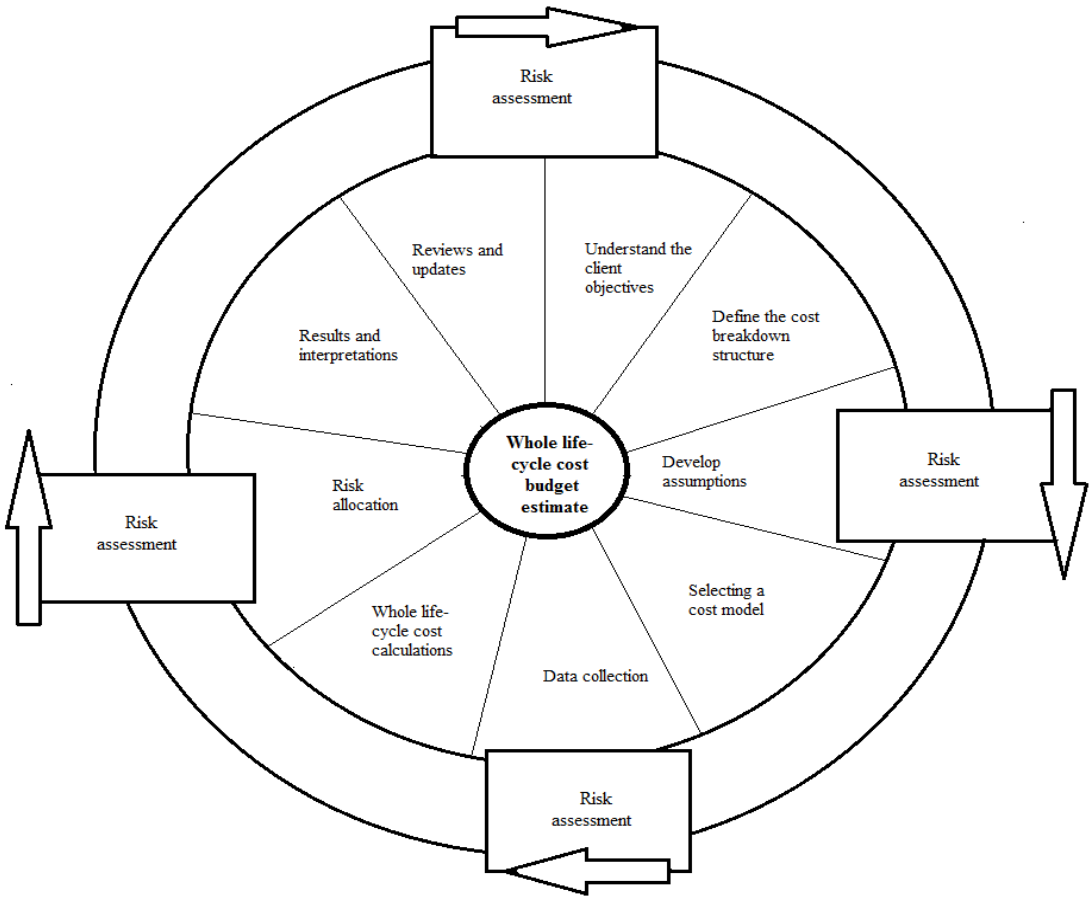


Figure 2. 14: An Integrated Framework for WLC Budget Estimation by Boussabaine and Kirkham, 2004

The limitations of this framework are that; it fails to extend the decision horizon to alternative design evaluation and selection; its applicability does not extend beyond the design stage; it fails to indicate the need for feedback of information to the early stages of project life-cycle.

2.5.4.7 WLC Implementation Approach by Flanagan and Jewell (2005)

This is 9-step implementation approach developed to aid decision-making in options evaluation and selection. The steps correspond to the decision-making stages. The approach clearly stipulates the need to iterate the evaluation process especially where initial capital cost exceeds available funding which then necessitates trade-off evaluation. In addition it emphasizes the need for sensitivity analysis to isolate volatile variables for closer evaluation.

The main limitation of this approach like most others is that it's usability at post design stage is constrained as it cannot be adopted in the evaluation of WLC activities like estimation of residual service life, WLC forecasting, WLC management and data analysis and storage for possible future use as feedback information to either, design stages of proposed projects, or retrofitting, renovation, and redesign effort for existing buildings. Figure 2. shows an outline of the stages.

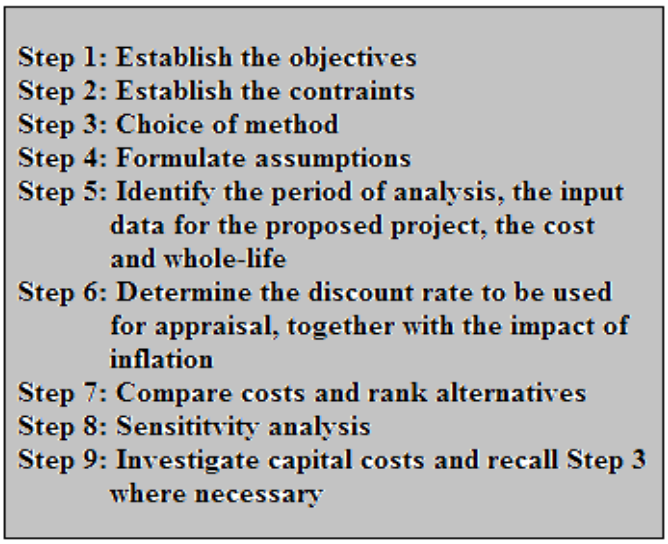


Figure 2.15: WLC Implementation Approach by Flanagan and Jewel, 2005

2.5.4.8 European LCC Common Methodology (Langdon,2007)

The European commission in 2004 underscores the need for a common LCC methodology amongst member states so as to improve the competitiveness of the construction sector. Consequently, the commission in 2006 initiated a project to develop a common methodology in order to address the need for a more consistent and robust approach to the application of LCC, encourage wider uptake of LCC, improve long term cost forecasting and optimization, stress the need for LCC to the sustainability agenda and encourage the practice amongst public and private sector clients and advisers (Langdon, 2010). The main advantage of this framework over all the others is the inclusion of sustainability analysis in WLC process, thus effectively covering the life-cycle performance of a project. Moreover, the 15-steps outlined in the methodology have demonstrably conformed to the decision-making process. For instance steps 1-7 of the methodology coincides with problem structuring while stages 8-15 coincides with problem analysis. Though the methodology has labeled risk and uncertainty analysis as optional, it has clearly stressed its need.

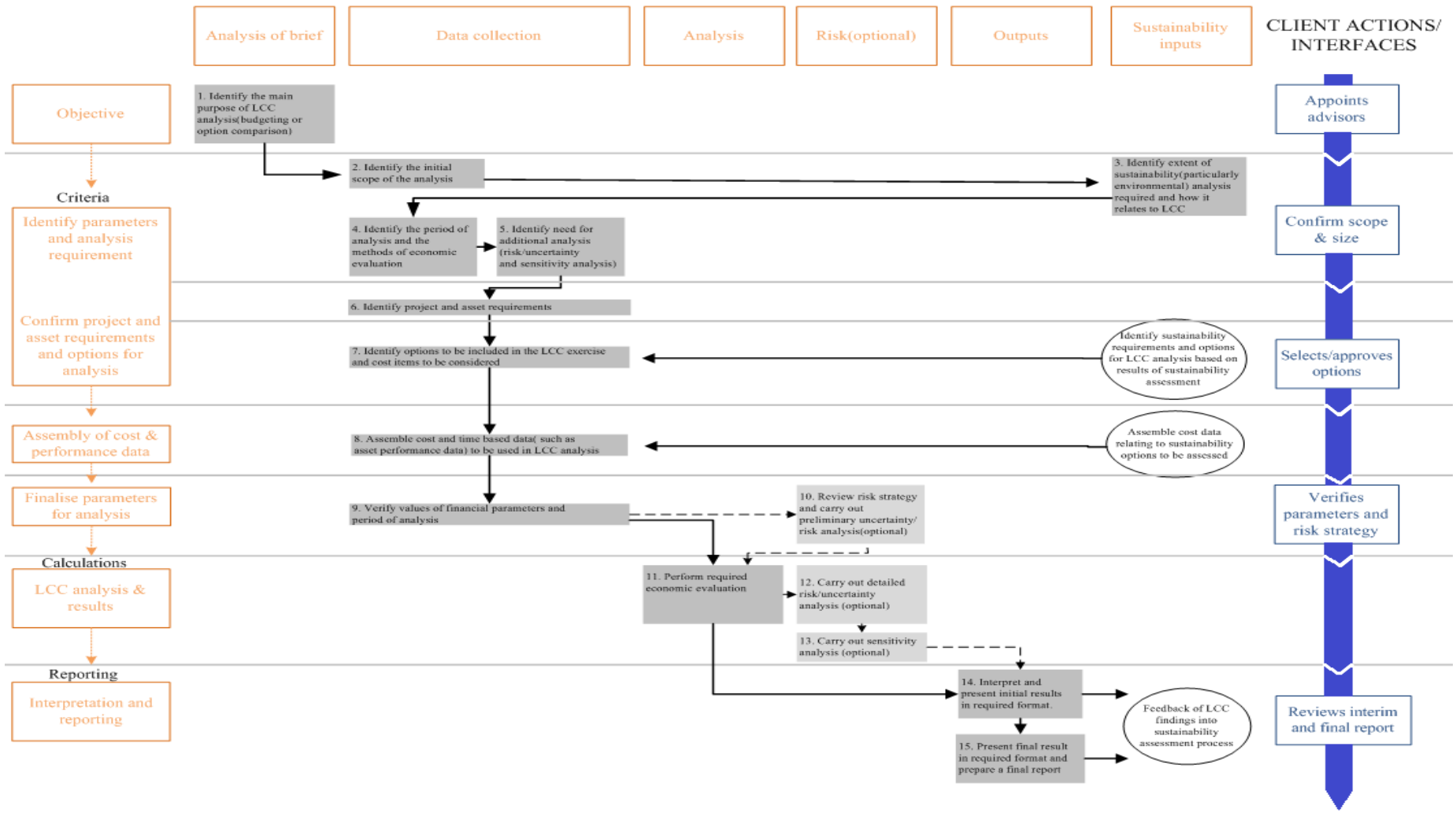


Figure 2. 15: European LCC Methodology by Langdon (2007)

The main limitation of this methodology is that it does not view the WLC process as a problem solving procedure. It therefore treats WLC discretely rather than holistically. Consequently, it does not indicate the need for feedback of information from post-occupancy to design stages. Figure 2.16 shows a flow diagram of the methodology.

2.5.4.9 Sequential Process for WLCosting (BSRIA, 2008)

This model presents WLC process in five simple and iterative steps. The structure of the maps out the decision-making process and supports options evaluation and selection. Steps one and two of the process represent problem structuring while steps 3, 4 and 5 represent problem analysis. An important provision in the model is feedback of information to the model development stage after sensitivity analysis. This captures the need to re-evaluate very sensitive variables used in the model to reconfirm their underlying assumptions.

One of the limitations of the process is that it is used for options comparison and selection which limits its use to the decision phase and thus not suitable for problem solving. Consequently, the process does not posit the need for feedback of information from post-occupancy stages to the early design stages.

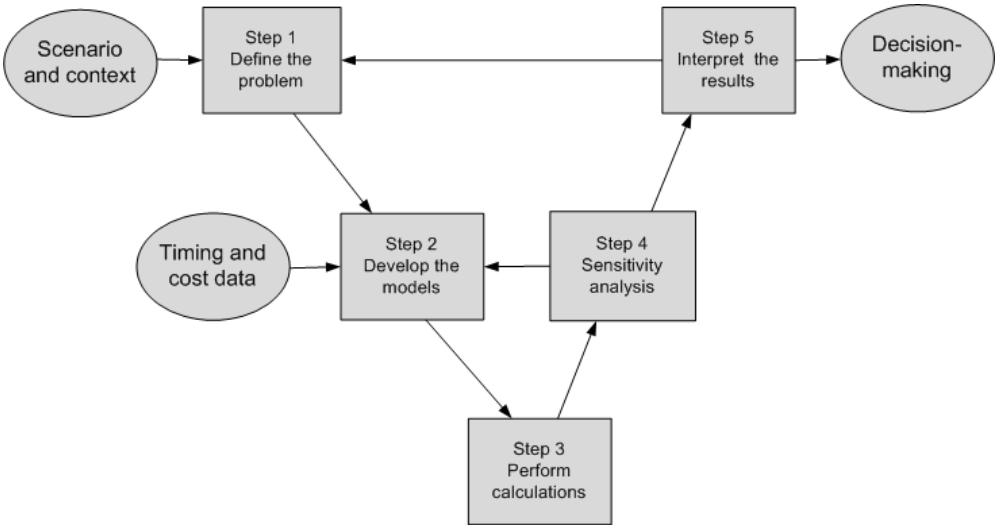


Figure 2. 16: Sequential Process for WLCosting by BSRIA (2008)

2.6 Existing WLC Analysis Tools

Existing WLC analysis tools which are supposed to aid professionals in making WLC evaluations have been criticized for their inability to find practical application in broad scenarios. Kishk and Al-hajj (2000) argued that existing WLC models uses sensitivity analysis and Monte Carlo simulations as risk analysis techniques. They noted that, sensitivity analysis does not quantify risk but rather aim at identifying variables that are risk sensitive thus, does not provide a definitive method of decision making. In addition it is a univariate approach thus is not effective when uncertainty in two or more variables is predominant. MC simulation on the other hand requires large amount of historical data, is complex, expensive in terms of both computational time and expertise required to interpret the result. Sobanjo (1999) proposed an algorithm to handle subjective uncertainty based on Fuzzy Set Theory (FST). Kishk and Al-Hajj (2000a) criticized Sobanjo's algorithm for assuming that interest rate and the analysis period were certain and that only Triangular Fuzzy Numbers (TFN) were considered. Kishk and Al-Hajj (2000a, 2000b, 2000c, and 2000d) proposed a series of algorithms based on FST aimed at overcoming the limitations of Sobanjo's algorithm. Ibrahim et al (2008a) criticised Kishk's algorithms for not considering various stages of design

evolution and did not suggest any Cost Breakdown Structure. They argued that data certainty and availability depend both on the stage in design and the input variable in question. Furthermore, the framework (Figure 2.17) upon which the algorithms were based does not support feedback information and only Artificial Neural Network (ANN), FST, probability and statistics were included as risk analysis techniques. Ibrahim et al (2008a, 2008b) proposed an algorithm based on FST aimed at mitigating the problems with Kishk's algorithm. The framework however uses only triangular fuzzy numbers to represent economic, revenue and cost data which does not reflect the true realities as subjective information could be represented by different fuzzy numbers depending on the perceived level of uncertainty.

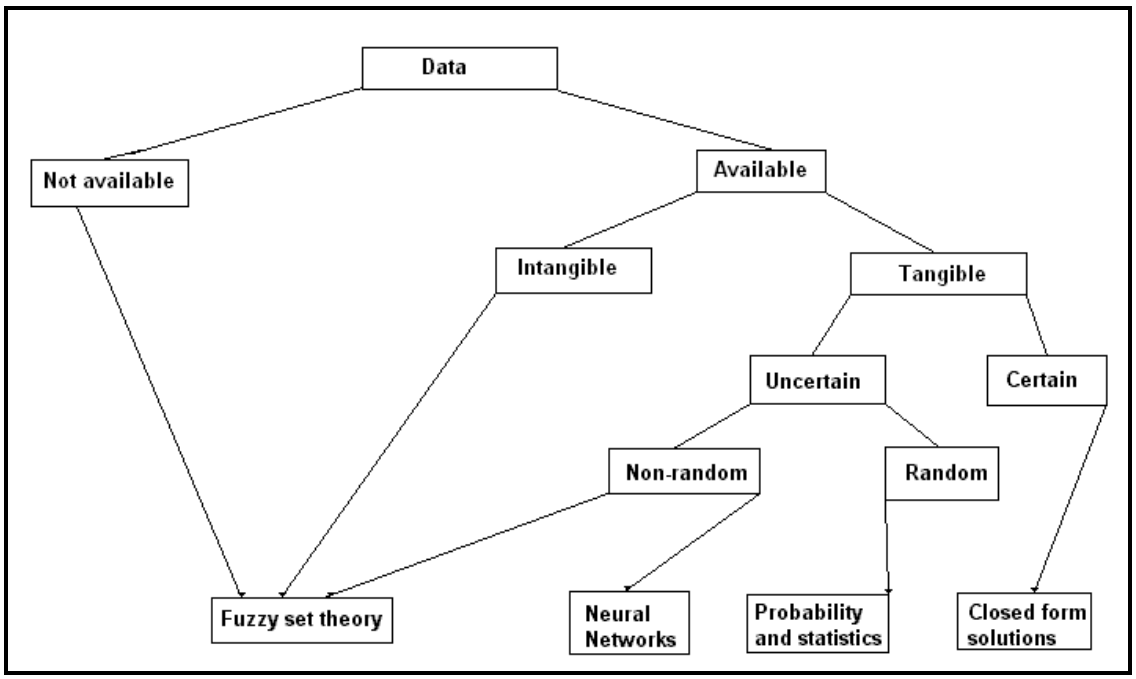


Figure 2. 17: Integrated WLC Framework(Source: Kishk and Al-Hajj, 1999)

Langdon (2006) prepared a summary of WLC analysis tools usable in the construction industry. Table 2.2 shows the different WLC analysis tools available in the market together with their sources, areas of application, economic evaluation technique and risk analysis tools they utilize. A close examination of the tools shows that only seven (ACEIT, Ampsol, Bid-Buildr, Kostenrefer-entimodel, LCProfit, LCCWare, and PARAP) of the tools can effectively be used in construction out of which four (Ampsol, Kostenrefer-entimodel, LCProfit, and PARP) are dedicated to building while the remaining three are general purpose. Of the four dedicated to building, only two uses NPV as a risk analysis technique while none of them incorporates risk analysis as functionality within the Software.

Table 2. 2:LCC IT Tools for the construction sector

Software	Developer	Availability	Areas of Application	Inputs	Output	Risk	Remarks
ACEIT	Tecolote Research Inc., USA. www.aceit.com	Commercial (Windows)	General	WBS, inputs variables of material quantity and cost, discount rate	NPV	SA, MCS	- It is a generic LCC tool. - A spreadsheet is used for presenting the cost structure and defining input values. - Equations are formulated to represent the relationships among variables.
Ampsol	Ampsol Ltd., UK www.ampsol.com	Free (web-based)	Buildings	Year of analysis, costs of acquisition, maintenance, and refurbishment, discount factors, and inflation rates are required.	NPV	None	- It only performs simple LCC calculation. - It cannot compare different designs.
Bid-Builder	Bid-Builder Ltd, UK. www.bid-builder.co.uk	Commercial (Windows)	Construction projects (including PFI/PPP)	BCIS and sub-elemental levels, or BOQ levels (if quantities are known)	NPV, net capital cost, annual life cycle spend	None	- What-if analysis can be performed. - It can perform up to 50-years lifecycle forecasts. - It is 'pre-configured' with industry standard building cost data and lifecycle cost forecasts based upon a wealth of PFI life-cycle forecasting experience.
BLCC 5.3	National Institute of Standards and Technology, USA http://www.eere.energy.gov/	Free (platform independent)	Energy and non-energy projects	Inputs similar to those for LCCID are required. Air pollution emission can also be entered.	NPV, NS, SIR, IRR, and DPB	None	- Files are saved in the XML format. - Only the energy price escalation rates in the USA are available

BridgeLCC 2.0	National Institute of Standards and Technology, USA http://www.bfrl.nist.gov/bridgelcc/welcome.html	Free (Windows)	Bridge construction	Information similar to that for Ampsol is required. Cost elements are also required. Pdf's can be assigned to the inputs	NPV	MCS, SA	- It is based on ASTM E917. - It helps evaluating the cost effectiveness of alternative construction materials. -It can only be used for bridge construction.
Kostenreferentiemodel	Stichting Bouwresearch, Netherland http://www.sbr.nl/	Windows	Residential buildings	Information of size, shape, costs and consumptions of a building	NPV	None	- Since the language of the tool is Dutch, the review was based on the information in the report of TG4: Life Cycle Costs in Construction. - The user can give either detailed input or rough estimation using verbal inputs. - The calculation is based on the Dutch standard
LCCID	Building Systems Laboratory, US http://www.wbdg.org/tools/lccid.php	Free (Windows)	Military and nonmilitary building construction	Costs of acquisition, maintenance, and refurbishment, and discount factor are required. Energy price escalation rates can also be entered	NPV	None	- It provides the option for energy study. - The user can provide rates of price escalation for fuel and non-fuel items. - Alternatives for cost comparison are allowed.
Relex LCC	Relex, US www.relexsoftware.co.uk	Commercial (Windows)	A generic LCC tool (for the manufacturing industry)	Inflation factors, quantities and unit rates of items, and other manufacturing costs	NPV	SA	- It does not have the pre-built equations for LCC for buildings. - It is not an ideal tool for construction.
LCProfit	Statsbygg, Norway http://www.statsbygg.no	Free (MS Excel)	Buildings (for rent)	Details prepared by the owner and the designer/planner.	The landlord's and the tenants' annual costs in MOM	None	- It is based on NS 3454 (The Norwegian standard). - Uncertainties are not captured. - Calculation factors (e.g. discounting factor) are fixed and revised annually by Statsbygg.

LCCWare 3.0	Isograph Inc., US http://www.isographsoftware.com/index.htm	Commercial (Windows)	A generic LCC model (can be applied to buildings)	Costs are saved in a tree-like cost breakdown structure	NPV	SA	- Data can be imported from or exported to MS Access and MS Excel. - The generic LCC software requires the formulation of equations, which are commonly available in LCC cost models for buildings.
PARAP	Delft University of Technology, Netherlands. http://www.bk.tudelft.nl/reh/projects/parap/	Web-based (demo version is available	Building cost calculation	Number of person expressed in full-time equivalent (FTE), location type, type of building, basement (yes/no), and number of storey	Required function area, usable area, let able area, gloss floor area, capital costs.	none	- In the demo version, only the capital costs (total and building elements) are available.
RealCost 2.1	Department of Transportation, US http://www.fhwa.dot.gov/infrastructure/asstmgmt/rc2104.htm	Free (MS Excel VBA)	Pavement projects	Inputs required include number of lanes, traffic-related information, discount factor, analysis period, and construction cost, minor maintenance cost, and service life of pavement	NPV	MCS	- It compares two alternatives at a time. - It is only applied to highway projects.

Where MOM = Management, operation, and maintenance; MCS = Monte Carlo simulation; Pdf = Probability distribution function; SA = Sensitivity analysis;
NS = Net savings; SIR = Savings-to-investment ratio; IRR = Internal rate of return; SPB = Simple payback; DPB = Discounted payback.

2.7 Economic Evaluation Techniques

These are investment appraisal techniques or capital budgeting techniques that enables an investor to take informed decision on long-term investment opportunity. The techniques according to Pandey (2005) could be divided into two broad groups of : Non-Discounted Cash Flow (NDCF) and Discounted Cash Flow (DCF) techniques, and. The most useful NDCF techniques include;Payback Period (PB);Discounted Payback Period (DPB);Accounting Rate of Return (ARR);Return On Capital Employed (ROCE); While the most useful DCF techniques are:Net Present Value (NPV); Internal Rate of Return (IRR); Savings to Investment Ratio (SIR); Benefit to Cost Ratio (BCR).

Not all of these techniques find usability in the construction industry. Dale (1993) identified PB, NPV and IRR as the most commonly used techniques in the building sector. However many researchers like (Boussabaine and Kirkham, 2003; Kishk et al, 2003a; Flanagan and Jewell, 2004) agree that the NPV method and its variants like Profitability Index (PI), IRR and Equivalent Annual Cost (EAC) are the most commonly used techniques. NPV and EAC method are mostly used in the evaluation of mutually exclusive projects while IRR is predominantly used in the screening or ranking of competing projects.

2.7.1 Simple Payback (SPB)

Pandey (2005) identified this method as one of the most popular and widely used capital budgeting method. It is defined as the period of time required to recover an initial capital outlay. Hence it is the ratio of the cash outlay to the annual cash inflow. Thus;

$$\text{SPB} = \frac{\text{initial cash outlay}}{\text{annual cash inflow}}$$

Further, Pandey (2005) highlighted that in taking decisions project's SPB is usually compared against standard payback period for similar projects. Project would then be accepted where the SPB is less than the standard. Dale (1998) noted that the standard does not exceed two or three years. This he said is in an attempt to reduce the long-term impact of inflation, interest rate, cash flows and taxation as the technique does not necessarily account for them. The main advantages of this method are that: the calculation is easy and result easily interpreted; it costs less in terms of analysis period and tools required; it helps investors to set shorter payback period thereby ensuring quick return on investment and shielding projects from long term risks and gives insight in to project liquidity. The disadvantages of the method on the other hand are that: the method fails to account for cash flow after payback; it does not consider time-value of money thereby assigning same weight to cash flows obtained at different periods; and the determination of the standard payback period for specific projects usually pose great challenge to analysts as no two projects are exactly the same. These short comings limits the application of the technique in building projects as buildings are usually long-term investments. Ellingham and Fawcett (2005) descried the technique as crude and should only be used for broad brush comparisons. Boussabaine and Kirkham (2003) suggested that the technique be used as screening method for projects that are clearly economical so as to avoid further WLC analysis which is unnecessary. Dale (1998) earlier noted that the technique is best applied at early stages of project investment to eliminate unrealistic projects with payback period in excess of ten years. In this way he asserted, unnecessary and complex calculations could be avoided by using SPB as a coarse filter of solutions at early stage. ISO 15686-Part-5 (2008) considered SPB to be useful in the following situations:where competing projects are clearly economical, the best could be selected on the basis of SPB, at early

stages as a screening tool to eliminate projects with SPB in excess of a benchmark, and to assess time periods within which investment is at risk.

2.7.2 Discounted Payback Period (DPB)

This technique is a variant of SPB method with the main difference being that cash flows are discounted to the present. This takes into account the time value of money thereby making the recovery period more realistic. DPB can therefore be defined as the period of time required to recover an initial investment on present value basis (Pandey, 2005). Discounted payback however shares all the advantages of the PB though it is more complex. It also shares its disadvantages with the exception of its inability to account for time value of money. Further, DPB can be used where SPB method is used so their areas of application are the same.

2.7.3 Accounting Rate of Return (ARR)

According to Pandey (2005), ARR also known as Return On Investment (ROI) is the ratio of the average after tax profit divided by the Average Investment. Put in another way, it is the ratio of the project's Average Annual Expected Net Income (AAENI) to its AI. Expressing the AAENI in terms of Earnings Before Interest and Tax (EBIT), then:

$\text{AAENI} = [\sum_1^n \text{EBIT}(1 - \text{T})]/2$ thus; $\text{ARR} = \frac{\text{AAENI}}{\text{AI}}$

The main advantages of this technique as noted by Pandey (2005) are that it is simple to use as it does not involve complex computations. It is also easy to understand and interpret; it makes use of accounting data which is readily available; it makes use of the entire stream of income over the entire project life. The limitations of the ARR are that it ignores time value of money and hence does not provide complete picture of projects value; it uses accounting profit which is based on arbitrary assumptions and choices and also includes non-cash items; a cut-off rate is used as a basis for comparison-usually

determined based on current return on assets-therefore where the rates for high performance projects are used as a yard-stick potentially viable projects may be rejected (Pandey, 2005).

2.7.4 Return on Capital Employed

Van Hore (1995) as cited by Boussabaine and Kirkham (2004) described this method as probably the most popular ratio tool used in measuring the economic performance of buildings based on capital invested. It simply measures how efficient a project generates profit from the capital employed. It may be defined as the ratio of Net Operating Profit (NOP) to Capital Employed (CE). That is:

$$\text{ROCE} = \frac{\text{NOP}}{\text{CE}}$$

The NOP could be expressed in terms of Earnings Before Interest and Taxes (EBIT) while the CE is simply Total Assets less Current Liabilities. A variant of this method is Return On Total Assets (ROTA) which measures profitability in relation to total assets and Return On Equity (ROE) which measures profitability in terms of shareholder's equity. The computation of ROCE is usually done from project's financial statement. Advantages of ROCE are that: it is widely used in practice due to its simplicity and ease of understanding; it evaluates projects in terms of profitability which investors find attractive as the essence of investment is usually gains. The limitations of the technique is that like ARR it does not consider time value of money; it expresses returns on capital as a percentage thus not revealing the true size of return- as a result a small scale project with high ROCE may be preferred to a large scale project with a smaller ROCE without considering the quantum of profit.

2.7.5 Net Present Value (NPV)

The NPV of a project is the difference between the present Value (PV) of all series of benefit and the PV of all series of costs associated with the project over its entire life span. Boussabaine and Kirkham (2003) expressed NPV mathematically as:

$$NPV = \sum [PV(b) - PV(c)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where; PV(b) is the discounted present value of benefits and PV(c) is the discounted present value of costs

Put in another way therefore, NPV is simply the difference between the PV of cash inflows and cash out flows. The technique enjoys wide acceptance and extensive use in the evaluation of alternatives at especially the design stage (Dale,1993). Expressing equation in the discounted form;

$$NPV = \sum_{t=1}^{n} \frac{b_t}{(1+d)^t} - \left\{ \sum_{t=1}^{n} \frac{c_t}{(1+d)^t} + c_0 \right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where; $\sum PV(b) = \sum_{t=1}^{n} \frac{b_t}{(1+d)^t}$; $\sum PV(c) = \sum_{t=1}^{n} \frac{c_t}{(1+d)^t} + c_0$; c_0 is the initial capital cost; b_t is the benefit at year t; c_t is the cost in year t; n is the analysis period; d is the discount rate. The acceptance rule for NPV is;

accept the project when NPV is positive

Reject the project when NPV is negative

May accept the project when NPV is zero

When used in selecting from mutually exclusive projects, the project with the highest NPV is the preferred option. According to Pandey (2005) NPV provides the most acceptable investment rule because;

it accounts for time value of money

it uses all cash flows occurring over the entire project life span

It is a measure of project's true profitability

it facilitates value additivity of projects as all cash flows are expressed in PV. The value of NPV of projects A & B is simply NPV(A)+NPV(B)

NPV is always consistent with shareholder's objective of value maximisation.

The limitations of NPV method are computational difficulties and the dependency of result on discount rate and cash flows. The estimation of the cash flows and the determination of the discount rate in practice is usually not a straight forward task. Forecasting cash flows is usually risky as future occurrences are uncertain. It is for this reason that sensitivity analysis on the rate and cash flows is always recommended to further substantiate the reliability of the result (Flanagan & Jewell, 2005; Boussabaine & Kirkham, 2004). In addition, when comparing mutually exclusive projects with unequal lives, the NPV technique may not be reliable as projects are not compared on the same basis. To overcome this limitation, Flanagan and Jewell (2005), Dale (2003), Kishk et al (2003a) and Dell'Isola and Kirk (2003) suggested the conversion of the NPV into Annual Equivalent (AE). AE represents a yearly outlay that would yield the same value at the end of the project's life. Dell'Isola & Kirk expressed AE as:

$\mathrm{AE} = \mathrm{NPV x}\left[\frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{n}}}{(1+\mathrm{i})^{\mathrm{n}}-1}\right]$; where; i is the discount rate and n is the analysis period.

Another limitation of NPV is that it does not identify the project that makes investment capital works the hardest. Dale (1993) suggested the use of Profitability Index (PI) when ranking projects. The project with the highest PI he suggested should be considered the best. He computes PI as $PI = \frac{NPV}{C}$ where c is the capital cost. The acceptance rule where PI is used is that: Accept the project where PI is greater than one; Reject the project where PI is less than one; may accept the project where PI is equal to 1.It should be noted that, PI

is directly proportional to NPV and so it increases and decreases with an increase or decrease in NPV. Pandey (2005) however advised analysts to be cautious when using PI to select from mutually exclusive projects. He asserted that PI does not consider differences in scale of projects. Large and small scale projects for instance may have equal PI. He thus advised that, PI be used in breaking ties between projects with almost equal NPV. It should be noted that, both NPV and capital cost could be expressed in AE form so that project PI can also be computed.

2.7.6 Internal Rate of Return (IRR)

IRR is one of commonly used methods of economic evaluation. It is also referred to as Yield On Investment (YOI), Marginal Efficiency of Capital (MEC), Rate of Return over Cost (RROC), and Time Adjustable Rate of Internal Return (TARIR) Pandey (2005). Boussabaine and Kirkham defined IRR as the rate of discount which when applied to the project cash flows, produces a zero NPV. Mathematically:

$$\sum_{t=0}^{n} \frac{A}{(1+IRR)^t} = 0$$

Where n is the analysis period; A is the net cash flows.

Where the cash flows are uneven over time the IRR is normally computed by trial and error. Where equal cash flows are generated over a project's life (as constant costs or revenues per annum), the IRR could be computed by equating the NPV to zero to obtain the present value factor of annuity from which a corresponding value of discount rate is obtained. It is important to note that NPV is always at maximum where the discount rate (d) is zero. Where d is equal to IRR, NPV=0 while NPV is negative where d is greater than IRR. Figure 2.18 serves to illustrate the points.

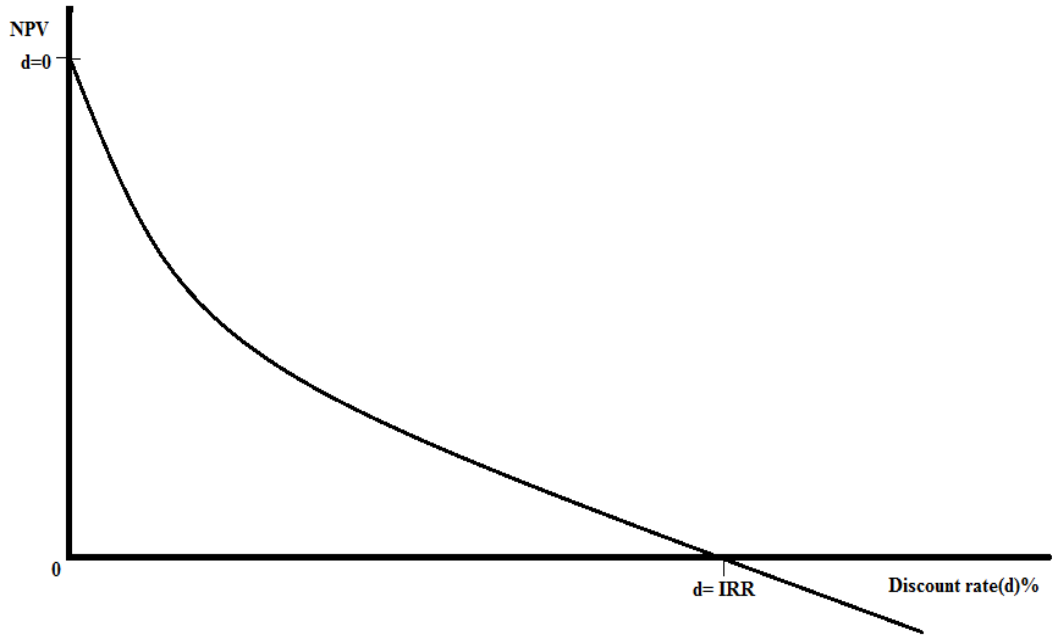


Figure 2. 18: Variations of NPV with Discount Rate for a Lending Type of Project

The decision rule is that only projects with IRR greater than or equal to predefined rate are accepted. Pandey (2005) suggested that the predefined rate should be the opportunity cost of capital (k). k according to Pandey (2005) is also referred to as the required rate of return, cut-off or hurdle rate. The main advantages of this method as noted by Kishk et al (2003a) are that; it is expressed as a percentage that is usually interpreted as the rate of return on capital invested. In addition they noted that, it does not require a discount rate- the determination of which is complex. Other strengths of the method as outlined by Pandey (2005) are that it accounts for the time value of money; it considers all cash inflows and outflow over the entire project life; its acceptance rules coincides with those of NPV. Despite these merits however, the results of IRR could be misleading and inconsistent (Flanagan and Jewell, 2005; Dell'Isola and Kirk, 2005) because a project could have multiple rates which goes contrary to the underlying assumption of cash flow varying with the IRR; unlike NPV, results obtained for different projects are not additive; the results of IRR evaluation becomes inconsistent when comparing mutually exclusive

projects. Due to theselimitations IRR is widely used as screening criterion where only projects with IRR equal to or greater than a benchmark rate. Its use in the comparison of mutually exclusive projects is however highly discouraged (Flanagan and Jewell, 2005).

It is important to emphasise the relationship between IRR and NPV. Figure 2.18 summarise this relationship. From the Figure, NPV is at maximum where discount rate is equal to zero; NPV is equal to zero where d is equal to IRR and NPV is negative where d is greater than the IRR (i.e. IRR<d). This clearly indicates that the decision rule for both NPV and IRR yields the same results. For instance where NPV is negative IRR is less than discount rate (opportunity cost of capital) the project is rejected. Where NPV is positive the discount rate (opportunity cost of capital) is less than IRR the project is accepted. Where NPV is equal to zero the discount rate is equal to IRR the project may be accepted. Pandey (2005) however argued that this condition subsist only in the case of independent conventional investments. He described conventional projects as projects that are characterized by an initial capital outlay which subsequently generates cash inflows throughout the life of a project. Non-conventional investments he maintained could generate alternate cash inflows and outflow at different times over projects life. Building projects of course should fall under the later class as they are capable of generating alternate incomes and expenditure (in the form of rent, sales of scrap equipment, replacement, repair, cleaning and utility costs) over their entire life span. Furthermore, he saw the need to distinguish between borrowing and lending types of projects. He described a lending type of project to be a project in which an initial capital outlay is made in anticipation for return at specific rate. The slope of NPV graph for the lending type of project is similar to Figure 2.18. That is NPV decreases with an increase in discount rate. The borrowing type of project on the other hand is characterized by an initial cash inflow

followed by subsequent cash outflows at a specific rate. Figure 2.19 indicates that NPV increase with an increase in discount rate.

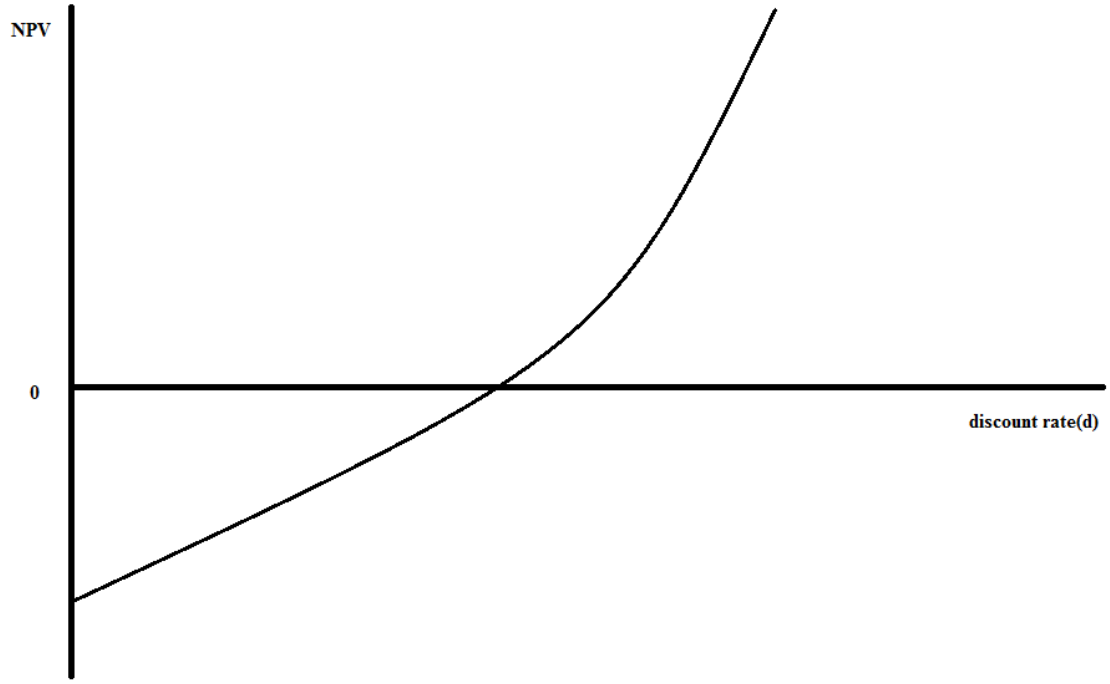


Figure 2. 19: Variations of NPV with Discount Rate for a BorrowingType of Project

Building projects could take both the form of lending and borrowing types. A building project financed by an investor qualifies as a lending project while a building project financed through mortgage is a borrowing type. Giving this background, the limitations of IRR over NPV can be identified in four scenarios. Firstly, IRR generates multiple rates when used to evaluate non-conventional investments. The problem according to Pandey (2005) emanates from the algebra of the IRR equation.

$$NPV = \frac{c_1}{1+r} + \frac{c_2}{(1+r)^2} + \; - - - - - - - \frac{c_n}{(1+r)^n} = 0$$

In solving for r, n roots of the equations are obtained. In comparison, NPV never generates multiple solutions. Secondly, differences in timing of cash flows often generate conflict between results obtained from IRR and NPV evaluations. This evolves from the fact that different projects have different cash flow patterns. While some projects may generate large sums of cash inflows at their early life, others may do so at a later date. In comparing

two mutually exclusive projects, conflicting results may be obtained. For example a project with the highest NPV may not necessarily have the highest IRR. When faced with conflicting result in evaluating mutually exclusive projects, it is better to use the NPV method as the criterion for evaluation as it is consistent with wealth creation. Thirdly, contradiction could also occur where the scale of investment in the projects to be compared greatly differs. A small scale project may generate smaller NPV and higher IRR while a large scale project generate comparatively higher NPV and smaller IRR with situation being reversed in other occasions. Under such a circumstance Pandey (2005) and Van Horne (2000) recommend the selection of the alternative with the highest NPV in so far as it generates an IRR higher than the opportunity cost of capital. Fourthly, where projects under comparison have different life spans, conflicting results may be obtained between NPV and IRR evaluation. For instance a project could have shorter life span yet generate huge cash inflows while the other may have long life but generate smaller cash inflows. This condition has the possibility of generating conflicting results between NPV and IRR evaluations. The consensus, however is that the project with higher NPV should be selected as it is consistent with wealth creation principle of the investor.

2.7.7 Adjusted Internal Rate of Return (AIRR)

Also known as Modified Internal Rate of Return (MIRR), this technique intends to address a major short coming of IRR. IRR as was explained earlier is based on the assumption that cash flows are reinvested at a rate equivalent to the IRR. This is not always true. The AIRR is the compound average rate that is calculated with a reinvestment rate different from the project's IRR (Pandey, 2005). According to Boussabaine and Kirkham (2003) the AIRR is used to compare against the Minimum Acceptable Rate of Return (MARR). Pouliqnes (1970) as cited by Boussabaine and Kirkham (2003) defined the MARR as "*The smallest amount of revenue considered acceptable for an organisation to undertake a*

project. Typically MARR is equal to the cost of capital plus a return sometimes referred to as the hurdle rate". The decision rule is that; accept the project where AIRR is greater than the MARR; reject the project where the AIRR is less than the MARR. Where the AIRR is equal to the MARR the project is economically neutral and so described as break-even. The mathematical formula for AIRR is given below:

$$AIRR = \sqrt[n]{\frac{FV(positive\ cahflows, cost\ of\ capital)}{PV(cash\ outlays, financing\ cost)}} - 1$$

Where n is the number of equal periods at the end of which the cash flows occurs, PV is present value, FV is future value. Mathematically PV and FV are defined as:

$PV = \sum_{t=1}^{n} \frac{R_t}{(1+d)^t}$ and $FV = \sum_{t=1}^{n} C_t(1+r)^t$, AIRR may be expressed as;

$$AIRR = \left\{ \sqrt[N]{\frac{\sum_{t=1}^{n} \frac{R_t}{(1+d)^t}}{\sum_{t=1}^{n} C_t(1+r)^t}} \right\} - 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where N is the number of equal periods at the end of which the cash flow occurs; n is the number of cash flows within N; R_t is the t^{th} positive cash flow; C_t is the t^{th} negative cash flow; d is the opportunity cost of capital and r is the finance cost.

Despite the advantages of the AIRR in addressing the issue of multiple discount rates, it has some disadvantages. First, both opportunity cost of capital and finance cost must be determined, and like the IRR, results obtained are not additive. Further the results could be inconsistent when used in comparing mutually exclusive projects.

2.7.8 Benefit to Cost Ratio (BCR)

This may be defined as the ratio of the discounted sums of benefits to discounted sums of costs over a project life. Mathematically;

$$BCR = \frac{\sum_{i=0}^{n} R_t(1+r)^{-1}}{\sum_{i=0}^{n} D_i(1+r)^{-1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

where R is the cash inflows; D is the cash outflows or disbursements; and r is the discount rate.

The project with the highest BCR is usually considered the best. The decision rules are: projects with BCR greater than one are economical; projects with BCR equal to one are economically neutral; and projects with BCR less than one are uneconomical. The advantages of BCR are that: it accounts for time value of money; it allows the comparison of projects through relative ratio where a project with BCR less than one is rejected; high BCR is indicative of high IRR while low BCR is indicative of low IRR; it is consistent with value maximisation principle as a project with BCR greater than one will have positive NPV while a project with BCR less than one will have negative NPV. Its disadvantages are that; it requires the estimate of cash flows and discount rate which are practically problematic; it does not capture scale of investment hence, two projects with vast difference in both investment and returns might have same BCR. This makes it unsuitable for the comparison of mutually exclusive projects.It is worth noting that, not all benefits are monetary in WLC evaluations. In fact benefits in building projects have been classified as tangible and intangible benefits. The intangible benefits (such as aesthetics, and comfort) are often subjective and therefore assessed through qualitative approach like weighted evaluation (Dell'Isola and Kirk, 1981; Dell'Isola & Kirk, 2003; Flanagan & Jewell, 2005; Norman, 2007). Under such a circumstance the BCR simply indicates the perceived amount of benefits per unit cost invested. Such a ratio however cannot be used purely for evaluation of building projects except for screening purposes- that is to further refine the decision horizon when ranking proposed projects. Put in another way, the ratio could be used to break ties between competing projects with almost equal economic BCR.

2.7.9 Savings to Investment Ratio (SIR)

This technique is mostly used to assess the potential for cost savings in proposed projects. Where a proposal to replace an existing system is in view with the hope of reducing operating and maintenance cost, the use of SIR as a decision aid would be helpful. The ratio represents a measure of the economic performance of a project in which increase in investment is related or compared with anticipated savings as a ratio in present value terms (Boussabaine & Kirkham, 2003). The decision rules are: a project with SIR greater than one is economically justified; projects with SIR less than one are not economically viable while projects with SIR equal to one are considered economically neutral. SIR is computed using the following formula.

$$SIR_{A:base} = \frac{\sum_{t=0}^{n} \frac{S_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}}$$

Where $SIR_{A:base}$ is the SIR of alternative A relative to base case; St is savings in year t in operating and running costs of alternative A over base case; Ct additional investment cost in year t on A over base case; r is the discount rate; and n is the analysis period.

The advantages of SIR are that: it accounts for time value of money, it is a relative measure thereby enabling the comparison of projects against a base case; it is consistent with value maximisation principle. Its disadvantages like the BCR are that it requires the estimates of cash flows and discount rate which are difficult to achieve; it does not compare scale of investment as such not suitable for the comparison of mutually exclusive projects. It however should be used as a ranking tool for comparing independent projects for the purpose of funds allocation (Boussabaine & Kirkham, 2003)

2.8 Work/Cost Breakdown Structures

The systematic breakdown of construction activities into smaller structures has been in practice for quite long. The Work Breakdown Structure (WBS) if properly defined and aligned with construction activities usually permits the allocation of costs thereby effectively serving as the Cost Breakdown Structure. WBS is usually related to identifiable elements of the structure under study. Robert & Harold (1999) noted that, by classifying a building into elements and sub elements, the collection and analysis of historical data would be standardised, communication between construction stakeholders enhances project management and reporting at all stages of project life-cycle. In order to foster harmony and consistency in the use and interpretation of WBS in the building industry, numerous attempts have been made to develop standard structures around the world.

In the USA, the UNI-FORMAT was published in 1975 by the then General Services Administration (GSA) (Dell'Isola and Kirk, 1981). The framework had seven levels of definitions that extended to products and materials and was intended for use at the design stage only. Developments in LCC however, necessitate improvement in the format to accommodate the In-Use stage of a building. This led to the publication of UNI-FORMAT II in 1997. Its usability at the entire building life-cycle makes it widely accepted in North America and Canada (Robert and Harold, 1999). The framework is divided into seven groups of elements each sub divided into three levels. The main elements include:

i. SUBSTRUCTUE
ii. SHELL
iii. INTERIORS
iv. SERVICES
v. EQUIPMENTS
vi. SPECIAL CONSTRUCTION AND DEMOLITION
vii. BUILDING SITE WORK.

Still in the USA the Construction Specification Institute (CSI) in 1963 published a 16 division format which was later referred to as the Master format. The most recent Master format is that of 2014 which saw significant increase in the number of divisions to fifty. These divisions are classified into two broad groups of:

PROCUREMENT AND CONTRACTING REQUIREMENT GROUP

SPECIFICATION GROUP

The first group consist of one sub group while the later group consist of four sub groups; Facility Construction; Facility Services; Site and Infrastructure and Process Equipment, containing 49 elements. The format is intended to be a guide for specification writing and to provide a system for organising data on construction requirement, products, and activities which facilitates communication amongst construction stakeholders, thereby meeting client's requirements, timelines and budgets (Construction Specification Institute& Construction Specification Canada, 2014).In the UK the Royal Institution of Chattered Surveyors (RICS) published the first edition of the Standard Form of Cost Analysis (SFCA) in 1961. The form divided buildings into group elements, elements and sub elements. The group elements are divided into seven classes of:

a) SUBSTRUCTURE
b) SUPERSTRUCTURE
c) INTERNAL FINISHES
d) FITTINGS AND FURNISHINGS
e) SERVICES
f) EXTERNAL WORKS
g) PRELIMINARIES

An element was defined as a major physical part of a building that fulfils a specific function or functions irrespective of its design, specification or construction (Building Cost Information Service, 2012).

Building Cost Information Service (BCIS) which was launched in 1961 and charged with the responsibility of collecting and disseminating elemental cost data amongst professionals published the second edition of the SFCA in 1969. Not much difference exists between the first and second editions. Further, developments in the areas of Building Information Modelling (BIM), changing procurement methods and means of information management, the growing need for whole-life data and emerging New Rules of Measurement (NRM) necessitate the publication of the third edition (Martin, 2012). The standard form identifies four levels of analysis:

a) Total building level

b) Group element level

c) Detailed element level

d) Sub-element level

The cost centres under each level are presented on Tables 2.3, and 2.4 below.

Table 2. 3: Cost Centres for Building Level Analysis

Element No.	Cost Centres
1.	Building
2.	External Works
3	Preliminaries
4	Design fees
5	Contingencies

Table 2. 4: Cost centres for Group Element Level Analysis

Element No.	Group Element
1.	Substructure
2.	Superstructure
3	Internal finishes
4	Fittings furnishings and equipment
5	Services
6.	Prefabricated building and building unit
7.	Work to existing buildings
8.	External Works
0.	Facilitating Works
9	Main Contractor's Preliminaries
10.	Main Contractor's overhead and profit
11.	Project/Design team fees
12.	Other Development/ project costs
13.	Risks

In addition, the RICS through its subsidiary the Building Maintenance Information Service (BMIS) published a Standard Form for Property Occupancy Cost Analysis (SFPOCA). The aim of the form according to Kirkham (2013) is to allow standardisation of the system of collecting and presenting occupancy cost data. The SFPOCA breaks down property occupancy costs into nine elements of:

a) Improvements & adaptations

b) Decorations

c) Fabric

d) Services

e) Cleaning

f) Utility

g) Administrative Costs

h) Overheads

i) External works

In another development, the growing desire to meet the specific and varied needs of property occupiers led to the establishment of International Property Databank Ltd (IPD) in 1994. The company's objective is to provide a standardised approach to comparing key elements of property performance related to cost, space, efficiency and effectiveness. In addition, the company provides an annual benchmarking service which provides an annual comparative assessment of property performance in order to improve accurate benchmarking. IPD occupiers published the International Total Occupancy Cost Codes (ITOCC) which is a real estate and facilities data classification system. The system facilitates the assessment of total occupancy costs and revenues. The first edition of the ITOCC was published in 1999 which provided a comprehensive and well defined metric for assessing occupancy costs. Since then the code has enjoyed wide acceptance. The ITOCC was launched in 2001 in response to the demands of global organisations for accurate benchmarking and forecast of costs related to total occupancy costs. The objectives of the ITOCC are to:

Set out an accepted global set of definitions and set of cost measurement; Help organisations make better and quicker decisions in a rapidly changing world; Improve performance monitoring of real estate and facilities managementetc.

The latest edition of the ITOCC is the fourth edition published in 2006 and contains five major headings as shown on Table 2.5

Table 2. 5: International Total Occupancy Cost Codes

Heading Label	Description
Heading A: Real Estate Occupation Cost	
A1	Rent
A2	Unitary charges
A3	Acquisition, disposal & removal
A4	Local property taxes
A5	Parking
A6	Associated facilities
A7	Occasional space
A8	Marketing & promotion
Heading B: Adaptation Equipment Cost	
B1	Fit-out and improvement
B2	Furniture & Equipment
Heading C: Building Operations Cost	
C1	Consolidated service charge
C2	Insurance
C3	Internal repair & maintenance
C4	M&E repair & maintenance
C5	**External & structural repair & maintenance**
C6	Minor improvements
C7	Internal moves/churn
C8	Reinstatement
C9	Security
C10	Cleaning
C11	Waste disposal
C12	Internal plants & decorations
C13	Grounds maintenance
C14	Water & sewerage
C15	Energy
Heading D: Business Support Cost	
D1	Telephones
D2	Catering
D3	Reception services
D4	Courier & external distribution services
D5	Post room & external distribution services
D6	Reprographics
D7	Disaster recovery
D8	Transport
D9	Archiving
Heading E: Occupancy Management Cost	
E1	Real estate management
E2	Facilities managers
E3	Project management

(Source: IPD, 1999)

The international standard ISO 15686-Part 5 has produced a generic cost classification that could be used to define the scope of WLC analysis. The classification however is intended to serve as a guide so that items not required may be excluded while additional ones could be added to meet the desired objectives of the analysis or national requirements. A key advantage of the CBS is that it clearly distinguishes between items of cost covered by WLC and LCC. The main cost centres are outlined on Figure 2.20.

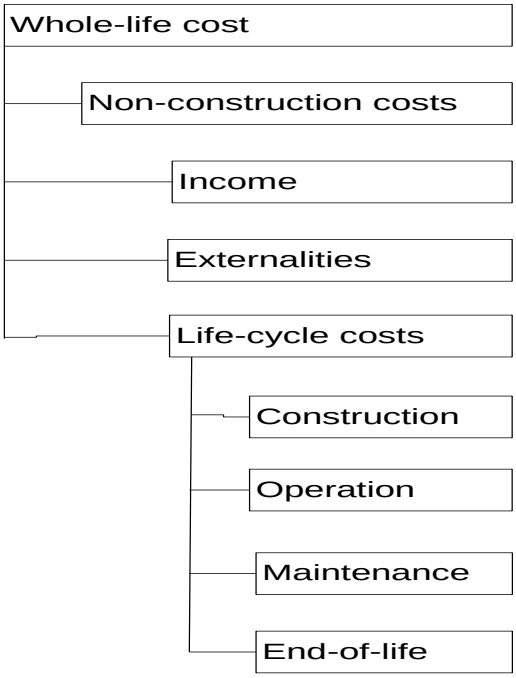


Figure 2. 20: Generic WLC Classification (Source: ISO 15686-5)

An important note is that the recommended levels of WLC analysis in appendix E of the ISO 15686-5 is similar to the BCIS analysis levels.

2.9 The Royal Institute of British Architects (RIBA) Plan of work

It has been explained in section 2.5.3 that both the potential for cost savings and types of decisions vary with project evolution stages. In line with this idea, the RIBA published a plan of work that serves as a guide on how construction process should be organised from the point of view of architectural inputs (Hughes, 2003). The first edition was published in 1961 and remained significantly unchanged until 2000 when it became apparent that there was the need to accommodate changing legislations, complexities in both projects and procurement methods. Due to the inability of the plan to reflect current realities of the construction sector, another plan was published in 2007. The 2007 edition despite the simplicity of its stages and the clarity of stage descriptions failed like its predecessors to address the current developmental needs of the construction industry. According to RIBA (2013), the 2007 edition only aligns with the traditional procurement route and makes

assumptions about timing of request for planning approval. Further, it fails to align with advancements in communication technologies and existing legislations. In addressing these limitations RIBA launched the 2013 edition. The core attributes of the 2013 edition according to RIBA (2013) are:" it acts across the full range of sectors and project sizes; it provides straight forward mapping for all forms of procurement; it interprets sustainable design process; it maps Building Information Modelling (BIM) process; andit provides flexibility in relation to planning procedures". In order to ensure smooth transition between the 2007 and 2013 editions, RIBA aligned the stages so that information and data could be feed forward. Table 2.6 shows the relationship between the stages of both editions.

Table 2. 6: Comparison of RIBA plan 2013 and 2007 stages

STAGE	2013 RIBA PLAN SATGES	CORRESPONDING 2007 STAGES
Stage 0	Strategic Definition	Certain activities derived from stage A-Appraisal.
Stage 1	Preparation of Brief	Residual tasks from stage A-Appraisal and Stage B-Design brief
Stage 2	Concept Design	Stage C-Concept
Stage 3	Developed Design	Stage D-Design development and part of Stage E-Technical design
Stage 4	Technical Design	Residual tasks of Stage E
Stage 5	Construction	Stage K-Construction to practical completion. Includes also Stage J mobilization
Stage 6	Handover and close out	Stage L-Post practical completion
Stage 7	In Use	This is a completely new stage

The RIBA 2013 stages can also be aligned with ISO 15686-5 project development stages as shown on Table 2.7.

Table 2. 7: Comparison of RIBA plan 2013 and ISO 15686-5

STAGE	ISO STAGES	RIBA STAGES
1	Planning	Stage 0 and Stage 1
2	Design	Stage 2: Concept design
		Stage 3: Detailed design
		Stage 4: Technical design
3	Construction	Stage 5: Construction
		Stage 6: Handover and closeout
4	Operation	Stage 7: In-use
5	End-of-life	

2.10 Whole Life Cost Analysis, Management and Planning

The core activities of WLC are divided into three main activities. These activities span through the entire life span of built assets and include the following:

2.10.1 Life cycle cost analysis (LCCA)

LCCA is a systematic breakdown of costs of a facility in accordance with a specific Cost Breakdown Structure (CBS) in preparation for future use for the purpose of forecasting, comparison or cost planning. Seeley (1996) pointed out that, it involves the collection and analysis of historic data on the cost of occupying comparable buildings. An important requirement for LCCA is that the cost data must be in context. The data must be associated with the type of building, location, procurement rout, level of usage, and quality of the building (Flanagan and Jewell, 2005). Figure 2.21 shows the classification of data required for an effective cost analysis.

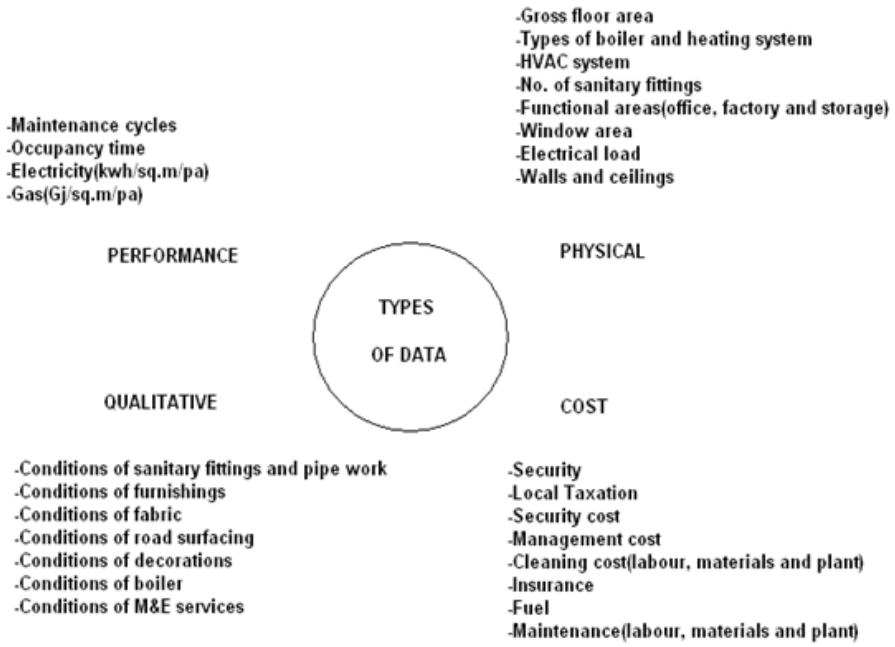


Figure 2. 21: Data for WLCA (Source: Flanagan and Jewel, 2005)

2.10.2 Whole Life Cost Management (WLCM)

WLCM is concerned with the control of costs at different stages of project's life cycle. Moreover it identifies areas where the cost performance differs from the cost plan so that cost control measures could be taken (Seeley, 1996). Flanagan and Jewell (2005) outlined five purposes of WLCM as:

a) To establish where performance differs from Whole Life Cost Plan (WLCP) projections, why the differences occur, whether they are significant, and whether current performance could be altered.

b) To make recommendation on more efficient utilisation.

c) To provide information on asset lives and reliability factors for accounting purposes.

d) To assist in the establishment of maintenance policy for the facility.

e) To give taxation advice on building-related items.

2.10.3 Whole Life-cycle Cost Planning (WLCP)

WLCP is concerned with the estimation of the probable WLC of a building, system, element, or component. Seeley (1999) described WLCP as the prediction of total cost of a building, part of a building, or an individual building element, taking account of initial capital costs, subsequent running costs and residual values, if appropriate, and expressing these various costs in a consistent and comparable manner by applying discounting techniques. It also includes planning the timing of work and expenditure on the building, and should also take into account such factors as the effects of performance and quality. Table 2.8 shows the relationship between data requirement for WLCA and WLCP while Table 2.9 depicts the sequence of linking WLCA, WLCP and WLCM.

Table 2. 8: The Relationship Between the Data Requirements of Whole Life Cost

Items	Whole Life Analysis	Whole Life Planning
Description of the facility location and consultants	Required	Required
Measurement of floor, window, wall, roof areas and any detailed elemental areas as required	Measurement from drawings or on site	Measurement from drawings
Performance (annual)	Actual records (possibly more than one year) - Use of electricity/gas - Water usage if metered - Security (Level authorized) - Cleaning frequency window, common areas) - Maintenance (Planned repairs and annual) - Grounds maintenance (Details of work)	Estimated (expert advice)
Annual and non-annual maintenance including routine maintenance, minor repairs and alterations/ adaptations /replacement	Actual records on component lives and planned maintenance (possibly more than one year)	Estimated
Operational cost (annual)	Actual records (possibly more than one year)	Estimated
Condition of facility	Site visit to determine condition of elements. Use any condition surveys that ore available	As specified
Discount rate, inflation rate, whole life	Not applicable	Provided by the client/owner

(Source: Flanagan and Jewell, 2005)

Table 2. 9: The Sequence Linking WLCA, WLCP and WLCM

Step	Actions
1.	**Get quantitative and qualitative data** Measure the areas Decide upon the performance requirements and the categories to be used for the whole life plan.
2.	**Gather data from past projects and specialist organizations.** - Select whole life analysis from past projects similar in size and type to the planned facility. - Consider how to aggregate the information, use benchmarks to ensure reliability. - Consider how to update the information to current prices using indices. - Decide what reliability can be placed on the data. - Cross-check figures with specialist contractors and with models
3.	**State assumption** - State all assumptions being made. State exactly what has been assumed and why
4.	**Using a Spread sheet** - Put all the information into a spread sheet, such as areas, unit rates, inflation rates, engineer's estimates for energy use, maintenance cycles, degradation of materials, energy consumption, cleaning cycles and insurance.
5.	**Select the time horizon fro analysis** - The time horizon is dependent upon the client's perspective for a PFI project, it may be 35 or 30 years; for a developer it may be 10 years, for a home owner it may be 15 years. It is usually the service life of the facility. For example if a bridge has a service life of 70 years. It would be unrealistic to try and forecast over its 70 years life.
6.	**Extrapolate into the future** - For a whole life plan, decide upon the service/designs life of components, obsolescence and renewal. - Decide what annual, cyclical and periodic maintenance will be required - Decide how inflation should be handled, either as one rate in the discount rate or whether different elements will inflate at different rates. - Produce a whole life plan.
7.	**Discounting** - If different options are being considered, discount future costs over the time horizon back to a net present value/cost. This enables the lowest cost option/best value to be identified.
8.	**Residual values** - Considered what value the facility or component may have as scrap or reuse. Often the residual value is in the land the facility uses.
9.	**Plot the results** - Check the sensitivity of decisions by testing with different rates
10.	**Check the sensitivity** - Monitor and modify the whole life plan through the design and construction phase into occupancy.
11.	**Monitor and modify** - Monitor and modify the whole life plan through the design and construction phases into occupancy.
12.	**Set up a frame work and system to collect operational and cost information for whole life management.** The data an be used for budgeting and for making informal decisions about the maintenance plan, energy costs and overheads.
13.	**Feed back information on performance and cost to the design team.**

(Source: Flanagan and Jewell, 2005).

2.11 Risk Analysis in Whole Life Costing

WLC evaluation involves the use of data that is often unreliable and subjective to make forecast that spans decades, involving assets whose use patterns and functional requirements could change and be affected by external factors like: changes in legislations and political, social and economic activities in the society within which they are located which points to the uncertainty and inherent risk in WLC evaluation. Kishk et al (2003a) summarised that, uncertainty is endemic to WLC and therefore its treatment is important to its successful implementation.

Boussabaine and Kirkham (2004), categorised the various risk analysis techniques that could b used in WLC into three broad groups of: Deterministic techniques (based on numerical computation of risks); Qualitative techniques (subjective assessment of risk); Quantitative techniques (statistical and probabilistic approaches to risk quantification).
This classification is ill-defined as it could be validly argued that deterministic techniques are also quantitative if the strict interpretation of the word is applied.

An examination of the various techniques within literature suggests only two broad classifications: Quantitative and Qualitative techniques. Qualitative techniques are subjective and consists of techniques like risk register, risk matrix, Influence diagrams, SWOT analysis, Brainstorming sessions, Likely/consequence assessment etc. The qualitative techniques on the other hand can be further classified into deterministic, stochastic, Statistical, Mathematical and analytical. Table 2.10 shows these classifications with examples of each.

Table 2. 10: Classification of Quantitative techniques

Deterministic	Stochastic	Statistical	Mathematical	Analytical
-Break-even analysis -Risk adjusted discount rate -Sensitivity analysis	-Decision tree -Monte Carlo/ Latin hypercube -Confidence Index Approach -Markov's theory	- Variance & Standard deviation, -Coefficient of variation, -Regression models	-Fuzzy Set Theory	-Genetic algorithm -Artificial Neural Network -Artificial Intelligence.

(Boussabaine and Kirkham, 2004)

The most important risk analysis techniques based on ISO 1586-5 and NP on PPP are: Risk Matrix, Sensitivity Analysis, Monte Carlo method, Risk Adjusted Discount rate. Other useful techniques reported in literature are Fuzzy Set Theory, Decision tree, and Confidence Index Approach. The following section discusses these techniques.

2.11.1 Risk Matrix

Risk Matrix (RM) is a qualitative risk assessment technique that helps to identify risky events with their associated scores. It assesses the impact of an event as a product of its probability of occurrence and its severity. It is usually presented in tabular form with the horizontal side showing various degrees of probability of occurrence and the vertical side showing various degrees of severity. Boussabaine and Kirkham (2004) indicated that the technique though subjective, is popular and widely used due to its simplicity. They identified four steps to be taken in the preparation of a RM:

a) Identification of risk involved in a product
b) Evaluation of the influence of these risks on the project
c) Assessing the likelihood of occurrence of the risk
d) Computing the financial impact of the risk.

Despite its popularity and usability however, Cox (2008) explained that it has four major limitations:

i. Poor resolution- RM can unambiguously compare only a small fraction of randomly selected pairs of hazards. It can assign identical ratings to quantitatively very different risks.

ii. Errors- It can mistakenly assign higher qualitative rating to quantitatively smaller risks and could be "worse than useless" with negatively correlated frequencies and severities.

iii. Suboptimal resource allocation- Resource allocation to risk reduction measures cannot be based on the categories provided by RM

iv. Ambiguous inputs and outputs- Input and output to R require subjective interpretation so different analysts may obtain opposite ratings for the same qualitative risks.

Despite these limitations however, RM has proven to be a useful tool in risk identification and scoring especially where there is dearth of historical data.

2.11.2 Sensitivity Analysis (SA)

SA is a technique that facilitates the determination of the influence of an independent variable on the dependent variable while keeping all other variables constant. In other words, the variable to be assessed is varied between two extreme points while its effect on the overall mathematical model is recorded and evaluated. It therefore helps to identify variables in order of sensitivity. Flanagan and Norman (1993) asserted that, SA identifies the point at which variation in the value of a variable could affect an investment decision. They further asserted that, the technique does not quantify risk but rather help to identify risks that are risk sensitive. Its major disadvantage is its inability to handle variation in two or more variables at a time, thereby making the process lengthy and too cumbersome where the variables to be evaluated are many.

2.11.3 Monte Carlo Method (MCM)

MCM is a stochastic simulation technique that evaluates uncertainty in a dependent variable or an entire model by randomly and iteratively selecting values of an entire set of independent variables. The selected values are used to compute the values of the dependent variable based on which a probability distribution is generated to properly define the risk profile of the dependent variable. Flanagan and Norman (1993) outlined the steps involved in MCS to include:

i. Identifying the variables to be evaluated
ii. Generating mathematical relationship between the independent and the dependent variables
iii. Defining the variables using probability distributions
iv. Generating random numbers to be used in the iterative selection of the values of the independent variables
v. Compute the corresponding values of the dependent variable
vi. Generating a probability distribution from the values of the dependent variable
vii. Computation of the distribution parameters like, mean, standard deviation, coefficient of variation, skewness, courtesies etc.

Its main advantage is that it evaluates risk in all variables concurrently thereby depicting a complete picture of the risk associated with an entire system. Its disadvantage however is that it is complex, computationally expensive and inefficient (Kishk et al, 2003a)

2.11.4 Risk Adjusted Discount Rate (RADR)

RADR incorporates risk premium as the requirement for an additional rate of return. The risk factor is added to the discount rate to obtain the RADR which is a reflection of the magnitude of risk associated with an investment. The higher the perceived risk associated with an investment, the higher the risk premium (Flanagan and Jewell, 2005). Mathematically:

RADR= $(r + i + rp)^t$ where

r- risk free rate

i- allowance for inflation

rp- risk premium

The main disadvantage of this method is the assumption that the rates are geometrically proportional to time which may not be entirely true.

2.11.5 Fuzzy Set Theory (FST)

FST is a tool for Artificial Intelligence (AI) that tries to mimic the human capacity for approximate reasoning and subjective assessment. Due to the dearth of WLC data expert judgment and opinion complements empirical data. Sobanjo (1999) maintains that even where empirical data is available, expert judgment is needed to in the interpretation of result. Kishk et al (2003a), and Boussabaine and Kirkham (2004) noted that FST could be used to model human and process subjectivity in WLC. Wang (2011) and Mohammad,Tarek,and Osama(2013) demonstrates the use of FST in WLC by developing a decision-making model that simplifies the ranking of competing design alternatives.

Bellman and Zadeh (1970) described a Fuzzy set as a class of objects in which there is no sharp boundary between those objects that belong to the class and those that do not. They gave a more precise definition as follows:

Definition; let X = {x} denote a collection of objects (points) denoted generically by x. Then a Fuzzy set A in X is a set of ordered pairs

$$A = \{(x, \mu_A(x)\}, \, x \in X$$

Where $\mu_A(x)$ is termed the grade of membership of X in A. μ_A : X μ is a function from X to space μ called the membership space. When μ contains only two points 0 and 1, A is non-fuzzy and its membership function becomes identical with the characteristic function of a non-fuzzy set. A notation convention for a Fuzzy set (A) when the universe of discourse X is discrete and finite, is:

$$\tilde{A} = \left\{ \frac{\mu_{\tilde{A}}(x_1)}{x_1} + \frac{\mu_{\tilde{A}}(x_2)}{x_2} + \frac{\mu_{\tilde{A}}(x_3)}{x_3} + - - - - \right\} = \left\{ \sum_i \frac{\mu_{\tilde{A}}(x_i)}{x_i} \right\} \ldots\ldots 3$$

When the universe is continuous and infinite, the fuzzy set A is denoted by;

$$\tilde{A} = \left\{ \int \frac{\mu_{\tilde{A}}(x)}{x} \right\} \ldots\ldots\ldots\ldots 4$$

In both notations the horizontal bar is not a quotient but rather a delimiter. The numerator in each term is the membership value in set A associated with the element of the universe indicated in the denominator. In equation 5 the summation symbol is not for algebraic summation but rather denotes the collection or aggregation of each element. Hence, the + signs are not algebraic "add" but are aggregation or collection operator. In the equation 4 the integral sign is not an algebraic integral but a continuous function-theoretic aggregation operator for continuous variables (Ross, 2004).

Ross (2004) explained that, all information about a fuzzy set are contained in its membership function. Figure 2.22 shows the properties of a fuzzy set.

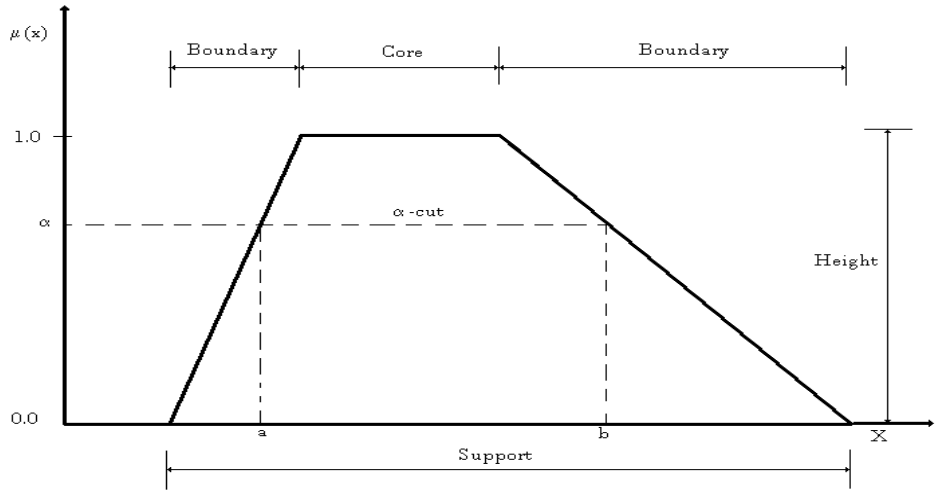


Figure 2. 22: Features of a fuzzy set (Source: Ross,2004)

- The core of the membership function for some fuzzy set A is defined as that region of the universe that is characterized by complete and full membership in the set A.
- The support of a membership function for some fuzzy set A is defined as that region of the universe that is characterized by nonzero membership in the set A.
- The boundaries of a membership function for some fuzzy set A, are defined as that region of the universe containing elements that have a nonzero membership but not complete membership.
- The height of a fuzzy set A, is the maximum value of the membership function.
- An alpha-cut set is a crisp set [a,b] defined by $A_\alpha = \{x|\mu_A(x) \geq \alpha$.

2.11.6 Decision Tree Analysis (DTA)

DTA is a graphical technique that clearly shows the structure of an investment decision. It depicts the alternative courses of action, the probability of a rise or fall in the values of an investment option, and the expected monetary values of the options all at a glance.

A special class of the decision tree is the binomial tree which is particularly useful in optionsevaluations consisting of only two possibilities of rise and fall. The binomial tree starts with a known value (present value) and propagates in equal successive time periods usually in years. Starting from the present the range of possible outcomes are estimated and represented on the tree as upward and downward movements. These lowest and highest values at the end of a period are represented by the upward and downward movements called "ticks" in the next period. Each tick begins at a preceding node and ends in a succeeding node. Figure 2.23 shows a graphical representation of a binomial tree with all its features.

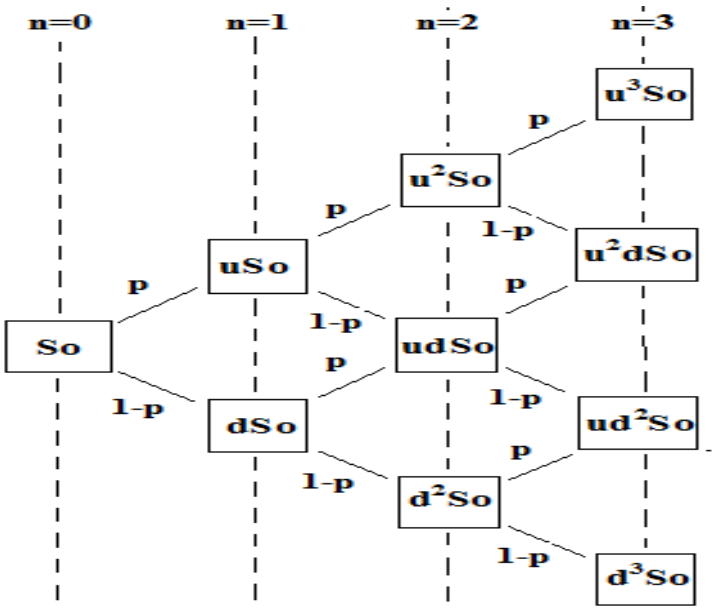


Figure 2. 23: Outline of a Binomial Tree

From the figure, $u = e^{\sigma\sqrt{t/n}}$ ----------5

d= $e^{-\sigma\sqrt{t/n}}$ ----------6

$$p = \frac{e^{rt/n} - d}{u - d}$$ ----------7

So is the initial sum and σ - is volatility

According to Ellingham and Fawcett (2006) option evaluation using a binomial tree is usually done in three basic steps.

Create the binomial tree

Compute the values at each node using equations 5,6, and 7 above.

Compute the discounted cash flows using the formula;

$$V = v + p_u \times \frac{v_u}{(1+r)} + p_d \times \frac{v_d}{(1+r)}$$

where:

V is the cumulative value at the node being studied

v is the value at the node being studied

V_u is the cumulative value at the upward parent node

V_d is the cumulative value at the downward parent node

p_u is the upward probability

p_d is the downward probability

r is the discount rate

2.12 The Black & Scholes Options Pricing Model

The Black-Scholes model was introduced by Black and Scholes (1973). It revolutionised options trading at that time and generated a boom in the options market around the world. The model generates theoretical estimates of the European style options based on some underlying assumptions (James and Van, 2002). Equations 8 to 10 show a mathematical representation of the model.

$$V_{co} = S_o N(d_1) - N(d_2) C_o e^{-rt} \text{ ----------8}$$

Where $$d_1 = \frac{\ln\left(\frac{S_o}{C_o}\right) + \left(r + \frac{\sigma^2}{2}\right)t}{\sigma * \sqrt{t}}; \text{ ----------9}$$

$$d_2 = d_1 - \sigma * \sqrt{t}; \text{ ----------10}$$

V_o is the current value of the option;

S_o is the current market value of the underlying asset;

N(d) cumulative normal probability density functions;

C_o is the exercise price of the option;

e is a constant 2.71828 the base of natural logarithm;

r is the risk-free rate of interest;

t is time to expiration of the option;

σ is the volatility of the annual rate of return on the underlying asset continually computed. The equations were derived based on the following assumptions:

Options are exercised only at expiration

Markets are efficient and there are no transaction costs

The value of underlying assets and the risk-free rates are constant during the life of the option.

No dividend is paid on the share (underlying asset) during the life of the option.

The rate of return on the underlying asset is log normally distributed

In property investments, six different options could be identified;

Option to develop;

Option to expand;

Option to switch use

Option to reconfigure;

Option for new technology; and

Option to abandon.

These options can be grouped into call or put option. According to Pandey (2006) a call option on a share (or asset) is the right to buy the share at an agreed exercise (strike) price. A put option on the other hand is a right to sell a share (or any asset) at an agreed exercise

price on or before a given maturity period. In the light of the above definitions, options to develop, expand, switch use, reconfigure, new technology are all call options whereas option to abandon is a put option. Table 2.11 summarises the various options and their meaning within the context of building investment as compiled from Ellingham and Fawcett (2005), Pandey (2006) and James and Van (2002). Fawcett (2011) however, posits that, life cycle options are numerous but can be grouped into three major groups of; life-cycle option to expand/upgrade; life cycle option to switch; and life cycle option to contract/ abandon.

Table 2. 11: Summary of Building Investment Options

S/No	Option name	Explanation
1	Option to develop	A right owned by a prospective investor to develop a piece of land.
2	Option to expand	A right owned by a prospective investor to expand an existing building.
3	Option to reconfigure	A right owned by a prospective investor to reorganise the internal arrangement and partitioning of an existing building.
4	Option to switch use	A right owned by a prospective investor to put an existing building to a different use
5	Option for new technology	A right owned by a prospective investor to incorporate a new technology to an existing building.
6	Option to abandon	A right owned by a prospective investor to safely abandon an unviable building investment by transferring ownership to another party.

Source: Ellingham and Fawcet (2005)

The put-call parity is a useful way of comparing put and call options. It assumes that for a every call option there is a corresponding put option. Put in another way, for every value of a call option a corresponding put option can be computed. Supposing equation 8 represents the value of a call option, the corresponding put option is given by equation 11.

$$V_{po} = S_o[N(d_1) - 1] + [1 - N(d_2)]C_o e^{-rt}$$ ----------11

A general equation for the evaluation of put options was put forth by Pandey (2006) as

$$V_{po} = S_p e^{-rt}[1 - N(d_2)] - S_o e^{-yt}[1 - N(d_1)]$$ ----------12

Where S_p is the strike price, and y is the yield

$$d_1 = \frac{\ln\left(\frac{S_o}{S_p}\right) + \left(r - y + \frac{\sigma^2}{2}\right)t}{\sigma * \sqrt{t}}$$ ----------13

$$d_2 = d_1 - \sigma * \sqrt{t}$$ ----------14

2.13 Summary of Literature Review

The history and definition of WLC as reviewed in Sec. 2.1 and 2.2 traced the evolution of WLC from terotechnology to cost-in-use and finally LCC. This enables the differentiation of the definition of sister terms like LCC, WLCC, WLC, and WLA. The ISO 15686-5(2008) definitions provides an important distinction between the terms. The benefits and uses of WLC analysis were reviewed in Sec. 2.3 to clearly identify areas in which it is most beneficial to investment appraisal.

The sources of regulations and guidelines for WLC were articulated in Sec.2.4 to facilitate the achievement of objective1. The sources includes amongst others; PP Act(2007); ICRC Act(2005); ISO 15686-5(2008), Procurement Procedures Manual(2011), Public Procurement Regulations for Goods and Works (2010). These sources collectively defines the discounting, uncertainty and risk analysis techniques, life-cycle stages, documentation and reporting format, sources of data and circumstances of use.

Impediments/barriers to the application of WLC and the limitations of existing analysis tools were reviewed in Sec. 2.5 and Sec. 2.6 respectively which provides the basis for the

achievement of objective2 and objective3. The impediments include: data scarcity, client's attitude, cost of implementation, lack of standard CBS, complexity of the process amongst others. Furthermore, the criteria against which existing WLC frameworks should be evaluated have been examined. These criteria are: problem/decision-making process, project life-cycle, uncertainty/risk analysis, and feedback and iteration requirements.

Sec 2.7 outlined important economic evaluation techniques that may be used for WLC assessment. They include; NPV, IRR, PBP, PI and BCR. Sec 2.8 explored the various CBS useful to WLC evaluations. The combination of ISO 1586-5 CBS and BCIS Elemental cost breakdown provides an excellent structure for WLC analysis, planning and management. The scope of WLC activities covered under WLC analysis, planning and management was reviewed in Sec. 2.10 while Sec. 2.11 addressed the various uncertainty and risk analysis techniques. Some useful techniques includes: Risk matrix, sensitivity analysis, Monte Carlo method, FST amongst others. Sec 2.7 to 2.11 provides support information for the achievement of objectives4 and objective5.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Introduction

The design of an effective research method requires that the philosophical basis, the theoretical perspective and the methodology be properly defined. In line with the aforesaid, this section discusses on the philosophical views that underpins the theoretical and methodological approach of this work. It begins by identifying the ontological, epistemological and axiological stand points of the research. Research approach and design are then proposed and aligned with both research methods used and the philosophical position of the work.

In addition, a reliable and widely acceptable WLC implementation framework must satisfy certain basic criteria. First, it must be in agreement with existing legal requirements; it must address the limitations of existing frameworks; it must overcome the impediments to the application of WLC and; be presented in a simple and easily adoptable manner. This section also discusses the procedure, tools and methods through which the framework was developed vis-à-vis the aforementioned requirements it must satisfy.

3.2 Research Philosophy

Pathirage,Amaratunga, and Halgh (2008) described research philosophy as an epistemological, ontological and axiological assumptions and basis that guides inquests and investigations in a research study. Failure to give a research study a proper philosophical grounding can seriously affect the quality of the research design (Easterby-Smith, Thorpe, and Lowe, 2002). Philosophy is generally divided into three broad classes of: Metaphysics, Epistemology, and Axiology.

3.2.1 Metaphysical Stance

Metaphysics is a branch of philosophy that studies existence, being and the world. Omorogbe (1999) identified the main concern of metaphysics as: problem of being, substance, essence and existence, universals, appearance and reality, unity and diversity, change and performance, causality, mind body and interaction, freedom and determinism. Aristotle described it as "first philosophy" and subdivided it into three branches of: Ontology, Natural theology, Universal science- The study of first principles of logic and reasoning.

Ontology and Universal science are the metaphysical branches related to scientific research. Mastin (2018) defines ontology as the study of the nature of being, becoming, existence, or reality as well as the basic categories of being and their relations. Four ontological dogmas are of interest to scientific research. These include realism, idealism, objectivism and subjectivism. Mastin(2018) further defined realism as the view that entities of a certain type, forms an objective reality that is ontologically independent of our conceptual schemes, linguistic practices, beliefs etc. Closely related to realism is objectivism which views reality as independent of the mind. It represents the view that there is only one correct description of reality whether we have any knowledge of it or not (Pathirage et al, 2008). An objective fact refers to a truth that remains true irrespective of time or place. In relation to scientific research both realism and objectivism emphasises reality as independent of the mind. In other words, there is a distinction between the researcher and the research domain. This represents the view of a research in natural sciences in which the researcher makes an observation of a natural phenomenon, formulates hypothesis, and evaluates the hypothesis through quantitative methods. Idealism on the other hand is the ontological doctrine that ideas or thoughts make up

fundamental reality. It posits that the only thing actually knowable is consciousness. According to Pathirageet al (2008), Idealists assumes that different observers may have different viewpoint and that truths vary from place to place and from time to time. Closely related to Idealism is Subjectivism which views reality as existing only in our minds. It posits that knowledge is subjective and that there is no external or objective truth. Both idealism and subjectivism coincide on their assumption that reality is of the mind and that different individuals construct different views of reality. This view clearly represents the view that underpins social science research which is based on qualitative research methods.The ontological view of this research is that of realist.

3.2.2 Epistemological Stance

Epistemology refers to the study of knowledge, that is what we know, how we know it and how valid and truthful it is. Crotty (1998), described epistemology as a way through which we understand and explain our acquisition of knowledge. It is also concerned with the source of knowledge and its relationship with the inquirer (Dawson, 2002). Some important epistemological dogmas applicable to scientific research are; empiricism, positivism, constructivism and rationalism. Encyclopaedia Britannica (2016) defines rationalism as "the view that regards reason as the chief source and test of knowledge". Rationalists believe that certain rational principles exist in logic, mathematics, ethics and metaphysics that are so fundamentally true that denying them causes one to fall into contradiction. The epistemological standpoint of this research is that of a rationalist.

3.3 Research Perspective

The research perspective of this study is design research. Simon (1999) described design research as the “sciences of the artificial”. Bayazit (2004) explained design research as a study and investigation into the artificial, made by humans excluding however the

activities of art and craft which he described as unscientific. Diverse design research processes have been proposed by different authors (e.g. Simon, 1999; Cross, 2000; Poggenpohl and Sato 2003 etc.). The steps involved could however be summarised into five sequential steps of; problem definition, data gathering/theoretical review, concept design, design development, Design evaluation and adjustment.

3.4 Research Approach

According to Wood and Welch (2010), researchers traditionally take two basic approaches: the Quantitative or Qualitative approach. All researches were presumed to fall under these two categories. They however noted that this two-dimensional approach is deeply flowed as some researches could be triangulated so that they share some of the traits of both approaches. Naum (1998) described a Quantitative research as objective in nature while Fellows and Liu (2003) relates it to positivism and social science research. Qualitative research on the other hand is subjective and tries to gain insight into people's perception of the world. Fellows and Liu (2003) further explained that the beliefs, understanding, opinions, views, and perceptions of people at both personal and group level are the subject of investigation in Qualitative research. Qualitative approach is often aligned with social science research (Holden, 2004). Table 3.1 summarises the differences between Quantitative and Qualitative approaches as reported by Wood and Welch (2010) and Naoum (1998).

Table 3. 1: Differences between Quantitative and Qualitative approach

Sno	Parameter	Quantitative Approach	Qualitative Approach
1	Ontology	**Objectivism/ Realism**	Subjectivism, Idealism
2	Epistemology	Positivism, **Rationalism**	Post positivism, Social constructivism
3	Nature	Objective	Subjective
4	Method	**Deductive**	Inductive
5	The observer or researcher	**Distant and independent**	Close and part of what is being observed
6	Human interest	Irrelevant	**The main driver of the research**
7	Explanation	**Must demonstrate causality**	Aims to increase general understanding of the situation based on subjective meaning systems
8	Research progression	through hypothesis and deduction	Through gathering rich data from which ideas are induced.
9	Concepts	Needs to be operational so that they can be observed	**Should incorporate stakeholder perspective**
10	Units of analysis	Reduced to the simplest terms. Reductionism	**May include the complexity of whole. Holistic approach**
11	Generalisation	Through statistical probability	**Theoretical abstraction**
12	Sampling	**Requires large number selected randomly**	Small numbers of cases chosen for specific reason
13	Role	**Fact finding based on relevance or records**	Attitude measurement based on opinions, views and perceptions measurement
14	Scope of findings	**Nomothetic**	Ideographic
15	Relationship between theory concepts and research	**Testing/ Confirmation**	Emergence/ development
16	Nature of data	**Hard and reliable**	Rich and deep

Source: Generated from Wood and Welch (2010) and Naoum (1998)

Design research shares some of the characteristics of a Qualitative and thus social science research. Firstly, human interest is the main driver of the research; secondly,design concepts incorporate stakeholder perspective; thirdly, generalisation is based on theoretical abstraction etc. Poggenpohl and Sato (2003) however identified three models a design research could take. These includes; empirical, theoretical and methodological. All the three models require the identification of research questions and follows deductive

research methods. They asserted that the goal of the methodological model is to develop useful procedures for practice or develop general procedures for further development of field specific methods and that the result of research are in the form of an application tool so as to assess its efficacy for the intended role. This research falls within the class of methodological design research. In view of this, the triangulated research approach was adopted since design research shares the traits of both quantitative and qualitative approach.

Figure 3.1 shows a schematic representation of the research process which follows both problem solving and design process. A top-down approach was implemented in which problem definition comes at the top of the echelon. The research activity then proceeds along three routs covering the articulation of legal requirement, implementation problems and processes and procedures for WLC which collectively coincides with problem structuring (the breakdown of problems into puzzles as proposed by Skitmore and Marston (1999)). Solutions to the puzzles are then proposed and integrated into a conceptual solution to the overall problem statement. The conceptual solution is then further developed to produce a process flow diagram and a corresponding programme flowchart and interfaces that would aid computer implementation.

3.5 Research design

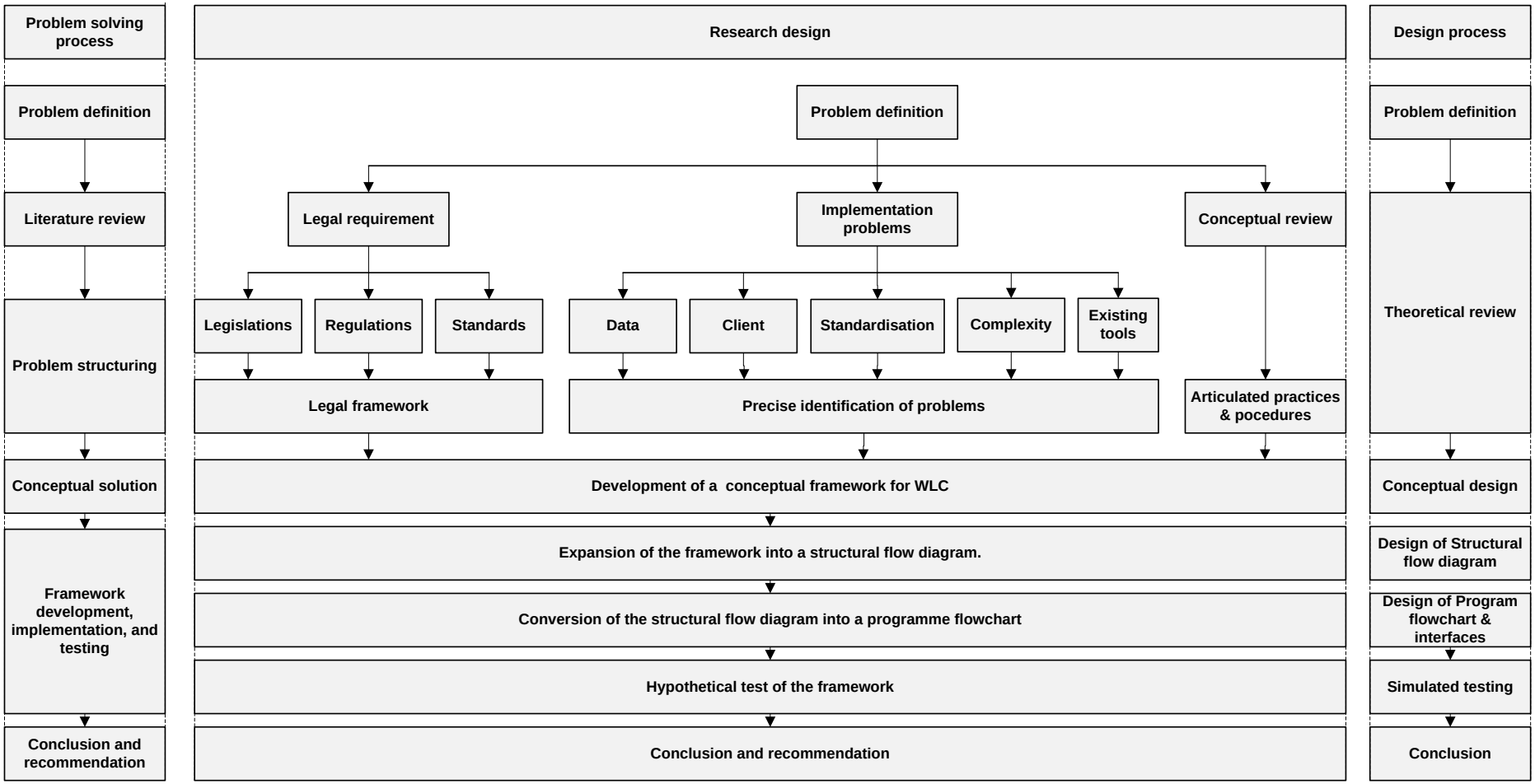


Figure 3. 1: Schematic representation of the research process

3.6 Research Method

This section discusses the procedure through which the WLC framework was developed. First literature survey was conducted to articulate the legal requirement, WLC barriers/challenges, and their possible solutions, and limitations of existing methodologies. A conceptual solution is then developed vis-à-vis the legal requirement, solutions to the implementation challenges, and limitations of existing methodologies. The next sections discuss in more detail the steps taken.

3.6.1 Literature Survey

3.6.1.1 Articulating legal requirement

The development of a legal framework requires the identification of all existing laws, rules, regulations, standards, guidelines and customs governing the application of WLC and the relationship between them. Firstly, to this end, a literature survey was conducted to identify existing legislations and regulations that are related to the subject matter. The following legislations were considered to be of significance: Public Procurement Act, 2007; Infrastructure Concession Regulatory Commission Act, 2005; Privatization and Commercialization Act; Fiscal Responsibility Act; National Policy on Public Private Partnership (ICRC); Public Procurement Manual (Bureau for Public Procurement)

Sections of these Acts in which reference was made to Value for Money (VFM) in public procurement and disposal of public assets, Whole Life Costing (WLC), and sources of data for economic evaluations were studied. A list of grey areas was prepared which formed the basis for conducting a structured interview at BPP, ICRC and SON. The interview was structured to elicit information: VFM drivers, guidelines and assessment in public procurement; relationship between VFM and WLC, Projects

in which WLC is recommended, Existing WLC regulations and guidelines published by the organisations, and the Challenges and success of WLC in public procurement.

3.6.1.2 WLC Implementation Challenges and Solutions

WLC implementation challenges/ barriers were critically examined from literature. Twenty-eight implementation challenges were identified from fourteen different literary sources. These challenges were classified into: Client related, Data related, Industry related, Method related, and practitioner's related. A critical review of the challenges was conducted to identify the most important. In addition, the cumulative frequency of reporting for each of the challenges was also computed. This is based on the assumption that the most significant of the challenges should be the most frequently reported. For each of the identified problems possible solutions were identified through literature search from diverse fields and domains. These solutions were then critically examined and a set of solutions generated for subsequent use in conceptual design.

3.6.1.3 Limitations of Existing Methodologies

A literature survey was conducted to identify existing WLC frameworks and the criteria against which they were evaluated. Weighted evaluation technique was used to carry out the assessment using a 3-point scale. The criteria were assigned equal weight of 1 while the 3-point scale was assigned scores of 0, 1, and 2 for no-compliance, partial-compliance and full-compliance respectively. The total score for each framework was expressed in percentages to facilitate comparison. A framework that satisfies all the 6 criteria would therefore obtain a total score of 12 points. Based on the evaluation result a hybrid of the existing frameworks was developed as a conceptual model by first identifying their strengths and weaknesses and combining the best of their positive

traits while eliminating their negative attributes. The same set of criteria and scoring process were used to evaluate the proposed framework

3.6.2 Framework Design

The framework was designed in three phases, namely: Conceptual framework, Process flow diagram and programme flowchart. The process flow diagram is a pictorial representation of the algorithm and the basic elements/activities of the framework while the program flowchart shows a pictorial representation of the logical process through which the framework can be implemented on a computer system.

3.6.2.1 Design of Process Flow Diagram

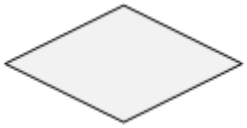
The framework structure was designed using the top-down approach. WLC process was first broken down into first level activities. Each activity was further broken down into its sub-activities bearing in mind the life-cycle stages at which they occur. The sub-activities were further broken down and the process continued until the lowest level of activities was obtained. The entire structural relationship was represented in a flow diagram in which activities were represented by rectangles and activity flow direction depicted by arrows. The design of the process flow diagram was achieved using Microsoft Visio.

3.6.2.2 Flowchart Design

In order to facilitate the development of application software that will mimic the implementation framework, the process flow diagram was further expanded to produce a programme flowchart. The flowchart was designed based on standard flowchart symbols and notations on Table 3.2 .The design of a program flowchart requires a clear definition of activities, inputs, outputs, variables, parameters and decisions which was

achieved by the translation of the process flow diagram into logical sequences and process. Microsoft Visio was also used to produce the programme flowcharts.

Table 3. 2: Flowchart symbols

SN.	Symbol	Definition
1		Start/End:The terminator symbol marks the starting or ending point of a system.
2		Input/output: Represents data/information input or output from a system.
3		Action or Process: Used to indicate mathematical or physical operation.
4		Decision: A decision or branching point. Lines representing different decisions emerge from different points of the diamond.
5		Subroutine: Indicates a sequence of actions that perform a specific task included in a larger process. The task is presented in a separate flowchart to which the main process flowchart refers
6		Database: Indicates a structured body of data or information that allows for searching and sorting.
7		Preparation: Indicates a preparatory activity like data preparation or variable initialisation.
8		Data storage: Indicates a step or stage at which data is stored
9		Display: Used to indicate the display of information on a visual display unit.
10		On page connector: Indicates the continuation point of a flow on the same page.
11		Off Page connector-out going: Indicates that flow continues on separate page.
12		Off Page connector incoming: Indicates the point at which flow continues on the current page.
13		Arrow Line: Indicates the direction of flow.

3.6.3 Implementation and Testing

This section discusses the procedure through which the implementation and testing of database and models were achieved.

The database was implemented using Microsoft Access application. Test data was used to test the database's abilityto store and retrieve information. The data obtained covers both global data likeinflation rate and interest rates and cost data like initial, operating and maintenance cost data.

Both the modified traditional and options-based mathematical models were implemented on a spread sheet. Two different investment scenarios were evaluated. Scenario1 assumed a test project financed from bank loan while Scenario2 assumed a project financed through savings. Using two different scenarios facilitates the assessment of the models' ability to support selection from two or more competing alternatives.

CHAPTER FOUR

4.0 DATA ANALYSIS AND FRAMEWORK DESIGN

4.1 Introduction

This chapter presents the result of data analysis, the design of detailed implementation framework and discussion of results. Summary of the articulated legal requirement was first presented, followed by analysis result on limitations of existing frameworks, impediments to WLC and their solutions, conceptual framework, process flow diagram for the implementation framework, user interfaces and programme flowchart.

4.2 Legal requirement for WLC

This section presents the result of interview conducted at the Bureau for Public Procurement (BPP), Infrastructure Concession Regulatory Commission (ICRC), Standards Organisation of Nigeria (SON) and extractions relating to WLC from PP Act, ICRC Act, SON Act, P&C Act, and FR Act. It also presents important regulations and guidelines related to the subject form Public Procurement Manual (PPM), National Policy on PPP (NP on PPP), ISO 15686: Part 5(ISO 15686-5), Public Procurement Regulations for Goods and Works (PPR), and PPP Toolkit.

4.2.1 Result of Interview with BPP

Below is an excerpt from the interview conducted with the Head of Training department at the BPP . VFM is described by the Bureau as the achievement of quality at the right time, cost and place in an efficient, transparent and open manner and that the core VFM drivers in any public procurement are cost, time, quality and transparency.

WLC assessment is recommended for the procurement of goods. Such goods include electrical and mechanical plants equipment, and devices. Such an assessment should be done at the earliest possible stage to maximise benefits in cases where the operating and maintenance cost of the good is substantial or where there is the need to break ties between two or more competing alternatives.

WLC is limited only to the procurement of goods because the operating/maintenance cost of some goods could exceed the initial cost in no time. Another reason is that such an assessment for an entire building is complex and may not be reliable.

At the moment the commission has not produced any WLC guideline nor has it adopted any WLC standard. Moreover it neither recognises nor recommends the use of ISO 15686-5. However research and publication is continuous perhaps such a guideline may be available in the future.

4.2.2 Result of Interview with ICRC

The following are excerpts from the interview conducted with the Public Relations Officer at the ICRC

The core VFM drivers include service delivery, risk assessment and allocation, project cost and user tariffs. Furthermore, VFM is preferably achieved at development and procurement stages of project life-cycle. Projects that give better VFM are identified by comparing the net present value of the project with its value if conventionally procured.

The commission has not published any guideline for VFM assessment. However, some guidelines are available as supplementary notes in the NP on PPP.

WLC should be applied as early as the development and procurement stages.

No guideline for WLC has been produced by the commission. ISO 15686-5 is not recognized nor recommended by the commission.

Most of the PPP projects have not pass through their full cycle so the success and challenges of WLC have not been fully documented.

4.2.3 Result of Interview with SON

The following are excerpts from the interview conducted with the Public Relations Officer at the SON.

SON is an affiliate and member body of the ISO and that ISO can represent Nigeria in all aspect of standardisation. This means that SON recognises all standards published by ISO including ISO 15686-5.

SON has not published any complimentary standard on WLC as there is already an existing ISO standard.

It is however necessary for the civil/building industry stakeholders to come together and decide on the circumstance of application. Stakeholders should convene a Technical Committee meeting to adopt the standard for it to become a Nigerian Industrial Standard and fully enforceable.

SON however can apply any standard it deemed necessary when economic issues are of concern.

Table 4.1 shows the summary of legal requirements for WLC derived from both interview and extractions from diverse literary sources. These provisions serve as a guide for developing the implementation framework.

Table 4. 1: Summary of Legal Requirements for WLC and their Sources

S/No	Description	Legal provision	Sources
1	Sources of WLC regulations	ICRC Act, NP on PPP, PPP Toolkit ISO5686-5 (SON is an affiliate of ISO. It recognises and recommends for use all ISO standards. PP Act, PPM, PPR, FR Act, P&C Act	ICRC SON BPP
2	WLC Application	Procurement of equipment where the operating and maintenance cost is substantial All PPP Projects Procurement of buildings, constructed assets and their parts	Item 51.2 of PPM NP on PPP-Part 2 Sec I of ISO 15686-5
3	Stages of WLC application	project development, project procurement, project implementation and project maturity bids evaluation Planning, Design, Construction, Operation & End-of-life	Sec. 2.1 of PPP Toolkit ISO 15686-5
4	WLC Analysis technique	Net Present Value Technique to be used during WLC analysis	Item 51.2 of PPM, Sec. 2.4 of NP on PPP, and Sec. 7.4.1 of ISO 15686
5	Risk Assessment	Risk should be assessed at all stages of project life-cycle It should be based on historical data or expert judgement where data is not available Monte Carlo analysis to be used where a range of possible costs is calculated	Sec. 2.3 of NP on PPP and Sec8.1 of the ISO 15686-5. Sec.2.1 and Part3 of NP on PPP Sec. 8.2 of ISO 15686-5
6	Data type	Preference should be given to real historical data. Where historical data is not available, expert opinion and judgement should be sought All projections of cost and revenues to be based on reliable and consistent data obtained from relevant statutory body	Sec. 2.1 ,2.2 and 2.3 of NP on PPP Sec. 11 sub-sec. 3c of FR Act
7	Cost variables to include	initial, operating, maintenance & environmental cost in addition to price Non-construction costs, income, externalities, construction cost, operations, maintenance & end-of-life.	Sec. 32 sub sec 4&5(a) of PP Act Sec. 4.2.2 of the ISO 15686-5
8	Purpose of WLC	Evaluation of different investment scenarios; comparison and selection of design or component alternatives; benchmarking of costs and benefits; and forecasting costs and benefits.	Sections 4.4.2, 4.5.1, 4.5.2, and 4.5.3 of ISO 15686-5
9	Disposal method	Disposal of public assets to be subject to P&C Act. The channels should be one of Trade-in; Sales to other public bodies; public auction; Sales by sealed bid; Negotiated sales; Set price; Sales to public officers and Destruction. Disposal should be timed to take place when the optimum returns can be obtained	Sections 55, and 56 of PPP Act, Items 89-90 and Item 92 of PPM and Part V of PPR Section 56 of PP Act
10	Discounting requirement	Discounting should be used in comparing projects with different future profiles of costs and revenues based on real or nominal discount rate. Future costs and revenues to be discounted to the present where an initial or future payment is expected to be made on an investment	Sec. 2.1 and 2.6 of NP on PPP Sec 4.8 and Sec. 5.4.5 of ISO 15686-5
11	WLC strategies	Range of alternatives should be looked into including do minimum or do-nothing options Analysis period should be based on Client's requirement	Sec. 2.4 of NP on PPP and Sec. 5.1 of ISO 15686-5 Sec. 5.3 of ISO 15686-5
12	Documentation format	WLC assessment can be done at built asset, elements and sub-elements levels Documentation is important as there could be potential liabilities on events that could happen many years into the life of an asset	Sec.9.2of ISO15686-5 Sec. 9.3 of ISO 15686-5

Source: Field Survey

4.3 Limitations of Existing WLC methodologies

Nine existing WLC frameworks and six evaluation criteria were identified from literature. The frameworks are: 5-step WLC implementation framework within an Integrated Environment by Al-Hajj et al (2001); EU LCC methodology (Langdon, 2010); An Integrated framework for WLC budget estimation (Boussabaine and Kirkham, 2004); WLC Framework to achieve best value (Kishk and Pollock, 2004); WLC Implementation Approach (Flanagan and Jewel, 2005); Process for LCC analysis (Building Services Research and Information Association (BSRIA), 2008); Framework for WLC in the National Health Service Estates UK (Kirkham and Boussabaine, 2000), 7-step implementation model (Ferry and Flanagan, 1991), and LCC implementation logic (Dell'Isola and Kirk, 1981). The evaluation criteria are: conformity with decision-making/ problem solving process; alignment with building life-cycle stages; inclusion of risk/uncertainty analysis; provision for process iteration; and incorporation of feedback mechanism.

Table 4.2 summarises the evaluation results for existing WLC frameworks. None of the frameworks fully satisfies all evaluation criteria. On the overall, the frameworks performed poorly in terms of conformity with problem solving, project life-cycle, and feedback requirement with average points of 0.9, 0, and 0.3 respectively out of a total of 2. Conversely, they all perform better in terms of complying with decision-making, uncertainty/risk assessment and iteration provisions with average points of 1.8, 1.8, and 1.6 respectively. Cumulatively, all the frameworks performed poorly with a score of 5.6 out of 12 which represent 44% score.

Table 4. 2: Evaluation Result for Existing WLC Implementation Frameworks

S/No	Name of Procedure	Area of application	Decision-making process	Problem solving process	Project life-cycle	Uncertainty & risk analysis	Iteration	Feedback	Total points	% score
1	7-step implementation model	Options evaluation	2	0	0	2	0	0	**4**	**33%**
2	LCC implementation logic	Options evaluation at design stage	2	0	0	0	2	0	**4**	**33%**
3	Framework for LCC in the NHSE	Cost planning / budgeting	0	0	0	2	0	2	**4**	**33%**
4	Framework for Implementing LCC	Options evaluation within OSCON environment	2	1	0	2	2	1	**8**	**67%**
5	LCC Framework to achieve best value	Options evaluation	2	0	0	2	2	0	**6**	**50%**
6	An Integrated framework for LCC budget estimation	Budgeting and benchmarking	2	0	0	2	2	0	**6**	**50%**
7	LCC Implementation Approach	Options evaluation	2	0	0	2	2	0	**6**	**50%**
8	EU LCC common methodology	Options evaluation	2	0	0	2	2	0	**6**	**50%**
9	Process for LCC analysis	Options evaluation	2	0	0	2	2	0	**6**	**50%**
		AVERAGES	**1.8**	**0.9**	**0**	**1.8**	**1.6**	**0.3**	**5.6**	**44%**

Source: Field Survey

4.4 Impediments to WLC Application and their Solutions

Prior to exploring possible solutions to implementation problems, it was considered expedient to profile the problems and identify the most important. Fourteen reports were published on the subject from 1993 to 2016 which include: Ashworth (1993), Bull (1993), Kish et al (1999), Clift and Bourke (1999), Cole and Sterner (2000), Flanagan and Jewel (2005), Norman (2007), Ibrahim (2010), Olubodun, Kangwa, Oladapo, and Thompson(2010), Bello (2012), Opoku (2013), Oduyemi, Okoroh, and Dean (2014), Higham et al (2015), and Akinrata (2016). Table 4.3 shows the WLC implementation problems and their cumulative frequencies of reporting. From the table, lack of demand by the client has the highest frequency so it is ranked the most important, followed by data scarcity (ranked 2nd), separation of capital from running cost, lack of understanding by the client, lack of standard implementation methodology (collectively ranked 3rd). Those impediments with very low frequency of reporting over long period (like multiplicity of client needs, time consuming data gathering process) were considered dormant and so insignificant. Items with asterisk were considered significant and thus inclusive.

Table 4. 3: Cumulative Frequency of Reporting for WLC Implementation Challenges

SN	Barriers	1993	1999	2000	2005	2007	2010	2012	2013	2014	2015	2016
	Client related											
1*	Lack of demand by the client	1	3	3	4	5	6	7	8	9	10	11
2*	Separation of capital from running cost	1	2	3	4	4	5	6	6	6	7	8
3*	Lack of understanding		1	2	3	4	5	5	6	7	8	8
4	Multiplicity of Clients needs		1	1	1	1	1	1	1	1	1	1
5	Affordability							1	1	2	3	3
6	Diverse nature of industry clients				1	1	1	1	1	2	2	3
7	Policy issues of asset management	1	1	1	1	1	1	1	1	1	1	1
	Data related											
8*	Data scarcity	1	2	3	4	4	6	7	7	8	9	10
9	Huge cost of data collection		1	1	1	1	1	1	1	1	2	2
10	Time consuming data gathering process		1	1	1	1	1	1	1	1	1	1
11	Limitation of existing databases			1	1	1	1	1	1	1	1	1
	Industry related											
12*	Lack of standard methodology			1	1	1	3	4	5	6	7	8
13	Lack of motivation in cost optimisation		1	1	1	1	1	1	2	3	3	3
14	Vague feeling about the technique	1	1	1	1	1	1	1	1	1	1	1
15	Disposal not a design consideration	1	1	1	1	1	1	1	1	1	1	1
16	Fixed procurement strategies		1	2	2	2	2	2	2	2	2	2
17	Over-abundance of cost models									1	1	1
18	Industry's relative lack of interest		1	1	1	1	1	1	1	2	2	2
19	Lack of procurement award incentives									1	1	1
20	Time-lag between design & availability of data on running cost of projects				1	1	1	1	1	1	1	1
21	No clear definition of responsibilities of buyers and sellers in terms operating & maintenance cost		1	1	1	1	1	1	1	1	1	1
22	Unique nature of the construction industry			1	1	1	1	1	1	1	1	2
23	Unstable economic situation											1
	Method related											
24*	Process complexity			1	2	3	3	4	4	4	4	4
25	Unreliable forecasts of cost and performance	1	2	2	3	3	3	3	3	3	3	3
26*	High level of risk & uncertainty		1	2	3	3	3	3	3	4	4	4
27	Result inaccuracy							1	1	1	1	1
28	Limitations of existing analysis tools			1	1	2	2	2	2	2	2	2
	Practitioners' related											
29*	Lack of knowledge	1	1	1	1	1	2	2	3	3	4	4
30	Concentration on services in demand.				1	1	1	1	1	1	1	1

4.4.1 Lack of Demand and Understanding by the Client

Lack of demand for WLC has been attributed to lack of understanding by the Client (Oduyemi et al, 2014; Higham et al, 2015). Fawcett (2011) noted that, Long-term building owners desire buildings that are not only cost effective but also adaptable to changing needs and amenable to growth. Traditional WLC models can only predict the affordability, profitability, operational efficiency, and residual value of proposed buildings but not design flexibility. This implies that the entire investment decision need of Clients has not been addressed by traditional models. For this reason,the concept of options analysis used in financial management was used to develop a set of WLC mathematical models that not only predict costs but also embedded life-cycle options. Four key decisions were considered: the viability of creating an option, the appropriate time the option should be best consumed, and the decisions to retain or abandon an option. These decisions were applied to: option to develop; option to expand; option to reconfigure; option to switch use; and option to abandon.

4.4.1.1 Formulation of Mathematical Model

Existing WLC models have some obvious limitations. These include;

Volatility of returns on investment is often not captured. For instance income streams in traditional NPV approach are considered constant.

The models can only tell whether an investment is viable but do not predict the best time an investment should be made

Options contained in the investment are often overlooked leading to under investment. This might not be unconnected with the traditional approach of focusing on income and expenditure thereby relegating potential future opportunities to the background.

Time, which is the most important variable and risk factor which other variables are dependent upon, is not the central independent variable in traditional models. Time/cost

relationships usually neglected in preference for cost/discount rate relationships. Yet it is the variable that makes WLC a unique approach in comparison with traditional estimates based on initial costs.

In order to address the above concerns two sets of mathematical model were proposed. The first set of models modifies the traditional approach to make time a central parameter in both analysis and presentation, and to enable the analysis at a cumulative level so that trend in costs, income, and net values can be produced. This facilitates the quick determination of both pay-back period and break-even point of a proposed investment. The second set of models modifies the Black-Scholes options pricing model to enable the determination of the optimal investment time, profitability index (PI), and Benefit to Cost Ratio (BCR).

The traditional model

Mathematically, the traditional model is often presented as:

$$WLC = \sum_{t=0}^{0} IC_t + \sum_{t=1}^{u} FC_t + \sum_{t=1}^{n} AC_t + \sum_{t=1}^{f} PC_t + \sum_{t=n}^{n} TC_t - - - 15$$

Where ICtis the initial costs at time t=0, FC_t is the discounted finance cost at time t, AC_t is the discounted annual cost at time t, PC_t is the discounted periodic cost at time t, TC_t is the terminal cost or value at time t=n, t is represents time in years, u is the loan repayment time, n is the investment life span, and f is the number of periods. The NPV is presented as:

$$NPV = \sum_{t=1}^{n} I_t - WLC - - - - - 16$$

I_t is the discounted annual income in year t.

Eq. 15 and 16 can take either the present value form (in which all discounting is relative to the present using a real discount factor) or the future value form (in which discounting is based on future worth using a nominal discount factor). The equations also compute the summation of each variable independently before summing up to arrive at an overall WLC in the case of Eq. 15 and NPV in the case of Eq. 16. This process does not yield any better information than the sums of individual cost and revenue centres in addition to the WLC and NPV.

i. Modified traditional model

Assuming that all costs and revenues are to be expressed in cumulative terms, (that is, the total costs and revenues for year t=2 equals the sum of all costs and revenues at the end of t=0, t=1and t=2) then eq. 15 and 16 can be modified using suitable cumulative discount factors. Equations 17 and 18 are the cumulative discount factors for real and nominal analysis.

$$D_{frt} = \frac{(1+dr)^t - 1}{(1+dr)^t * dr} - - - - - - 17$$

$$D_{fnt} = \frac{(1+dn)\{(1+dn)^t - 1\}}{dn} - - - - - - 18$$

Where D_{frt} and D_{fnt} are the real and nominal discount factors at year t, dr and dn are the real and nominal discount rates, and t is the year of analysis.

The Cumulative Annual Cost for year t is given by;

$$CNPV_t = \sum_{t=0}^{t} I_t - \sum_{t=0}^{0} IC_t - \sum_{t=0}^{t} FC_t - \sum_{t=0}^{t} AC_t - \sum_{t=0}^{t} PC_t - \sum_{t=0}^{t} TC_t - - - 19$$

Using the ISO15686-5 CBS for a real analysis, equation 19 becomes;

$$CNPV_t = D_{frt} \times I_t - (NCC + CC) - D_{frt} \times AC - \left\{\sum_{t=1}^{f_{ot}} \frac{POC}{A_t} + \sum_{t=1}^{f_{mt}} \frac{PMC}{A_t}\right\} - TC_n \quad -20$$

Where NCC is the non-construction cost, CC is the construction cost, AC is the annual costs, POC is the periodic occupancy cost, PMC is the periodic maintenance cost and A_t is the amount of ₦1 factor denoted mathematically as $A_t = (1 + dr)^t$.

For a nominal analysis;

$$CNFV_t = D_{fnt} \times I_t - (NCC + CC) - D_{fnt} \times AC - \left\{\sum_{t=1}^{f_{ot}} A_t \times POC + \sum_{t=1}^{f_{mt}} A_t \times PMC\right\} - TC_n - -21$$

ii. Option appraisal models

In consideration of options value, a building investment value should be the sum of its net present value and the value of options contained within. Mathematically;

$$I_v = NPV + O_v - - - - - -22$$

Where I_v is the investment value;

NPV is the traditional net present value of an existing investment;

O_v is value of all options contained within the asset under study.

Expanding O_v,

$$O_v = O_D + O_E + O_S + O_R + O_T + O_A - - - 23$$

Where O_D is option to develop; O_E is option to expand; O_S is option to switch use; O_R is option to reconfigure; O_T is option for new technology and; O_A is option to abandon.

For an existing asset the value of the option to develop is zero as the owner has exercised his right to develop. While for a proposed investment (Where the underlying asset is non-existing) the prospective investor is only holding a right to develop together with the other options the proposed development contains. Therefore, for a proposed development, investment value equals Options value. Thus;

$$I_v = O_v = O_D + O_E + O_S + O_R + O_T + O_A - - - - - 24$$

In compliance with section 3.2.9, two types of analysis must be distinguished; real and nominal analysis performed based on real and nominal discount rates respectively. Based on real and nominal analysis, two discount factors could be deduced (real and nominal discount factors).

$$D_{fr} = \frac{(1+dr)^n - 1}{(1+dr)^n * dr} - - - - - 25$$

$$D_{fn} = \frac{(1+dn)\{(1+dn)^n - 1\}}{dn} - - - - - 26$$

Where D_{fr} and D_{fn} are the real and nominal discount factors while dr and dn are the real and nominal discount rates.

a) Option to develop

Let the aggregate income expected from investment at a time t be represented by I_t. Let also t_1, t_2, t_3, up to t_n represent equal intervals of time while I_a and C_t represent the annual income and cost incurred at a time t respectively. Then;

The present value of all series of income expected at time t_0 is given by;

$$E_0 = I_A * D_{fr} - - - - - -27$$

The future values of all series of income expected at a time t_0 is given by;

$$E_f = I_A * D_{fn} - - - - - -28$$

Where E_0 is the present value and E_f is the future value of all annual incomes expected from the investment. It follows therefore that the present value of all annual incomes expected from an investment at time t in real value terms is;

$$E_t = \frac{E_0}{(1+dr)^t} - - - - - -29\,,$$

while the future value of all annual incomes expected in nominal terms is given by;

$$E_t = E_f(1+dn)^t - - - -30.$$

Using B-S model the value of the option to develop O_D (being a call option) at any given time t is denoted by;

$$O_{Dt} = E_t N(d_{t1}) - C_t e^{-td} N(d_{t2}) - - - -31$$

Where d is the discount rate which could be either real or nominal,

$$d_{t1} = \frac{\ln(E_t/C_t) + (d+\sigma^2/2)t}{\sigma(\sqrt{t})} - - - - - 32\,,$$

$$d_{t2} = d_{t1} - \sigma(\sqrt{t}) - - - - - 33.$$

C_t is the cost incurred in a particular year which is the sum of the Initial cost (I_c), Annual recurring costs (A_c), Periodic cost (P_c) and Terminal cost (T_c). Mathematically;

$$C_t = I_{ct} + A_{ct} + P_{ct} + T_c - - - -34$$

For real analysis,

$$C_t = \frac{(NCC+CC)}{A_t} + \frac{D_{fr}A_c}{A_t} + \left\{\left(\sum_{i=1}^{f_o}\frac{POC_i}{A_t}\right) + \left(\sum_{j=1}^{f_m}\frac{PMC_j}{A_t}\right)\right\} + \frac{TC}{A_t} - - - - - 35$$

Where NCC is non- construction cost, CC is construction cost, A_c is annual cost, POC_i is the periodic operating cost in the i^{th} period, PMC_i is the periodic maintenance cost in the i^{th} period, TC is the terminal cost, f_o is the number of periods for operating cost, f_m is the number of periods for maintenance cost and A_t is the amount of ₦1 factor denoted mathematically as $A_t = (1+dr)^t$.

For the nominal analysis;

$$C_t = A_t(NCC+CC) + A_t D_{fr} A_c + \left\{\left(\sum_{i=1}^{f_o} A_t\, POC_i\right) + \left(\sum_{j=1}^{f_m} A_t PMC_j\right)\right\} + A_t TC - 36$$

Where $A_t = (1+dn)^t$

Equations 31 through to 36 above allow the recalculation of the value of option to develop at different time periods thereby enabling the identification of time at which the value of the option to develop is at maximum. This is very important as development could be delayed until its optimum value can be achieved. In addition, it is worth noting that the set of equations could be used to evaluate all forms of calloptions as represented by equation 8 of section 2.11.7.

b) Option to Expand

Option to expand is similar to the option to develop in many ways. First it is also a call option as the holder can buy it at any time before expiration. Like an option to develop the holder of option to expand would be interested in when best to expand. Lastly both options to develop and option to expand involve an initial capital outlay in anticipation for future returns. The major difference between the two is that option to expand is dependent on either an existing asset or an option to develop without which it seizes to exist. Equation 22 can be used in conjunction with equations 31 through to 36 to evaluate option to expand and subsequently investment value in both real and nominal terms. Equation 31 however, must be modified to reflect option to expand.

$$O_{Et} = E_t N(d_{t1}) - C_t e^{-td} N(d_{t2}) - - - - - -37$$

In this case O_{Et} is option to expand.

c) Option to Switch Use

Option to switch use is also a call option that is contingent upon an existing asset or a proposed development. The objective is first to evaluate the value of the option at various times so as to be able to determine the time at which the value of the option is optimum and secondly determine the point in time at which the value of the option to

switch use outweigh the asset value or the option to develop on which it is contingent. Such point is the best time to switch the use of the underlying asset. It suffices then to say that, the ratio of value of option to switch use to the NPV of the underlying asset should be greater than or equal to 1. Mathematically, $^{O_s}/_{NPV_{asset}} \geq 1$. O_s can also be computed as a call option using the following equation.

$$O_S = E_t N(d_{t1}) - C_t e^{-td} N(d_{t2}) - - - - - - 38$$

O_s is the option to switch use.

d) Option to Reconfigure

Option to reconfigure is also a call option that is dependent on an underlying asset. Unlike other call options however, the time to reconfigure is not important as its essence is to improve flexibility in terms of configuration thereby enjoying the benefits it comes with. The investment value under such a situation is denoted by equation 22 and 24.

For an existing asset:

$$I_v = NPV + O_v - - - - - - 39.$$

For a proposed development:

$$I_v = O_v = O_D + O_R - - - - - 40$$

Since option to reconfigure is a call option it also can be expressed in the form of equation 37.

e) Option to Abandon

In contrast option to abandon is a put option as it gives the holder the right to sell an asset at a given time before expiration. In addition it is also dependent upon an

underlying asset or option to develop that is dividend paying. Following the same procedure as in previous sections,

$$D_{frt} = \frac{(1+dr)^{n-t}-1}{(1+dr)^{n-t} * dr} - - - - - 41$$

$$D_{fnt} = \frac{(1+dn)\{(1+dn)^{n-t}-1\}}{dn} - - - - 42$$

Where D_{frt} and D_{fnt} are the real and nominal discount factors at any time t while dr and dn are the real and nominal discount rates. The present value of all series of income expected at any time t is given by;

$$E_t = I_A * D_{frt} - - - - - 43$$

The future values of all series of income expected at a time t is given by;

$$E_t = I_A * D_{fnt} - - - - - 44$$

Let the strike price be represented by S_p and the dividend expected at any time t be represented by D_t and the amount of ₦1 for the real and nominal discount rates be represented by A_r and A_n respectively. Then; $A_r = (1+dr)^t$; $A_n = (1+dn)^t$; present value of strike price $S_{pv} = S_p \times {}^{1}/_{A_r}$;future value of the strike price $S_{fv} = S_p \times A_n$; Dividend $D_t = E_0 - E_t$, Yield $y = {}^{D_t}/_{E_t}$; and E_o is as defined in equations 27 and 28.

Using equations 12, 13 and 14,

$$O_A = S_v e^{-dr(n-t)}[1-N(d_2)] - E_t e^{-(n-t)}[1-N(d_1)] - - - - - 45$$

$$d_{t1} = \frac{\ln(E_t/S_v) + (d - y + \sigma^2/2)(n-t)}{\sigma\left(\sqrt{n-t}\right)} - - - - - 46\,,$$

$$d_{t2} = d_{t1} - \sigma\left(\sqrt{n-t}\right) - - - - - - 46.$$

Where S_v can take the values of S_{pv} or S_{fw}

The time at which the investment should be abandoned is when the NPV of the underlying asset is less than the O_A. In other words the ratio of the option to abandon to the value of the underlying asset is greater than or equal to 1. Mathematically, $O_A/NPV_{asset} \geq 1$ where $NPV_{asset} = E_t - C_t$.

4.4.2 Data Scarcity and Implementation Cost

Implementation cost has been attributed to cost of data collection which is also related to data scarcity by many authors (Kishk et al, 2003a; Ferry and Flanagan, 1991; Bull, 1993). The cost of data collection is high because historical data is not available, so huge amount of resources is usually deployed to collect data that is suitable for the situation at hand. Sec. 2.1, 2.2 and 2.3 of NP on PPP requires expert opinion and judgment to be sought where historical data is not available. The application of Fuzzy Set Theory (FST) in the handling of subjective linguistic statements offers great opportunity in mitigating the data scarcity problem (Sobanjo 1999; Kishk et al 1999, Kishk et al, 2000). The technique was incorporated in the design of the framework as it provides a simple way of presenting and analysing linguistic variables. To achieve this fit, a model selection framework was first designed to aid the selection of an appropriate analysis model based on data type (which could either be quantitative or qualitative) data availability, certainty, and sample size. The model selected helps to identify precisely the data and model types required. For instance, Fuzzy membership Functions (FMF) should be used where data obtained is quantitative, uncertain, of small sample, and non-random or where the data obtained is subjective. Figure 4.1 shows an outline of the model selection framework.



Figure 4. 1: Proposed Model Selection Framework

To optimise the benefits of the framework a database was designed to ease data storage, retrieval, and the selection of an appropriate model. The database addresses the following:

Data integrity- This can be achieved by capturing project general, physical and performance data in order to keep the data in context.

The storage of cost/revenue data using appropriate normalisation factors to facilitate level and comparative analysis. ISO recommends Building, Group-element, Element, and Sub-element level analyses. Cost per functional unit/Cost per GFA, cost per group element, cost per element and sub-elements were used as normalisation factor for each of the respective levels.

The storage of data in a variety of formats and the transformation of data from one format to another so as to ensure data flexibility and provides more information

available for WLC evaluation. The transformation was achieved by transforming higher level data formats to the lowest level.

Table 4.4 shows the different data formats and their levels. Both Fuzzy Membership Function and Probability Density Function are at the same level as each can be transformed to the other.

Table 4. 4: Levels of Data Format

LEVEL	DATA FORMAT
1	Single point data
2	Two-point data
3	Three-point data
4	Fuzzy Membership Function
4	Probability Distribution Function
5	Multi-data

Table 4.5 shows the different data types available, their descriptors (an arbitrary name assigned to facilitate the identification of a data type) and a brief explanation while Table 4.6 summarises how transformation is achieved between different formats.Detail of the database design is given in section 4.7.3.

Table 4. 5: Summary of Data Types and their Sources

Data Type	Descriptor	Source	Remarks
Crisp	Single-point	Flanagan & Jewell(2005)	Discrete numeric data type usually representing precise values
Range	Two-point		Discrete numeric data type that gives the lowest and highest values of a data item.
Mean & Range	Three-point	Boussabaine & Kirkham(2004), Dell'Isola & Kirk(2003)	Discrete numeric data type that represents the lowest, Likely and highest values of a data item.
Statistical	Multi-data	Kishk & Al-Hajj(2001)	Discrete numeric data that can be of small or large sample. The large sample can be transformed into continuous data types.
Stochastic	PDF	Boussabaine & Kirkham(2004)	Probability density functions that are continuous and could be Uniform, Triangular or Normal.
Linguistic	Fuzzy statement	Sobanjo(1999), Kishk et al(2003a)	These are verbal statement that can be represented as a Fuzzy number using a continuous FMF.
	Bayesian statement		E.g. The cost of item A is around ₦ X
	Rectangular statement		E.g. the cost of item A is between ₦ X &₦ Y
	Triangular statement		E.g. the cost of item X is between ₦ X &₦ Z and likely ₦ Y
	Trapezoidal statement		E.g. The cost of item A is between ₦ W &₦ Z and likely between ₦ X &₦ Y

Table 4. 6: Summary of Transformations Between Data Formats

Level	Data format	Single-point data	Range data	Three-point data	FMF	PDF	Multi-data
1	Single-point data	-	-	-	-	-	-
2	Range data	Compute the average	-	-	-	-	-
3	Three-point data	Use the mid value	Use the lowest and highest values	-	-	-	-
4	Fuzzy Membership Function	Defuzzify the membership function	Use the lowest and highest values of the FMF	Use the lowest, highest and defuzzified value	-	Transform using probability possibility consistency principle	-
4	Probability Distribution Function	Use the central value of the PDF	Use the lowest and highest values of the PDF	Use the range and the central value of the PDF	Transform using probability possibility consistency principle	-	-
5	Multi-data	Compute the average of the multi-data	Use the range of the multi-data	Use the range and average of the multi-data	Regroup data into fuzzy sets	Convert data to frequency distribution and fit-in a PDF	-

4.4.3 Separation of Capital fromRunning Cost

Separating the initial capital cost of a proposed project from its running cost has been a long time tradition. This tradition has been attributed to lack of sufficient funds for the project which makes building owners to focus on construction cost and the desire by property developers to maximize profit by minimizing initial cost thereby transferring the running costs to the prospective buyers and occupiers of the building (Bello, 2012; Oduyemi et al, 2014; and Higham et al, 2015). Solution to this problem lies with the regulatory authorities and professional bodies as it is purely attitudinal.

4.4.4 Complexity of the Process

This problem has a reporting frequency of 4 and has been dormant since 2010 as shown on Table 4.3. Process automation using computer programmes has drastically reduces this problem. It is not surprising therefore for the problem to wane over time.

4.4.5 High level of risk and uncertainty

This problem has also been relatively dormant over the years. This is because there are several sophisticated risk and uncertainty assessment tools that can be deployed for the evaluation of complex WLC problems (Kishk et al 2000a, 2000b; Wang et al, 2004; Ammar and Zayed, 2013). Some of these tools have been captured on the model selection framework presented on Figure 4.1. In fact each model has an inbuilt risk and uncertainty analysis capability.

4.4.6 Lack of knowledge by Professionals

This problem was reported four times out of a total of fourteen reports representing about 29%. This implies that, the problem is relatively not significant. Moreover, Bello (2012) reported that Nigerian Quantity Surveyors have the requisite skills to carry out full WLC studies

4.5 The Conceptual Framework

Figure 4.2 shows a schematic representation of a proposed framework that is aimed at satisfying all the laid down criteria. The framework consists of top and bottom bars which represent project life-cycle and problem-solving stages respectively. The process begins at the inception/feasibility stages where clear project objectives are set out which corresponds to problem definition in decision-making process. The next phase involves the generation of alternative design solutions after which the criteria against which the designs are evaluated and compared are set forth. The cost and performance variables are then identified and the relationship between them established. Depending on the variables included suitable input data is then retrieved from a database processed/transformed to the required format and profiled to clearly establish its characteristics.

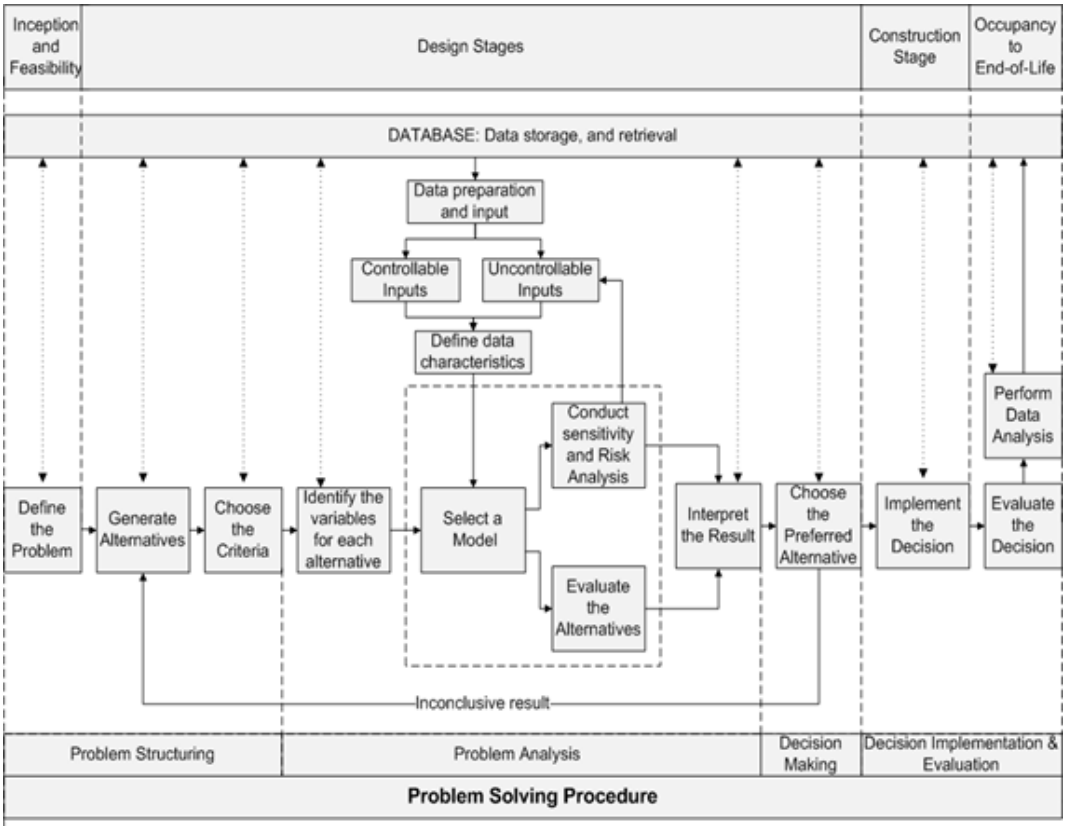


Figure 4. 2: Conceptual Framework for WLC

The data characteristic is then used as a guide for identifying and selecting a suitable WLC model. The model is then operated to evaluate each of the generated alternatives followed by a sensitivity and risk/uncertainty analysis. Sensitive variables are then reconfirmed and reassessed and a final WLC evaluation result produced. Decision is then taken on the most preferred alternative that is subsequently implemented at the construction stage. The building is then subjected to continuous evaluation at the occupancy stage through to end-of-life. It should be noted that the model takes care of iteration requirement through a loop between the point of decision-making and generation of alternatives. This is important as it enables the regeneration of alternatives where the evaluation result turns out to be inconclusive. The loop also represents the iterative nature of the design stage where different designs at various levels of detail are generated and evaluated. Another fit of the framework is the feedback mechanism between the operating/End-of-life stage to the input stage via a database that stores both project related and global data/information. This implies the possible recycling of information back to the design stage to facilitate; the decision to redesign, retrofit, demolish or abandon an existing building at its end-of-life or the WLC planning, and management of an existing building. The dotted two-point arrows represent the continuous interaction between the analyst and the database at different stages of WLC analysis. The efficacy of the proposed framework was tested and the result indicates that it outperforms all the exiting frameworks with a score of 11 out of 12 which represent about 92%. Table 4.7shows the evaluation result.

Table 4. 7: Evaluation Result for Conceptual Framework

S.No	Scoring Criteria	Score
1	Decision-Making	2
2	Problem Solving	2
3	Project Life-cycle	2
4	Uncertainty and risk analysis	2
5	Iteration	1
6	Feedback	2
	Total	**11**

4.6 Process Flow Diagrams

At the topmost level of the activities is WLCosting which constitute a number of sub activities. These activities include:Data analysis and storage; Data preparation; WLC appraisal; Risk analysis.

The sub activities under each of the above headings are presented in the form of an algorithm and discussed ahead.

4.6.1 Algorithm for Data Analysis, and Storage

i. Identify the type of analysis
ii. Select the project life-cycle stage
iii. Specify general project information
iv. Specify projects physical and performance data
v. Identify both the quantitative and qualitative data items to include in the analysis.
vi. Identify the corresponding data format for each of the quantitative data
vii. Input data for both the quantitative and qualitative variables.

The types of analyses were divided into project and non-project related analysis. The project related analysis involves variables that are project dependent. That is, those variables dependent on project characteristic. The non-project related analysis on the

other hand involves those variables that are constant across all projects. These are also referred to as global variables. Table 4.8 below summarises both classes of the variables.

Table 4. 8: Summary of Project Related and Non-project Related Variables

Project related variables	**Non-project related variables**
Non-construction costs	Inflation rate
Externalities	Discount rate
Income	Interest rate
Construction costs	Lending rate
Building cost	Mortgage rate
External works	Opportunity cost of capital
Preliminaries	Bonds rate
Design fees	Location adjustment factors
Maintenance costs	Time adjustment factors
Operation costs	Building cost indices
End-of-life	Building price indices
Residual value	
Disposal costs	

The project life-cycle was classified into five stages of: Planning, Design, Construction, Operation and End-of-life in accordance with the ISO 15686-5 provision. The design phase is however further subdivided into concept design, developed design and technical design in accordance with RIBA 2013 plan.

The general project information relates to information needed to identify a project. This includes: Project title, description, location, type, structure, Commencement date, completion date, procurement route, and occupation date.

Project physical data refers to those set of data that defines the physical characteristics of the building. These includes: Gross Floor Area(GFA), Average height of floors, Total building height, Total accommodation, Circulation space, Usable floor area and number of floors. Project performance data on the other hand refers to those set of data that determines the service performance of a building. These include; Average daily use

hour, Average number of users, Building maintenance requirement, and building quality rating.

Scoping WLC assessment is an important requirement of ISO 15686-5. It involves the identification of all the variables to be included in WLC analysis. These variables are classified into Quantitative and Qualitative data. The quantitative variables have been earlier outlined in Table 4.8. The cost breakdown for construction and maintenance costs were varied through the project evolution stages to reflect the amount of information available. Building, Group element, Element, Sub-element and Component level analysis were used for planning, concept design, developed design, technical design, and construction stages respectively. The qualitative data were further subdivided into Building related, Environment related, and Social related. Building related quality data covers intangibles like aesthetics, comfort, functionality, and prestige. Environmental related data captures the impact of the building at inputs level (raw material extraction and material/components manufacture), construction, operation, and end-of-life. The social related data encompasses items like impact of building on: culture, tradition, religion, economic wellbeing, transport and communication facilities, and other social amenities within the vicinity of the building. The building related data was omitted at the post construction stages as assessment at that stage is mostly concerned with effect of the building on social activities and environment.

Finally, the data sets are entered to complete the analysis and append the databank.

Figure 4.3 shows the process flowdiagram produced based on the foregoing discussion. From the figure, the first stage involves identifications of the analysis type which could either be project related or non-project related. The non-project related analysis is done for global variables. These variables were divided into five classes. These classes are interest rates, lending rates, inflation rates time and location adjustment factors. The time adjustment factors were further sub-divided into cost indices and price indices. The project related analysis on the other hand requires the identification of project type, then the project life-cycle stage at which the analysis is being conducted. The identification of the life-cycle stage is important as the level of detail required increases from planning through to construction, and operating stages. At the planning stage the first set of variables to be identified are classified into general project information and projects physical data. Other variables are classified as either quantitative or qualitative types. The qualitative data sets were divided into building related, environment related social related and service life data. The quantitative data types on the other hand were further sub-divided into non-construction cost, income, externalities, construction cost, operations cost, maintenance cost and en-of-life, in accordancewith ISO recommendation.

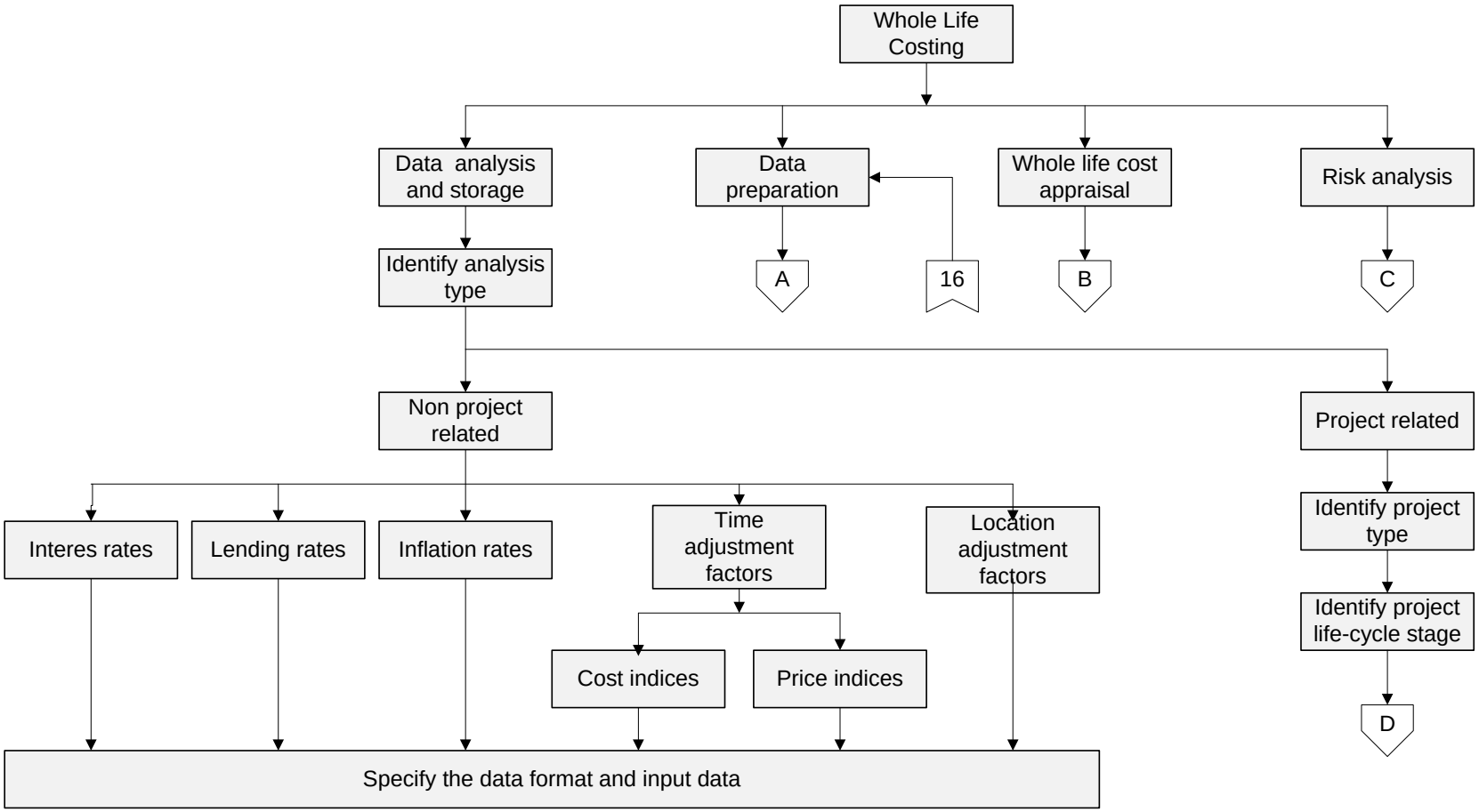


Figure 4. 3: Process Flow Diagram for WLC

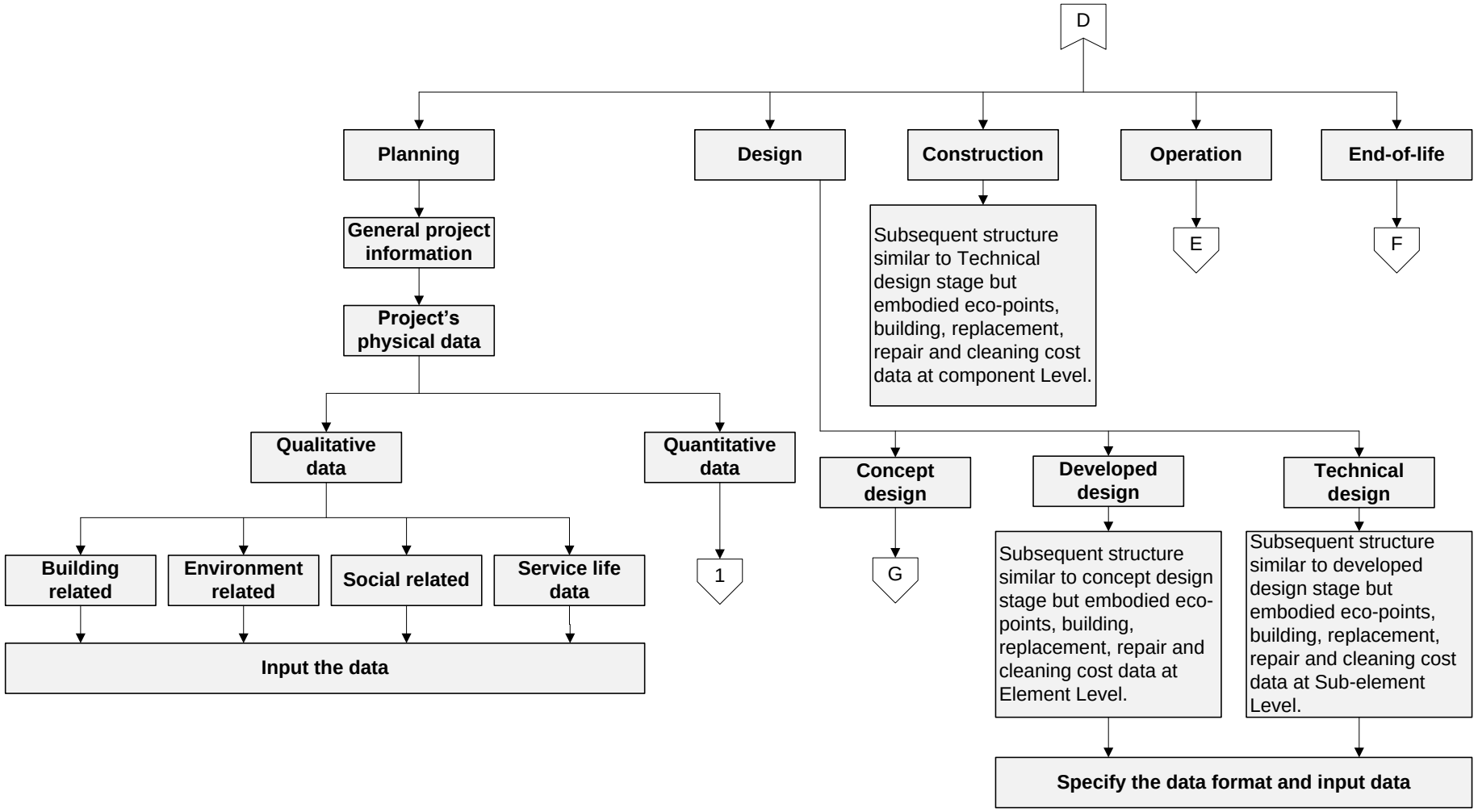


Figure 4. 4: Process flow Diagram for Data Analysis and Storage

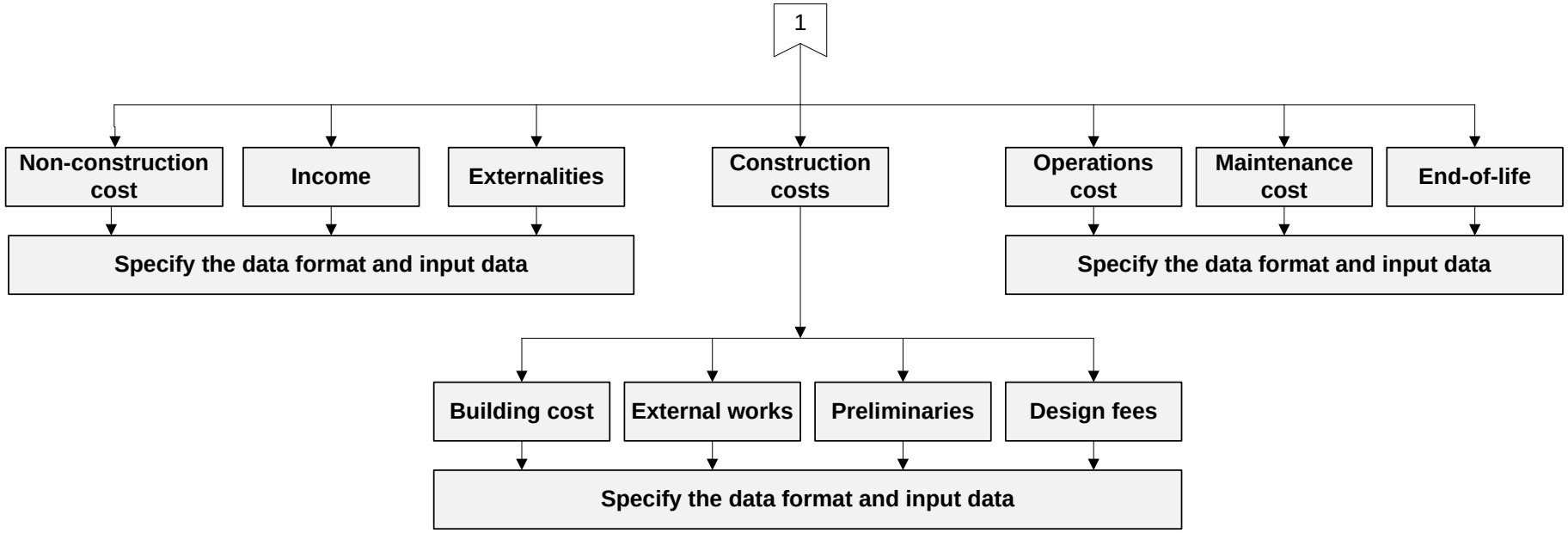


Figure 4.4: Process flow Diagram for Data Analysis and Storage Continues

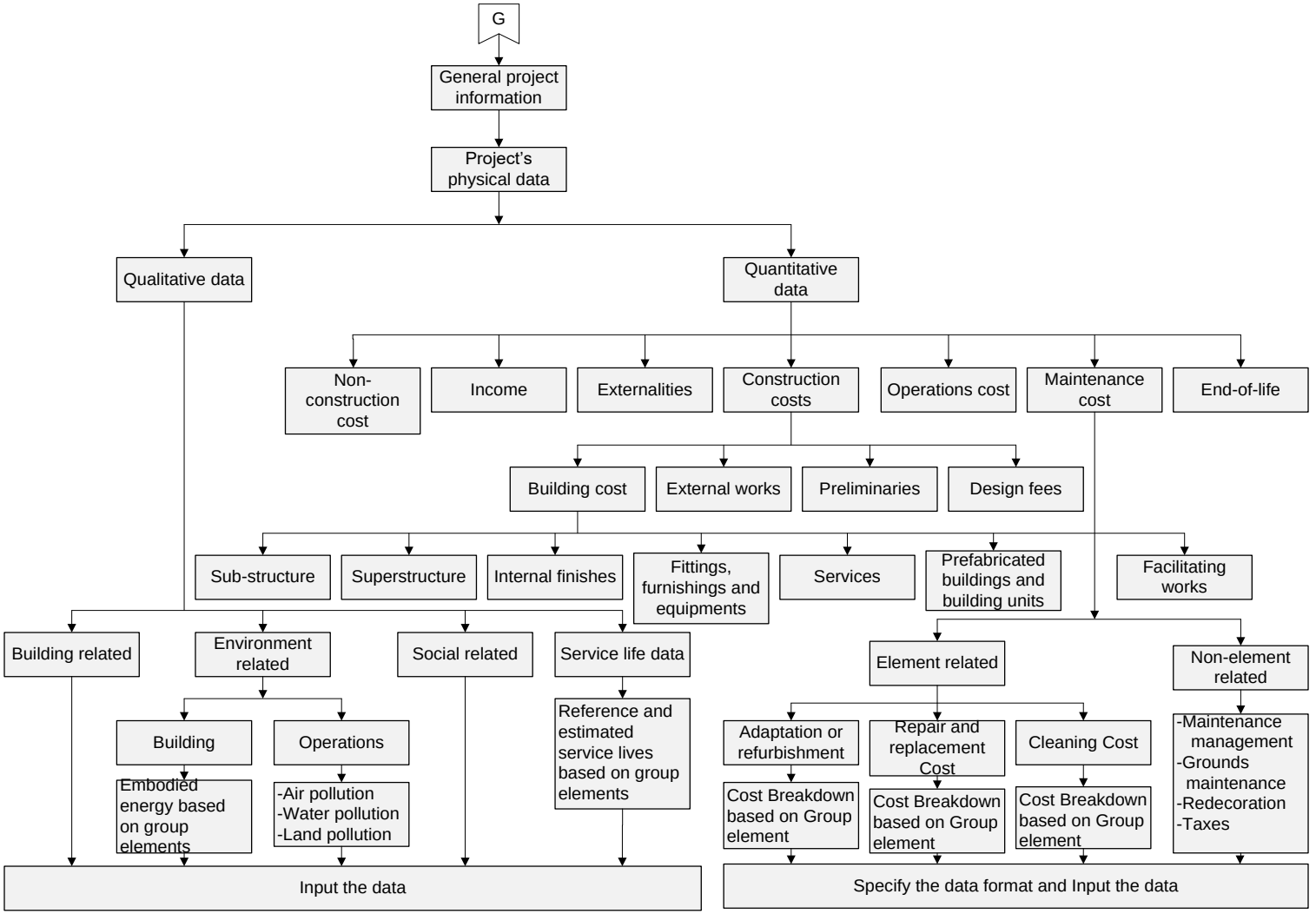


Figure 4.4: Process flow Diagram for Data Analysis and Storage continues

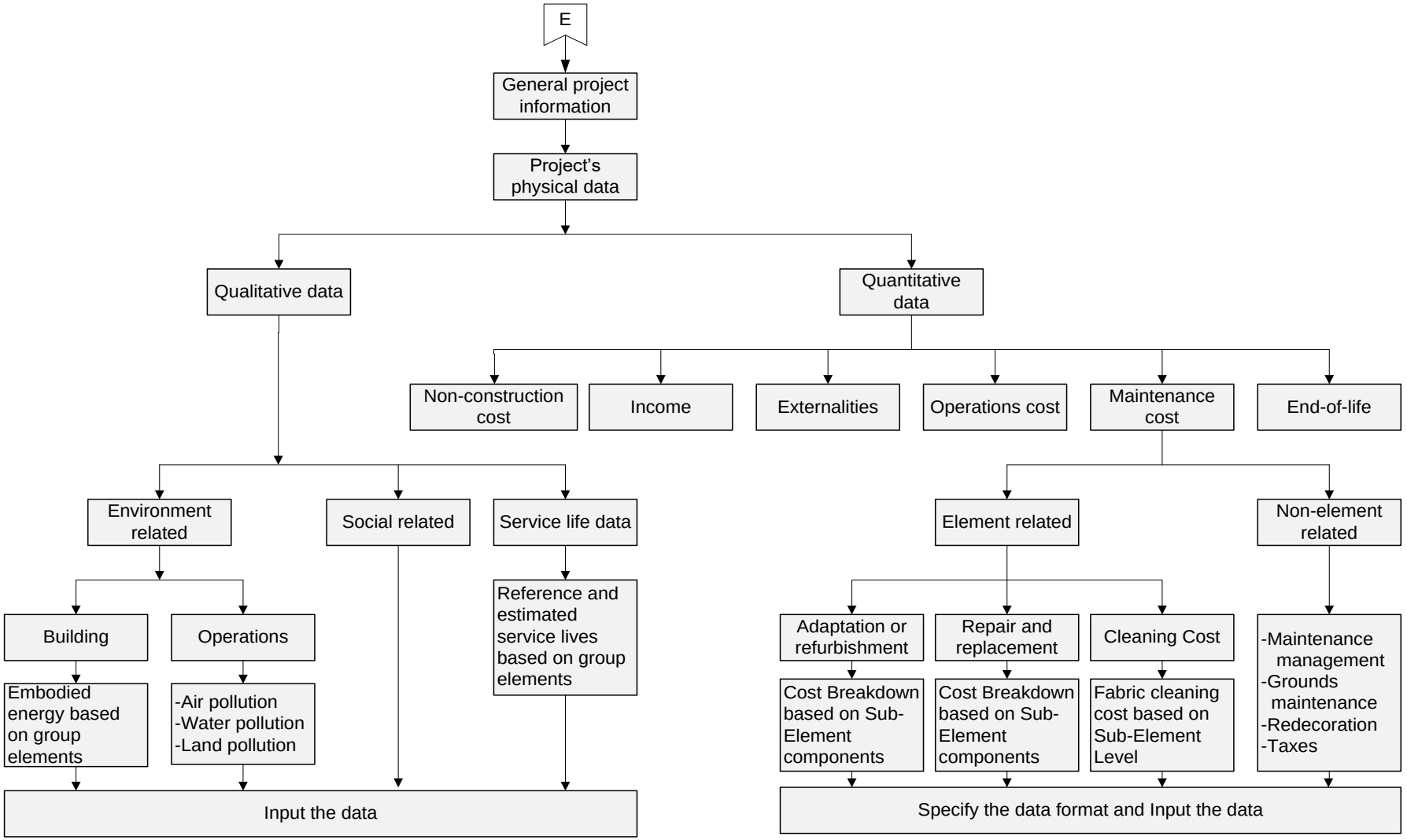


Figure 4.4: Process flow Diagram for Data Analysis and Storage continues

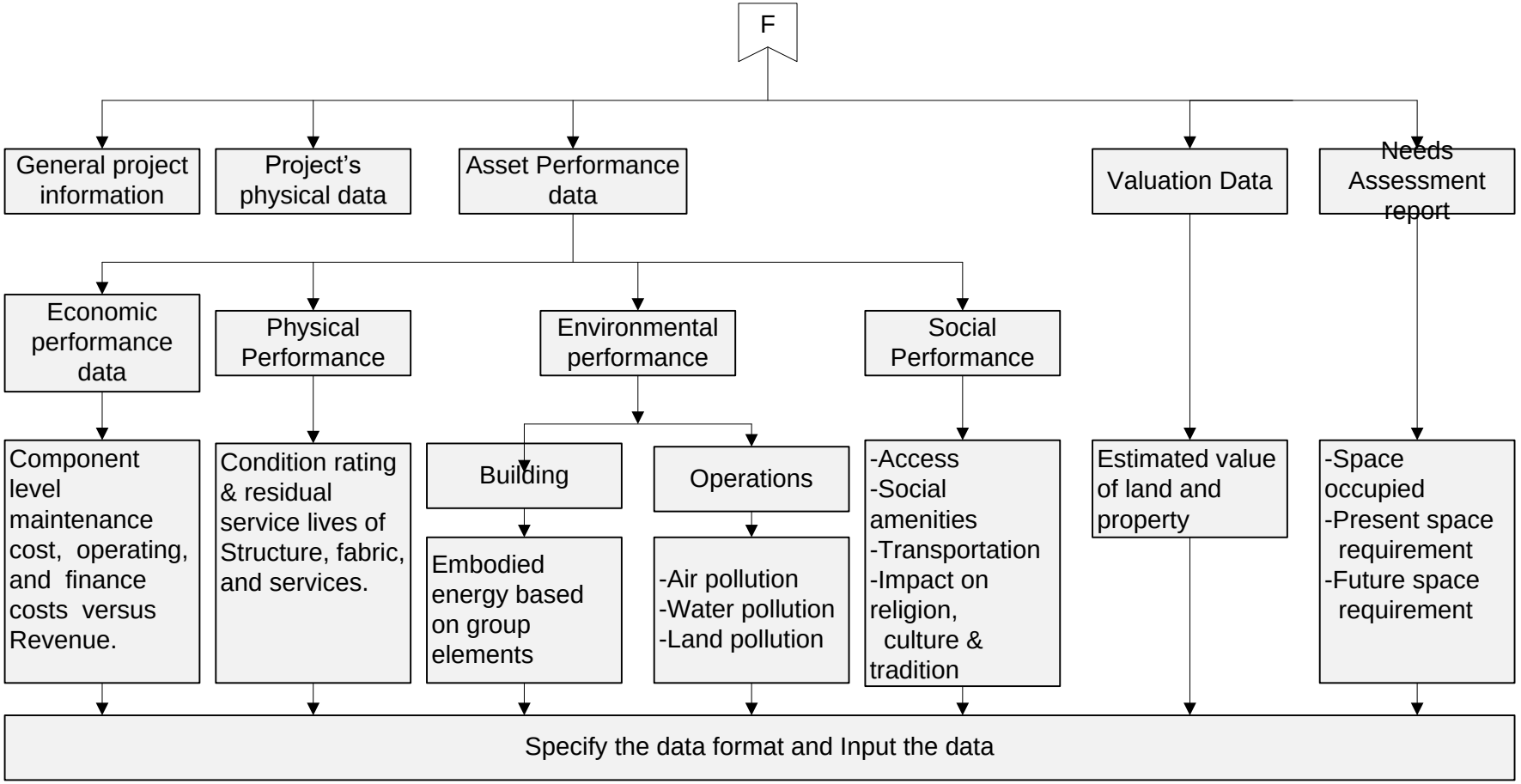


Figure 4.4: Process flow diagram for data analysis and storage Continues

The construction cost was further sub-divided into Building cost, External works, and Preliminaries in accordance with BCIS building level analysis.

The basic structure and sequence of activities at the design stage is similar to that of the planning stage. However, the levels of detail has increased as data is now required at group element level and variables are further broken down to achieve refined level of information. The design stage was broken down into concept design, developed design and technical design in accordance with RIBA plan. At the concept design stage to be specific, environment related data under qualitative data was further broken down into building related and operations related. Environmental data that is building related is building embodied energy, while operations related data have to do with the levels of air, water and land pollution. In addition, building cost was further broken down into seven group elements of: sub-structure; super-structure; internal finishes; fittings, furnishings and equipment services; and prefabricated buildings and building units in accordance with BCIS group element level. Maintenance cost was also sub-divided into element related and non-element related costs. This is important as it facilitates the analysis of data at elemental level. The element related data includes; adaptation or refurbishment, repair and replacement and cleaning cost. The final stages emphasize the need to input and store the structured data in a suitable format.

The structure and sequence of activities at the developed design, technical design and construction stages are essentially similar, but all element-related data are provided at elemental, sub-elemental and component levels respectively. In addition, information at the operations stage is provided at component level. Data analysis at this stage does not include construction cost which has been omitted.

The main goal of data analysis at the end-of-life is to facilitate decision making on disposal method. Data analysis activities at the end-of-life stage were broken down into five sections; the general project information, projects physical data, asset performance data valuation and needs assessment information. The first three sections are similar to those earlier explained in preceding life-cycle stages. Valuation data covers information on the current market value of the land, building and associated facilities. The needs assessment data captures the current user need in relation to building function. It captures data relating to present space occupied, present/future space requirement. The data obtained are finally, classified according to specific data format and stored for future use.

4.6.2 Algorithm for data preparation.

The algorithm for data preparation consists of the following steps;

i. Where data is searched from database;
ii. Specify general project information
iii. Specify project physical data
iv. Identify the life cycle stage of the proposed project
v. Define the scope of the assessment
vi. Conduct a database search
vii. Edit the list by removing the undesirable data sets
viii. Integrate the data to the lowest format.
ix. Select an appropriate WLC model.

The algorithm outlined above was developed on the understanding that, data preparation depends on the data analysis stage as the quality of prepared data is dependent on the quality, relevance and volume of data stored in the databank. The first stage to data preparation is the identification of search criteria. Where a database

search is to be conducted, the criteria for querying the database must be set. The search criteria in this situation are the general project information, project physical characteristics and the life-cycle stage of the proposed project. The search criteria are then further refined by scoping the WLC assessment. Scoping involves the selection of data centres both quantitative and qualitative that relates to both costs and performance. These cost centres are relevant to the search process as they precisely identify the variables on which the search is focussed.

The database is then queried to obtain a list of possible data candidates for inclusion in the assessment. A final selection is made by removing from the list any undesirable data items.

The data items are then adjusted for time and location after which variable level risk assessment and adjustment is conducted. The risk assessment is achieved by first identifying relevant factors capable of influencing each variable, and then assessing both their impact and probability of occurrence. The data items are then risk adjusted and integrated. The integration is achieved at two levels: data level and cost centre level. The data level integration converts all data items under same cost centre to the lowest format while a centre level integration transforms data at cost centre level to the lowest format. An appropriate WLC model is then selected with which an appraisal is conducted. The entire data preparation process is presented in Figure 4.5. The level of data format was defined in accordance with Table 4.4, while integration was achieved in accordance with Table 4.5 and model identification in accordance with Figure 4.1.

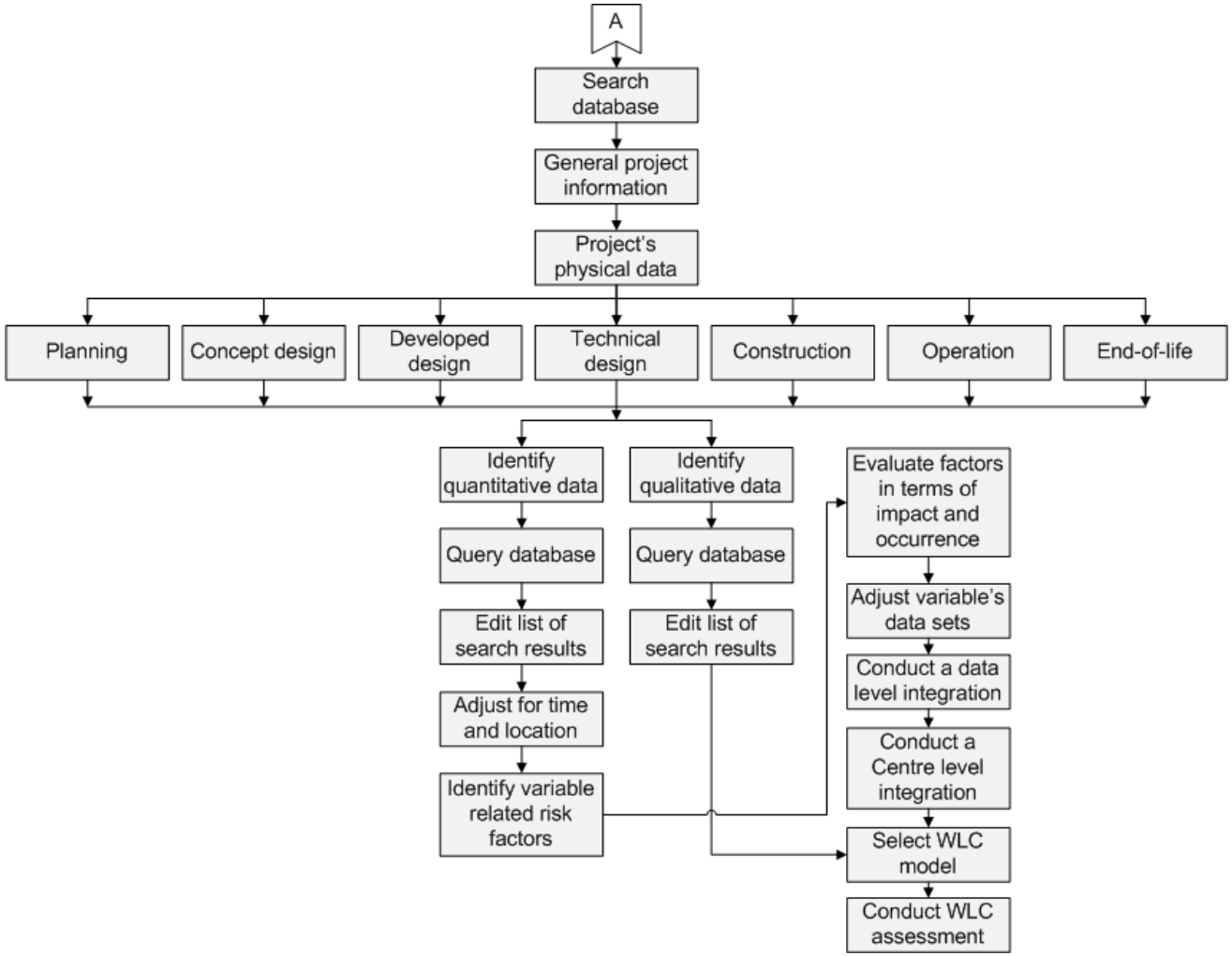


Figure 4. 5: Process Flow Diagram for Data Preparation

4.6.3 Algorithm for Whole Life Appraisal

The following algorithm outlines the steps, and sequence of activities required at the WLC appraisal stage:

i. Identify the project life-cycle stage at which WLC appraisal is required.
ii. Identify the purpose of the analysis
iii. Select the type of evaluation
iv. Select the evaluation method
v. Identify the variables needed for the evaluation
vi. Conduct the evaluation
vii. Interpret the result

The identification of the project life-cycle stage at which WLC appraisal is to be conducted is important as it will determine the type and level of evaluation. The next stage involves the identification of the purpose of analysis that includes: planning/budgeting, comparison of alternatives, cost check and control, options assessment, cost/revenue forecast depending on the life-cycle stage at which WLC appraisal is needed. The type of performance evaluation to be done is then selected. The evaluations are divided into four broad groups of: Economic, Physical, Social and environmental. The next stage is concerned with the selection of an appropriate evaluation method especially for physical evaluation. The evaluation methods for service life planning for instance are: factor, operating cost, Markov's chain, and reliability theory based methods. The next stage involves the identification of the precise variables needed for the evaluation. This stage is important as it aligns the data already prepared at the data preparation stage and the WLC appraisal stage thereby identifying missing or unnecessary data items included or omitted from data

preparation. The evaluation is then conducted and the result evaluated.Figure 4.6 shows the process flow of activities under Whole Life Cost appraisal. The first stage requires the identification of the life cycle stage at which WLC appraisal is to be performed. At the planning stage, the major activities are related to planning and benchmarking. These activities are either on economic, physical, social or environmental performance. Planning/benchmarking of economic performance was achieved at two levels; benchmarking costs/revenues and options evaluation. Benchmarking costs and revenues requires that a do-northing or do-minimum alternative is first identified, followed by the identification of costs and revenue centres. These costs and revenues are then benchmarked to enable a WLC evaluation of both the do-nothing alternative and benchmarked alternative based on a preselected economic evaluation technique. The benchmarked and do-nothing alternatives are then compared and the result interpreted. Options evaluation on the other hand requires first the identification of the options to benchmark, followed by the identification of the base case which could be the do-nothing alternative. The cost and revenues centres are then identified and benchmarked following which both the option and base case are evaluated and compared using their NPV and the result interpreted and reported.

The physical performance was divided into two broad groups, service life planning, and the planning of other attributes. Two methods for service life planning were suggested; the factor and the operating cost method. The factor method requires the reference service life (RSL) of the proposed project to first be specified. The factors that could possibly affect the reference service live are then identified and scored. The RSL is then adjusted to obtain an Estimated Service Life (ESL). The result is then interpreted and reported.

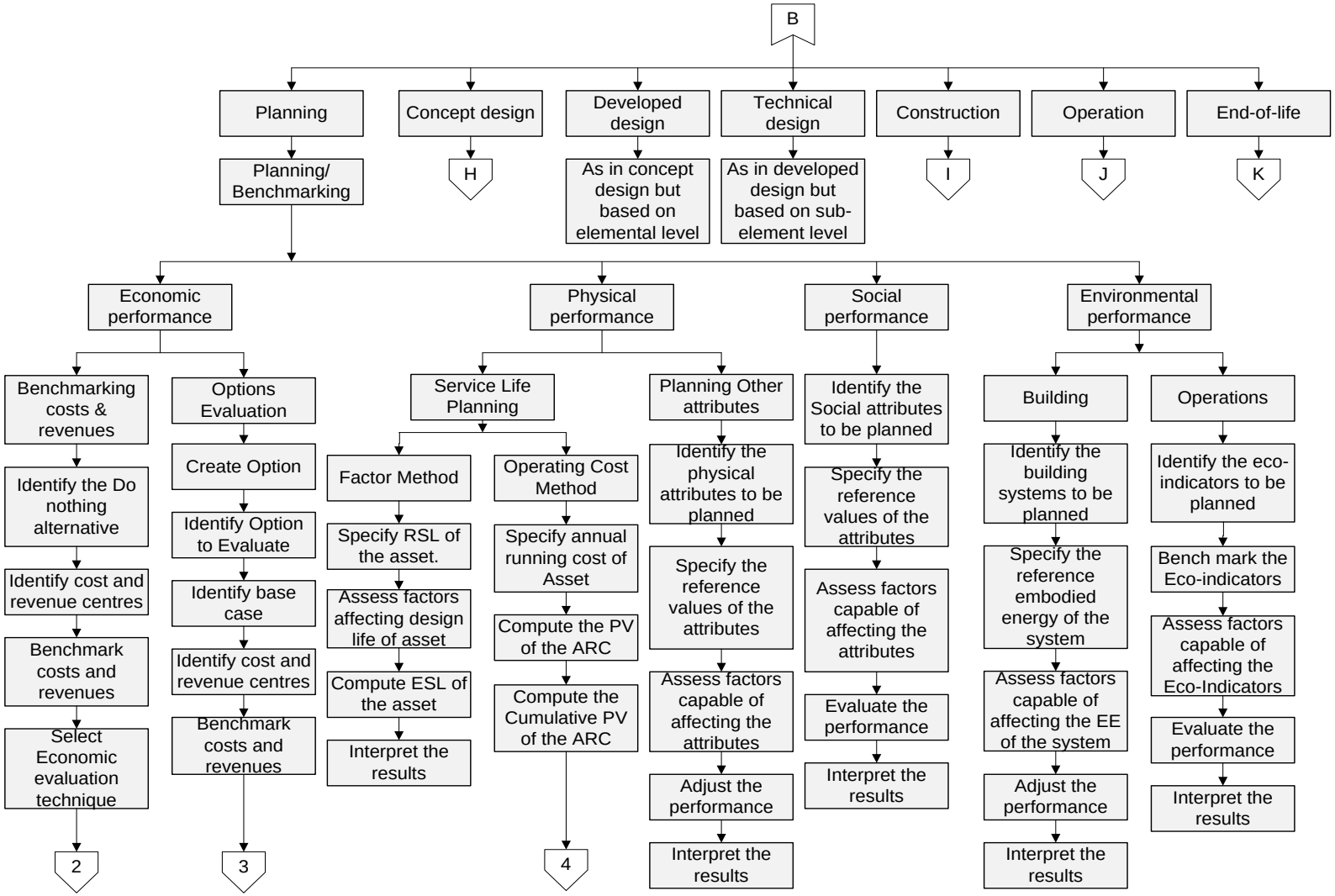


Figure 4. 6: Process Flow Diagram for WLC Appraisal

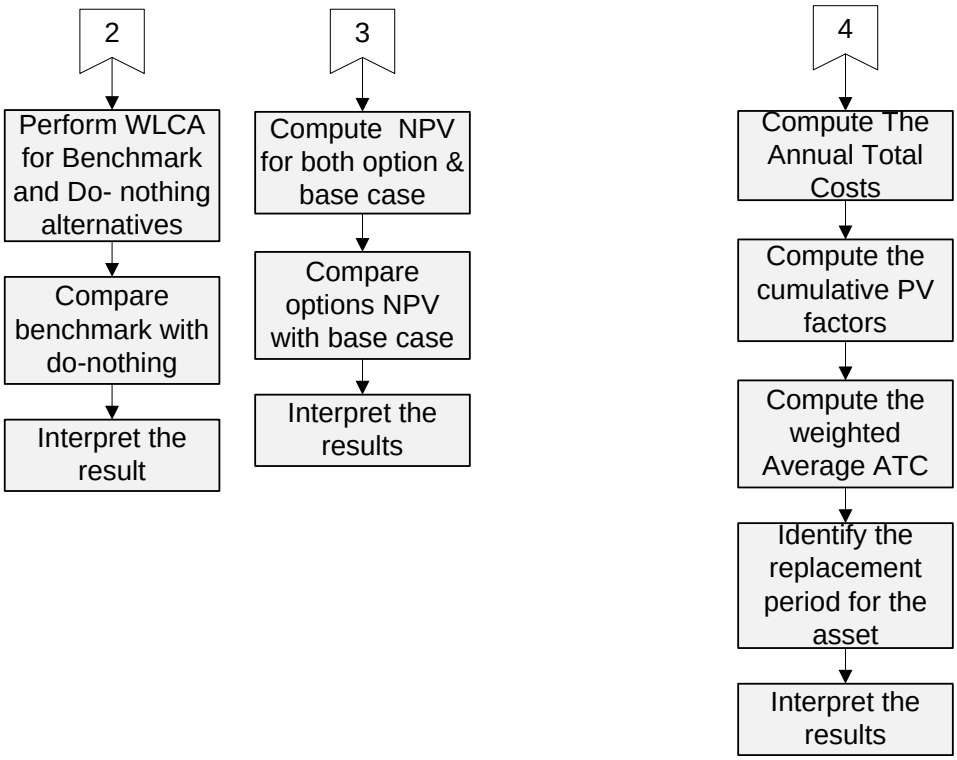


Figure 4. 6: Process Flow Diagram for WLC Appraisal Continues

The operating cost method requires the Annual Running Cost (ARC) of an asset, system or element to be estimated first. The present values (PV) and the commutative PV of the ARC are then computed to obtain the Annual Total Cost (ATC). The cumulative PV factors and the weighted ATC are then computed. The estimated replacement period for the asset is then evaluated and the result interpreted. Planning other physical performance indicators requires that first, the relevant attribute be identified. The reference value for the attribute is then specified. The factors capable of affecting the attributes are then identified and assessed; the adjusted values of the attribute's performance are then computed followed by result interpretation.

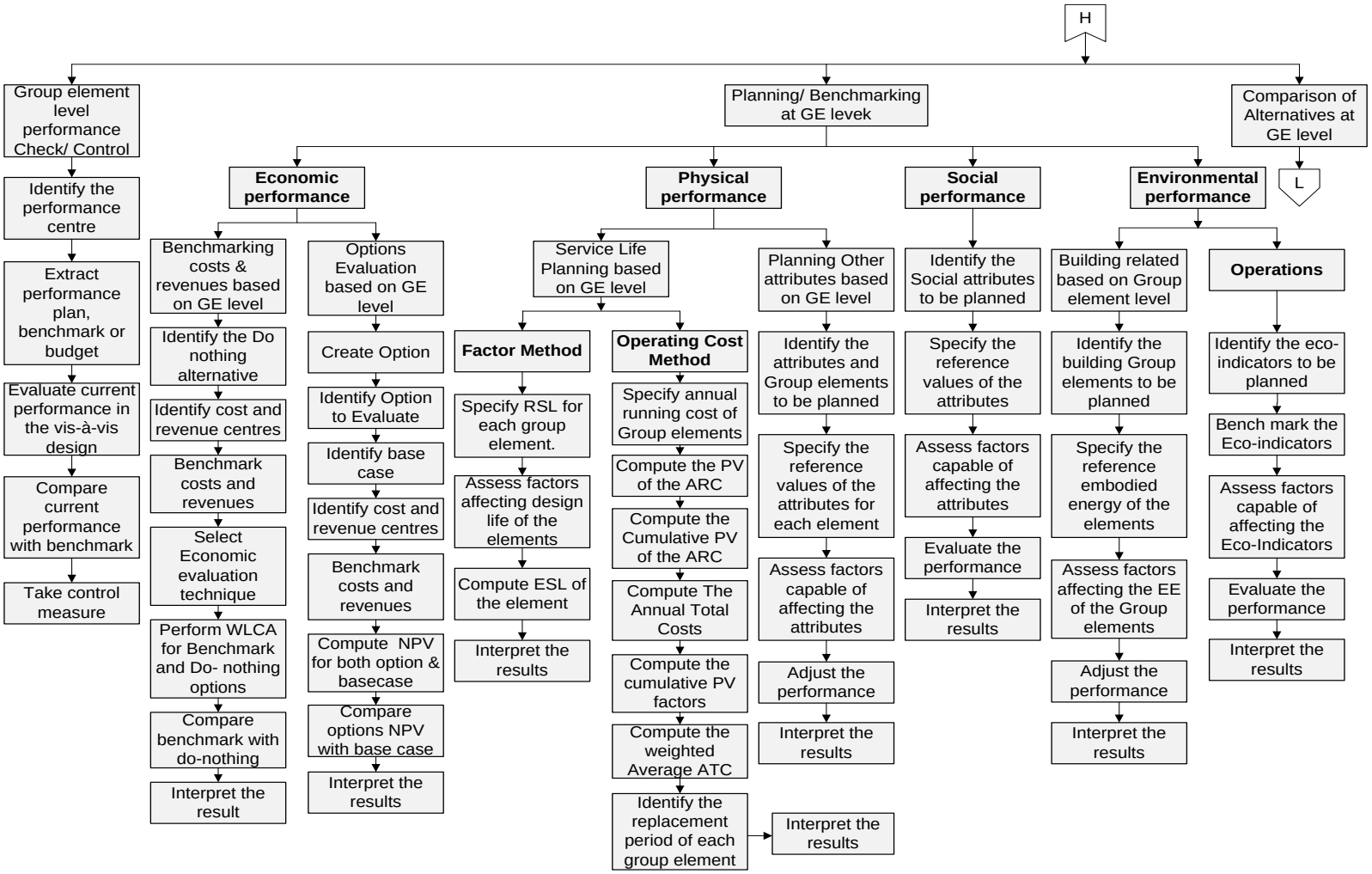


Figure 4. 6: Process Flow Diagram for WLC Appraisal Continues

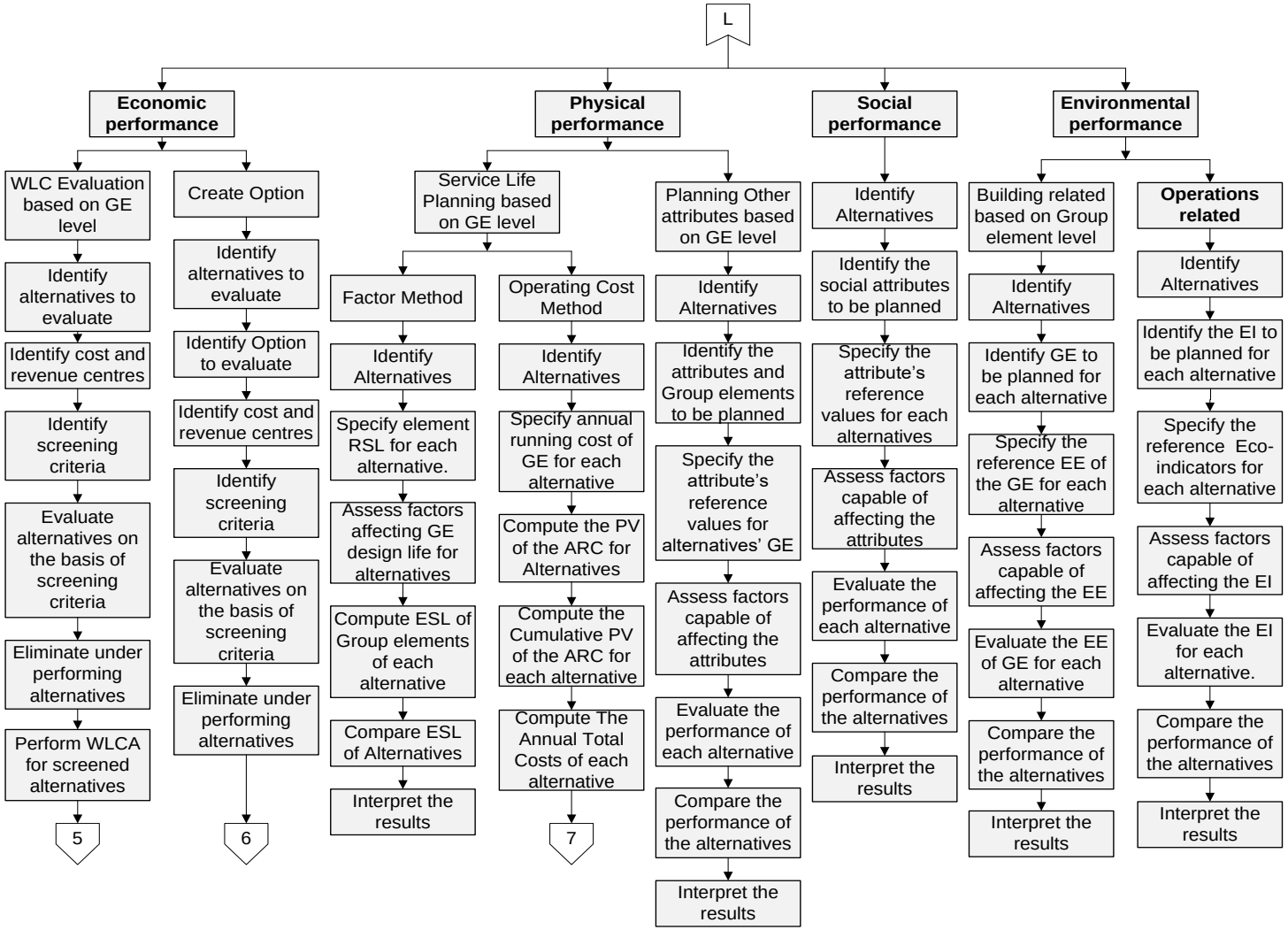


Figure 4.6: Process Flow Diagram for WLC Appraisal Continues

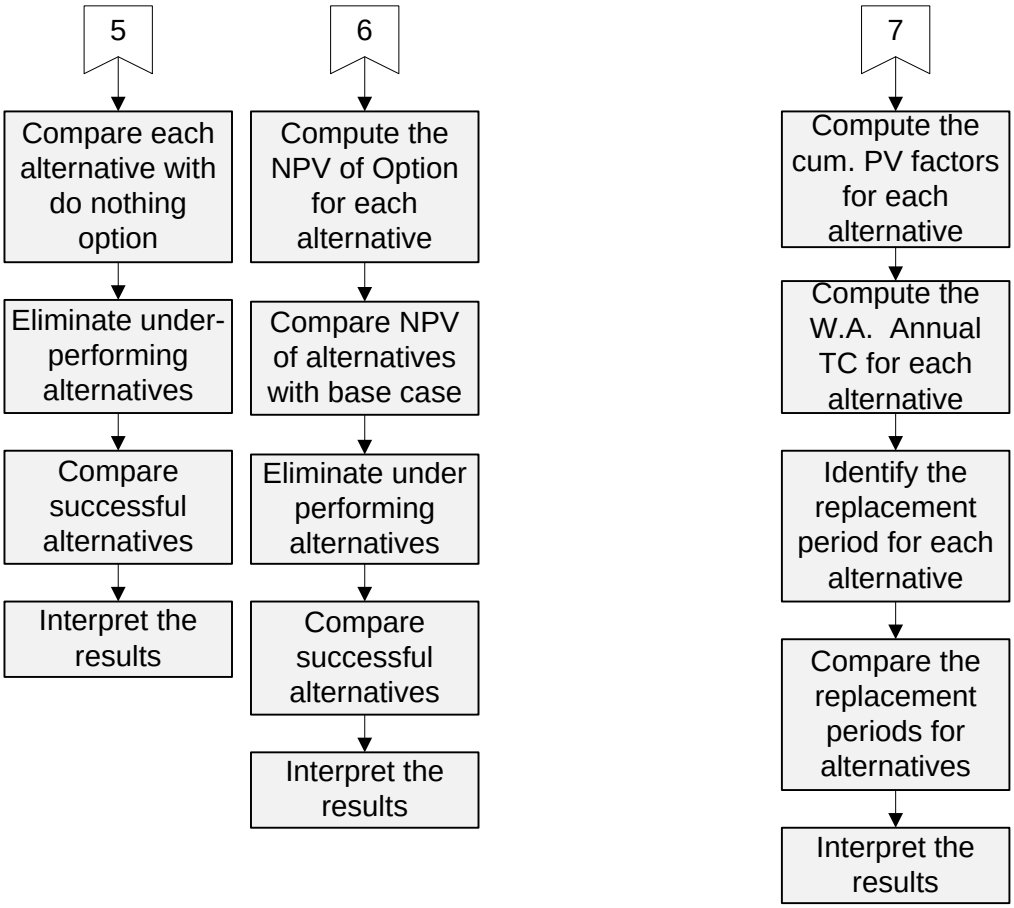


Figure 4.6: Process Flow Diagram for WLC Appraisal Continues

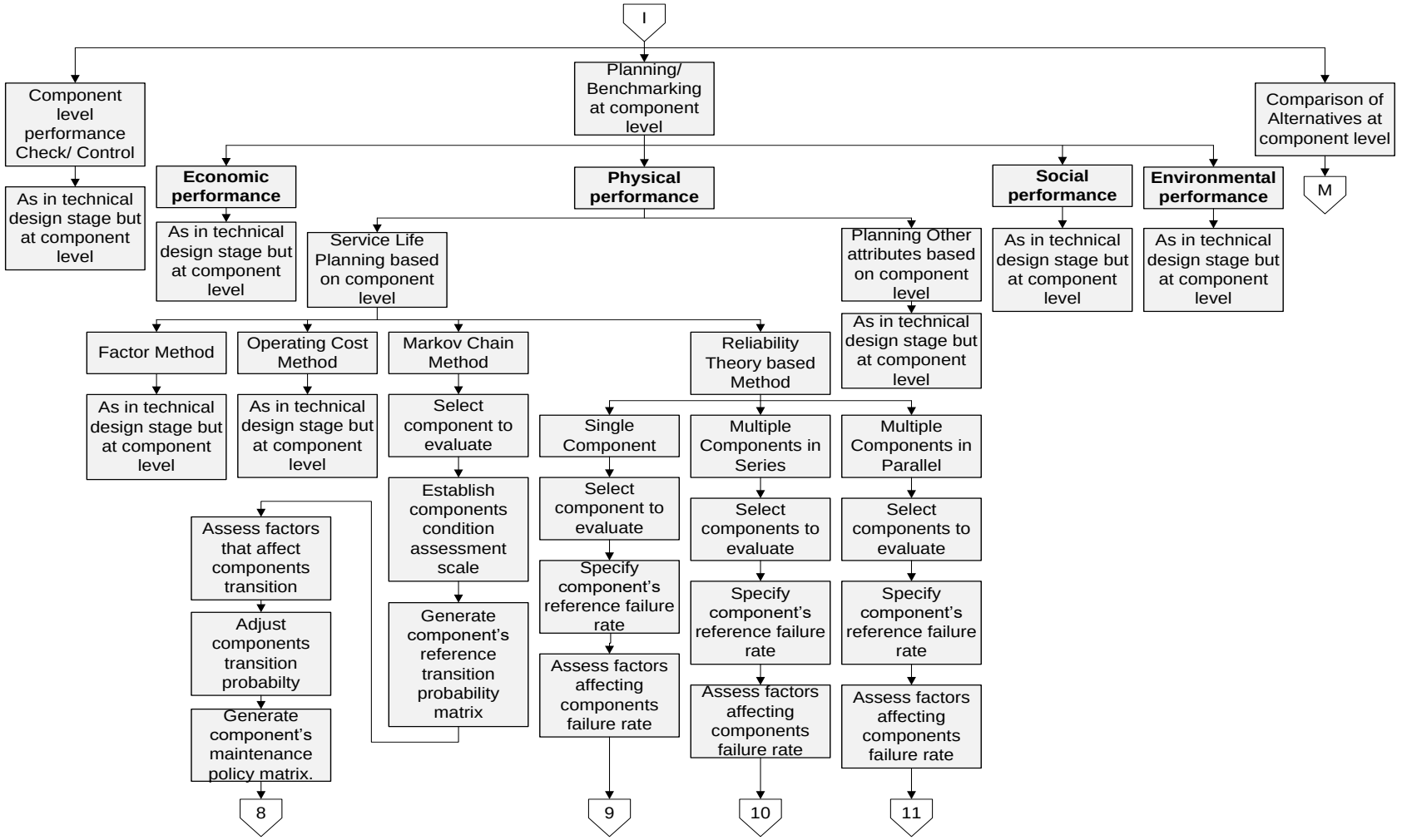


Figure 4.6: Process Flow Diagram for WLC Appraisal Continues

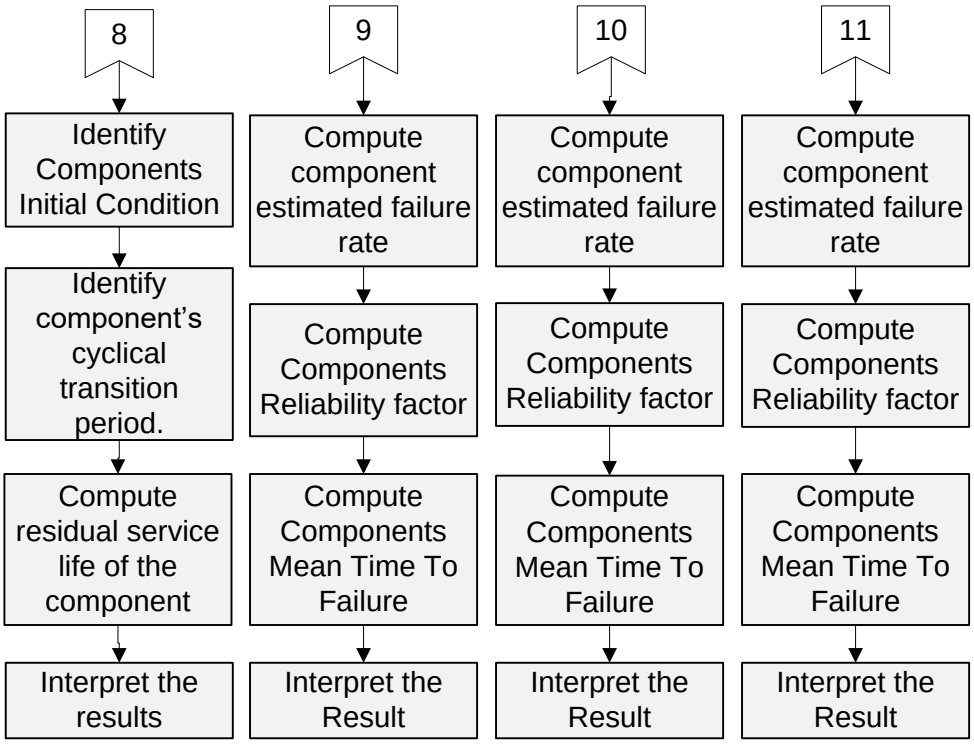


Figure 4.6: Process Flow Diagram for WLC Appraisal Continues

Benchmarking social performance requires the identification of the social attributes to be planned. The reference values of the attributes are then specified. The factors capable of affecting the attributes are identified and evaluated. The social performance of the asset is then estimated by adjusting the reference values of the attributes. The result is then finally interpreted.The environmental performance is benchmarked under two separate headings; Building related and Operations related. The building related environmental performance is benchmarked by first identifying the system to be benchmarked. The reference embodied Energy (EE) of the system is then specified. The factors influencing the system's embodied energy are then identified and assessed.

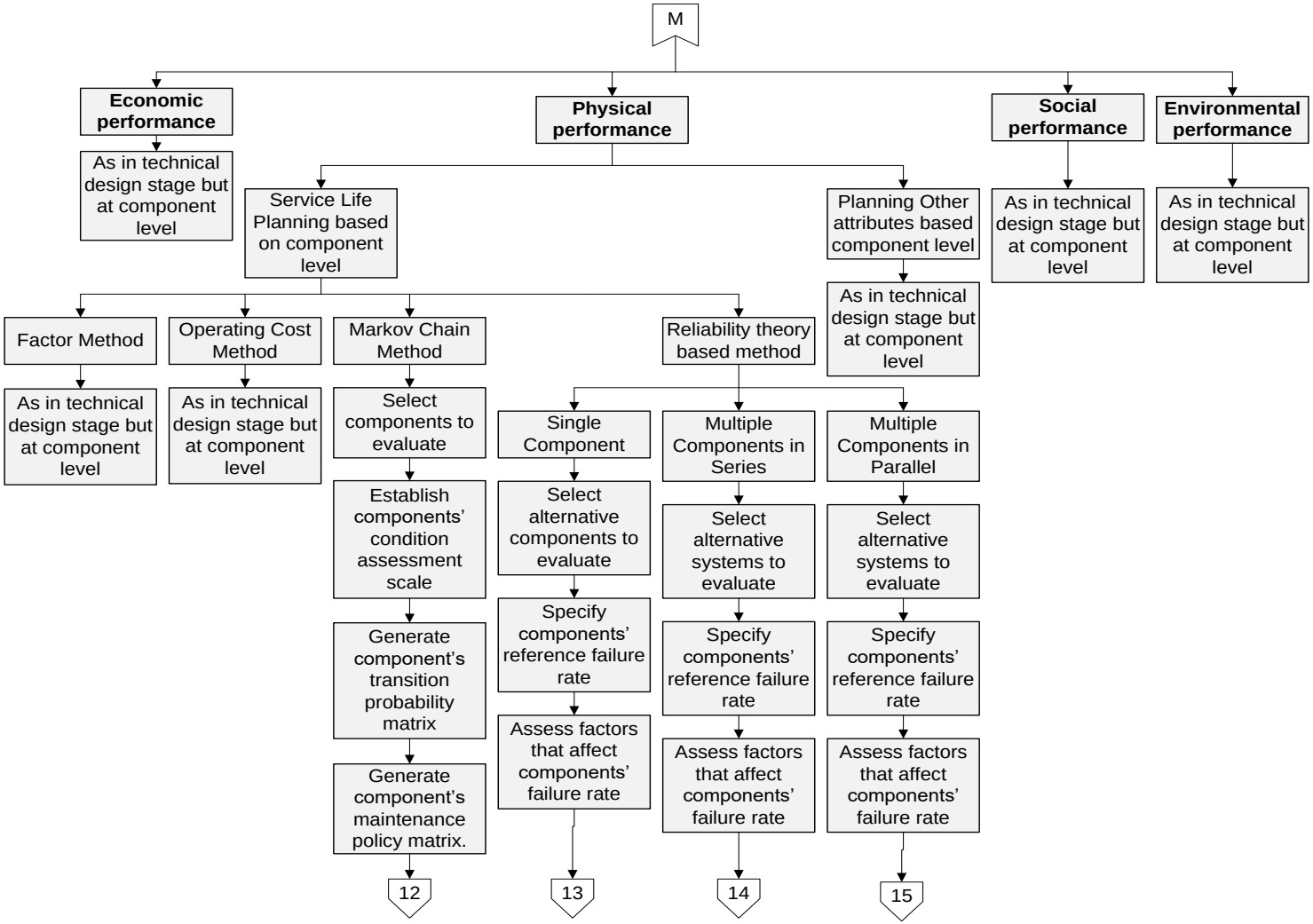


Figure 4.6: Process Flow Diagram for WLC Appraisal Continues

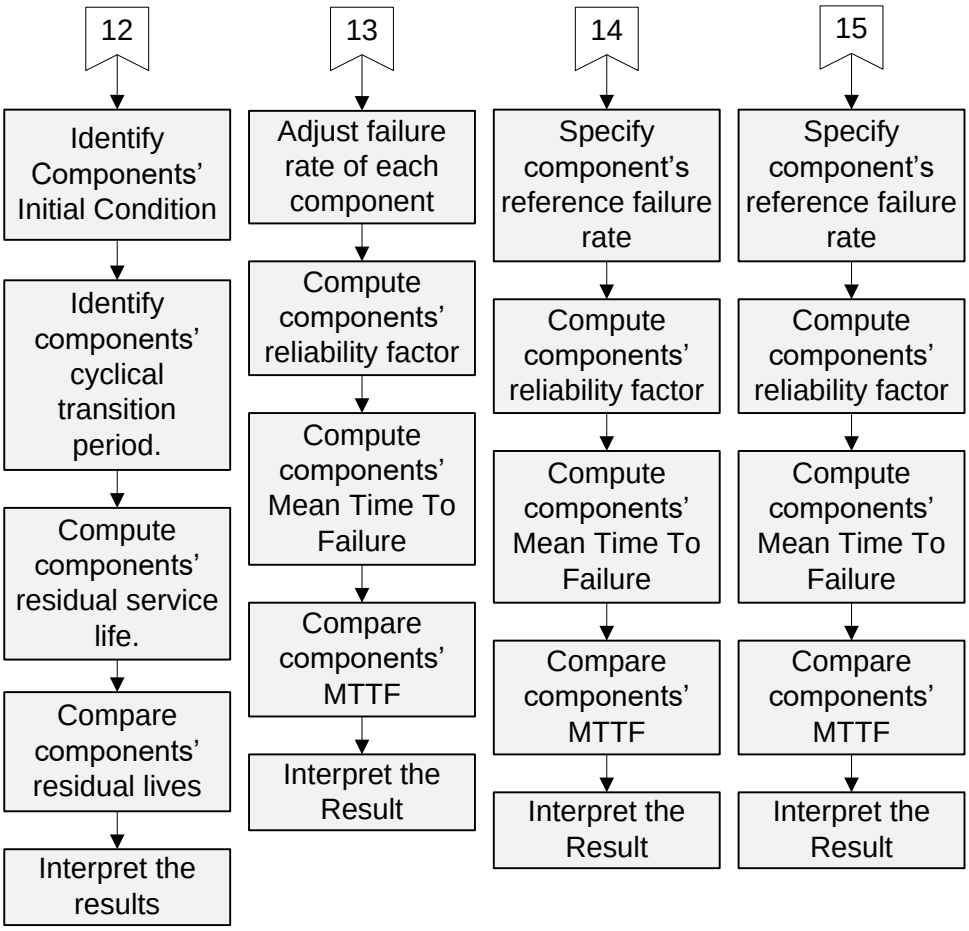


Figure 4.6: Process Flow Diagram for WLC Appraisal Continues

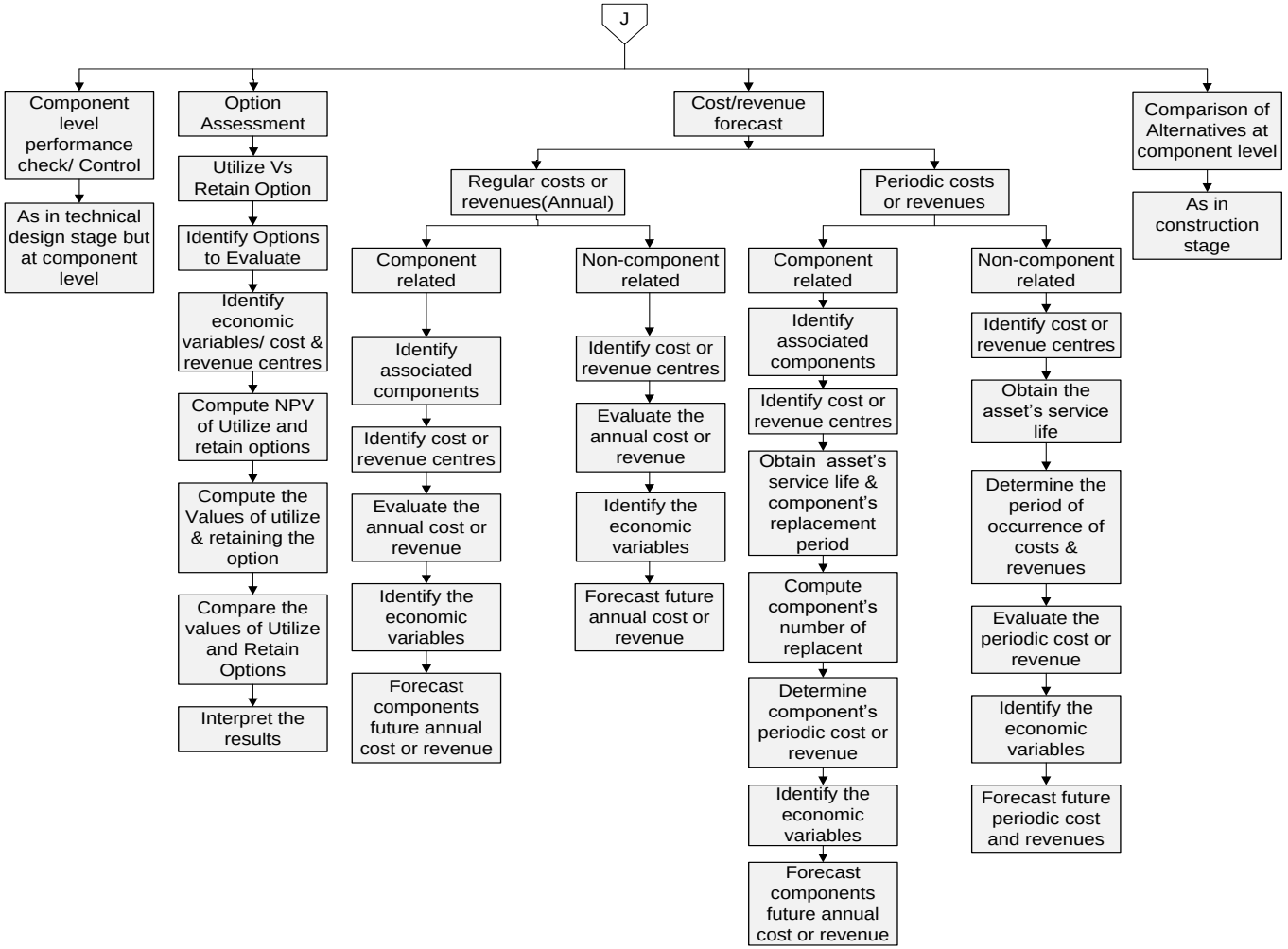


Figure 4.6: Process Flow Diagram for WLC Appraisal Continues

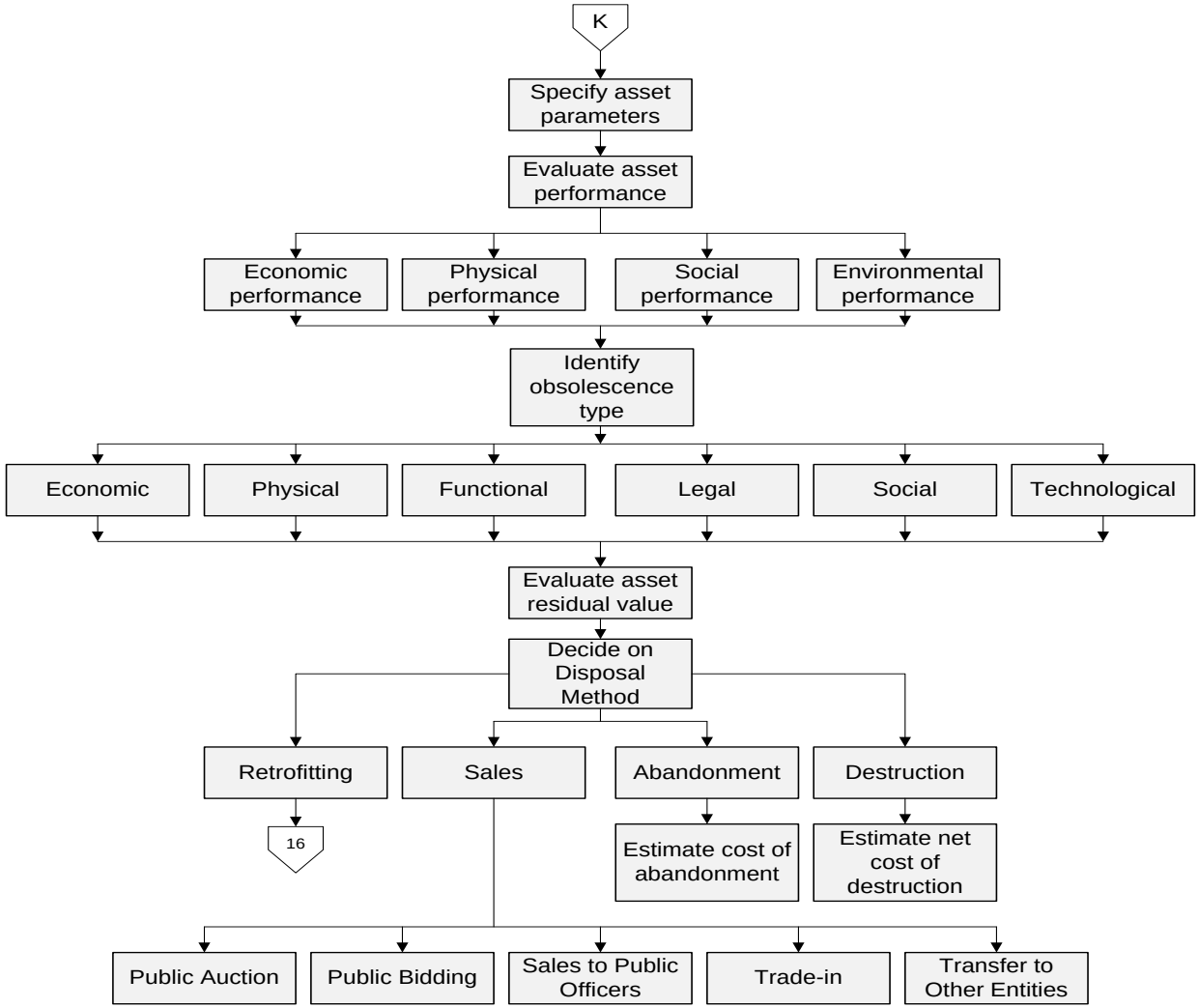


Figure 4.6: Process Flow Diagram for WLC Appraisal Continues

The reference performance of the system is then adjusted and the result interpreted. Benchmarking or planning the operations related environmental performance on the other hand requires first the identification of the eco-indicators to be planned. The indicators are then benchmarked using reference values. The factors capable of affecting the eco-indicators vis-à-vis the system or element under study are then adjusted to obtain an estimated performance. The result is then interpreted for report purposes.

From Figure 4.6, WLC activities at the concept design stage are achieved at group-element level. That is because at least an outline design of the proposed project has been prepared which would enable the identification of the nature and structure of the proposed project. Activities at the concept design stage were divided into three groups; Performance check and Control, Planning and benchmarking, and comparison of alternatives. Performance check and control is useful where a budget, benchmark or plan had been prepared at the planning stage. It involves first identifying the performance centre which could be economic, physical, social or environmental. The performance of the asset is evaluated in the light of the concept design and compared with the benchmark to initiate a control measure where intolerable deviations are obtained.

Planning and benchmarking activities at the concept design stage are similar to those of the planning stage, except that evaluations are now conducted at group element level where possible. The comparison of design alternatives was divided into economic, physical, social and environmental performance evaluations conducted at group-element level.

The comparison of the economic performance of design alternatives is achieved through WLC and options evaluation. The WLC evaluation requires alternative designs to be first identified. The cost and revenues centres are then identified followed by the identification of screening criteria. The screening criteria could be functional, regulatory, social, environmental, physical or economic requirements. Each alternative is then evaluated on the basis of the screening criteria and a set of successful design candidate selected. The screamed alternatives are then evaluated on the basis of WLC and then compared with the do-nothing (or do-minimum) alternative to further eliminate underperforming alternatives. The third screening is achieved by comparing the remaining alternatives against each other to obtain the best candidate or candidates in terms of WLC. Options evaluation on the other hand enables the identification of economic options each design alternative contains or is capable of accommodating. The process begins by identifying the alternative designs and economic options to evaluate. The cost and revenue centres that could be required for the evaluation are then identified. The first screening of the design alternatives is achieved by first identifying the screening criteria and evaluating each alternative on the basis of the criteria. The NPV of successful alternatives is then computed and compared against a base case. The base case may be status quo or do-nothing option. The alternatives that successfully pass the second screening are then compared against each other and the best-performing alternative in terms of embedded or embeddable option is identified.

Comparison of design alternatives based on physical performance could be achieved through service life planning or physical attributes. In using service life as a basis for comparison, the factor method or operating cost method could be used. The factor method requires first the identification of the alternatives to be compared, followed by specifying group-elements reference service lives for each design alternative. The

factors capable of affecting the service life of each alternative are then identified and evaluated. The reference service life (RSL) of each alternative is then adjusted to obtain the estimated service life (ESL). The ESL of the alternatives is then compared to determine the one that performs best.

The operating cost method on the other hand first requires design alternatives to be identified. The ARC of group elements of each alternative is then specified. The PV of the ARC and the commutative PV of the ARC are then computed for each alternative. The Annual Total cost (ATC) of each alternative is then computed. For each alternative the commutative PV factors is calculated based on which the weighted average of the ATC is computed. The replacement period or service life of each alternative is identified and compared against each other.

The comparison of alternatives on the basis of other physical performance attributes requires the group-elements and their associated physical performance indicators to be identified. The reference values of the indicators or attributes are then specified. The factors that impact on the attributes are also identified and assessed. The reference values of the attributes are then adjusted for each group element across all the alternatives. The estimated cumulative performance of the alternatives is then compared to identify the preferred alternative.

Comparing the social performance of design alternatives requires that the social attributes to be planned are identified and reference values assigned to them for each alternative. The factors that affect the attribute are then identified and assessed. The result of the assessment is then used to adjust the reference values of the attributes for each alternative. The estimated social performance values are then used to compare alternatives against each other.

Comparison of alternatives on the basis of environmental performance is achieved in two ways; building related and operations related. The building related comparison is based on group elements. It requires first the identification of the design alternatives to be compared followed by the selection of the group elements to be included in the assessment. The elements Embodied Energy (E.E) are then specified for each alternative design solution. The factors capable of changing the reference values are identified, assessed and used to adjust the reference values of the E.E. The estimated values of the E.E. of the alternatives are then compared to determine the most preferred alternative. Comparison of alternatives on the basis of environmental burden contributed by operations needs the alternatives to be identified. The Eco-indicators (E.I.) to be assessed are then identified for each alternative and assigned reference values. The factors capable of influencing the E.I, are then identified and assessed vis-à-vis the alternative designs. The reference values are then adjusted to obtain an estimated value for the E.I associated with each alternative. The estimated scores for each alternative are then compared to identify the best design solution.

The structure and sequence of activities at the developed and technical design stages is similar to that of concept design. However, the level of detail is at elemental and sub-elemental for developed and technical design stages respectively.

WLC activities at the construction stage like the concept design stage are also divided into three sections, performance check and control, planning/benchmarking and comparison of alternatives. WLC appraisals at this stage are however, all at component level. In addition, the basic structure and sequence of activities for performance check and control are similar to those of concept design except that in this situation performance break-down is at the component level. Planning and benchmarking activities are also similar to those of concept design stage except for service life

planning under physical performance which now includes two more options; the Markov's Chain and reliability theory based method. The Markov's Chain method requires that components to be evaluated are identified and condition assessment scale established. Components reference transition probability matrix is then generated. The factors capable of changing the transition probabilities are then identified and assessed. The transition probability matrix is then adjusted based on the assessment result. The component maintenance requirement matrix and initial condition are established, which enables the determination of the components cyclical transition period. The components residual service life is then computed and results interpreted.

The reliability theory based method for service life planning are divided into three sections of; single component, multiple components in series and multiple components in parallel. The procedure for all three is the same though the formulas used in the computations vary. The components to be evaluated are first identified, and their reference failure rates established. The factors affecting the failure rates are then identified, assessed, and used to adjust the reference failure rates already established to obtain the components' estimated failure rates. The reliability factors of the components are then determined based on which the components Means Time to Failure (MTTF) is computed.

Comparison of alternatives is also essentially similar to the concept design stage but for the addition of Markov's chain and reliability theory based methods. The Markov's Chain process requires first the identification of components to compare. Conditions assessment scale is then established. The transition probability and maintenance requirement matrixes are then generated for each component. Components' initial condition is then identified and their cyclical transition period computed. The components residual periods are then computed and compared to select the best.

Comparing components on the basis of reliability can be achieved for single components, multiple components in series and multiple components in parallel. The procedure for the different arrangements is the same. The process requires the alternatives under comparison to be first identified. The reference failure rate for each component is specified. The factors that affect the failure rate of components are then identified and assessed. The components reference failure rates are then adjusted and used to compute components reliability factor. The components' MTTF is then computed and compared to identify the preferred alternative.

The operations stage was divided into four different activity sections; performance checks and control, options assessment, cost and revenue forecast and comparison of alternative components. The component level performance check and control is similar in both structure and activity sequence to the construction stage.

The options assessment stage facilitates the evaluation of the decision to either utilize or retain an option contained in a building. The first step is the identification of the options to evaluate. The cost and revenue centres and the economic variables to be used in the evaluation are then identified. The NPV of both utilizing and retaining the options alongside the options values are computed and compared to ascertain the best option.

Cost and revenue forecasting was divided into two processes involving forecast of regular costs and revenues and the forecast of periodic costs. The separation is important as each category has a different evaluations procedure. The regular cost or revenues are those cost or revenue that occurs regularly within same time period (e.g annual costs). The periodic costs occur over a number of years. Both costs were further divided into component and non-component related to enhance the

classification. Forecasting component related regular cost and revenues requires first the identification of the components after which the cost and revenue centres are identified and evaluated to obtain AC and revenues. The economic variables are then identified and used to forecast the future values of the components annual costs and revenues.

Forecasting the non-component related regular costs or revenues requires the identification of the cost and revenue centres, followed by the determination of the economic variables based on which the future AC and revenues are forecasted. Forecasting component related periodic costs and revenues involves, first the identification of the components and their cost and revenue centres. The assets service life and the component's replacement period are then obtained and used to compute components number of replacement. The components periodic costs and revenues, together with economic variable are determined and used to forecast the costs and revenues.

The non-component related periodic costs and revenues are forecasted by first identifying the cost and revenue centres. The asset's or building's service life and the period of occurrence of the cost or revenues are then determined and used to calculate the estimated number of occurrence of the cost or revenue. The periodic costs and revenues are then obtained and used vis-à-vis an already identified global variables to forecast the future periodic costs and revenues.

The end-of-life stage comprises of five sequential steps. The first step requires the specification of asset parameters, which includes both asset general and physical information. The second step involves the evaluation of asset performance which could be economic, physical social or environmental. The third step requires the type of

obsolescence to be identified which could be; economic, physical, functional, legal, social or technological. The fourth step involves the estimation of the assets residual value through valuation inspection and report in accordance with ISO and SBD provisions. The sixth step involves decision making on whether to retrofit, sale, abandon or destroy vis-à-vis the results of the aforementioned steps. If the decision to retrofit, modify, or adapt is taken then the asset is given a new life which means early stage activities would be engaged. If the decision to sale is taken, it could be achieved through public auction, public bidding, sales to public officers, trade-in and transfer to other entities in accordance with public procurement Act, SBD and regulations for the procurement of works. Where the decision to abandon or destroy is taken then the estimated cost of abandonment and the net cost of destruction are computed respectively.

4.6.4 Algorithm for Risk analysis.

The following algorithm was followed to design a process flow diagram for WLC risk analysis.

i. Identify and assess variable related risk factors and adjust variables accordingly
ii. Conduct WLC assessment
iii. Conduct sensitivity analysis
iv. Reassess sensitive variables and underlying assumptions
v. Identify project related risk factors
vi. Evaluate both quantitative and qualitative risk factors
vii. Compute percentage risk reserves
viii. Re-conduct WLC assessment and incorporate risk reserve.
ix. Identify the model type used in conducting WLC assessment in (b) and (h) above.

x. Compare alternatives in the light of the model used

xi. Evaluate result vis-à-vis sensitive variables

xii. Rank the alternatives from best performing to worst performing.

xiii. Assess the reliability or confidence measure of ranking

xiv. Interpret the result.

The design of the risk analysis framework was made based on the assumption that alternatives under study have passed through the WLC appraisal stage and three layers of screening. Where an alternative clearly out-perform the others at the appraisal stage, this stage would be unnecessary. However, where alternatives are still tied despite passing through three layers of screening, then risk analysis is then used to further separate the alternatives and possibly identify the best.It is assumed that variable level risk analysis had been performed during data preparation and an initial WLC appraisal performed. Sensitivity analysis is then conducted to isolate sensitive variables. The variables are then reassessed to confirm or adjust their values and any underlying assumption.Project related risk factors are then identified and assessed to obtain percentage risk reserve (or contingency sum). The WLC is then adjusted by factoring risk reserve in the cumulative WLC. Alternatives are then compared based on the evaluation model used. Where there are still ties in the ranking of alternatives, sensitivity analysis is then used to check the robustness of any decision that may be taken. The alternatives are then ranked, and the reliability of the ranking established through a confidence measure. In case there is still tie in the performance of alternatives, the alternative courses of action are either to modify the selection criteria, or to adjust the alternative design or describe the process as inconclusive.

Figure 4.7 shows the process flow diagram of the risk analysis stage. From the figure, sensitivity analysis is first conducted to identify and reassess sensitive variables

alongside their underlying assumptions. The project related risk factors (both quantitative and qualitative) are also identified and evaluated to compute percentage risk reserves and update the WLC. Where deterministic evaluation technique was used, the WLC assessment of alternatives is compared and the impact of sensitive variables on the comparison assessed. The alternatives are then ranked and the result of the analysis interpreted. Where statistical technique was used, the regression models of the alternatives are compared. The alternatives are then ranked and regression coefficient computed for each alternative. The result of the analysis is then interpreted and reported. Where a black-box model was used, the range of outputs for each alternative is compared. The alternatives are then ranked and the reliability of the ranking assessed. The result is then interpreted and reported. Where stochastic WLC assessment is used, the PDF of the alternatives are compared and ranked. The reliability of the ranking is then assessed using a confidence level and the result interpreted and reported. Where Fuzzy assessment is used, the FMF of the alternatives are compared and ranked. The truth value of the ranking is computed and the result interpreted. Where qualitative assessment is used, weights are attached to each decision criteria. The alternatives are then evaluated on the basis of the decision criteria. The performance of each alternative is compared against the others and a ranking obtained. The results are then interpreted and reported.

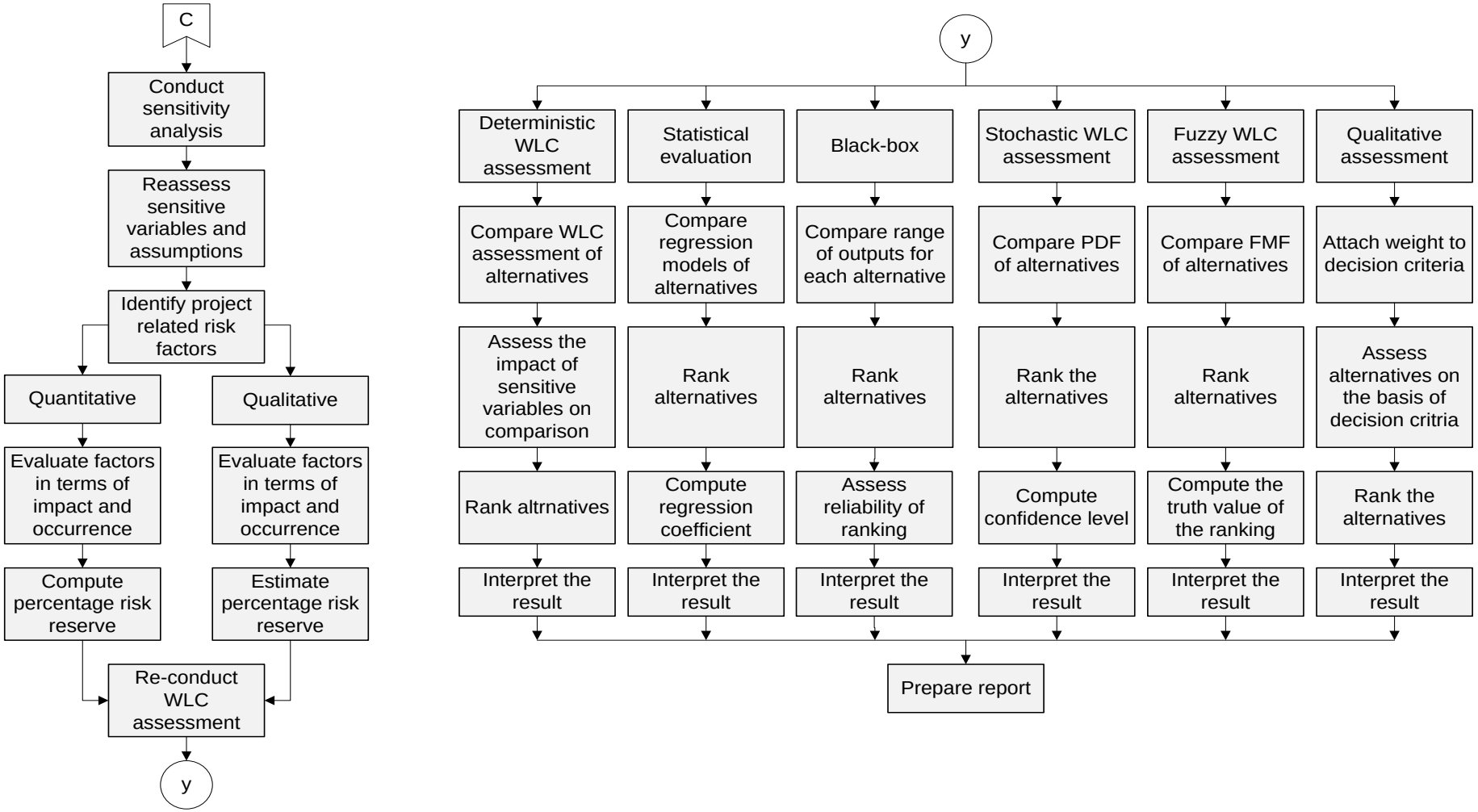


Figure 4. 7: Process Flow Diagram for Risk Analysis

4.7 User interfaces, Flowcharts and Database

This section discusses the design of the input and output interfaces, flowcharts and database and their integration into an overall system in accordance with the process flow diagram presented and discussed in section 4.6. The designs were achieved under five headings: Main interface, data analysis, data preparation, WLC appraisal and risk analysis.

4.7.1 Main Interface

At the topmost level of the user interface a main form was used as a container of all other WLC activities. The main form titled "Whole Life Costing" contains a menu bar which in turn contains six menu items. These items are; File, Data analysis, Data preparation, WLC appraisal, Risk analysis and Help. Figure 4.8 shows the design of the main form and plates1 to 59 shows the drop-down menus under each menu item.

4.7.2 Data Analysis

Operations under data analysis begins with the selection of the menu item on the menu bar which displays a drop-down menu containing project related and non-project related items. The selection of the project related menu displays a submenu containing choices of life-cycle stages. The selection of any of the stages transfer control to data analysis routine which enables the input and storage of data in a database. Figure 4.9 shows a flowchart representation of the start of logic of activities under data analysis. The flowchart is a representation of the selection process for data analysis on the menu bar where a choice is made between project related and non-project related analysis based on which control is transferred to the relevant subroutine.

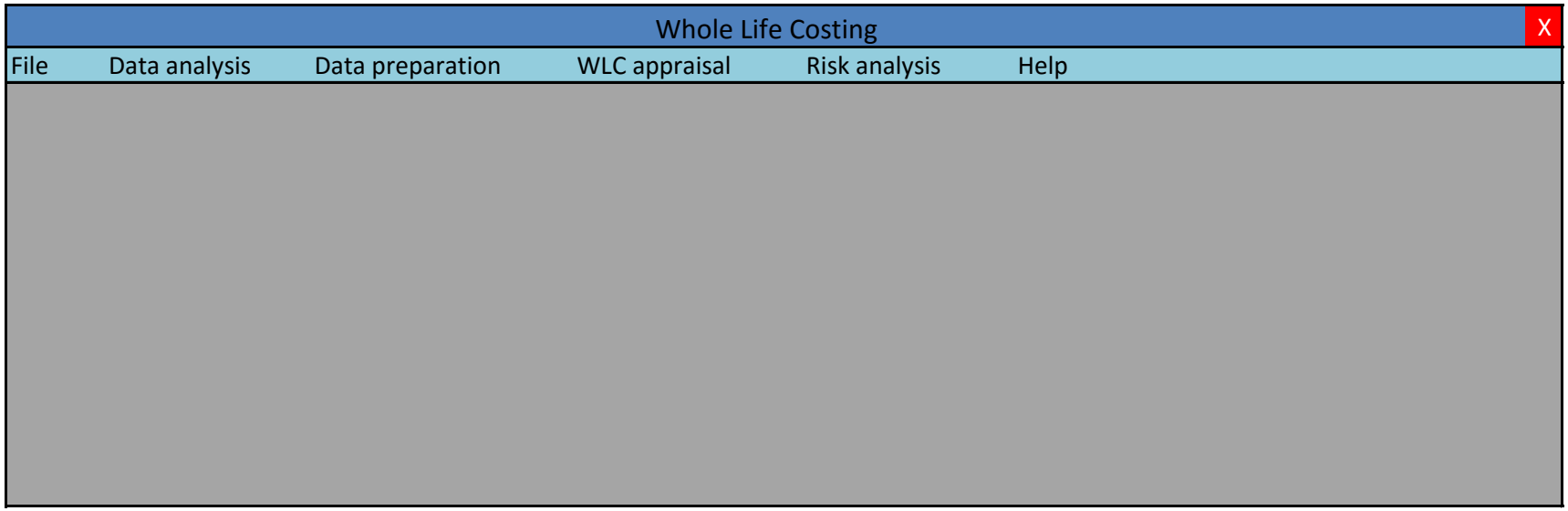
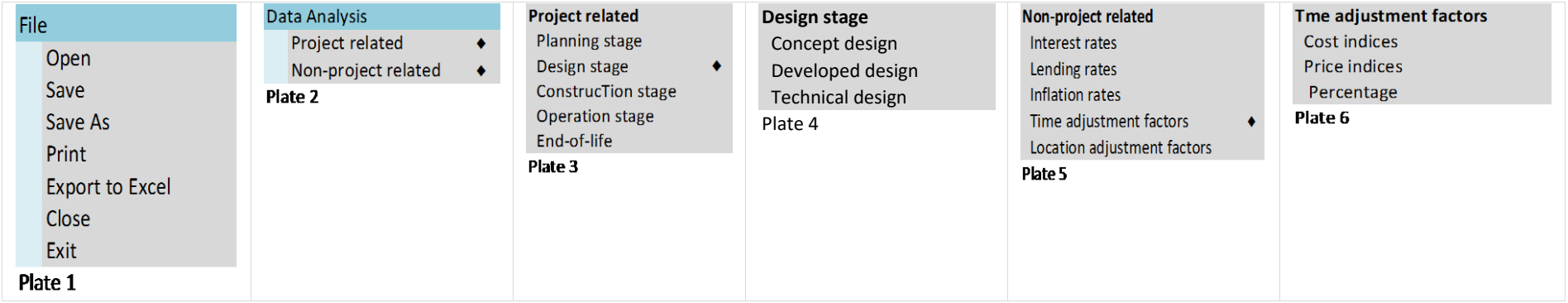


Figure 4. 8: Main WLC application form



Data preparation Prepare from file Search database **Plate 7**	WLC appraisal Plannin stage(BL) ♦ Dasign stage ♦ Construction stage(CL) ♦ Operations stage(CL) ♦ End-of-life ♦ **Plate 8**	**Planing stage** Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ Plate 9	**Economic performance** Budgeting Benchmarking Options evaluation Plate 10
Physical performance Service life planning Planning other attributes **Plate 11**	**Environmental performance** Building related Operations related **Plate 12**	**Dasign stage** Concept design(GEL) ♦ Developed design(EL) ♦ Technical design(SEL) ♦ **Plate 13**	**Concept design** Performance check & control Planning & benchmarking ♦ Comparison of alternatives ♦ **Plate 14**
Planning & benchmarking Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ **Plate 15**	**Economic performance** Benchmarking Options evaluation **Plate 16**	**Physical performance** Service life planning Planning other attributes **Plate 17**	**Environmental performance** Building related Operations related **Plate 18**
Comparison of alternatives Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ **Plate 19**	**Economic performance** Benchmarking Options evaluation **Plate 20**	**Physical performance** Service life planning Planning other attributes **Plate 21**	**Environmental performance** Building related Operations related **Plate 22**

Developed design Performance check & control Planning & benchmarking ♦ Comparison of alternatives ♦ **Plate 23**	**Planning & benchmarking** Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ **Plate 24**	**Economic performance** Benchmarking Options evaluation **Plate 25**	**Physical performance** Service life planning Planning other attributes **Plate 26**
Environmental performance Building related Operations related **Plate 27**	**Comparison of alternatives** Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ **Plate 28**	**Economic performance** Benchmarking Options evaluation **Plate 29**	**Physical performance** Service life planning Planning other attributes **Plate 30**
Environmental performance Building related Operations related **Plate 31**	**Technical design** Performance check & control Planning & benchmarking ♦ Comparison of alternatives ♦ **Plate 32**	**Planning & benchmarking** Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ **Plate 33**	**Economic performance** Benchmarking Options evaluation **Plate 34**
Physical performance Service life planning Planning other attributes **Plate 35**	**Environmental performance** Building related Operations related **Plate 36**	**Comparison of alternatives** Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ **Plate 37**	**Economic performance** Benchmarking Options evaluation **Plate 38**
Physical performance Service life planning Planning other attributes **Plate 39**	**Environmental performance** Building related Operations related **Plate 40**	**Constructon stage** Performance check & control Planning & benchmarking ♦ Comparison of alternatives ♦ **Plate 41**	**Planning & benchmarking** Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ **Plate 42**

Economic performance Benchmarking Options evaluation **Plate 43**	**Physical performance** Service life planning Planning other attributes **Plate 44**	**Environmental performance** Building related Operations related **Plate 45**	**Comparison of alternatives** Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ **Plate 46**
Economic performance Benchmarking Options evaluation **Plate 47**	**Physical performance** Service life planning Planning other attributes **Plate 48**	**Environmental performance** Building related Operations related **Plate 49**	**Operations** Performance check & control Options assessment Cost & revenue forecast ♦ Comparison of alternatives ♦ **Plate 50**
Cost & revenue forecast Regular costs & revenues ♦ Periodic costs & revenues ♦ **Plate 51**	**Regular costs & revenues** Component related Non-component related **Plate 52**	**Periodic cost & revenues** Component related Non-component related **Plate 53**	**Comparison of alternatives** Economic performance ♦ Physical performance ♦ Social performance Environmental performance ♦ **Plate 54**
Economic performance Benchmarking Options evaluation **Plate 55**	**Physical performance** Service life planning Planning other attributes **Plate 56**	**Environmental performance** Building related Operations related **Plate 57**	**End-of-life** Condition survey Plate 58
Risk analysis Risk assessment **Plate 59**			

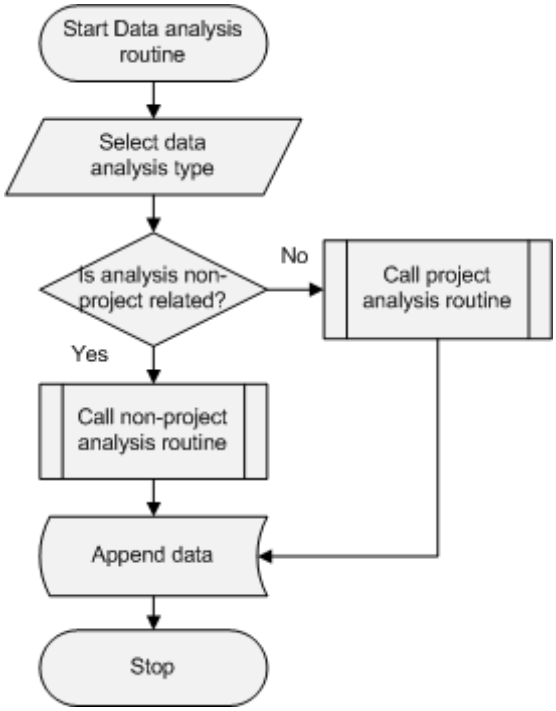


Figure 4. 9: Flowchart Representation of Data Analysis Routine

If for instance the project related subroutine was selected, the project analysis subroutine is then called which prompts the selection of a life-cycle stage at which the analysis is required. Control is then passed to one of seven subroutines corresponding to the preselected analysis stage. After the execution of the subroutine control is then eventually transferred back to the data analysis routine where data is appended. Figure 4.10 shows the flowchart representation of the project analysis subroutine. Where the planning stage is selected for instance, control is transferred to the planning-analysis subroutine shown in Figure 4.11, where a prompt for the input of general project information and scope of the analysis is displayed using project information form, Physical and performance data form and analysis scoping form respectively. Figures 4.12, 4.13 and 4.14 show an outlook of the forms. From Figure 4.11 where quantitative data is part of the scope of the analysis as indicated in the scoping form, Data Input routine shown on Figure 4.12 is invoked and the relevant data type selection form is

displayed to enable the selection of a data format for each data centre after which data entry forms for each of the defined data set is displayed for data input.

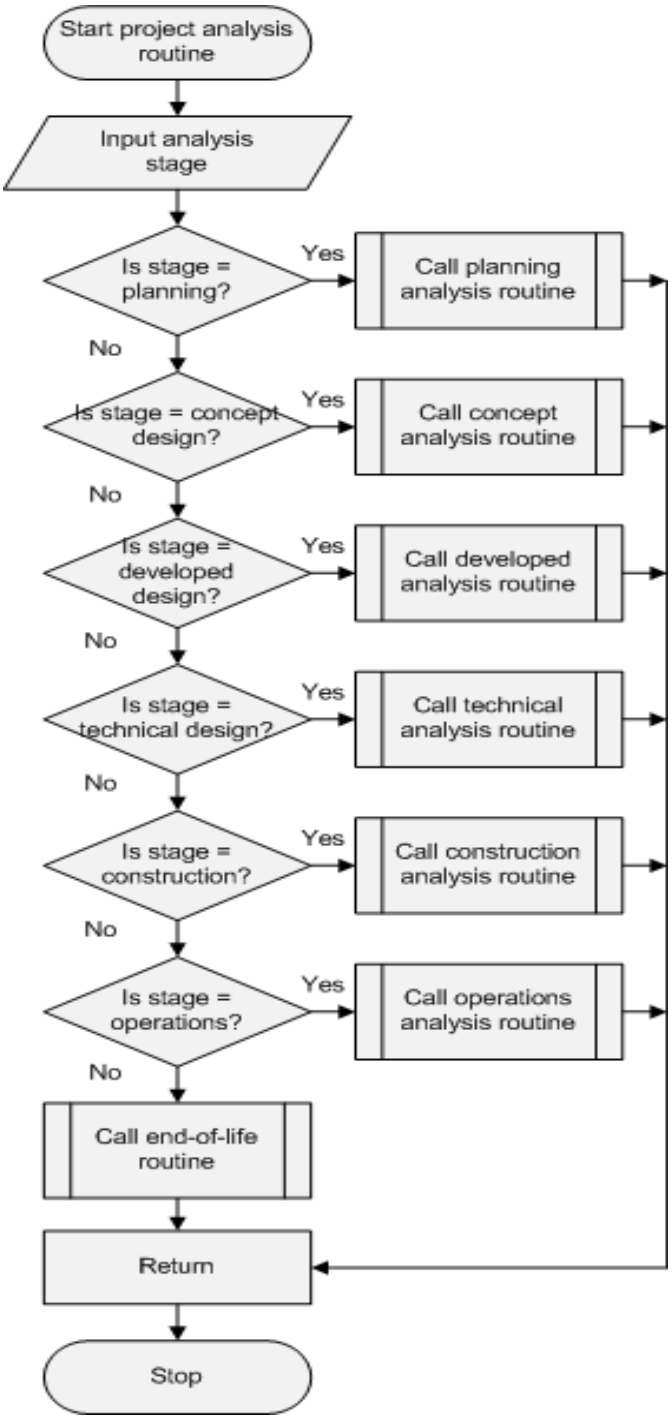


Figure 4. 10: Flowchart Representation of Project Analysis Subroutine

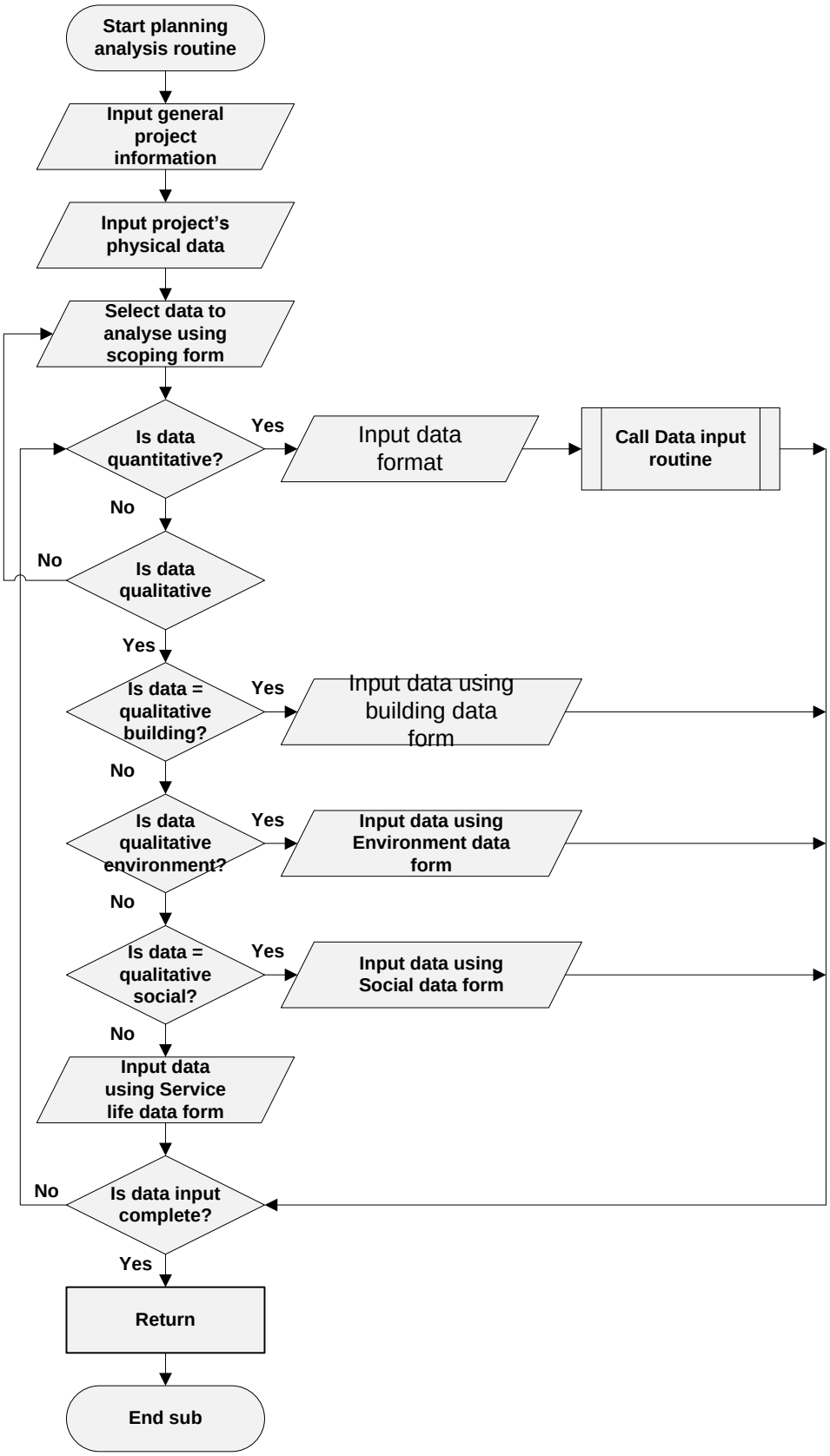


Figure 4. 11: Flowchart Representation of Planning Analysis Subroutine

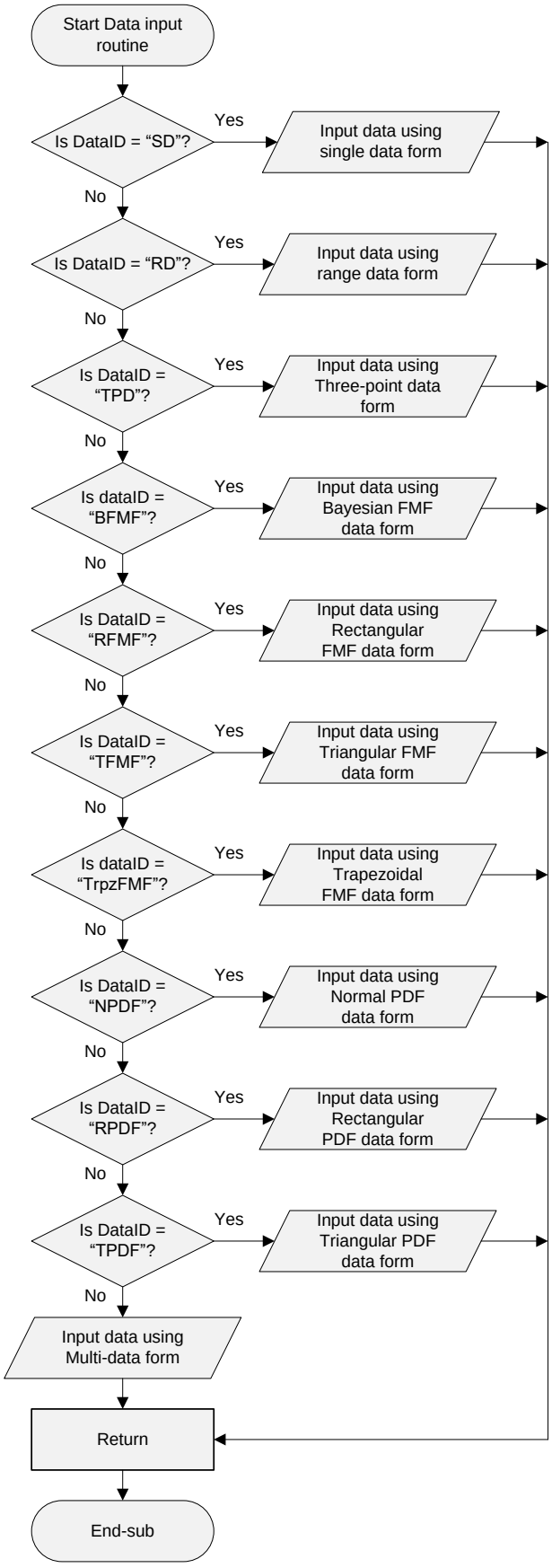


Figure 4. 12: Flowchart Representation of Data Input Routine

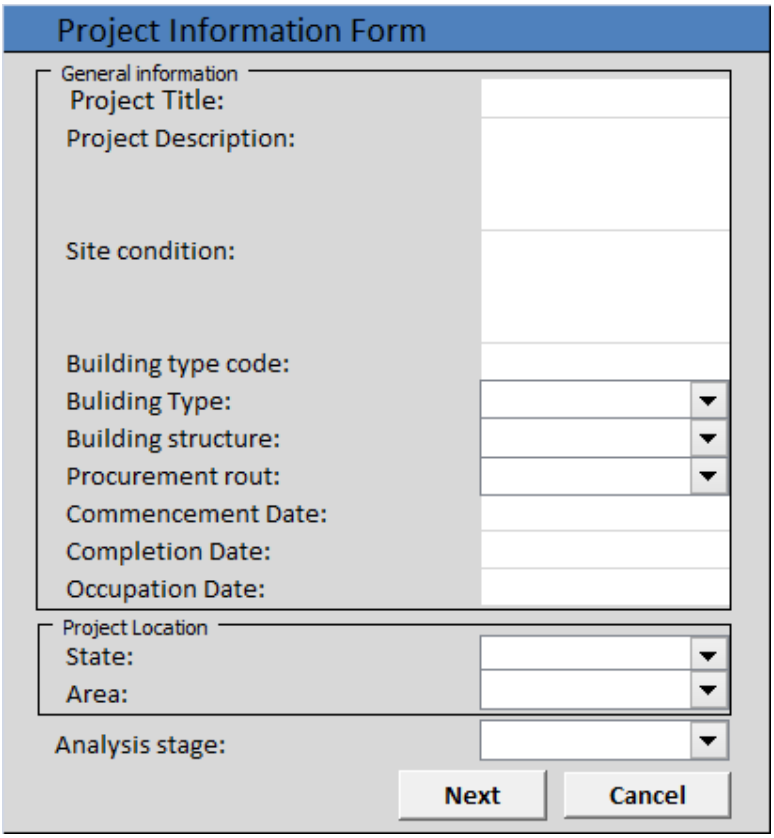


Figure 4. 13: Project Information Form

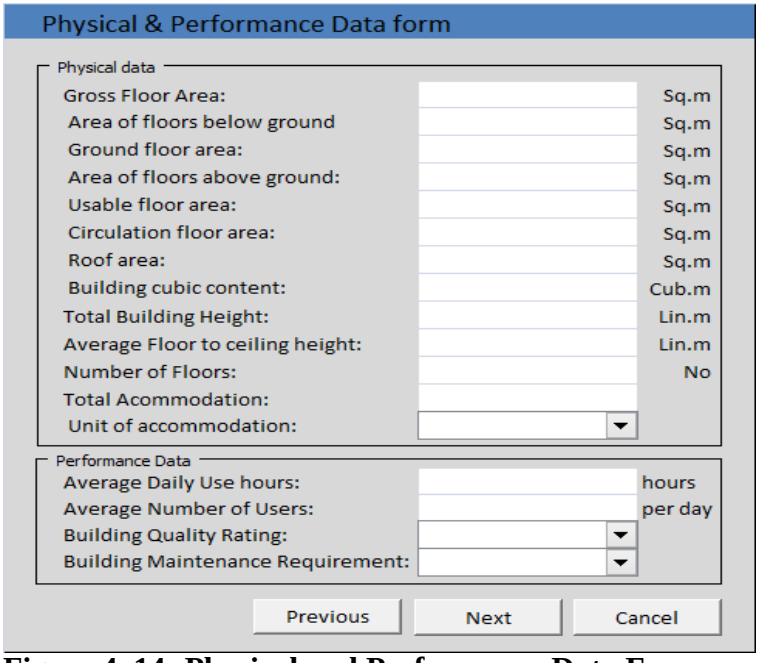


Figure 4. 14: Physical and Performance Data Form

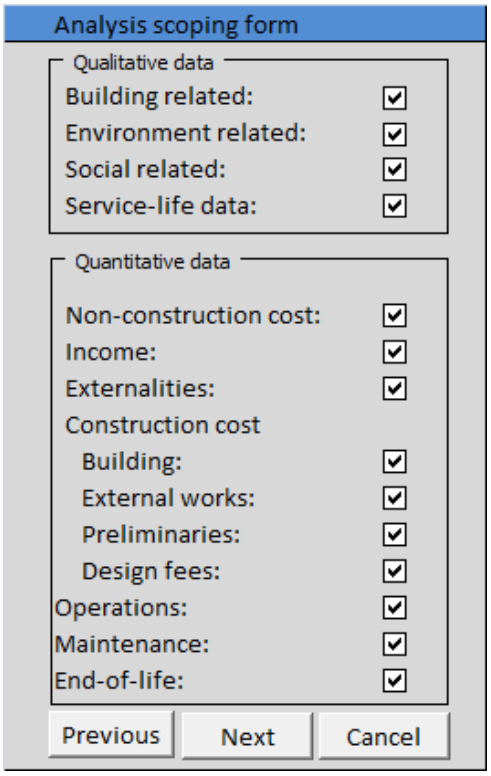


Figure 4. 15: Analysis Scoping Form

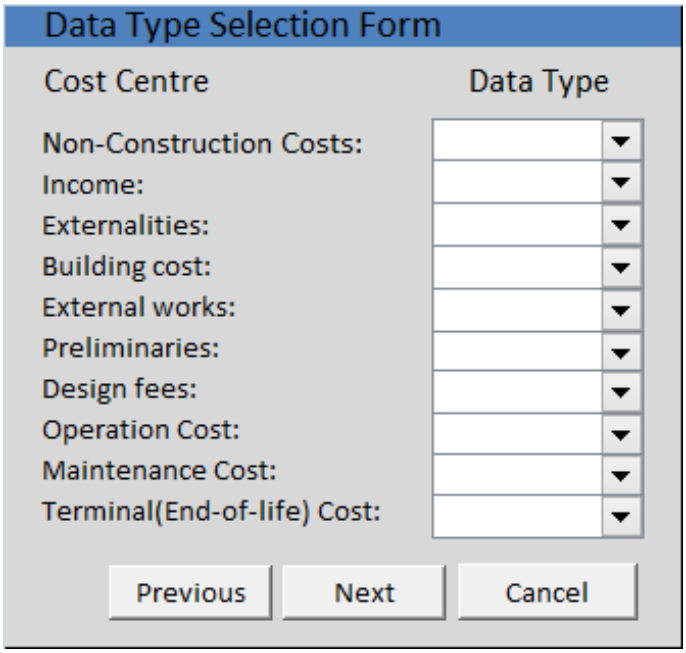


Figure 4. 16: Data Type Selection Form

Figure 4.16 shows the data type selection form for building level analysis while plates 60 to 70 shows the data input forms for the eleven data types.

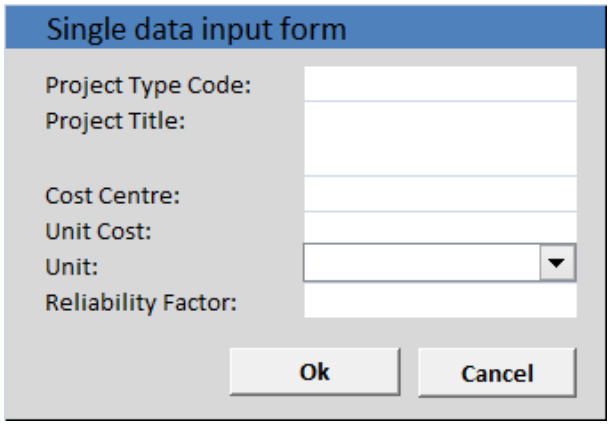


Plate 60: Single data input form

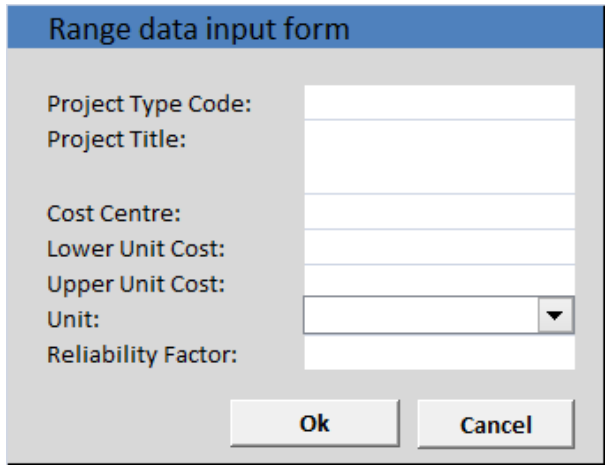


Plate 61: Range data input form

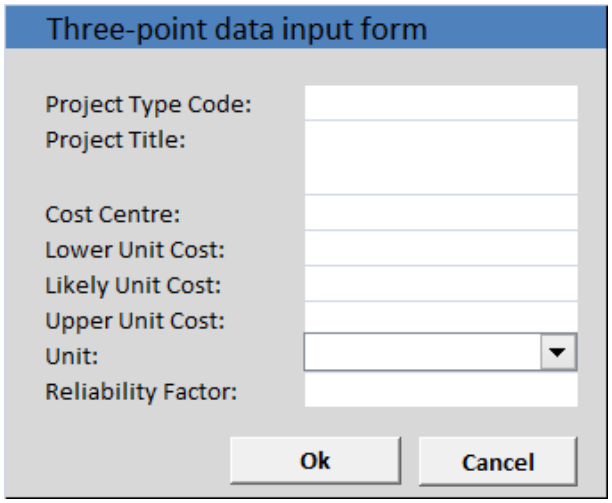


Plate 62: Three-point data input form

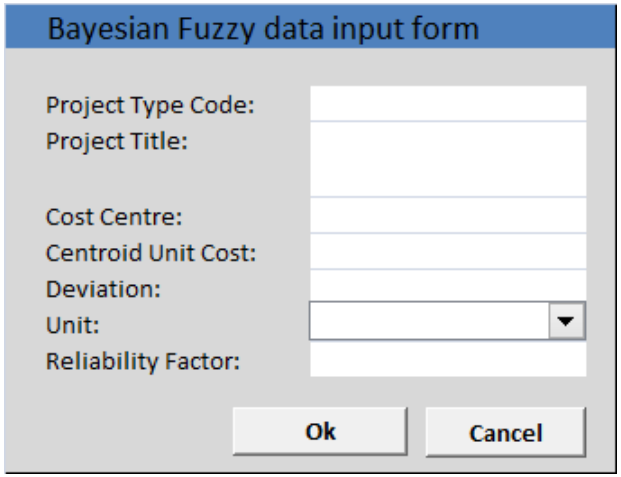


Plate 63: Bayesian fuzzy data input form

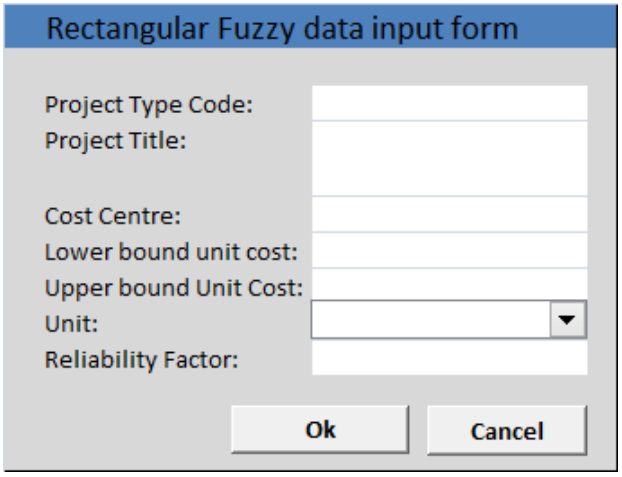


Plate 64: Rectangular fuzzy data input form

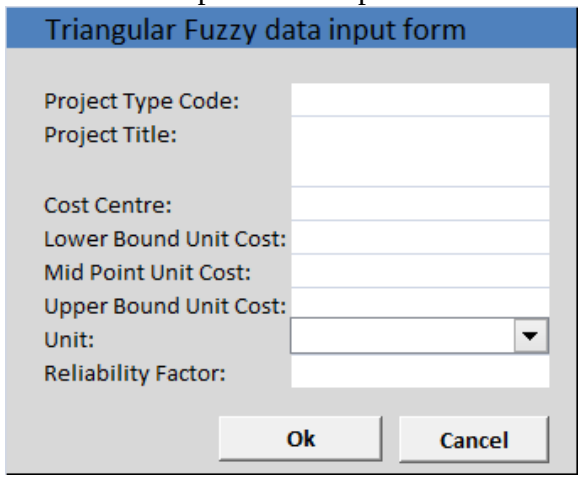


Plate 65: Triangular fuzzy data input form

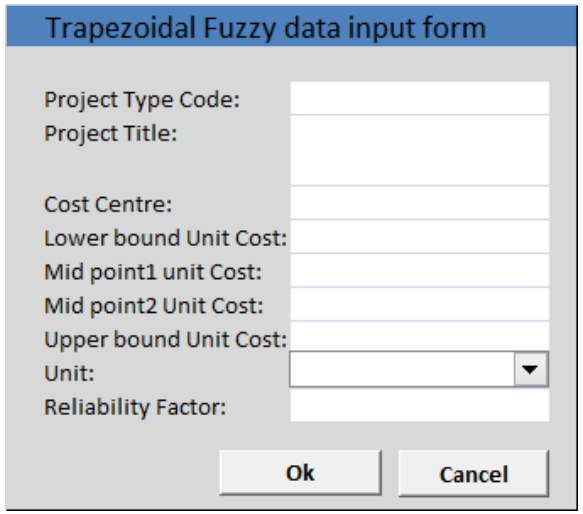


Plate 66:Trapezoidal fuzzy data input form

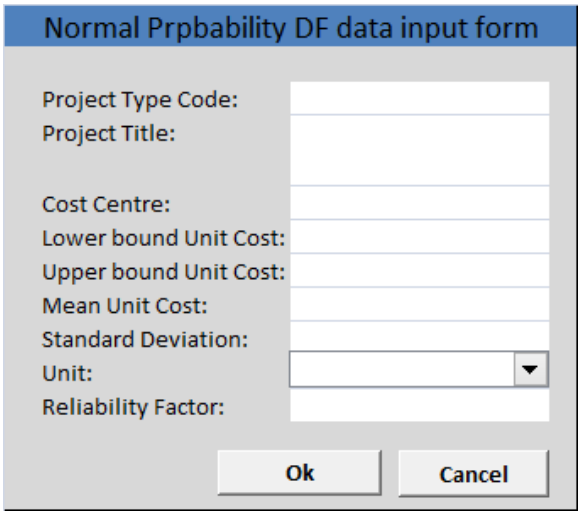


Plate 67: Normal PDF data input form

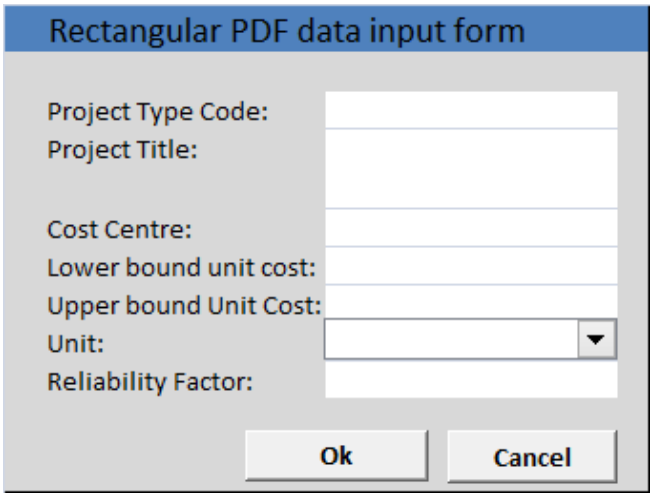


Plate 68: Uniform PDF data input form

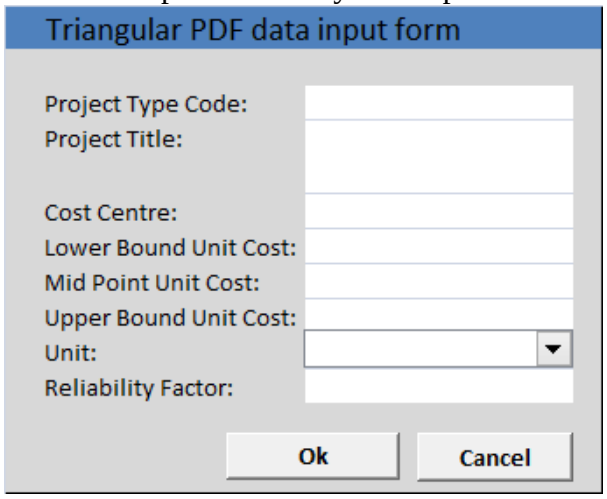


Plate 69: Triangular PDF data input form

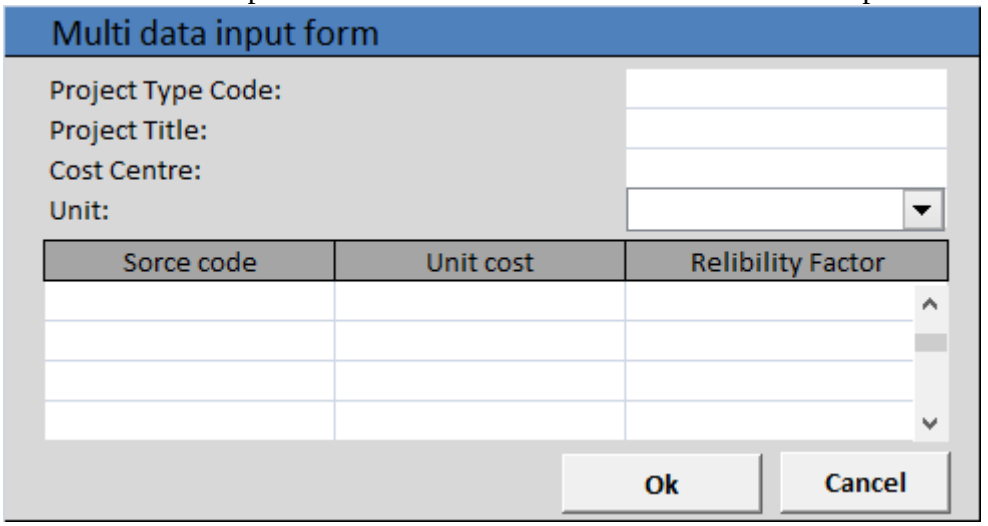


Plate 70: Multi data input form

Where building related qualitative data is in focus, the building data form shown in Figure 4.17 is displayed to enable the scoring of the various building related parameters. The list of parameters was made generic to enable the addition or omission of other parameters. Where the qualitative data is environment related, environment data form is displayed to facilitate data input for building, operations and maintenance eco-centres. Moreover, where focus is on social or service life related data the social data form and service life data forms are displayed to enable the scoring of building's social attributes and the input of the estimated service life of the building. Figure 4.18 and 4.19 shows the Social data form and the Environment data forms respectively. The social data form enables both negative and positive scoring of attributes as the impact of a building on social parameters could be positive or negative. Like the building data attributes, the social related attributes were made generic to facilitate their update. The service life data form is shown on Figure 4.20. The data input process is repeated until all data items identified at the scoping stage are imputed.

Going back to the main menu bar, and where the non-project related item under the data analysis menu is selected, control is transferred to non-project analysis routine. Figure 4.21 is a flowchart representation of the routine. From the figure, a prompt for the identification of the variable to analyse first appear. This is achieved at the menu level (as in plate 5). Where interest rate, lending, or inflation rate is selected, the rates input form shown on Figure 4.22 is displayed to enable the imputation of data. Where location adjustment factor is selected, the location factors form (Figure 4.23) is displayed, and where price or cost indices are selected, the indices data form (Figure 4.24) is presented to prompt the input of relevant data. After the data input is complete, control is transferred to the main form where another activity session is initiated.

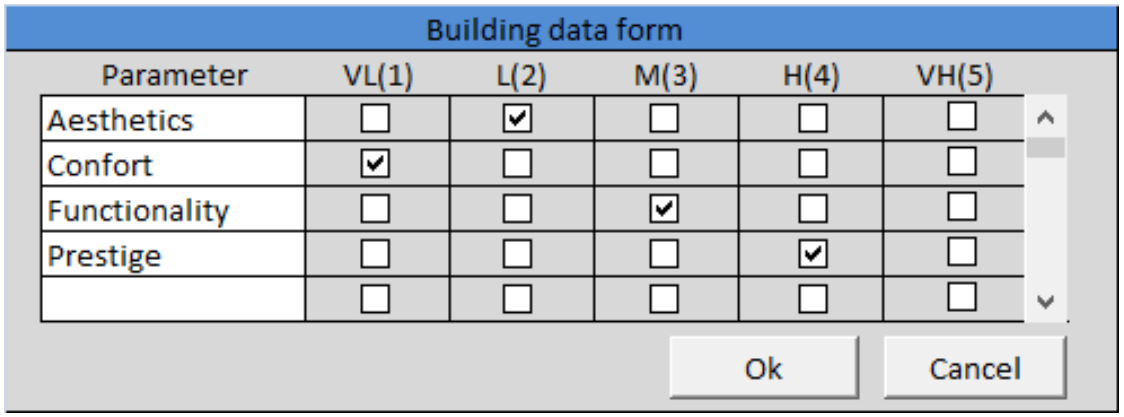


Figure 4. 17: Building data form

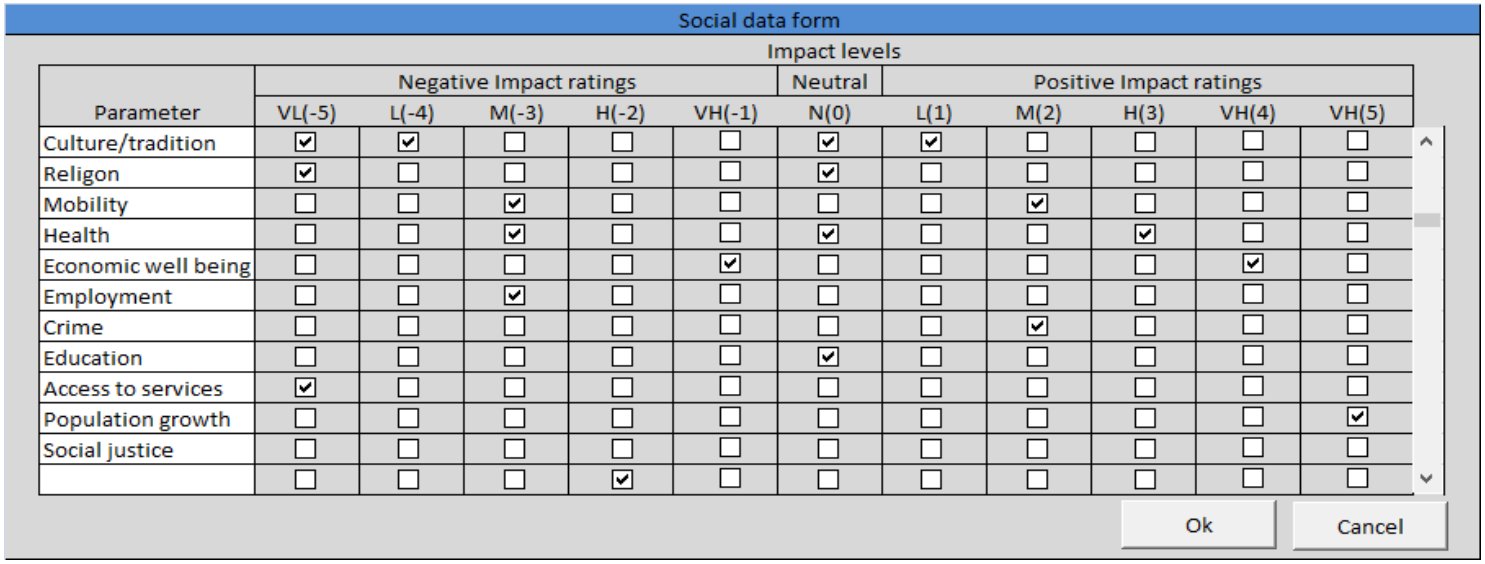


Figure 4. 18: Social data form

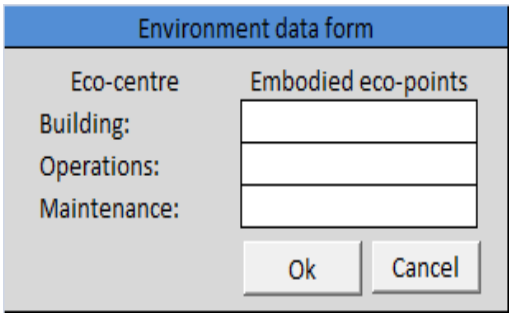


Figure 4. 19: Environment data form

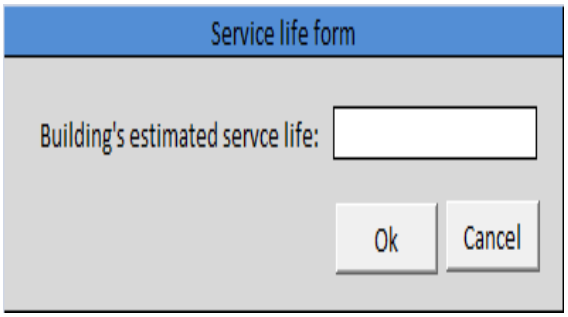


Figure 4. 20: Service life data form

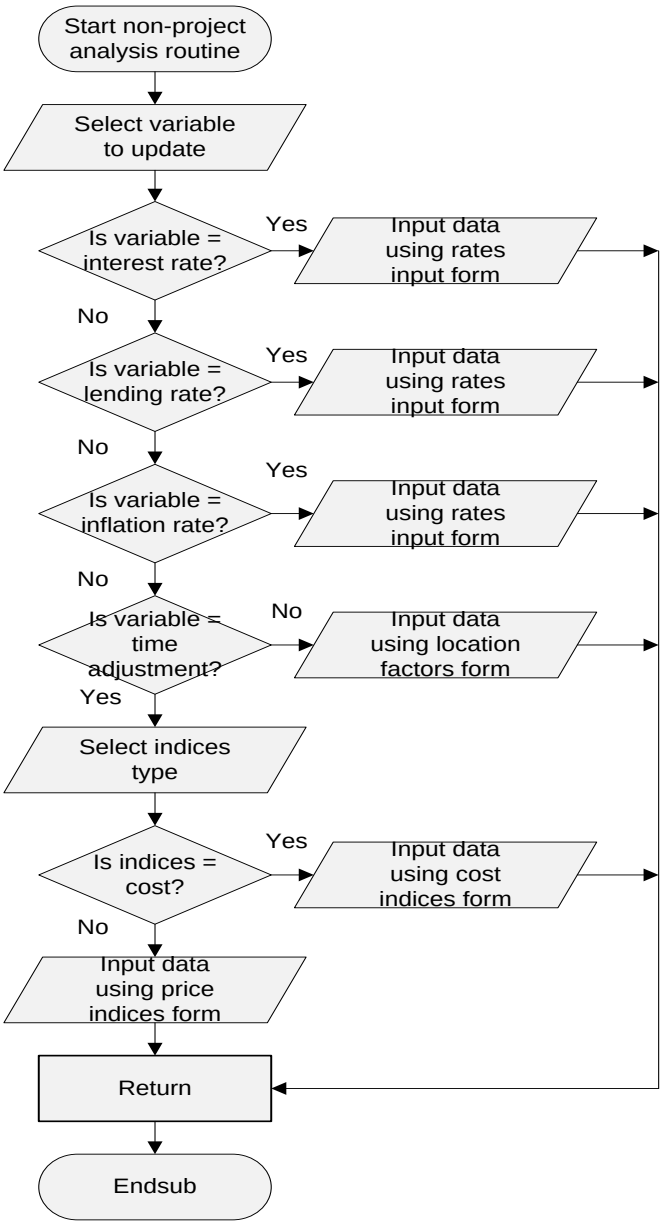


Figure 4. 21: Flowchart representation of non-project related analysis routine

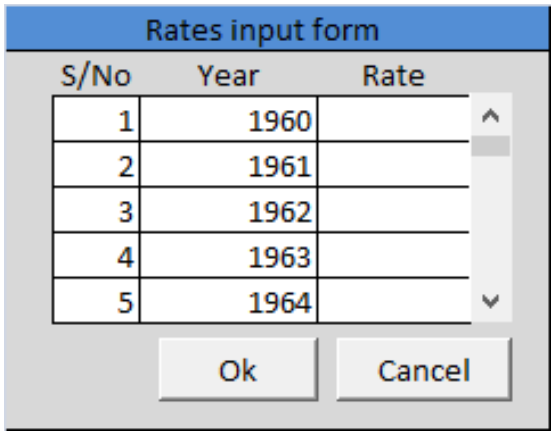


Figure 4. 22: Rates input form

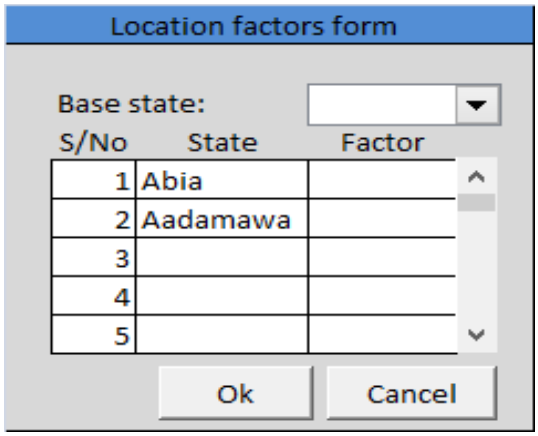


Figure 4. 23: Location factors form

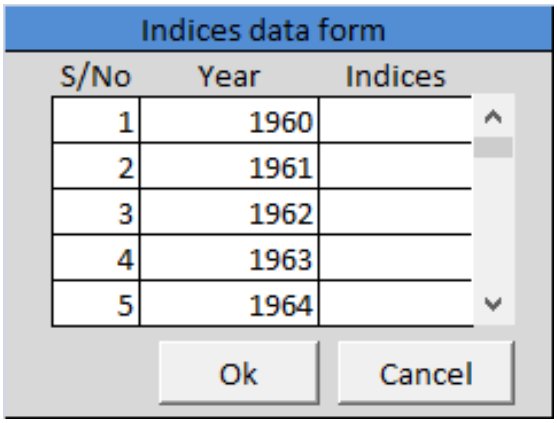


Figure 4. 24: Indices data form

The structure of concept analysis, developed analysis, technical analysis and construction analysis routines are similar to that of the planning stage. However analysis scoping and data type selection, for quantitative and some qualitative data are achieved at group-element, element, sub-element and component levels for concept, technical and developed design and construction stages respectively. In addition, the levels of detail for the various cost centres was further broken down to provide more detailed information. Where concept design stage is selected for instance, a first level data scoping form similar to the one shown on Figure 4.12 is displayed. For each data centre checked on the first level form, a corresponding second level scoping form is displayed to finalise the scoping process. Samples of the data scoping and data type selection form for the concept design stage are presented on Figures 4.25 to 4.42.

Corresponding data entry forms similar to those of plates 60 to 70 are then displayed for each of the quantitative data centre to complete the data entry process.

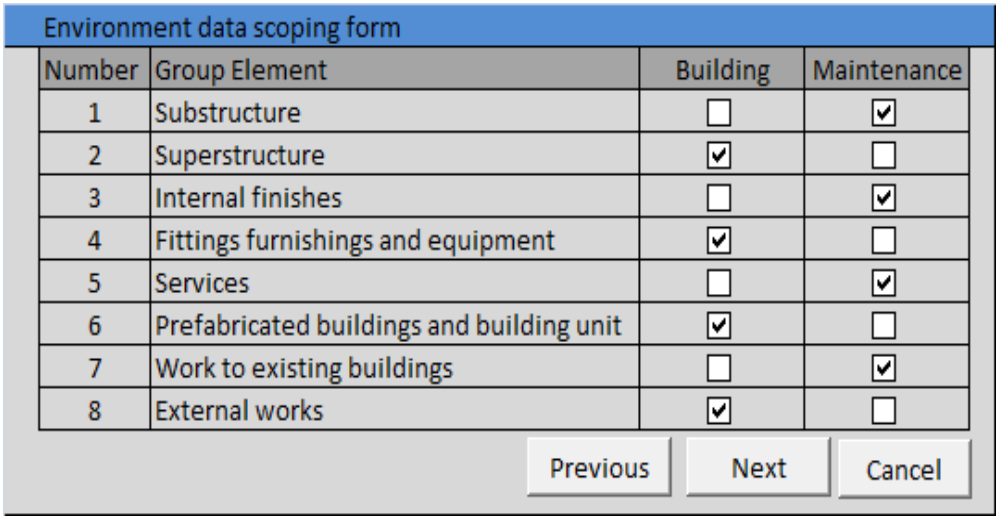


Figure 4. 25: Data scoping form for building's environmental burdens

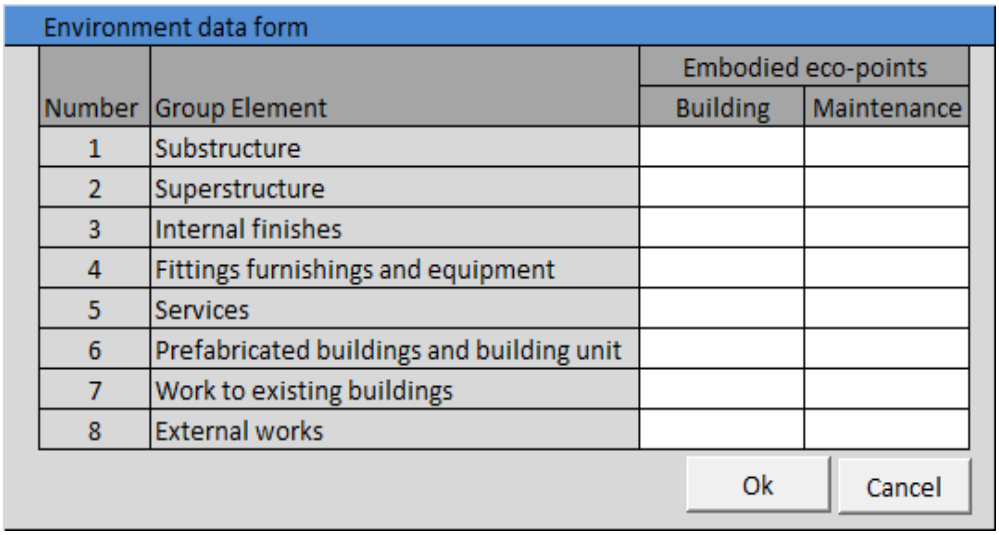


Figure 4. 26: Data collection form for building's environmental burdens

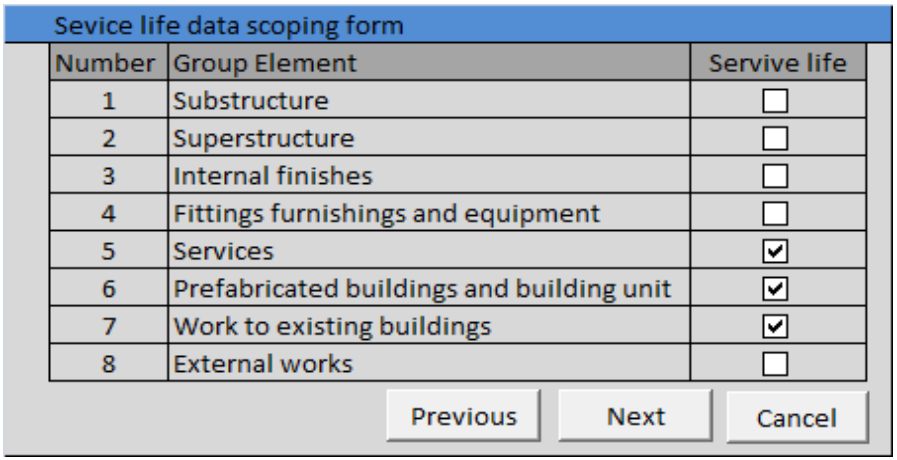


Figure 4. 27: Building service life data scoping form

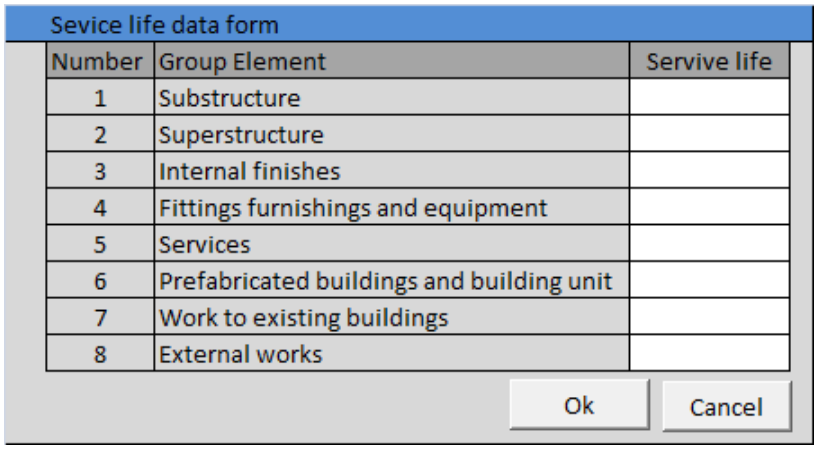


Figure 4. 28: Data collection form for building's service life

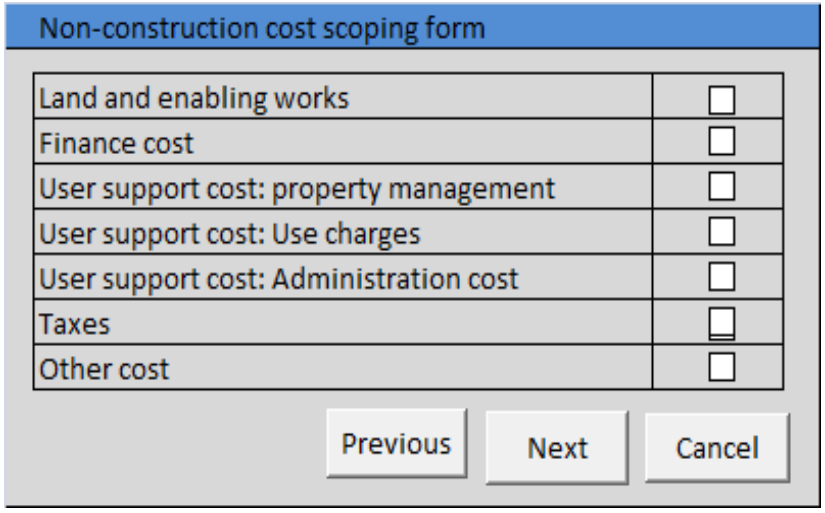


Figure 4. 29: Data scoping form for non-construction cost

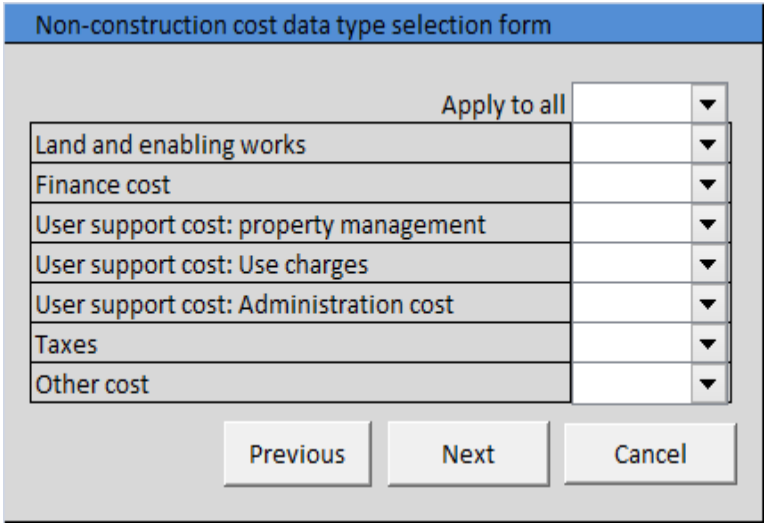


Figure 4. 30: Data entry form for non-construction costs

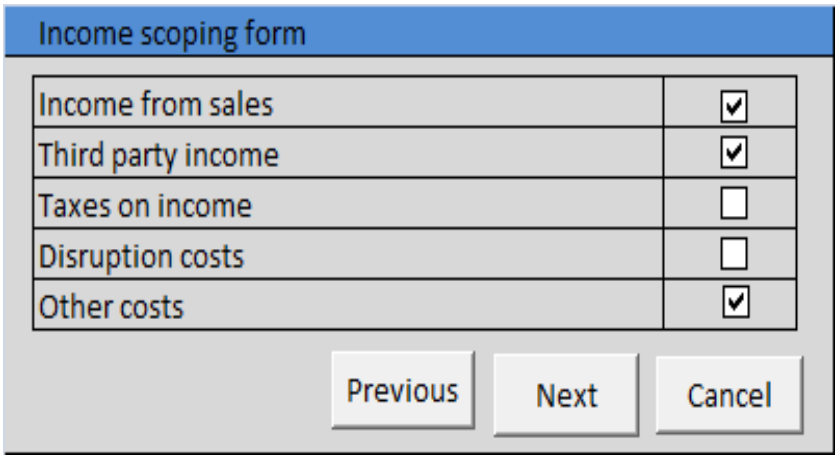


Figure 4. 31: Income data scoping form

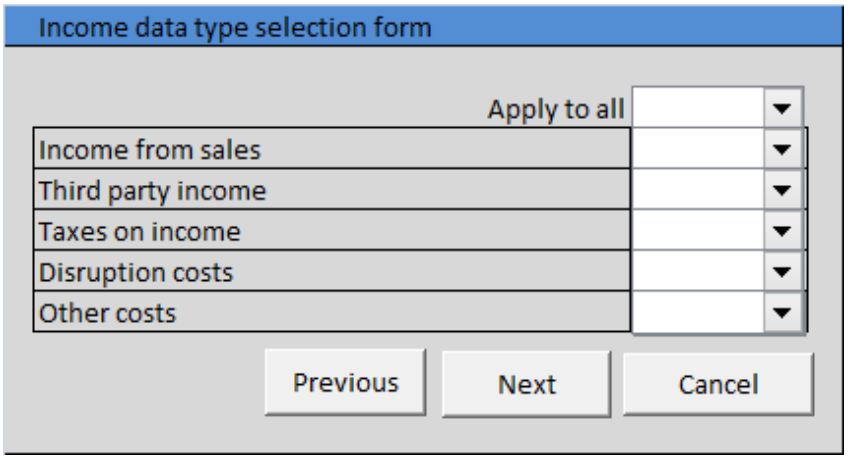


Figure 4. 32: Income data entry form

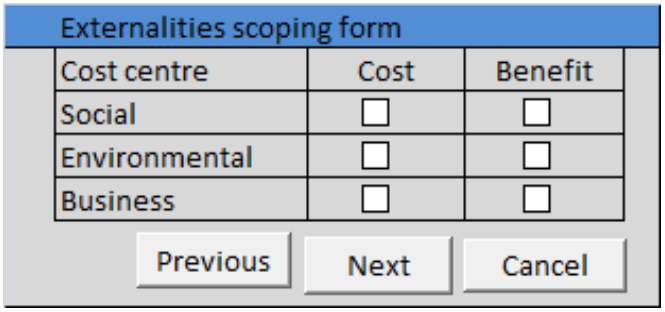


Figure 4. 33: Externalities data scoping form

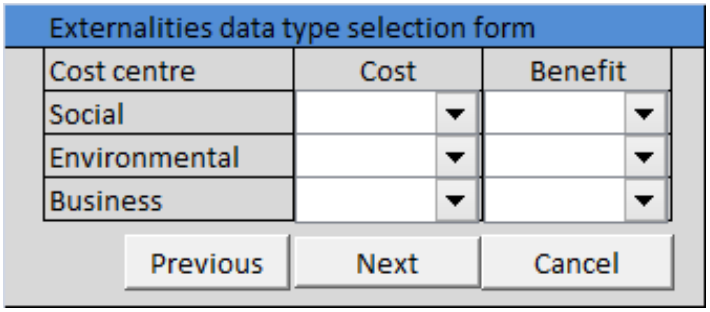


Figure 4. 34: Externalities data entry form

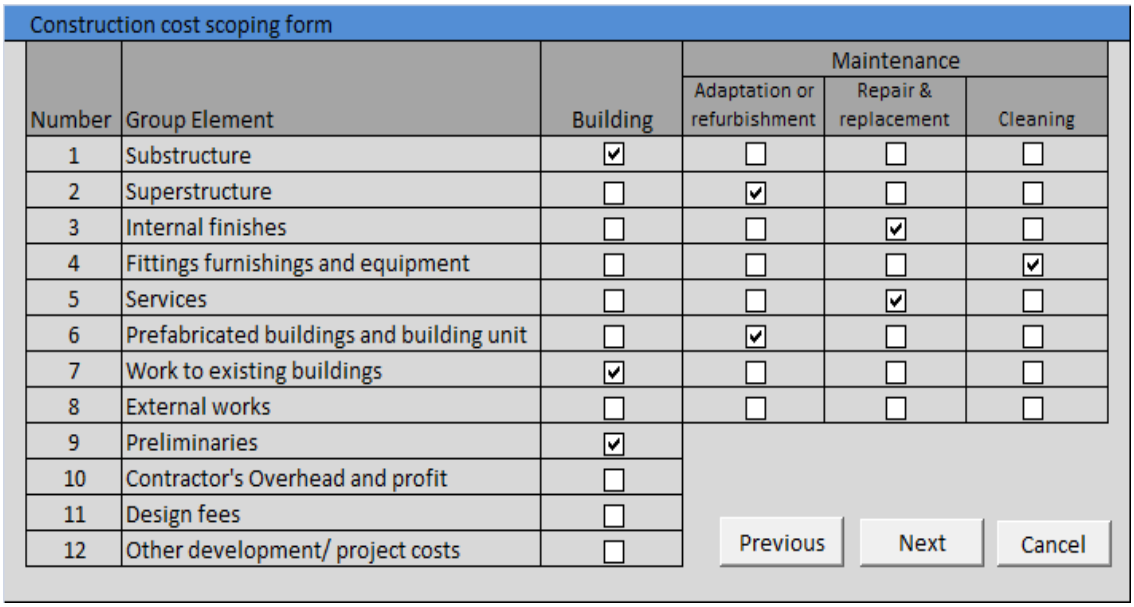


Figure 4. 35: Data scoping form for construction cost

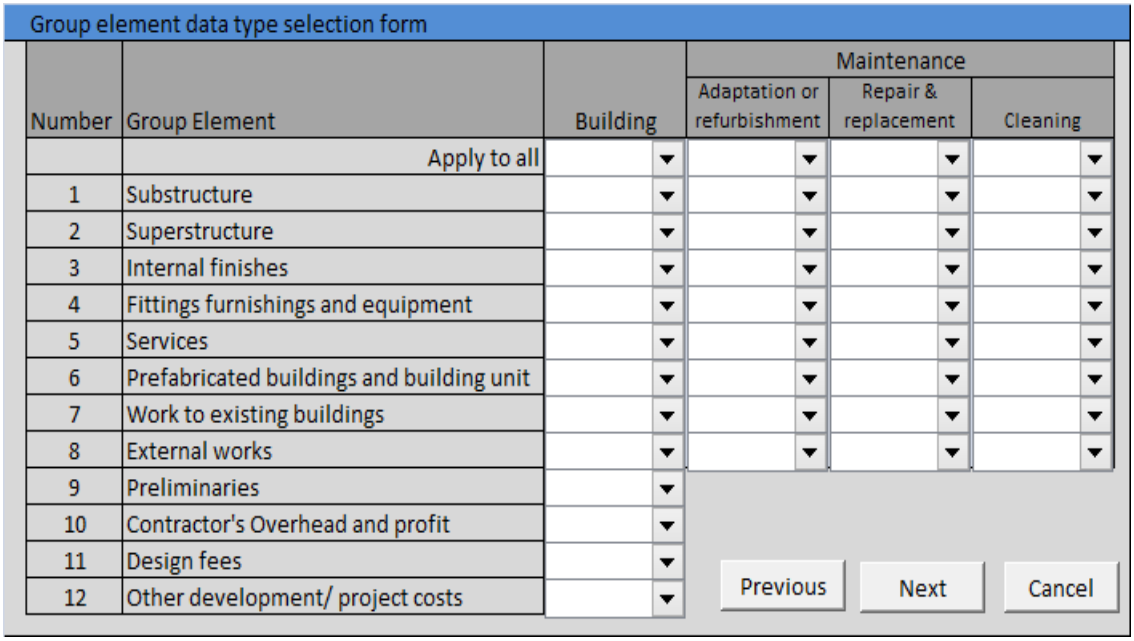


Figure 4. 36: Data type selection form for initial and maintenance cost

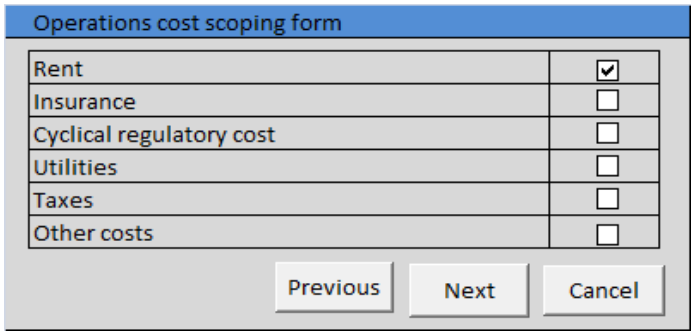


Figure 4. 37: Data scoping form for operations cost

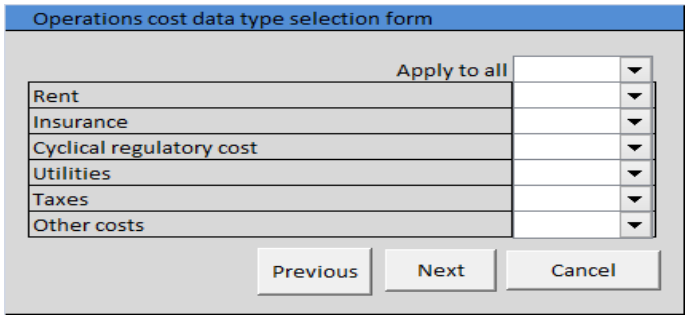


Figure 4. 38: Data type selection form for operations cost.

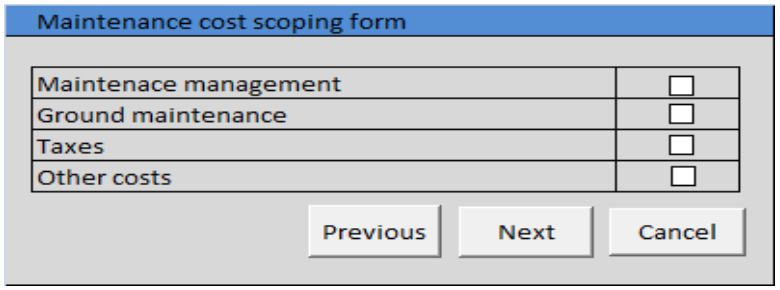


Figure 4. 39: Data scoping form for maintenance cost

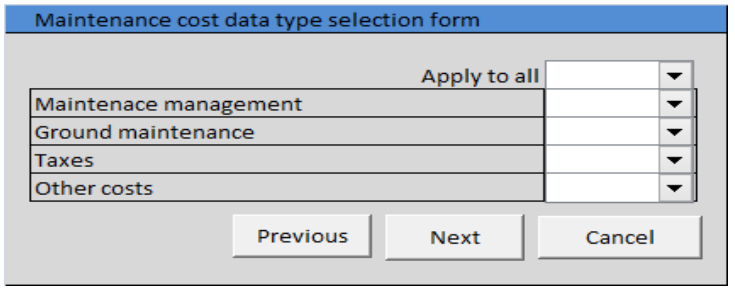


Figure 4. 40: Data type selection form for maintenance cost

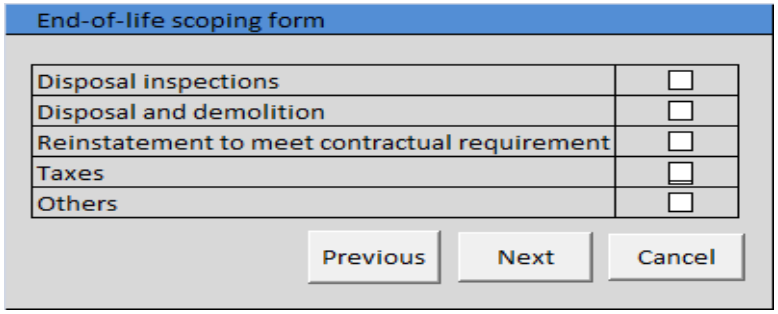


Figure 4. 41: Data scoping form for end-of-life

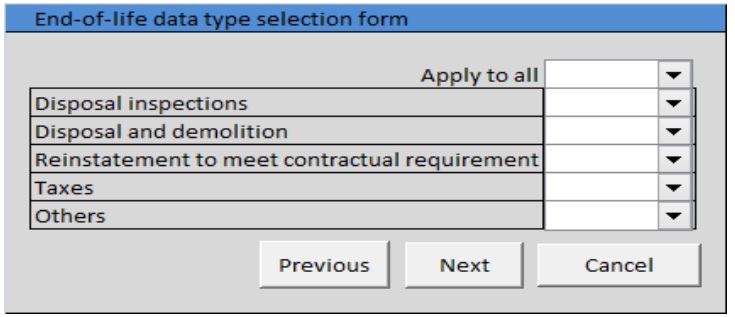


Figure 4. 42: Data type selection form for end-of-life

4.7.3 Database Design

The database was designed to facilitate the storage and retrieval of data in a structured manner. The data structure which facilitates the organisation of the database into tables, records fields and the establishment of relationship had been developed in section 4.2.1, while the data collection forms were designed and presented in section 4.3.2. The design of the forms facilitated the assignment of a table to each form with each data field on the form representing a field on the table. The main table is the "Project information table" consisting of thirteen fields each corresponding to a field on the "Project information form" and an additional field (ProjectID) which serves as the table's Primary Key (PK) and uniquely identifies each record on the table. Some of the fields on the table like; Building type, Building structure, State, Area and Analysis stage, were represented on the table using the Foreign Keys(FK) of their corresponding list tables. In other words, the options under each of the fields were registered on a separate table who's PK was represented as a FK on the "Project information" table to qualify them as "look-up" fields and also establish a relationship between the tables. Table 4.9, 4.10, 4.11, 4.12, and 4.13 shows the list of items under each table. The states table contains a list of the states of the Federation and the Federal Capital Territory.

The "Physical and performance data" table records the data collected on the "Physical & performance data form". The table consist of seventeen fields that correspond to the data fields on the form and a PK. Unit of accommodation, Building Quality Rating, and Building maintenance requirement were represented by the PK of their list tables. Tables 4.14, 4.15 and 4.16 shows the list of items contained in each look-up field alongside their unique codes.

Table 4. 9: Building Types and their Codes

S/No.	BuildingID	Building Description
1	ComBldg	Commercial Building
2	FarBldg	Farm Building
3	HosBldg	Hospital Building
4	HotBldg	Hotel Building
5	OfficeBldg	Office Building
6	RecBldg	Recreational Building
7	RelBldg	Religious Building
8	ResBldg	Residential Building
9	SchBldg	School Building
10	IndBldg	Industrial building

Table 4. 10: Building Structures and their Codes

S/No.	StructureID	Description
1	Concrete	Concrete Framed Structure
2	Prefab	Prefabricated Structure
3	Steel	Steel Framed Structure
4	Timber	Timber Framed Structure
5	Unframed	Unframed Structure

Table 4. 11: Procurement routes and their Codes

S/No.	ProcurementID	Description
1	TP	Traditional
2	MC	Management contacting
3	CM	Construction management
4	DB	Design and build
5	CC	Concession contracts
6	PPP	Public Private Partnering

Table 4. 12: Area Locations and their Codes

S/No.	AreaID	Area Description
1	Rural	Rural Areas
2	Suburban	Suburban Centers
3	Urban	Urban Centres

Table 4. 13: Life Cycle Stages and thier Codes

S/No.	StageID	Description
1	PStage	Planning
2	CDLStage	Concept design
3	TDStage	Technical design
4	DDStage	Developed design
5	Cstage	Construction
6	OStage	Operation
7	EOLStage	End-of-life

Table 4. 14: Units of Accommodation and their Codes

S/No.	UnitID	Description
1	OUT	Output
2	BED	Bed
3	SEAT	Seat
4	BRom	Bedroom
5	SM	Sq.m
7	CM	Cub.m
8	BAG	Bag
9	HEAD	Head
10	MAN	Person
11	PACK	Package
12	BIRD	Bird
13	ANIMAL	Animal
14	INP	Input

Table 4. 15: Quality Ratings and their Codes

S/No.	QualityID	Quality Description
1	HQ	High Quality
2	LQ	Low Quality
3	MQ	Medium Quality
4	VHQ	Very High Quality
5	VLQ	Very Low Quality

Table 4. 16: Maintenance Requirements and their Codes

S/No.	MaintenanceID	Policy Description
1	KE	Keep in excellent condition
2	KG	Keep at least in good condition
3	KF	Keep at least in fair condition
4	TP	Tolerate poor condition
5	TB	Tolerate bad condition

A one-to-one relationship was established between the "Project information" Table and "Physical & performance data" table as each project should have a physical and performance characteristics and conversely each physical and performance record should be associated to only one project. The analysis scoping table consist of five fields including a PK. An important field on this table is the DatacentreID which is a FK that relates the "Data centre" table containing a list of all the data centres and their

associated unique codes. The projectID and StageID fields are FKs that relates scope field (a Boolean field that takes a value of true or false) with a specific project and analysis stage. A list of the data centres and their associated codes is outlined in Appendix 1. The "Data record" table relates each project, analysis stage, data centre, and scope through ScopeID FK on one hand and data type collected through the "Data type selection form" and recorded on the "Data record" table. The "Data Type" table is also a list table containing all available data formats and their associated codes. A list of the records contained in the table is shown on Table 4.17 below.

Table 4. 17: Data Types and their Unique Codes

S/No.	DataID	Description
1	BFMF	Bayesian Fuzzy Membership Function
2	MD	Multi-data
3	NPDF	Normal Probability Distribution Function
4	RD	Range data type
5	RFMF	Rectangular Fuzzy Membership Function
6	UPDF	Uniform Probability Distribution Function
7	SD	Single data type
8	TFMF	Triangular Fuzzy Membership Function
9	TPD	Three Point data type
10	TPDF	Triangular Probability Distribution Function
11	TrpzFMF	Trapezoidal Fuzzy Membership Function
12	QBR	Qualitative building related
13	QSR	Qualitative Social related
14	QER	Qualitative Environment related
15	QSLR	Qualitative service Life related

Depending on the selected format for each data centre, an appropriate data input form is used to collect and record data on one of the corresponding fifteen number data tables. Each of the data tables is related to the "Data record" table through the DatarecordID FK to complete the relationship chain.

The non-project related data collected with the aid of Rates, location factors, and Indices, input forms presented on Figures 4.22, 4.23, and 4.24 are recorded on five

tables. Data collected using the "Rates input form" is recorded on the "Rates able" which is related to the “Rate types" table through the RatetypeID FK. The "Rate types" table contains a list of the available rates as shown on Table 4.18. The year and Rates fields record the values of a rate and the corresponding year of occurrence. The information imputed through the indices data form is stored on the indices table. The IndicestypeID FK relates the "Indices table" with the "Indices type” list table that contains a list of available indices and their codes. The indices value and the year in which it occurs are recorded under Year and Indices fields of "Indices table". Table 4.19 contains the list of indices and their codes. The location factors data is recorded on a single table; "Location factor" table which contains four fields including a PK. The relative state, states and their location factors are recorded under Base state, State and Factor fields. Figure 4.43 shows the schematic representation of the database, while Table 4.20 is a summary of the field types for each table.

Table 4. 18: Rates Type and their Codes

S.No.	RatetypeID	Description
1	1	Inflation rate
2	2	Discount rate
3	3	Borrowing rate
4	4	Lending rate
5	5	Mortgage rate
6	6	Opportunity cost of capital
7	7	Bonds rate

Table 4. 19: Indices Types and their Codes

S.No.	IndicestypeID	Description
1	1	Building price indices
2	2	Building cost indices
3	3	Labour indices
4	4	Material
5	5	Plant cost indices

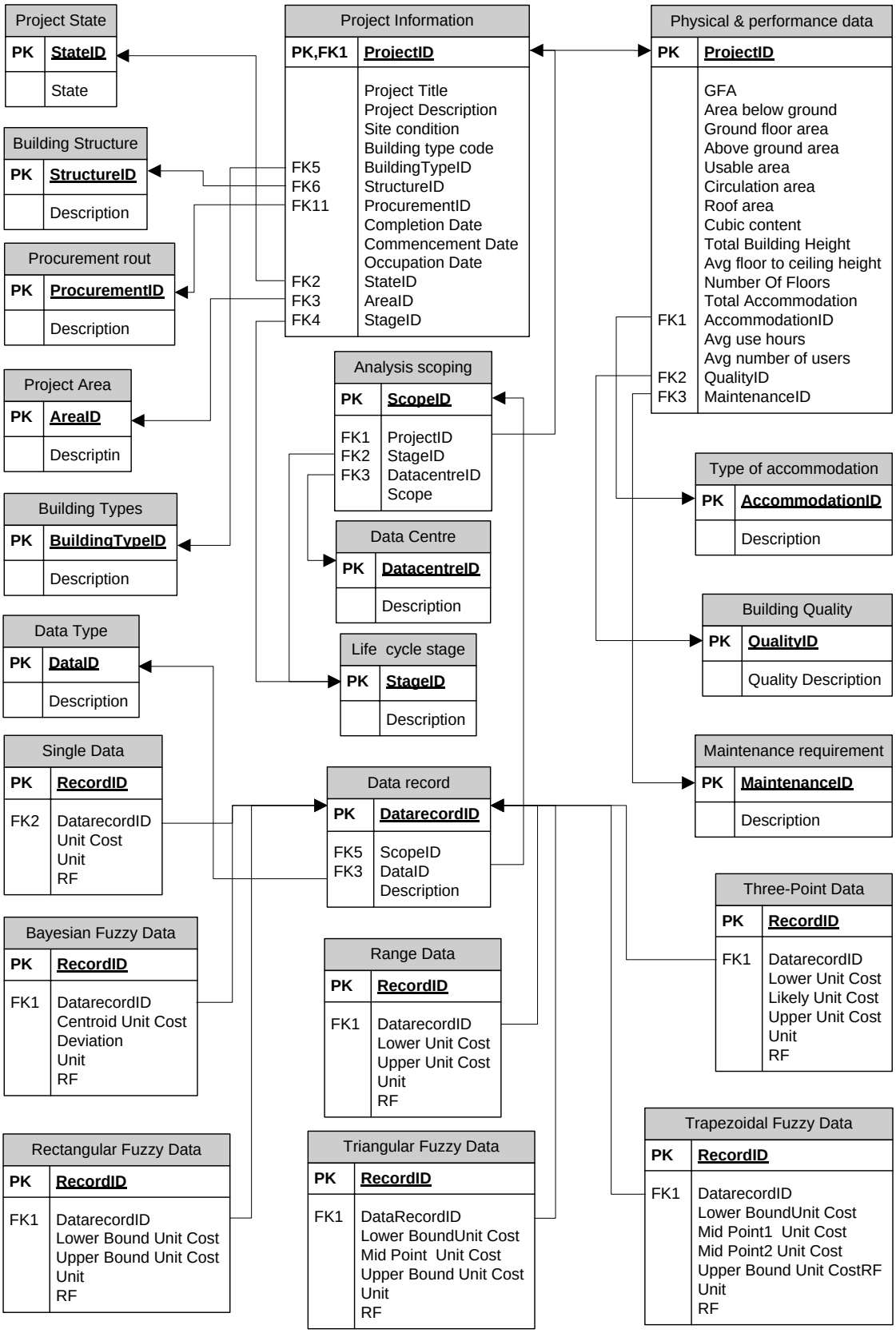


Figure 4. 43: WLC Analysis Relational Database

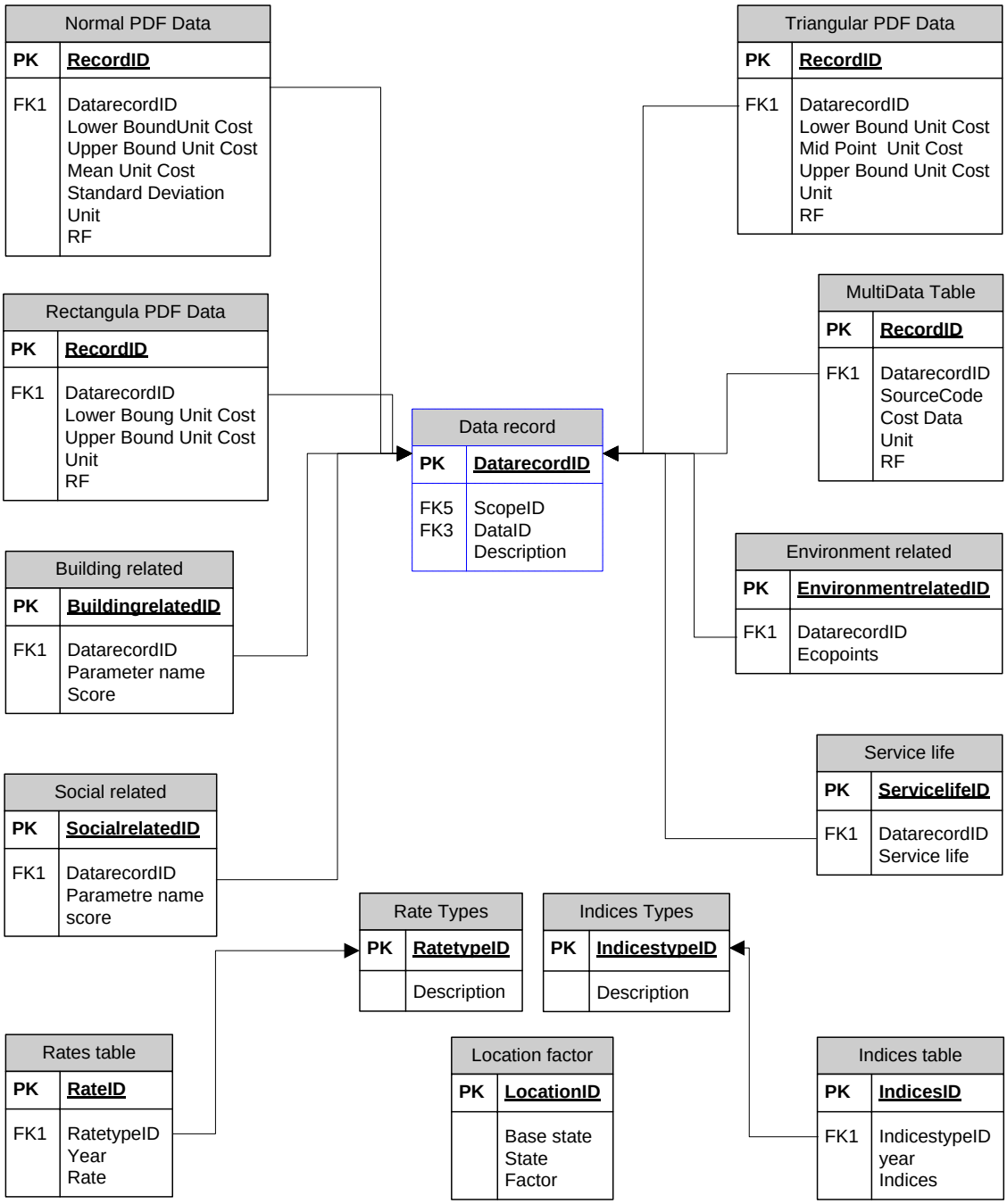


Figure: 4.43: WLC Analysis Relational Database Continues

Table 4. 20: Summary of Field Types for Database Tables

Table Name	Field name	Field type
Project Information	ProjectID	PK, AutoNumber
	Project title	Text
	Project Decription	Memo
	Site condition	Memo
	Building type code	Text
	BuildingTypeID	FK, Alphanumeric
	StructureID	FK, Alphanumeric
	ProcurementID	FK, Alphanumeric
	Completion date	Date
	Commencement date	Date
	Occupation date	Date
	StateID	FK, Alphanumeric
	AreaID	FK, Alphanumeric
	StageID	FK, Alphanumeric
Physical & performance data	ProjectID	PK, AutoNumber
	GFA	Real number
	Area below ground	Real number
	Ground floor area	Real number
	Above ground area	Real number
	Usable area	Real number
	Circulation area	Real number
	Roof area	Real number
	Cubic content	Real number
	Total building height	Real number
	Avg floor to ceiling height	Real number
	Number of floors	Integer number
	Total accommodation	Integer number
	AccommdationID	FK, Alphanumeric
	Avg use hours	Real number
	Avg number of users	Integer number
	QualityID	FK, Alphanumeric
	MaintenanceID	FK, Alphanumeric
Analysis scoping	ScopeID	PK, AutoNumber
	ProjectID	FK, AutoNumber
	StageID	FK, Text
	DatacentreID	FK, Text
	Scope	Boolean
Project State	StateID	PK, Text
	Description	Text
Building Structure	StructureID	PK, Text
	Description	Text
Procurement rout	ProcurementID	PK, Text
	Descripton	Text
Project Area	AreaID	PK, Text
	Description	Text
Building Types	BuildingtypeID	PK, Text
	Description	Text

Data Type	DataID	PK, Text
	Description	Text
Data Centre	DatacentreID	PK, Text
	Description	Text
Life cycle stage	StageID	PK, Text
	Description	Text
Data record	DatarecordID	PK, AutoNumber
	ScopeID	FK, Text
	DataID	FK, Text
	Description	Text
Type of accommodation	AccommodationID	PK, Text
	Description	Text
Building Quality	QualityID	PK, Text
	Description	Text
Maintenance requirement	MaintenanceID	PK, Text
	Description	Text
Single Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Unit cost	Currency
	Unit	Text
	RF	Real number
Range Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Lower unit cost	Currency
	Upper unit cost	Currency
	Unit	Text
	RF	Real number
Three-Point Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Lower unit cost	Currency
	Likely unit cost	Currency
	Upper unit cost	Currency
	Unit	Text
	RF	Real number
Bayesian Fuzzy Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Centroidr unit cost	Currency
	Deviation	Real number
	Unit	Text
	RF	Real number
Rectangular Fuzzy Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Lower bound unit cost	Currency
	Upper bound unit cost	Currency
	Unit	Text
	RF	Real number
Triangular Fuzzy Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Lower Bound unit cost	Currency
	Mid Point unit cost	Currency

	Upper Bound unit cost	Currency
	Unit	Text
	RF	Real number
Trapezoidal Fuzzy Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Lower Bound unit cost	Currency
	Mid Point1 unit cost	Currency
	Mid Point2 unit cost	Currency
	Upper Bound unit cost	Currency
	Unit	Text
	RF	Real number
Normal PDF Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Lower Bound unit cost	Currency
	Upper Bound unit cost	Currency
	Mean Unit cost	Currency
	Standard Deviation	Real number
	Unit	Text
	RF	Real number
Rectangular PDF Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Lower bound unit cost	Currency
	Upper bound unit cost	Currency
	Unit	Text
	RF	Real number
Triangular PDF Data	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Lower Bound unit cost	Currency
	Mid Point unit cost	Currency
	Upper Bound unit cost	Currency
	Unit	Text
	RF	Real number
MultiData Table	RecordID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Source	Text
	Cost data	Currency
	Unit	Text
	RF	Real number
Building related	BuildingrelatedID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Parameter name	Text
	Score	Integer number
Social related	SocialrelatedID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Parameter name	Text
	Score	Integer number
Environment related	EnvironmentrelatedID	PK, AutoNumber
	DatarecordID	FK, AutoNumber
	Ecopoints	Integer number
Service life	ServicelifeID	PK, AutoNumber

	DatarecordID	FK, AutoNumber
	Service life	Integer
Rates table	RateID	PK, AutoNumber
	RatetypeID	FK, AutoNumber
Rates types	RatetypeID	PK, AutoNumber
	Description	Text
Indices Types	IndicestypeID	PK, AutoNumber
	Description	Text
Indices table	IndicesID	PK, AutoNumber
	IndicestypeID	FK, AutoNumber
	Year	Date
	Indices	Integer
Location factor	LocationID	PK, Text
	Base state	Text
	State	Text
	Factor	Real

4.8 Data Preparation

This process begins with the selection of "Data preparation" on the main menu bar (Figure 4.8) which displays a drop down menu containing two options: "Prepare from file"; and "Search database". The “Prepare from file” option enables the selection of an existing analysis that would be used to conduct a WLC evaluation using the Analysis Selection Form shown on Figure 4.45. The search database option enables the querying of the database to produce a single or multiple set of results based on predefined set of criteria. Figure 4.44 shows a flowchart representation of the process. From the figure, the search criterion which includes the general project information and project physical and performance data are specified using the "Project information query form" and the "Physical and performance data query form" displayed on Figures 4.450 and 4.47.

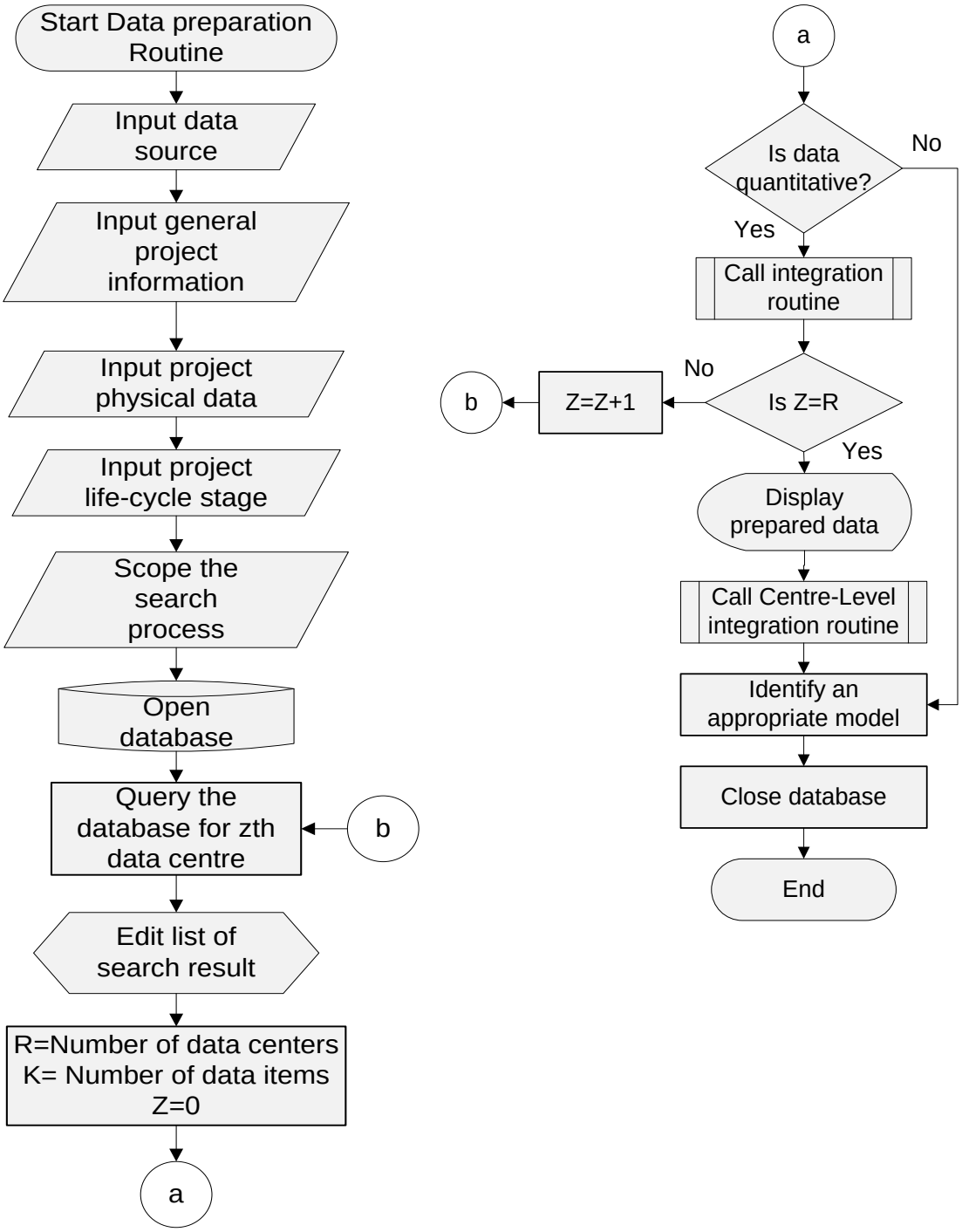


Figure 4. 44: Data Preparation Routine

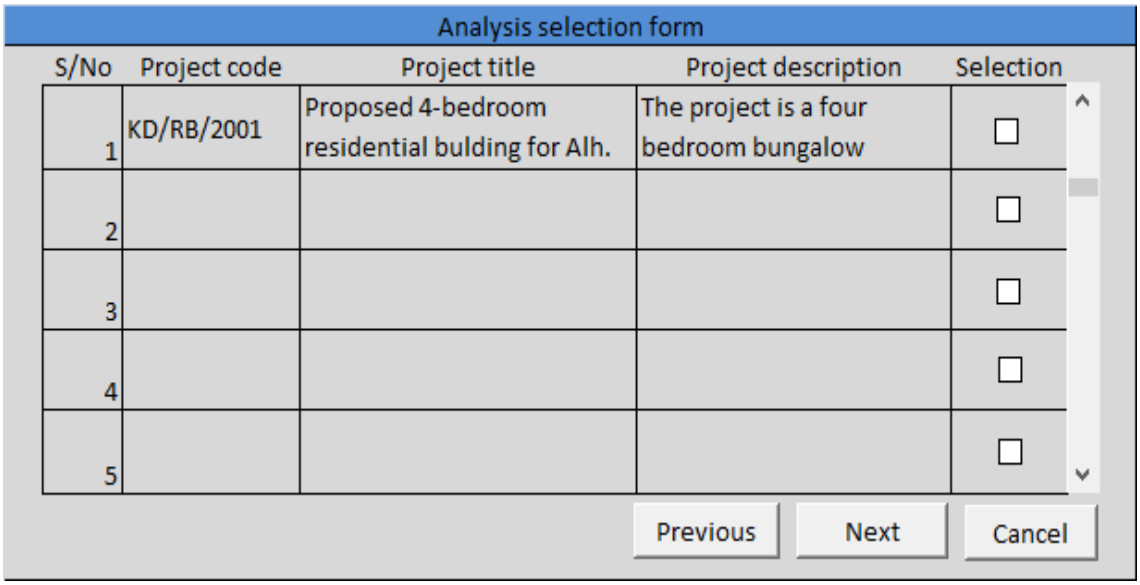


Figure 4. 45: Analysis Selection Form

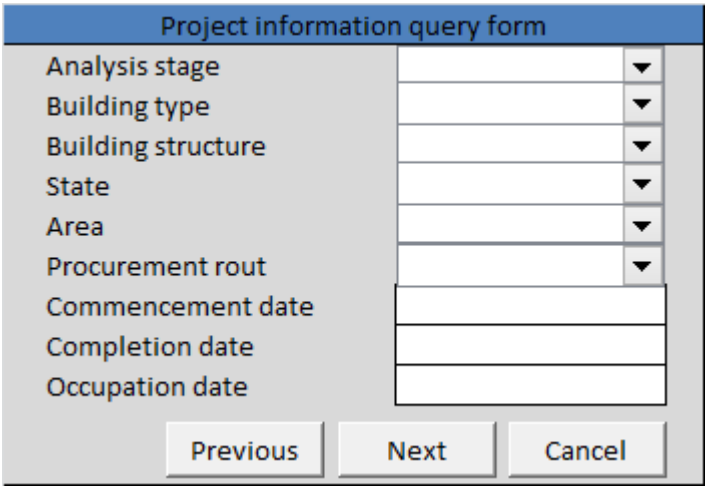


Figure 4. 46: Project Information Query Form

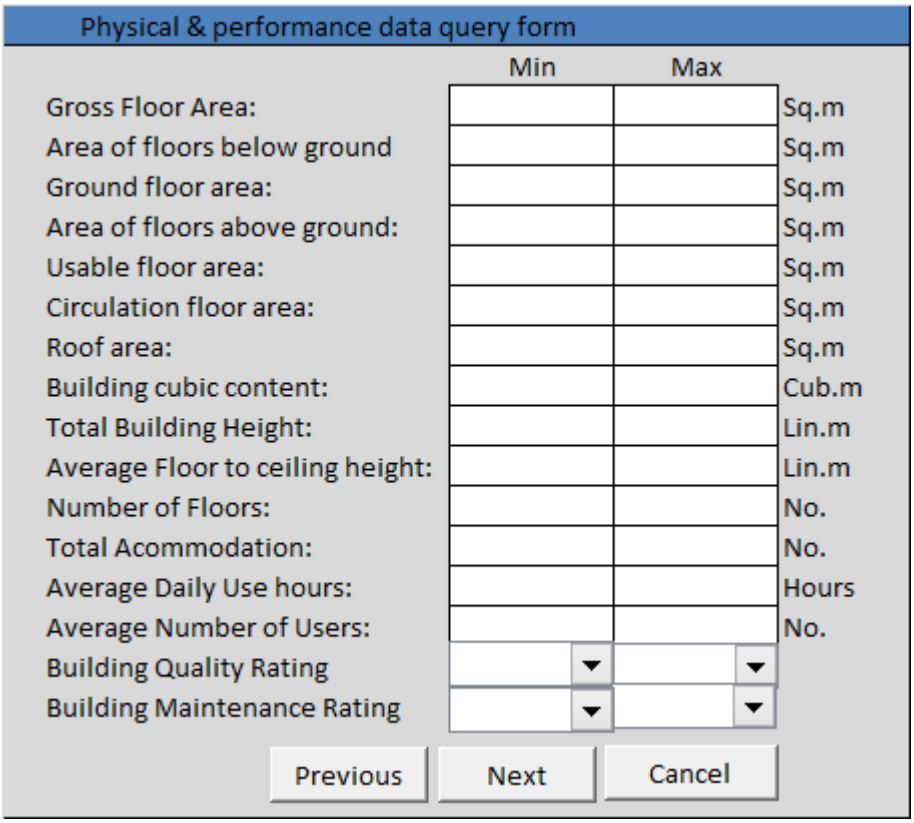


Figure 4. 47: Physical and Performance Data Query Form

The search process is then scoped using the data scoping forms similar to those of Figures 4.15, 4.25, 4.27, 4.29, 4.31, 4.33, 4.35, 4.37, 4.39, and 4.41. The database is then opened and a wild search conducted to extract data that satisfies the search criteria for the first data centre. The search result is then displayed on a "Data search/edit form" displayed on Figure 4.48. The search result can be edited by removing unwanted data type using the remove button. Where the data set is qualitative an appropriate WLC assessment model is selected. Where on the other hand the data set is quantitative, the "Integration routine" is called to convert the data set to the lowest format. The process is repeated for the entire data centres specified on the data scoping form after which the result is displayed using the data summary form shown on Figure 4.49. The view data button of the data summary form permits the viewing of the data parameters computed during cost centre level data integration. A centre level integration is then conducted to

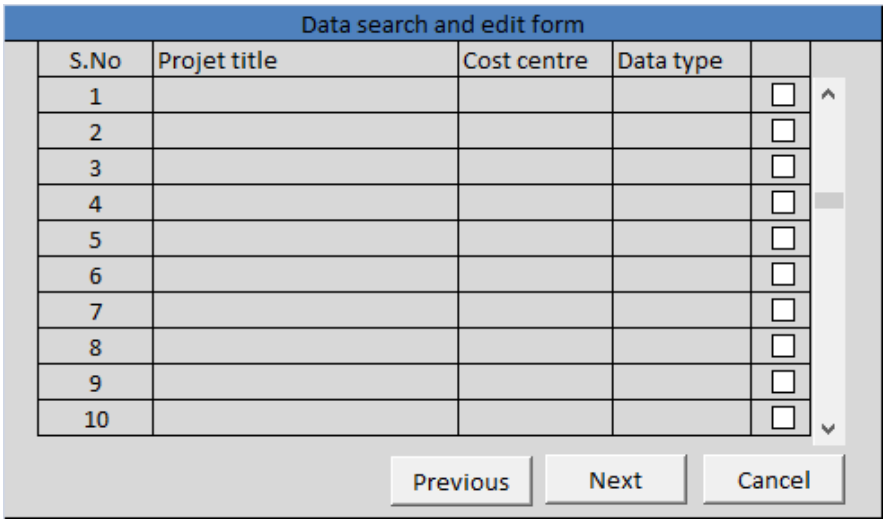


Figure 4. 48: Data Search and Edit Form

transform all data to similar format. An appropriate model is then selected, the database closed and the session ended. Prior to calling the "Integration routine" the selected or queried data are numbered in accordance with the selection or search order to give each data centre and data set a unique index as demonstrated on Figure 4.49 under the S.No and Sub.No columns. This unique number is used to identify the project general information, cost centres and their associated data types and data values. In addition, the number is used as an index for array variables used in subsequent routines.

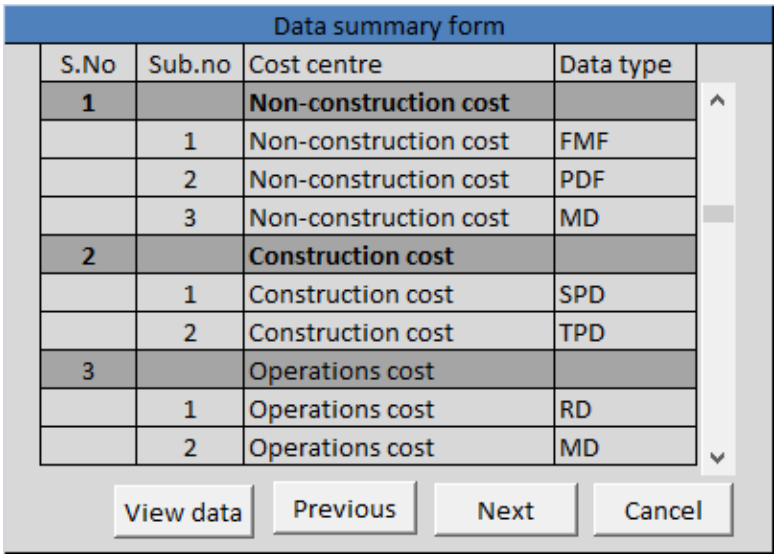


Figure 4. 49: Data Summary Form

The "Integration routine" first identifies the lowest data format and transfers control to the relevant subroutine. Where for instance the single point data is the lowest format, "Single point routine" is called which converts all higher level data formats to single point data. Figure 4.50 shows a flowchart representation of the “Integration routine" comprising six instances where either "Single point routine", "Range data routine", "Three point routine", "PDF routine"; "Fuzzy data routine"; and "Multi-data routine" subroutines are initiated to actualise the conversion of data to similar format.

The single point routine begins with the initialisation of i and TAF variables, where i is represents the unique identifier of each data format and TAF stores the value of time adjustment factors. The data type for each data item is identified through the datatype(i) array variable used to transfer control to the relevant conversion subroutine in which an appropriate adjustment or conversion formula is applied to compute the single point data equivalent and stores same in another array variable SDT(i). Where the data type is single point data (SPD), the “SPDTOSPD Routine” is invoked which first adjusts data for time and location and call upon “Risk Assessment Routine” to accomplish data level risk assessment. Similarly, where the data is a range data type, “RDTOSPD Routine is called upon to convert it to a single point data format. The entire process is iterated through a loop that increases the value of i at each instance until it takes up the value of k - the total number of data items. The average of SDT(i) is then computed and stored in another array AVGSPD(z) which represents the aggregate of all the data items. Figure 4.51 shows a flowchart representation of the "Single point routine" while Figures 4.52 and 4.53 shows a flowchart representation of the “SPDTOSPD Routine” and the “RDTOSPD Routine” routines respectively. Other transformation routines are presented in Appendix 2.0 to 2.2.

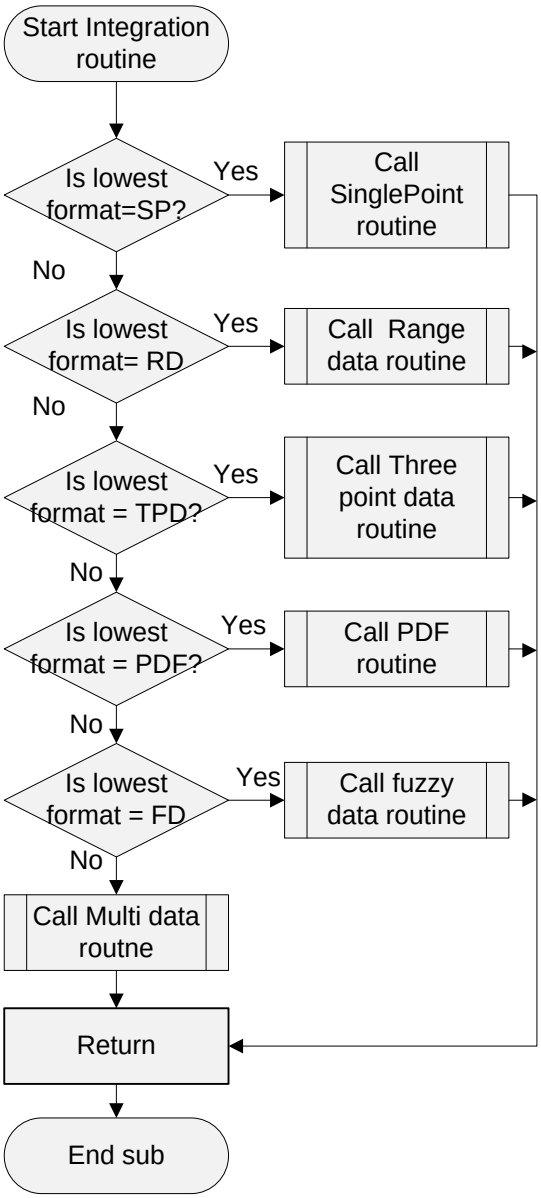


Figure 4. 50: Flowchart Representation of the Integration Process

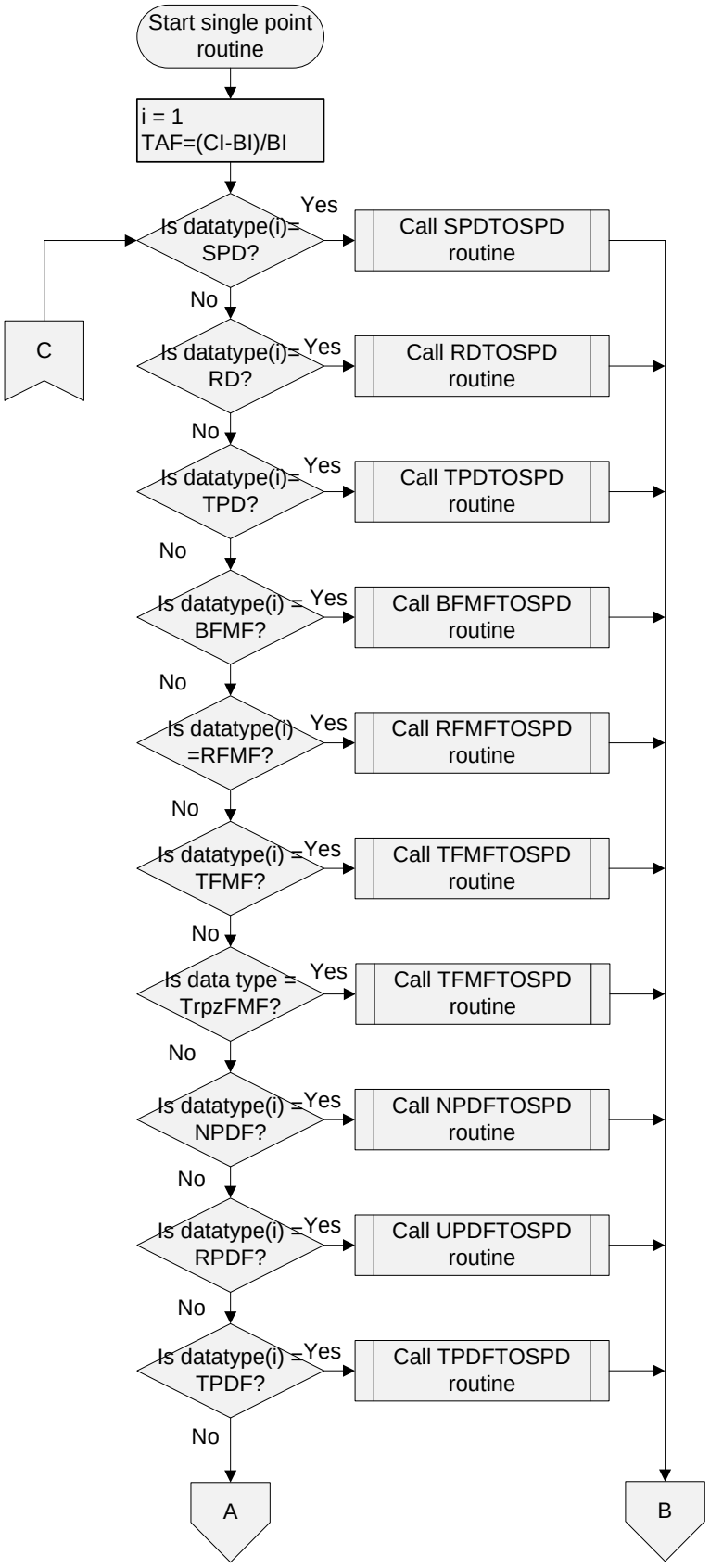


Figure 4. 51: Flowchart Representation of the Conversion Process from other Data Formats to Single-Point Data

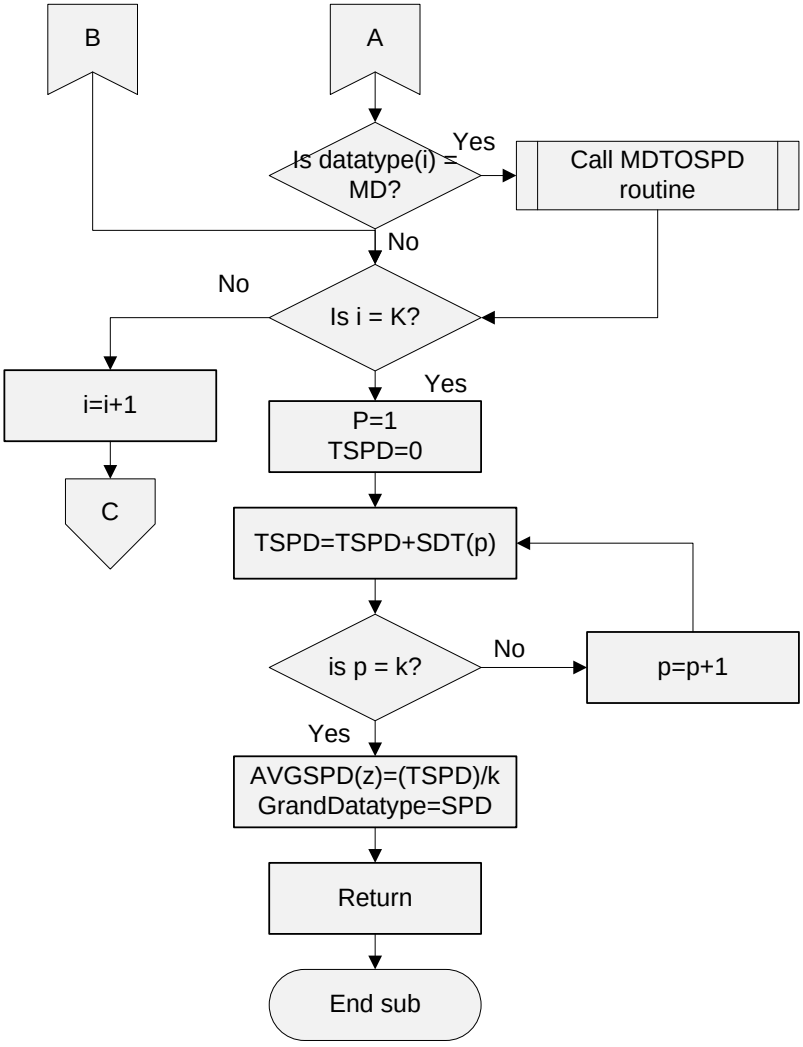


Figure 4.51: Flowchart Representation of the Conversion Process from other Data Formats to Single-Point Data continues.

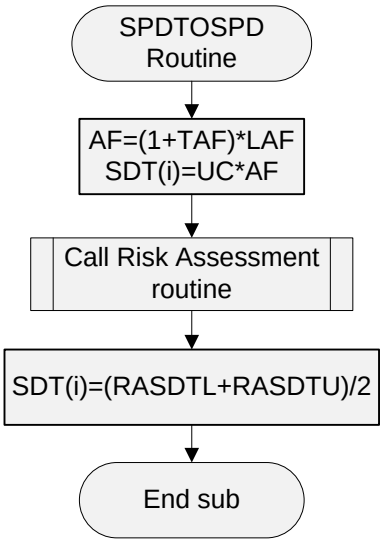


Figure 4. 52: Flowchart Representation of Single-point to Single-point Routine

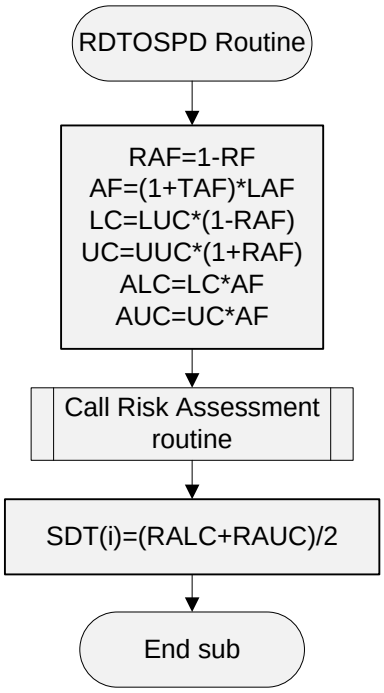


Figure 4. 53: Flowchart Representation of Range Data to Single-point Routine.

The logic behind the "Range data routine" and the "Three point routine" are similar except that they convert higher level data to range and three-point data types respectively. The converted range data is stored in LRDT(i) and URDT(i) array variables representing the lower and upper ranges for the i^{th} data item, while the three-point data values are assigned to LTPD(i), LKTPD(i) and UTPD(i) array variables representing the lower, likely and upper values for the i^{th} data item. The average for the lower and upper range data are returned by the variables AVGLRD(z) and AVGURD(z) respectively, while the averages for the lower, likely and upper three-point data are returned by the array variables AVGLTPD(z), AVGLKTPD(z) and AVGUTPD(z). Appendixes 3.0 to 3.4, and 4.0 to 4.3 show the flowchart representation of transformation process from other data formats to Range and Three-point data respectively.

The "PDF routine" converts FMF and MD formats to probability density functions. The routine first identifies the data type by inspecting the variable datatype(i) and calling one of five conversion subroutines as shown on Figure 4.54. Where the data type is BFMF for instance, "BFMFTOPDF routine" is called in which the FMF is transformed to PDF. The routine as shown on Figure 4.55, first adjusts the data for time and location, before calling “Risk Assessment routine” where the lower and upper bounds, and the standard deviations are adjusted and returned by the variables RALV, RAUV and RASD respectively. The data and fuzzy membership values along with the corresponding areas underneath the fuzzy function are then computed using two dimensional array variables X(i,j), Fuzzy(i,j) and Area(i,m). Furthermore, the corresponding relative frequencies RF(i,j) are determined and adjusted to obtain the probability values Prob(i,j).

The "RFMFTORPDF routine", "TFMFTOPDF routine" and TRPZFMFTOPDF routine" in the PDF routine all have similar logic While “MDTOPDF routine” converts multi-data to PDF by generating a probability distribution function. Appendixes 5.0 through to 5.3 show the five routines in their order.

Following the execution of the transformation subroutines, an aggregation routine called "PDFsummation routine"(Appendix 5.4) is executed which combines all data items into a single PDF. The “PDFsummation routine" uses three different routines; "Normal Frequencycuts", "Rectangular Frequencycuts", and "Triangular Frequencycuts"; to generate frequencies and corresponding data values for un-transformed PDF. Appendixes 5.5, 5.6, and 5.7 show a flowchart representation of the "Normal frequencycuts", "Rectangular frequencycuts" and "Triangular frequencycuts" routines respectively.

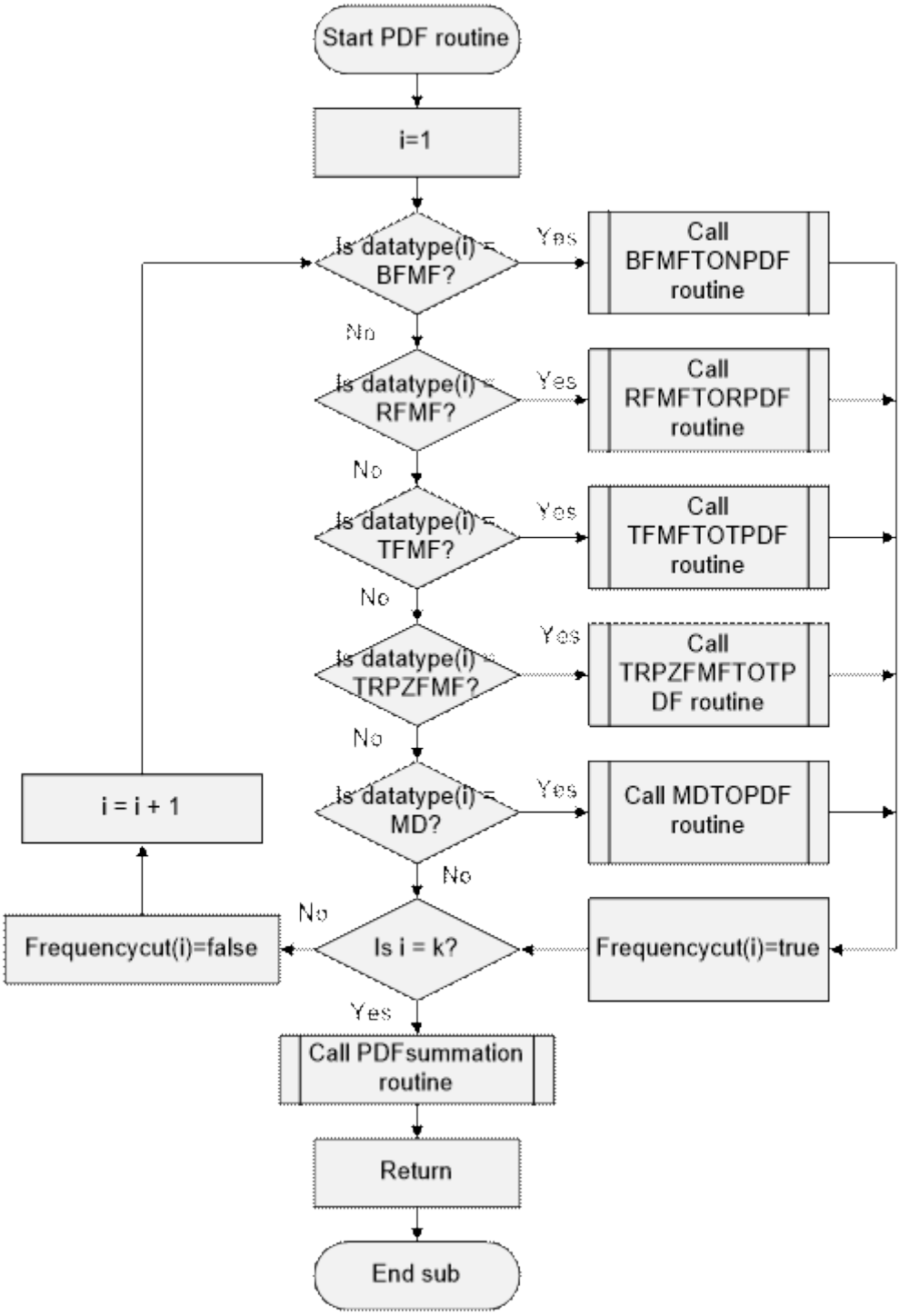


Figure 4. 54: Flowchart Representation of PDF Routine

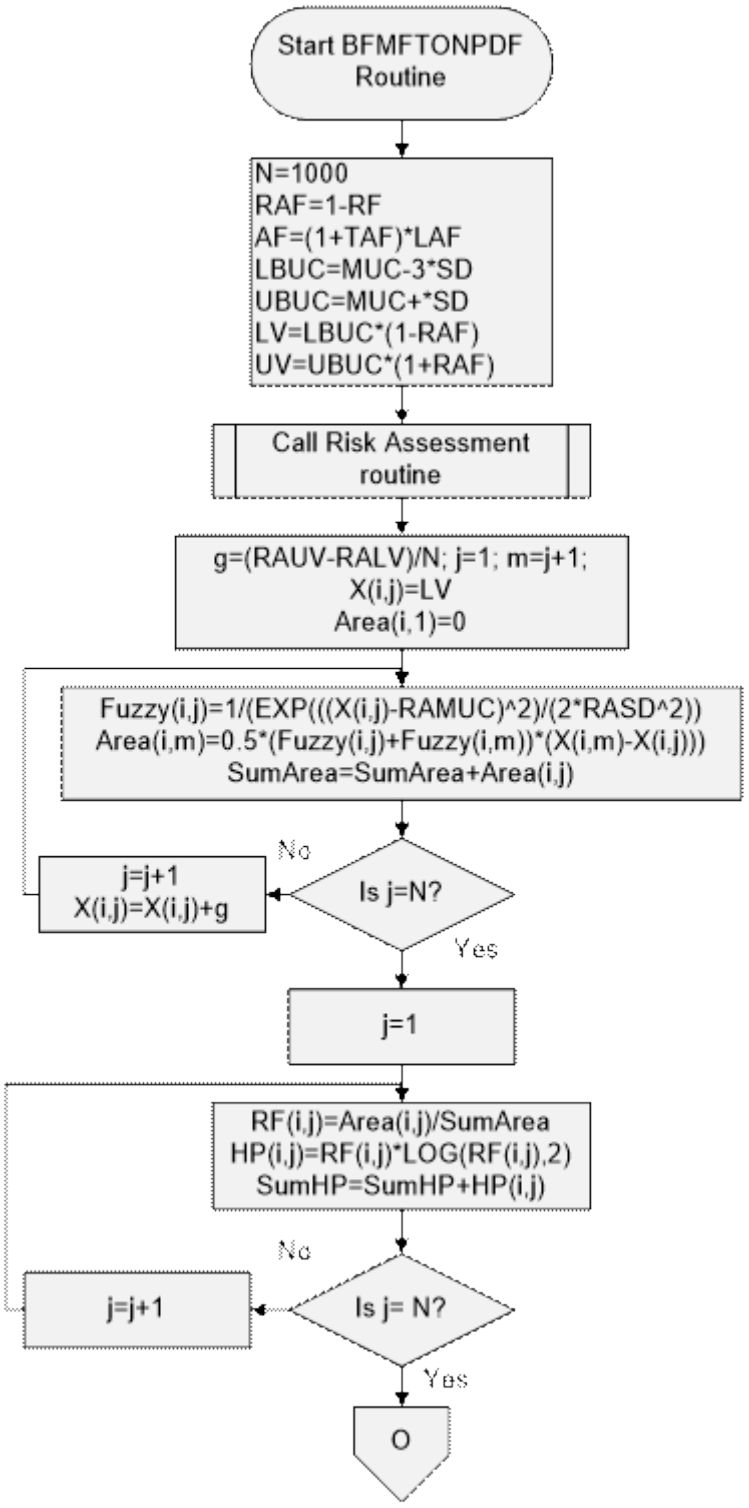


Figure 4. 55: Flowchart Representation of the Conversion Process of Bayesian FMF to NPDF

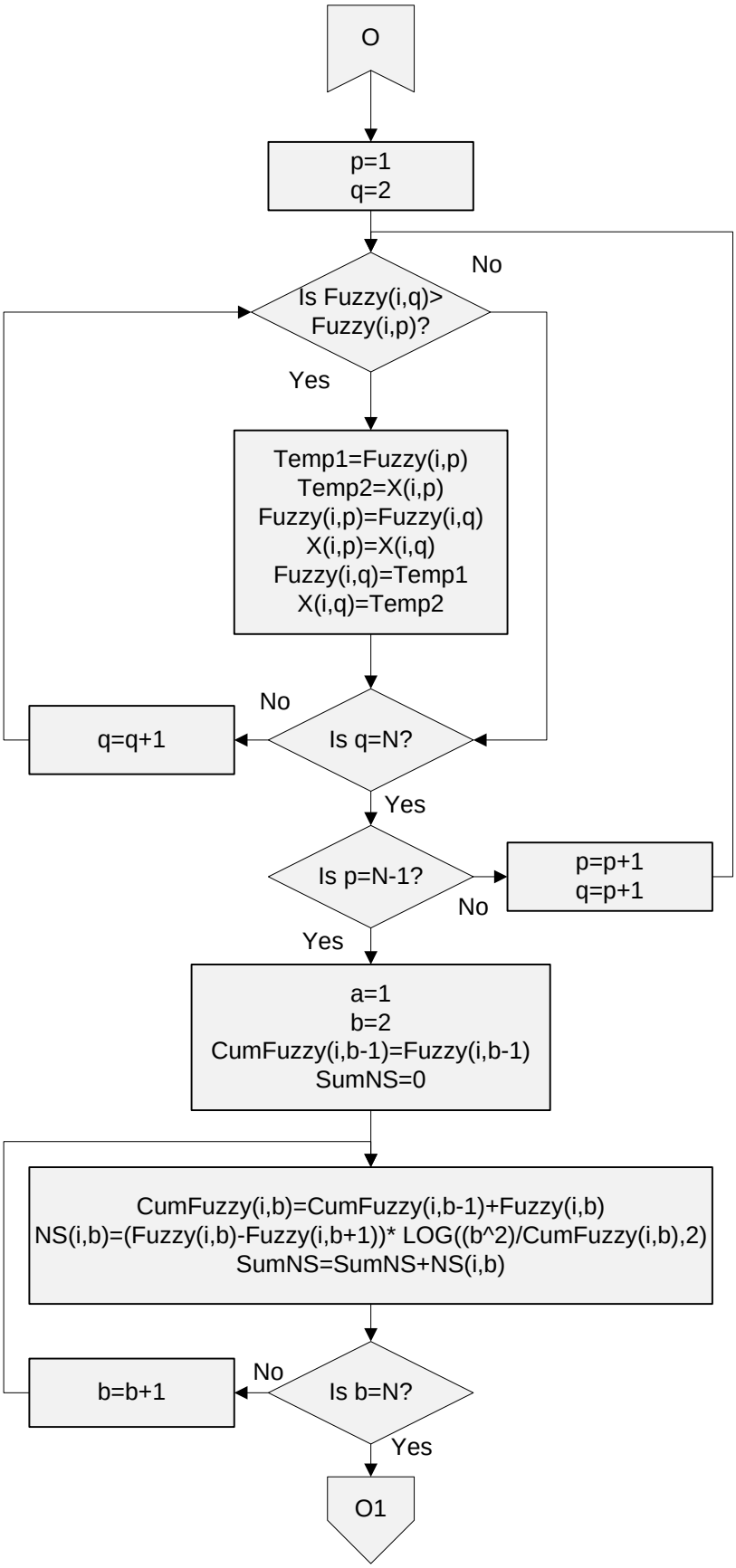


Figure 4.55 Flowchart Representation of the Conversion Process of Bayesian FMF to NPDF continues

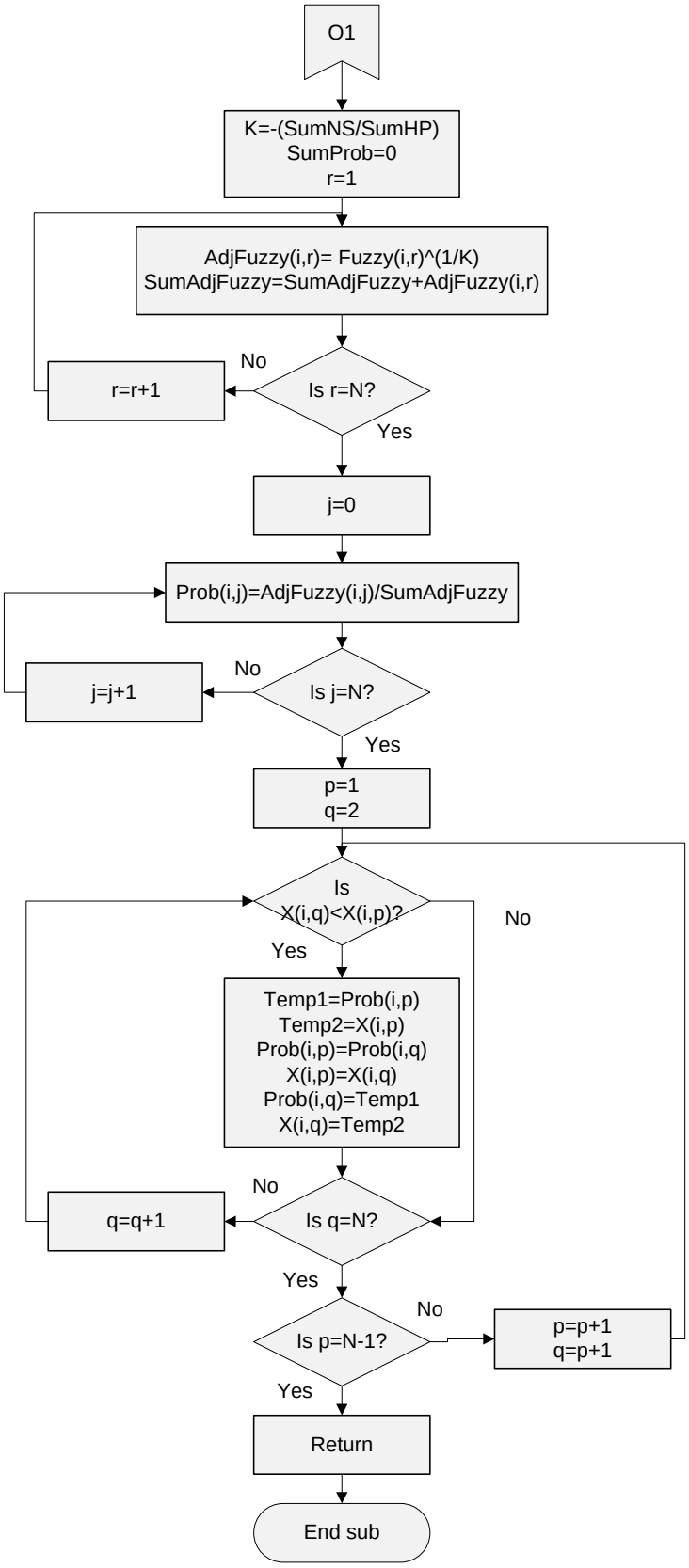


Figure 4.55 Flowchart Representation of the Conversion Process of Bayesian FMF to NPDF Continues

The FMF routine converts PDF and MD formats to FMF. The routine first evaluates the type of PDF through the datatype(i) variable and calls one of "NPDFTOFMF routine", "UPDFTOFMF routine", "TPDFTOFMF routine" and “MDTOFMF routine”. The four subroutines are responsible for transforming normal, uniform, triangular PDF and Multi-data formats respectively into FMF. The NPDFTOFMF routine computes the data and corresponding frequencies and relative frequencies in two dimensional arrays X(i,j), F(i,j) and RF(i,j). Each of the subroutines utilises the probability possibility transformation and returns two dimensional variable Fuzzy(i,r) containing the corresponding membership values of X(i,j). The logic behind the "RPDFTOFMF routines" and "TPDFTOFMF routine" is similar to that of "NPDFTOFMF routine". At the end of the transformation process, the generated fuzzy membership functions are then combined through the “FMFSummation routine" to generate an average membership function in a two dimensional arrays GrandX(z,i) and GrandFuzz(z,r). The "FMFSummation routine" consists of four subroutintes; "Bayesian alphacuts routine"; "Rectangular alphacuts routine"; "Triangular alphacuts routine"; and "Trapezodal alphacuts routine” that generate alphacuts by identifying the FMFs that did not undergo transformation and calling one of four subroutines that corresponds to the data type. Figure 4.56 and 4.57 shows flowchart representation of “FMF routine” and “NPDFTOFMF Routine” subroutine respectively. Appendixes 6.0 to 6.2 shows the flowchart representation of transformation process from other data formats to fuzzy data format while Appendixes 6.3 and 6.4 to 6.8 are a flowchart representation of “FMF summation routine” and Fuzzy alpha-cuts subroutines respectively. The multi-data routine shown on Figure 4.58 primarily adjusts data for time and location in preparation for WLC appraisal. Figure 4.59 is a flowchart representation of risk assessment routine which achieves data level risk assessment.

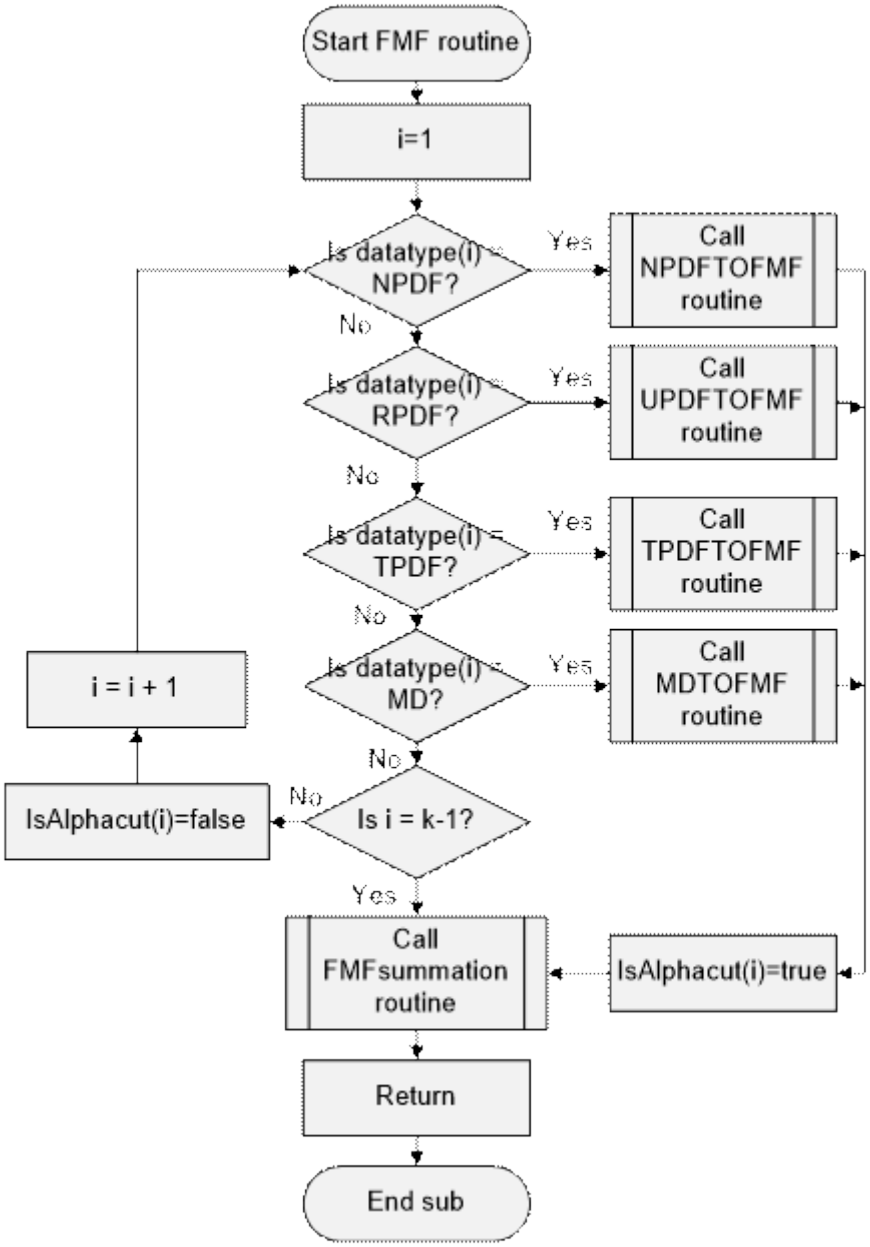


Figure 4. 56: Flowchart Representation of Transformation Process from other Data Types to FMF

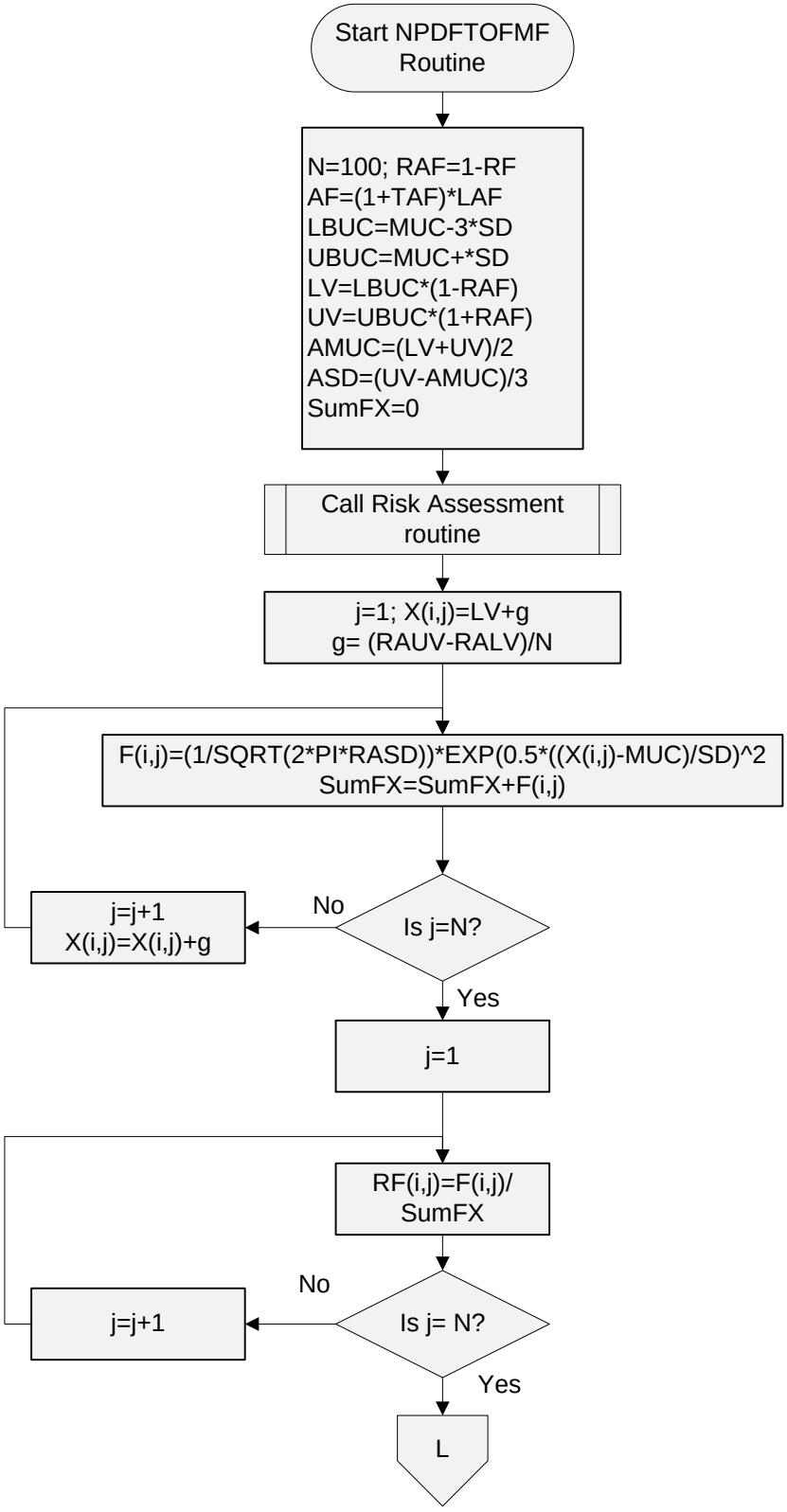


Figure 4. 57: Flowchart Representation of Transformation Process from NPDF to FMF

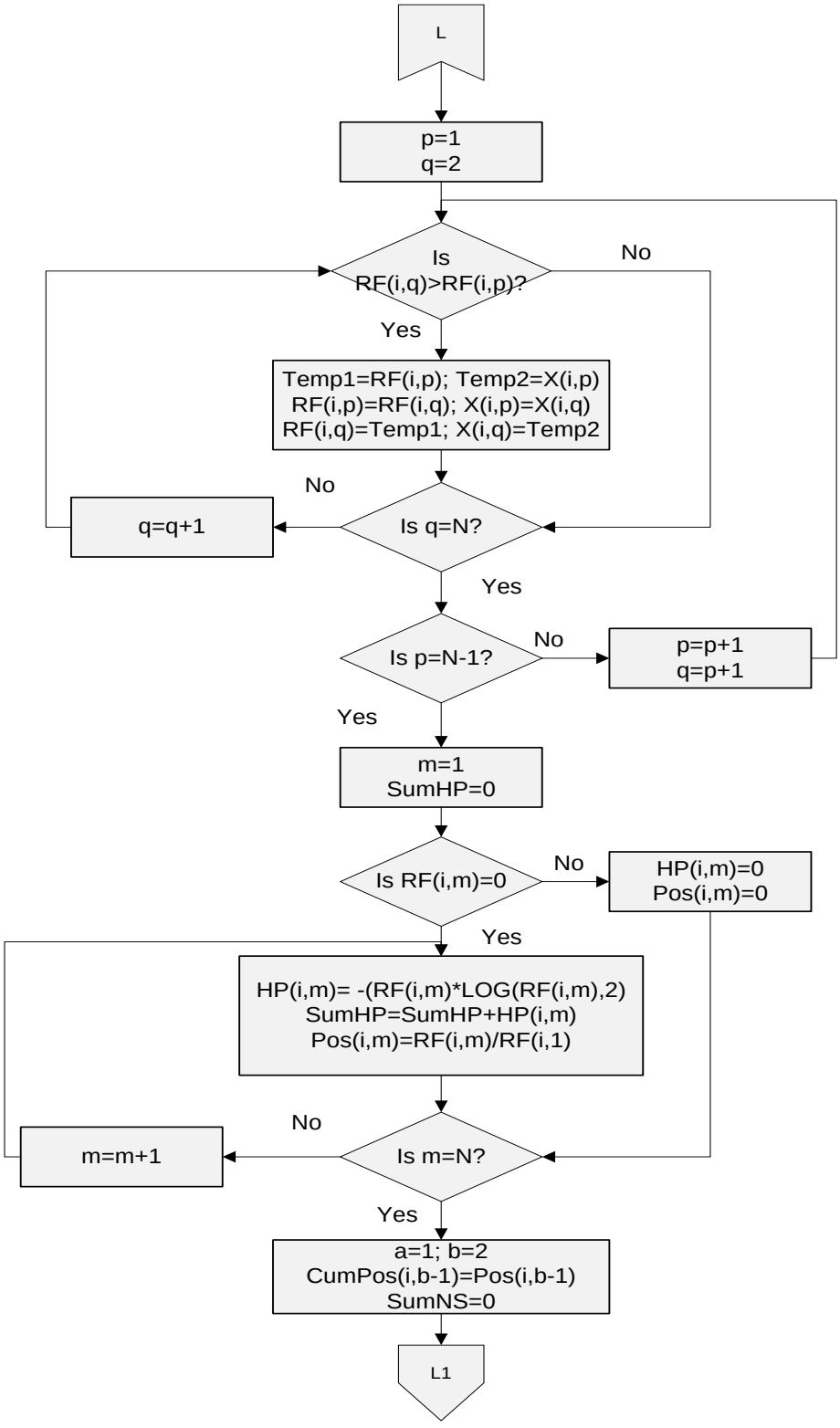


Figure 4.57: Flowchart Representation of Transformation Process from NPDF to FMF continues

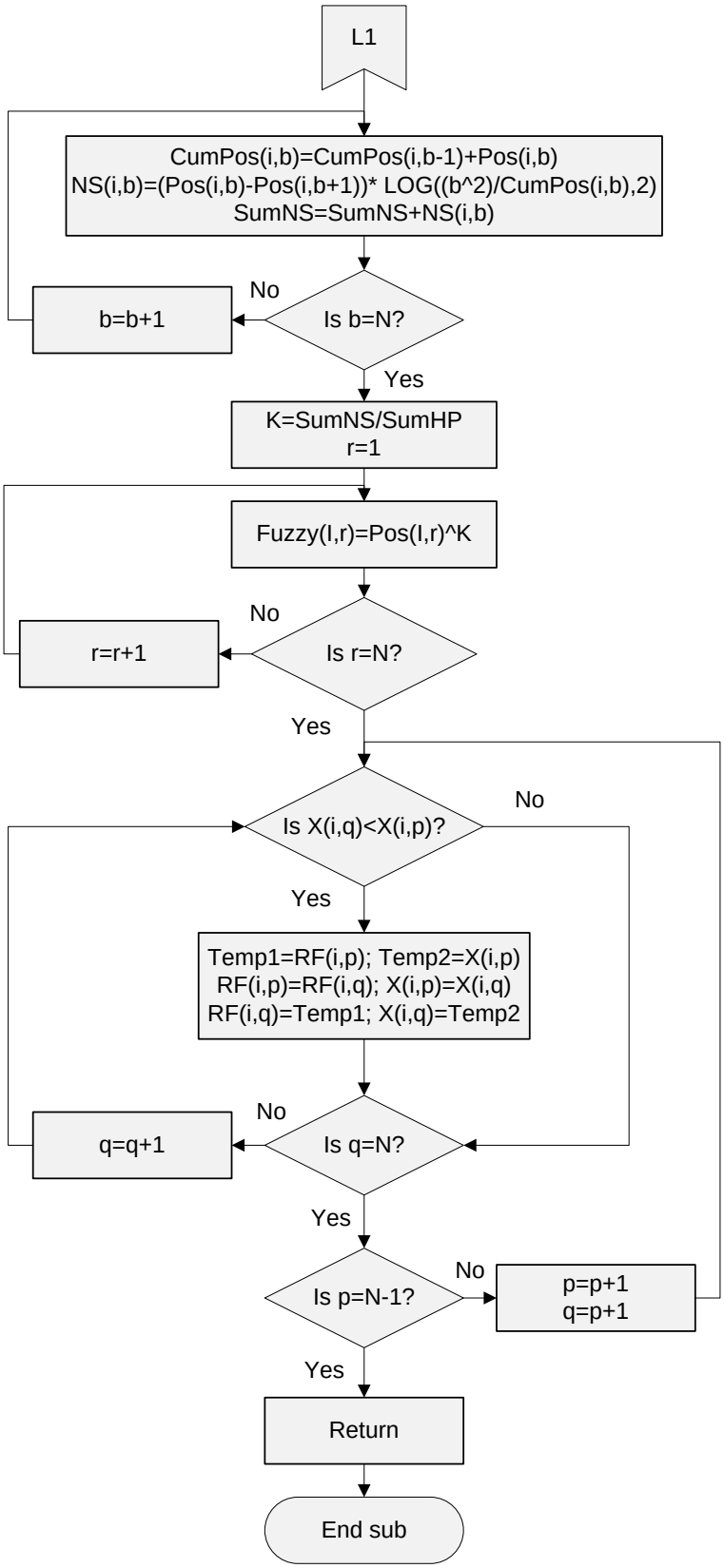


Figure 4.57: Flowchart Representation of Transformation Process from NPDF to FMF continues

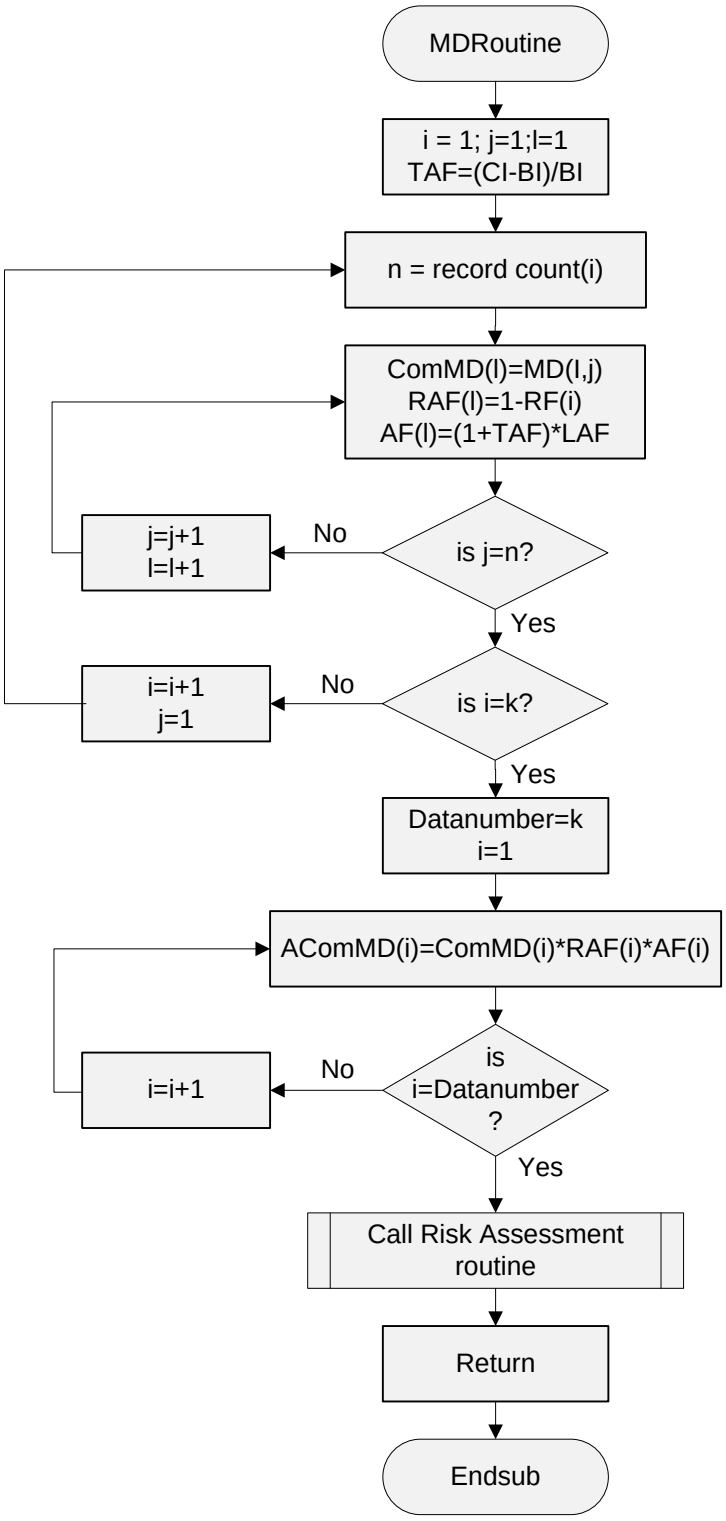


Figure 4. 58: Flowchart Representation of the Adjustment Process for Multi-data

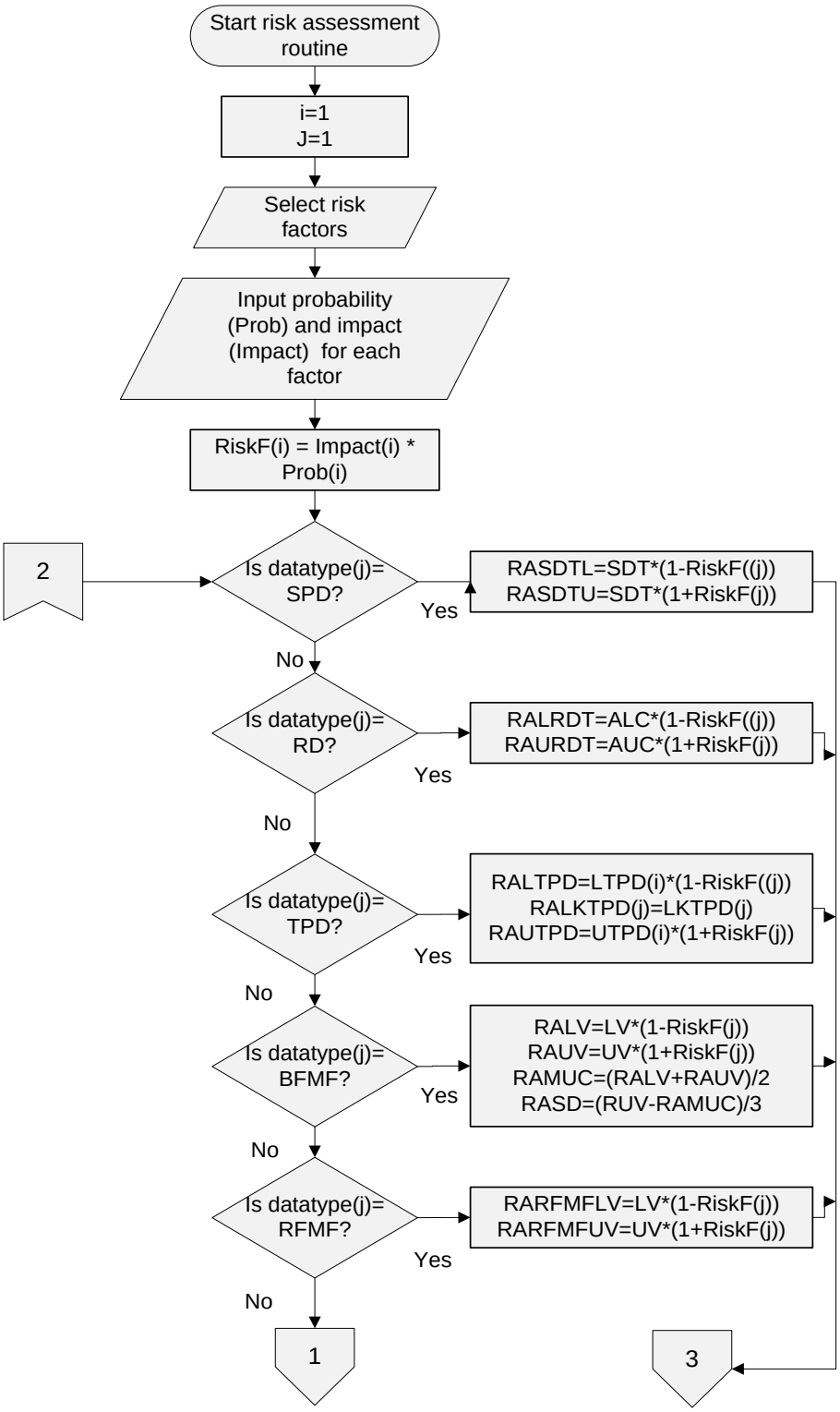


Figure 4. 59: Flowchart Representation of Data Level Risk Assessment

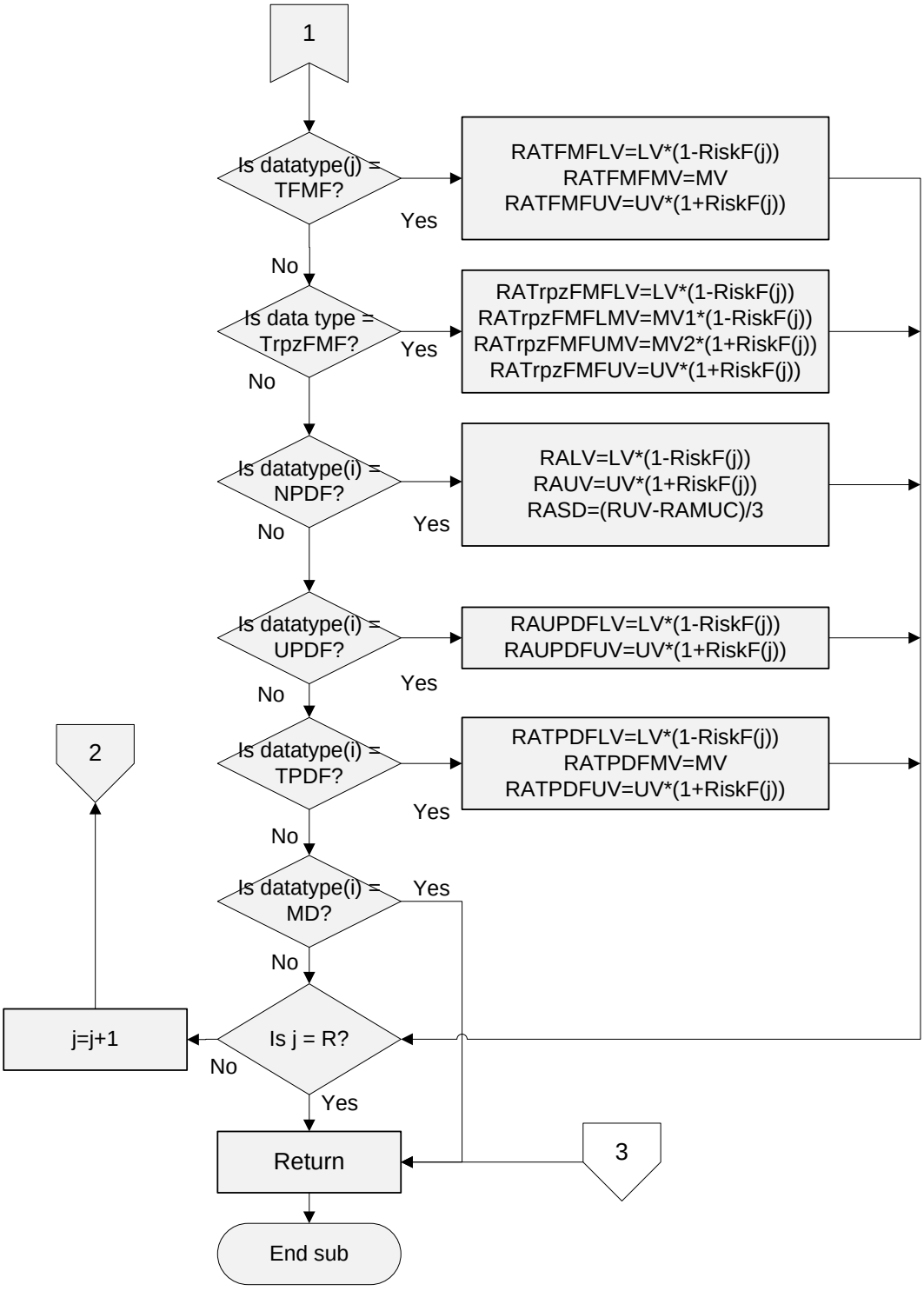


Figure 4.59: Flowchart Representation of Data Level Risk Assessment Continues.

4.9 WLC Appraisal

This section discusses the design and flowcharting of WLC appraisal process. The process begins with the selection of "WLC Appraisal" menu from the main interface. The life-cycle stage of the asset at which the appraisal is to be conducted and the type of evaluation to be conducted is then selected from the drop-down menu.

4.9.1 Budgeting

Budgeting at the planning stage would require the selection of item one on the drop-down menu as shown on plates 8, 9 and 10 of section 4.7.1 following which control is transferred to "Budgeting routine" shown on Figure 4.60 below.

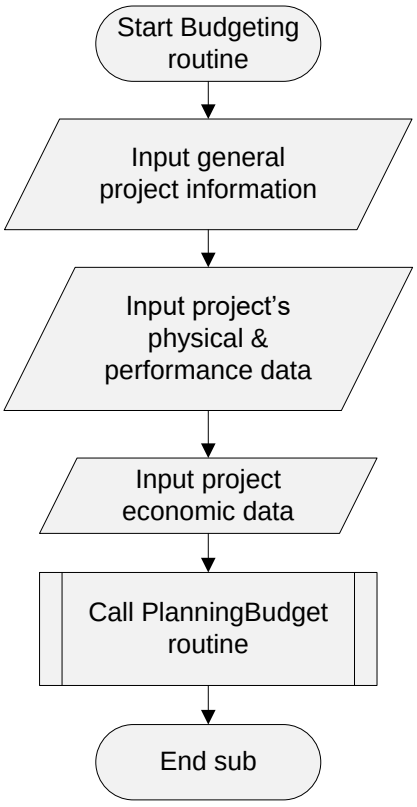


Figure 4. 60: Flowchart Representation of Budgeting Routine

The project's general information is inputted using the Project Information Form on Figure 4.13, while the physical and performance data is entered with the aid of Physical and Performance Data Form on Figure 4.14. The input of economic data is achieved using the Economic Data Form in Figure 4.61.

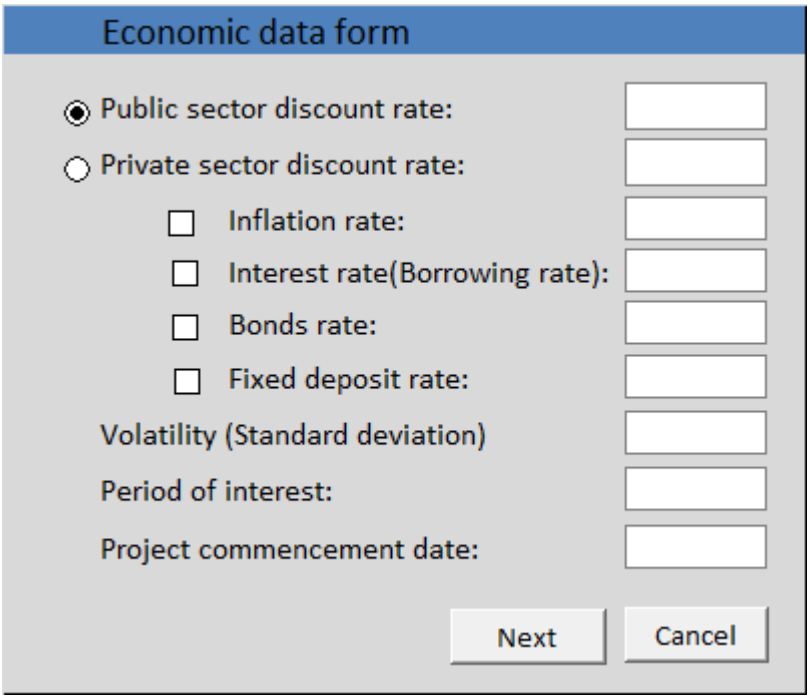


Figure 4. 61: Economic Data Form

The "PlanningBudget Routine" on Figure 4.62 is then invoked which activates one of six subroutines depending on the data type selected during the data preparation stage. Where the data type is single-point for instance, the "SPBudget" subroutine is activated which then performs the WLC budget analysis and the result displayed on a spread sheet. Figure 4.63 is a flowchart representation of the SPBudget routine. The routine first initialises all variables then identifies the "incidence" of each data item then transfer control to the relevant rout where future values of each data centre is computed

and stored under the SPFW() array variable. The computation is repeated for each data centre over the entire analysis period.

The annual totals and their cumulative values are then computed and stored under the AnnualT() and CuAnnualT() array variables.The logic behind the range data and three-point data budget routine is similar to that of single-point routines as shown on Appendixes 7.0 and 7.1.

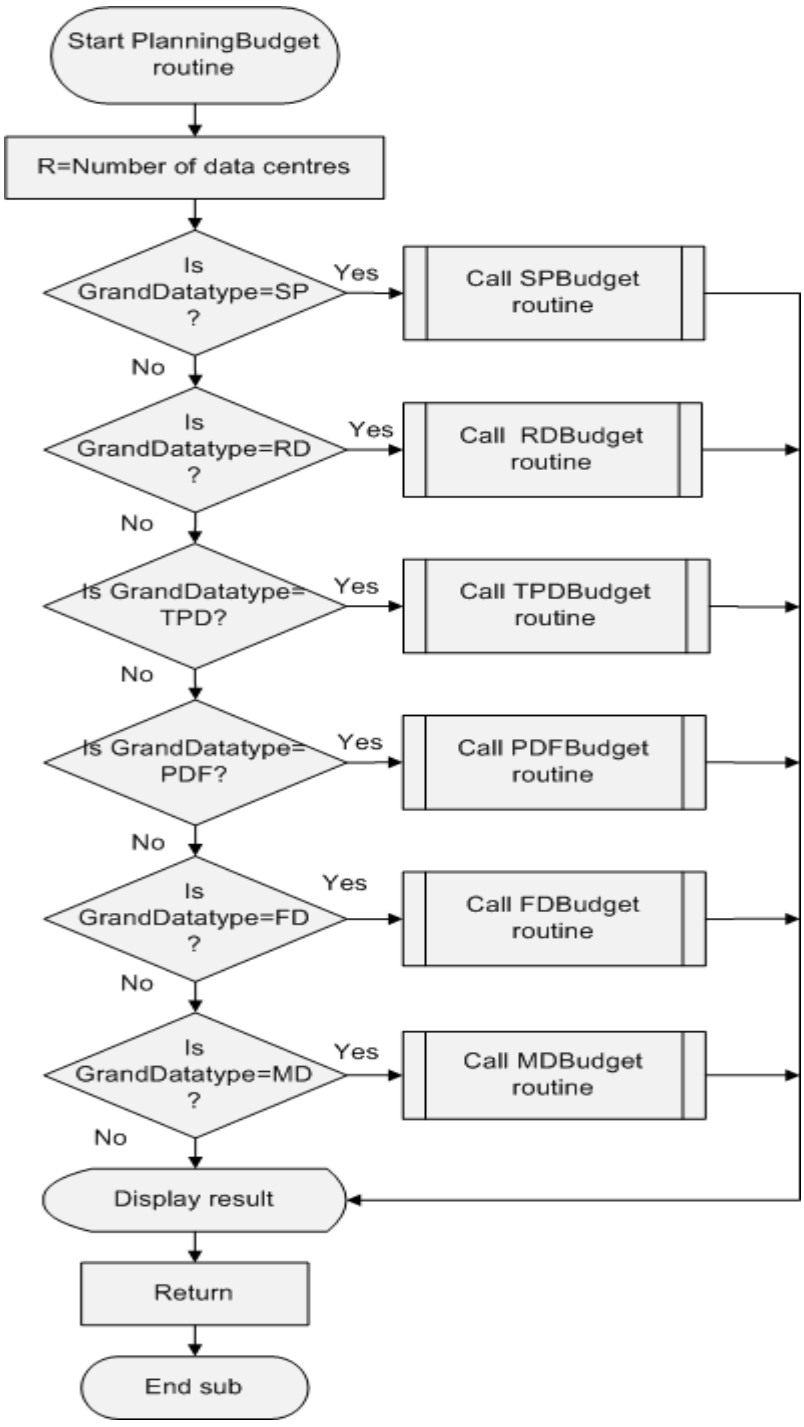


Figure 4. 62: Flowchart Representation of Planning/ Budget routine

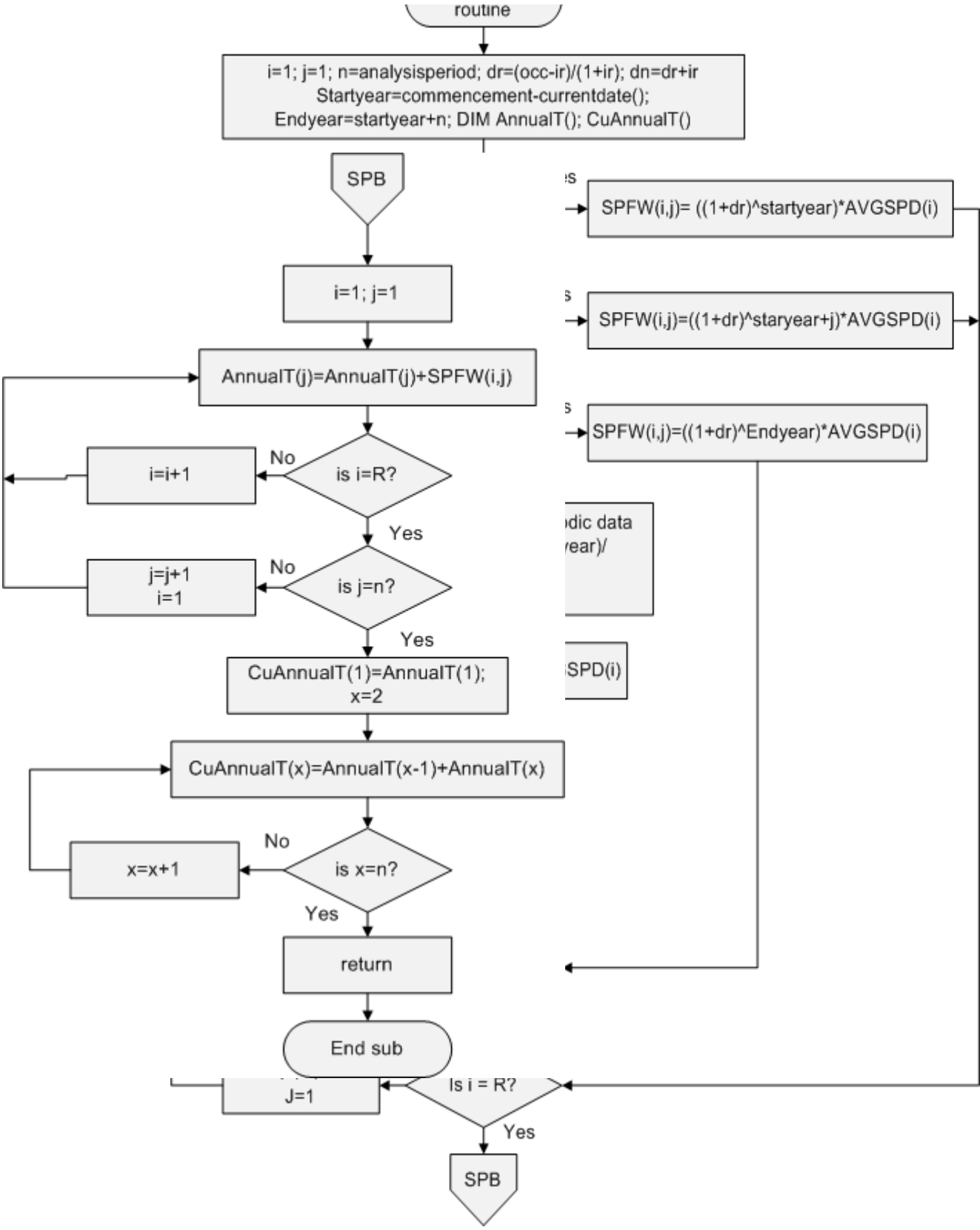


Figure 4. 63: Flowchart Representation of Single-point Budget Routine.

Figure 4.63: Flowchart Representation of Single-point Budget RoutineContinues

Where the data type is a PDF on the other hand, the “PDFBudget” routine is initiated. As shown on Figure 4.64, the “PDFBudget” routine consists of six different

subroutines; the “PDFInitial”, “PDFAnnual”, “PDFTerminal”, “PDFPeriodic”, “PDFBudgetAT” and “PDFBudgetCumm”. The first four handles initial, annual, terminal, and periodic cost data depending on the incidence of the data centre. The last two routines generate the annual total and cumulative total PDFs respectively. Where the incidence for a cost item is annual for instance, the PDFAnnual subroutine which transforms the PDF of the cost item into a future worth PDF is invoked. The process is repeated for the entire data centres after which the annual totals and cumulative PDFs are computed through the “PDFBudgetAT” and “PDFBudgetCumm” subroutines. Appendix 7.2 shows the flowchart representation of the “PDFInitial”, and “PDFTerminal” subroutine while Appendix 7.3 shows the flowchart representation of “PDFAnnual” and “PDFPeriodic” subroutines respectively. Appendixes 7.4 and 7.5 show the flowchart representation of the “PDFBudgetAT” and “PDFBudgetCumm” routines respectively. The process logic for fuzzy data is similar to that of PDF data. The “FDBudget” and “MDBudget” routines handle the budgeting process where the data is Fuzzy or Multi-data respectively. Appendixes 7.6 through to 7.11 show the flowchart representations of “FDBudget” and “MDBudget” routines with their associated subroutines.

4.9.2 Benchmarking

The process of benchmarking begins with the selection of the second item of plate 10 on section 4.7.1. Therefrom, the logic behind “Benchmarking” is quite similar to that of “Budgeting” routine except that instead of expressing results as future values, “Benchmarking” routine expresses results in present values using the present value factor.

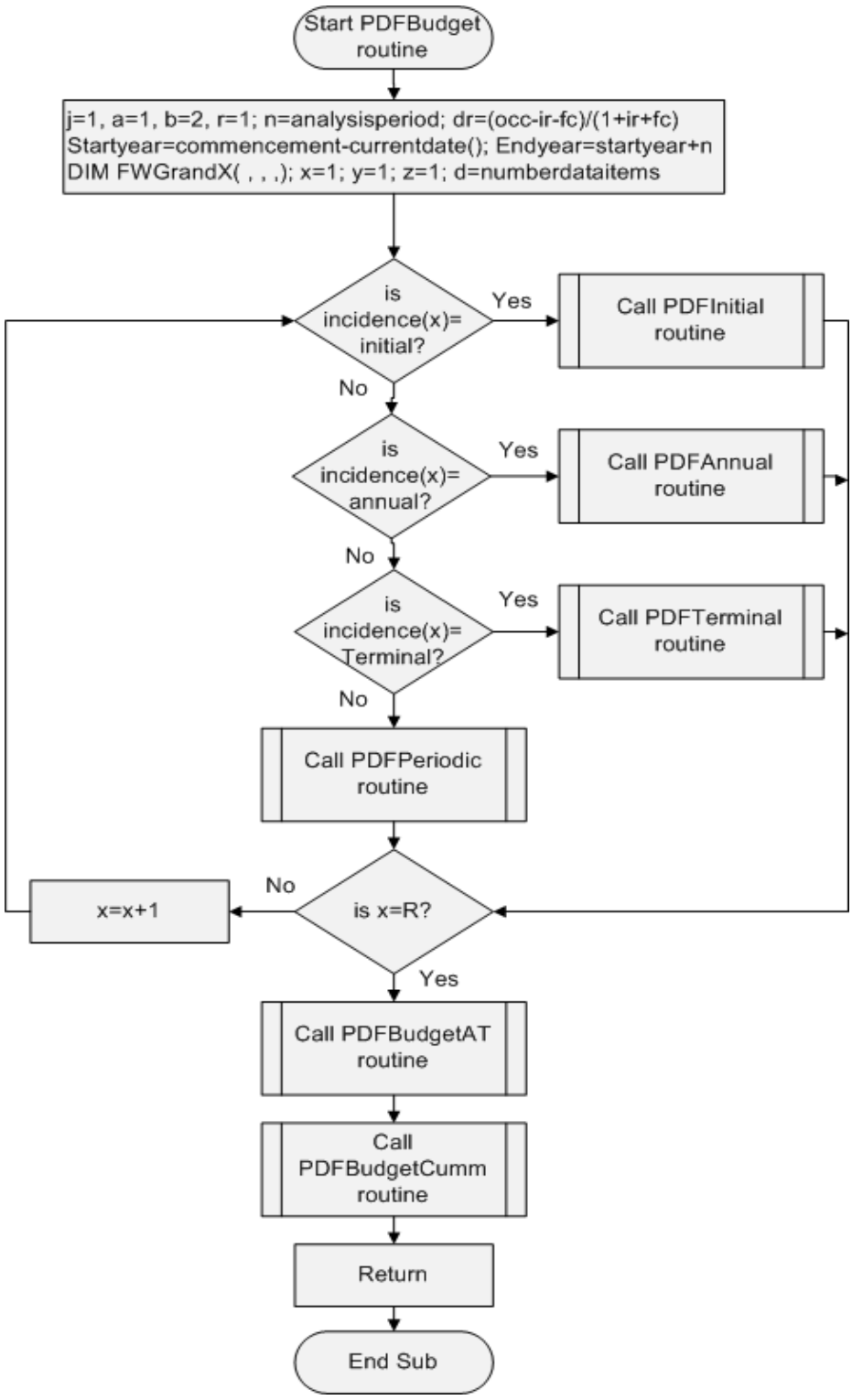


Figure 4. 64: Flowchart representation of the PDF budgeting routine

4.9.3 Options evaluation

Options evaluation begins with the selection of the third item on plate 10 oin section 4.7.1. The "Options" routine on Figure 4.65 shown below is activated. From the Figure,

the Project Information Form on Figure 4.17 is displayed to facilitate the input of general project information. The physical and performance data is then entered via the Physical and Performance Data Form on Figure 4.18 Project economic data is then entered using the Economic Data Form in Figure 4.61.

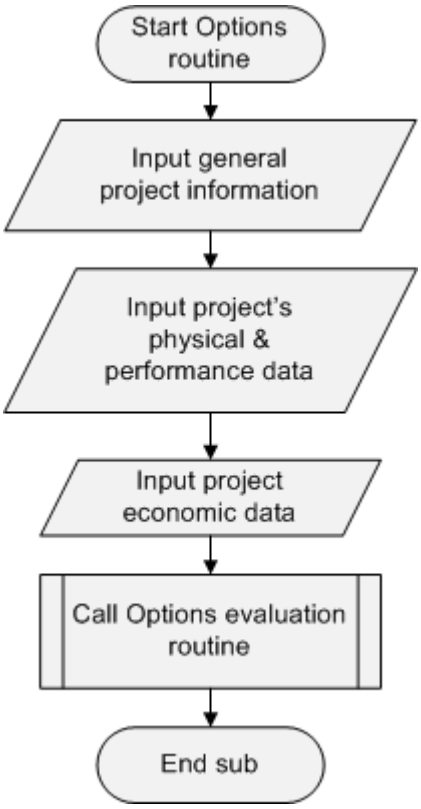


Figure 4. 65: Flowchart representation of the options routine

The Options Evaluation routine on Figure 4.66 is then invoked. The routine first displays the Options Selection form (Figure 4.67) which permits the selection of the type of option to evaluate.

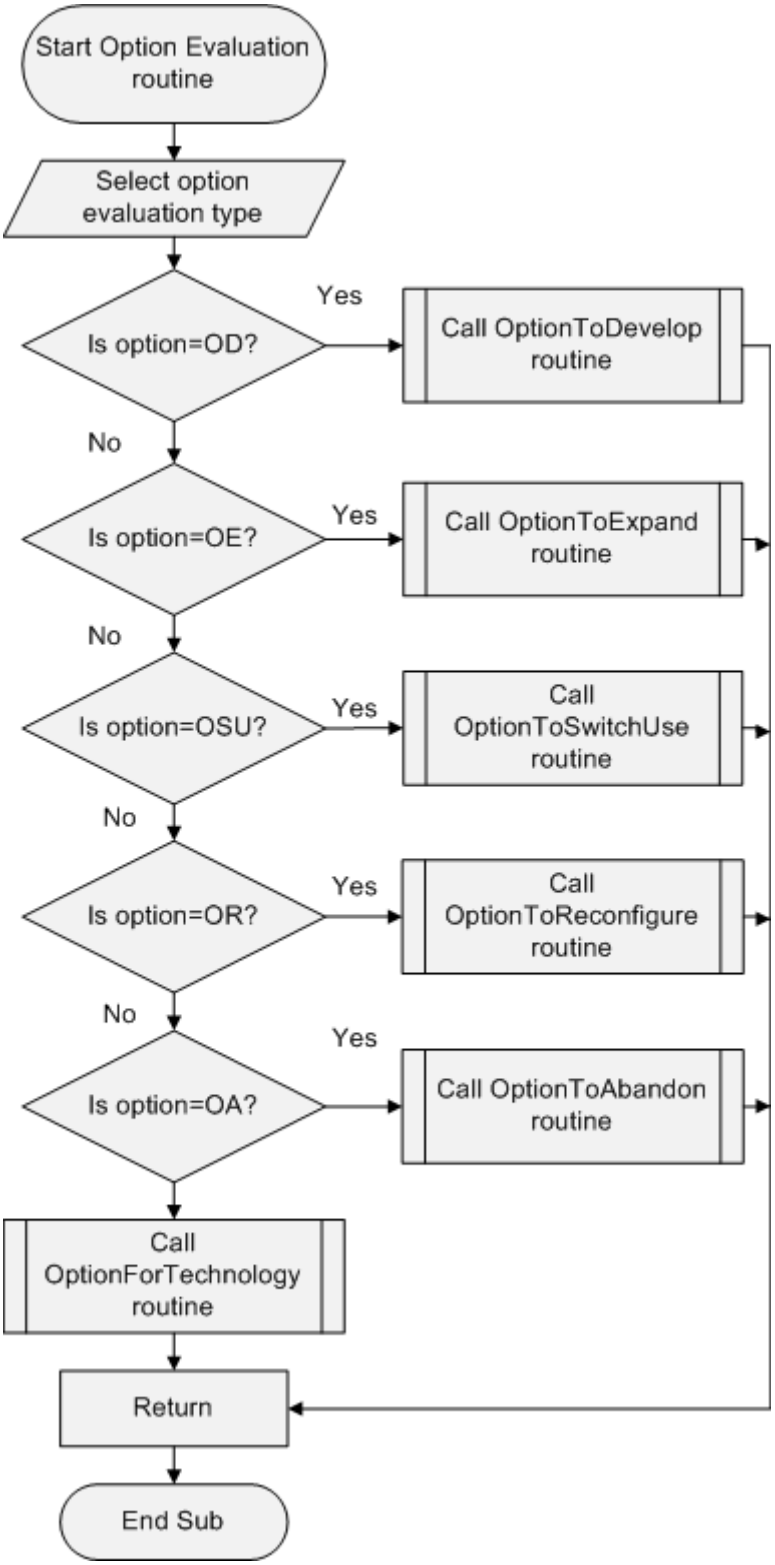


Figure 4. 66: Flowchart Representation of the Options Evaluation Routine

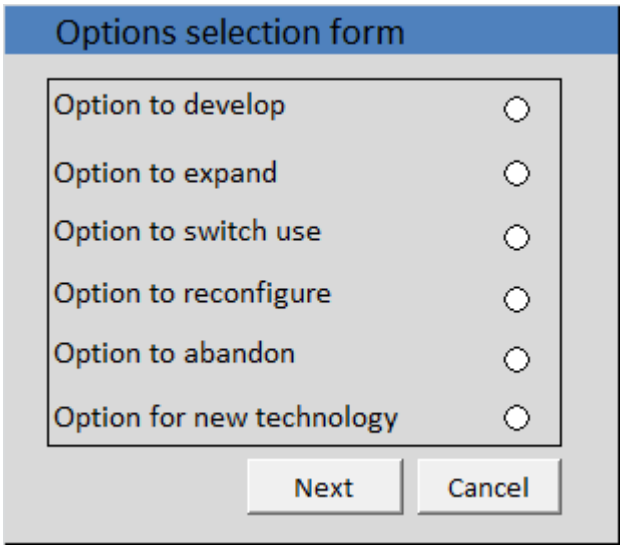


Figure 4. 67: Options Selection Form

Depending on the type of option to evaluate one of six subroutines is invoked. Where option to develop is selected for instance, "OptionToDevelop" routine is activated. Depending on the data type, "OptionToDevelop" transfers control to one of six subroutines (SPODev, RDODev, TPDODev, PDFODev, FDODev and MDODev) through which the computation of the option values is accomplished. Figure 4.68 shows the flowchart representation of the "OptionToDevelop" routine while Figure 4.69 shows the "SPODev" routine. The routine first initialises all variables after which the incidence of each data centre is identified and an appropriate discount factor applied to compute the present value of the data centre. The annual totals of the data centres are then computed after which the annual option development value is calculated. The process is similar with other data formats.

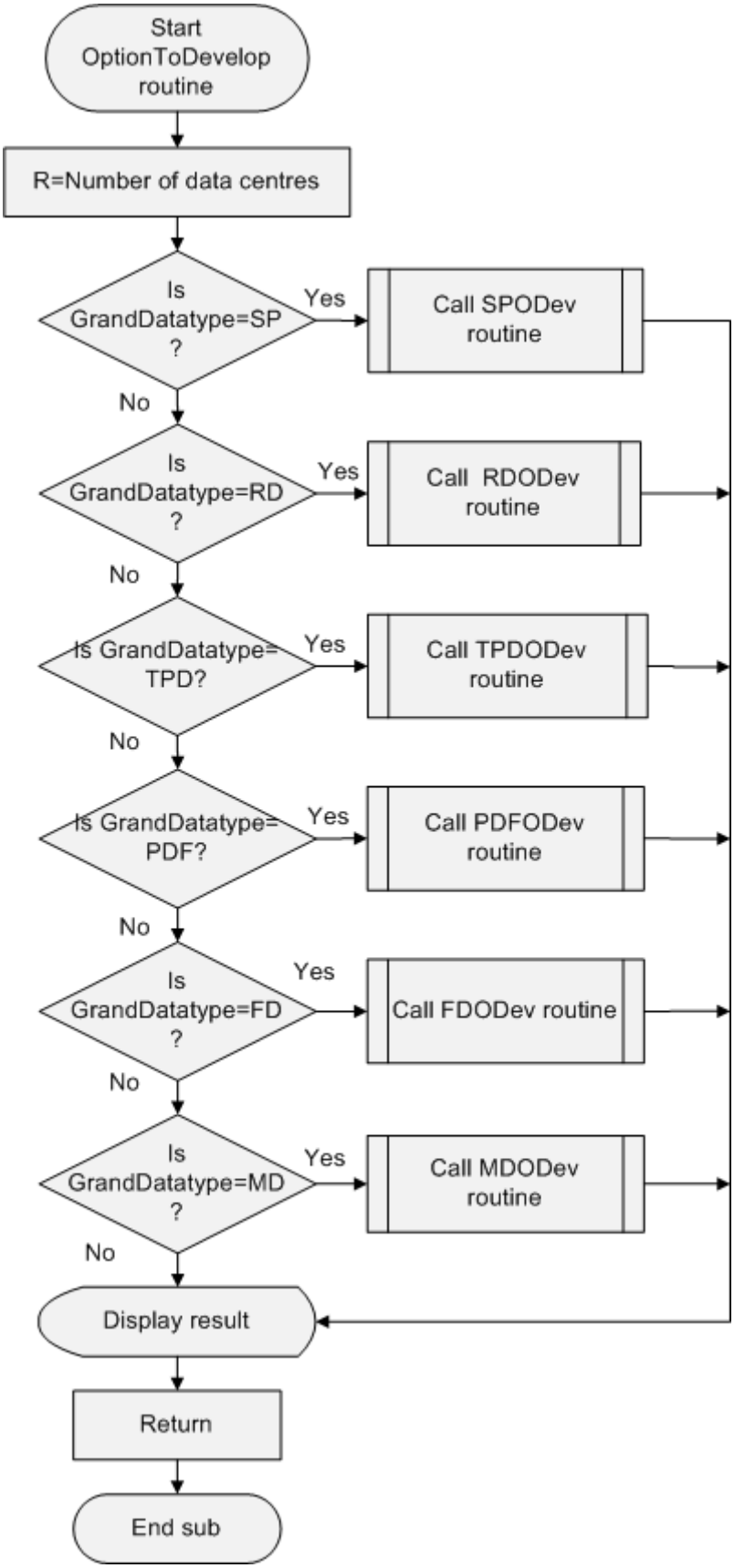


Figure 4. 68: Flowchart Representation of Option to Develop Routine

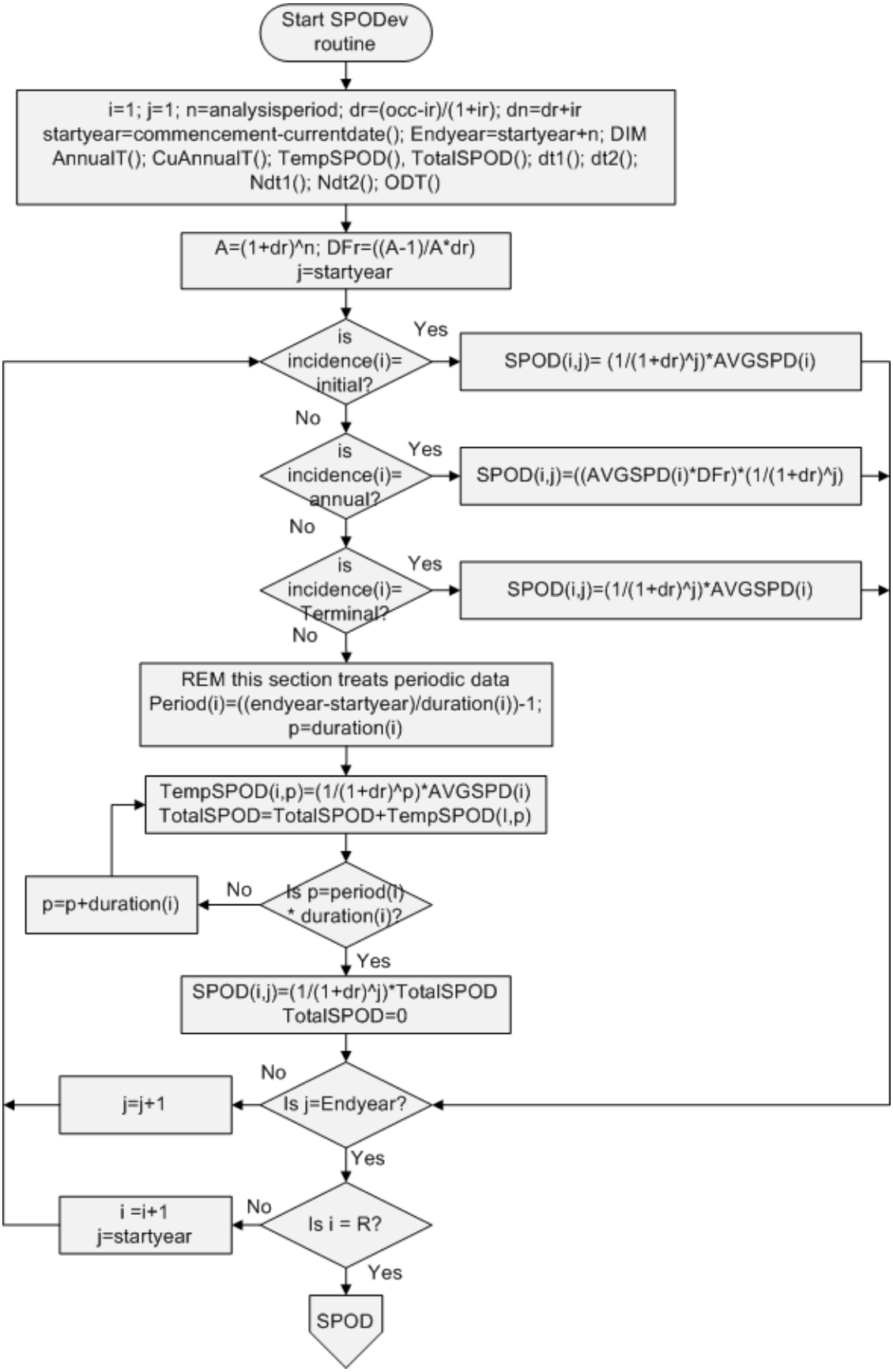


Figure 4. 69: Flowchart Representation of Option to Develop Routine for Single-point Data

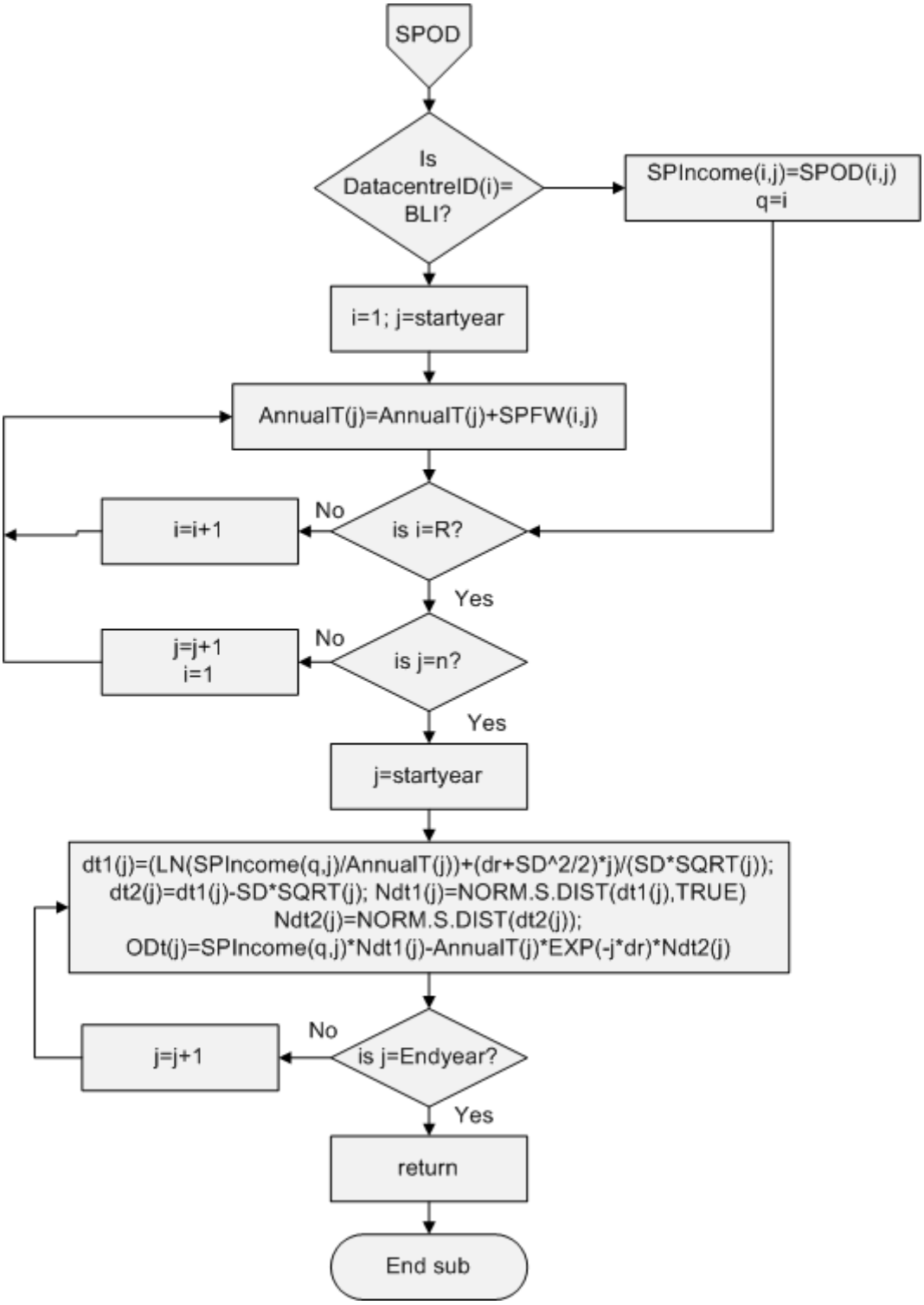


Figure 4.69 Flowchart Representation of Option to Develop Routine for Single-point Data Continues.

CHAPTER FIVE: FRAMEWORK IMPLEMENTATON AND TESTING

5.1 Introduction

This section discusses computer implementation and testing of;the database in order to ascertain its reliability and robustness for data storage and retrieval;the transformation and integration algorithms in order to ascertain their efficacy and reliability;the mathematical models for both the conventional and options-based WLC analysis.

5.2 Implementation and Testing of Database Storage and Retrieval System

The database was implemented using MS Access application. It was then populated using test data obtained from multiple sources. The data obtained cuts across the different data types identified in section 4.4.3 so as to facilitate a complete evaluation of the transformation and integration process. Table 5.1 details the data collected and their sources.

Table 5. 1: Summary of Data and their Sources

S/NO	DATA TYPE	SOURCE
1	Inflation rate	Federal Bureau of statistics
2	Interest rate	Commercial Banks
3	Volatility	Estate Management firms
4	Cost of land	Estate Management firms
5	Cost of building	Quantity Surveying firms
6	External works	Quantity Surveying firms
7	Preliminaries	Quantity Surveying firms
8	Design fees	Quantity Surveying firms
9	Operating cost	Estate Management firms
10	Maintenance cost	Estate Management firms
11	Terminal cost	Estate Management firms
12	Location adjustment factors	Published price books
13	Time adjustment factors	CBN statistical bulletin

A proposed project for which WLC analysis is to be conducted was selected. The project is a proposed student's hostel at Zango, Samaru, Zaria, of Kaduna state. Table 5.2 is a summary of the client's brief on the proposed project.

Table 5. 2: Summary of Client's Brief

S/No	Description	Client's requirement
1	Building type	Residential
2	Land	450Sq.m
3	Location	Samaru, Zaria
4	Structure	Unframed
5	Accommodation	12 Number, 1-bedroom, self-contained terrace units..
6	Maximum GFA	212Sq.m
7	Soft and hard landscaping	238Sq.m

The general information and physical/performance data for the proposed project forms the basis for querying the database using the "Project information query form" and the "Physical and performance data query form" as outlined in section 4.4. Tables 5.3 and 5.4 summarises the general information and physical/performance query data of the proposed project.

Table 5. 3: Project Information Query Data

S/No	Description	Requirement
1	Analysis stage	Planning
2	Building type	Residential
3	Building structure	Unframed structure
4	State	Kaduna
5	Area	Suburban
6	Procurement rout	Traditional
7	Commencement date	-
8	Completion date	-
9	Occupation date	-

Table 5. 4: Project Physical and Performance Query Data

S/No	Description	Min.	Max.
1	Gross Floor Area	170	300
2	Area of floors below ground	0	0
3	Ground floor area	170	300
4	Area of floors above ground	0	0
5	Usable floor area	-	-
6	Circulation floor area	-	-
7	Roof area	-	-
8	Building cubic content	-	-
9	Total building height	5.5	7.0
10	Average floor to ceiling height	2.9	3.3
11	Number of floors	1	1
12	Total accommodation	3	5
13	Average daily use hours	20	24
14	Average number of users	45	50
15	Building quality rating	HQ	VHQ
16	Building maintenance rating	KG	KE

The search process was then scoped to select the cost and performance data to include and the database queried to produce the data profile on Table 5.5 below.

Table 5. 5: Profile of Data from Database Query

S/No	Sub.No	Cost Centre	Data type
1		Non-construction cost(Initial)	
	1	Land	SPD
	2	Land	SPD
2		Non-construction cost(Annual)	
	1	Finance	SPD
	2	Finance	RD
3		Income	
	1	Income	RD
	2	Income	TPD
4		Building	
	1	Building	GFMF
	2	Building	NPDF
5		External works	
	1	External works	RPDF
	2	External works	TFMF
6		Preliminaries	
	1	Preliminaries	MD
	2	Preliminaries	TPD
7		Design fees	
	1	Design fees	TFMF
	2	Design fees	NPDF
8		Operations	
	1	Operations	MD
	2	Operations	RFMF
9		Maintenance	
	1	Maintenance	SPD
	2	Maintenance	TPD
10		End-of-life	
	1	End-of-life	TPDF
	2	End-of-life	TrpzFMF

Table 5.5indicates that 10 cost centres were selected during the scoping process, 2 data sets were generated for each data item during the query process. Appendix 9 shows the complete set of data for each of the data centres. From the table the lowest data type in

hierarchy is the SPD. All higher level data types are thus to be converted to SPD in accordance with the conversion rules outlined on Table 4.6 of section 4.4.3

5.3 Implementation and Testing of Transformation Algorithms

The purpose of this section is to test the robustness of the adjustment, transformation and integration algorithms. The data transformation process outlined in sections 4.7.2 was first implemented using MS excel spread sheet vis-à-vis its inbuilt visual basic programming language.

5.3.1 Non-construction Cost: Land

The data for Non-construction cost: land is shown on Table1 of Appendix 9. Table 5.6 shows the data transformation for the cost of land. The data sets for the cost of land are both SPD, so each cost item is first adjusted for time and location using the Adjustment Factor (AF) prior to computing their average. The average cost of the two data sets which is still a SPD now serves as the adjusted cost of land.

Table 5. 6: Transformation for Non-construction Cost Data: Land

S/No	Sub.No	Data type	Unit cost	AF	Adjusted values
1	1	SPD	4,600.00	1.1543	5,309.78
1	2	SPD	4,000.00	1.1625	4,650.00
				Total	9,959.78
				Average	**4,979.89**

5.3.2 Non-construction Cost: Finance

The data for Non-construction cost: Finance is shown on Table1 and Table2 of Appendix 9.0. The data set for cost of finance consist of single-point and range data type. Table 5.7 and 5.8 shows the adjustment for time, location and Reliability Factor (RF). The RD type is first converted to SPD after which the average of the two values was computed to obtain the transformed data for finance cost shown on Table 5.9.

Table 5. 7: Adjusted Single-point Data for Cost of Finance

S/No	Sub.No	Data type	Unit cost	AF	Adjusted values
2	1	SPD	7,771.60	1.1115	8,638.13

Table 5. 8: Adjusted Range Data for Cost of Finance

S/No	Sub.No	Data type	AF	Adjusted LUC	Adjusted UUC	Average
2	2	RD	1.1625	6,681.47	8,239.22	7,460.34

Table 5. 9: Transformation/Integration for Non-construction Cost: Finance

S/No	Sub.No	Data type	Adjusted values
2	1	SPD	8,638.13
2	2	SPD	7,460.34
		Total	16,098.48
	SPD cost of finance		8,049.24

5.3.3 Income

The data for Income is shown on Table2 and Table3 of Appendix 9.0. The data sets for income comprises of range and three-point data types. Tables 5.10 and 5.11 show the data adjustments for the range and three-point data types respectively. After the adjustment, the range data set is then converted to SPD by computing the average of the lower and upper costs while three-point data is converted by simply taking its likely cost. The mean of the two values is then computed to obtain the average unit cost of income for the proposed building. Table 5.12 is a summary of the transformation process.

Table 5. 10: Range Data Adjustment for Income

S/No	Sub.No	Data type	AF	Adjusted LUC	Adjusted UUC
3	1	RD	1.14	4,857.75	6,400.80

Table 5. 11: Three-point Data Adjustment for Income

S/No	Sub.No	Data type	AF	Adjusted LUC	Adjusted LkUC	Adjusted UUC
3	2	TPD	1.143	4,577.72	6,743.70	7795.26

Table 5. 12: Transformation for income

S/No	Sub.No	Data type	Adjusted LUC	Adjusted LkUC	Adjusted UUC	Average
3	1	RD	4.857.75	-	6,400.80	5,629.28
3	2	TPD	4,577.72	6,743.70	7,7995.26	6,372.23
					Total	12,001.50
					Average income	6000.75

5.2.4 Building

The data for building cost is shown on Table 4 of Appendix 9.0 and Table 8 of Appendix 9.2. The data sets comprises of Gaussian FMF (GFMF) and Normal PDF (NPDF). Both data sets are first adjusted for time and location prior to transformation. Table 5.13 shows the adjusted GFMF for building cost and Figure 5.1 shows the initial and adjusted functions labelled as X1 and X2 respectively. A shift to the right from X1 to X2 is indicating an increase in cost due to changes in time and location. The standard deviation remains constant since the reliability factor is 1.

Table 5. 13: Gaussian Fuzzy Membership Function Adjustment for Building Cost

S/No	Sub.No	Data type	AF	ALB	ACUC	AUB
4	1	GFMF	1.143	16,260.00	22,860.00	29,460.00

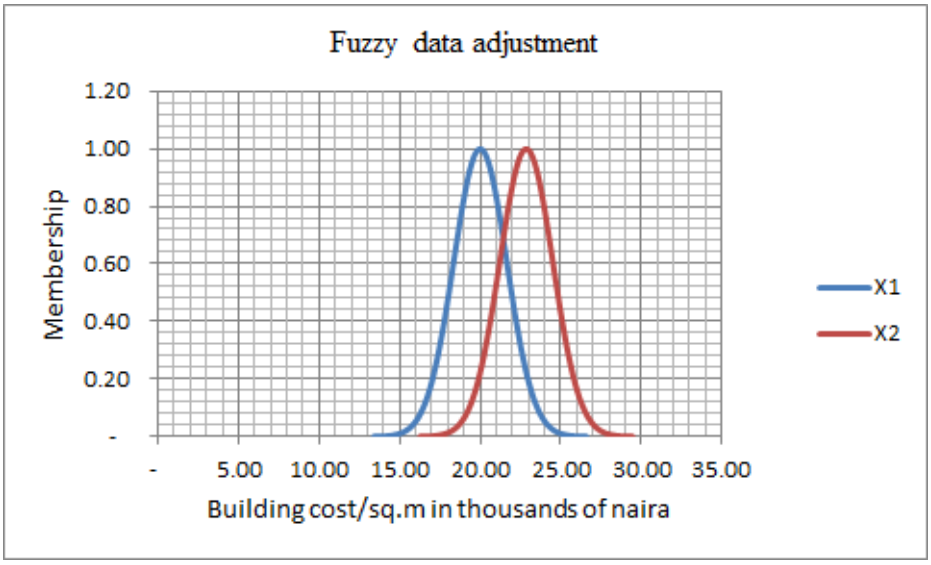


Figure 5. 1: Gaussian Fuzzy Data Adjustment for Cost of Building

Table 5.14 shows the adjustment for Normal PDF parameters. Figure 5.2 shows the graphical representation of the original PDF prior to adjustment labelled as X1 and the adjusted PDF labelled as X2. The shift from X1 to X2 is indicative of increase in building cost due to changes in time and location. The standard deviation also increases as a result of adjustment for RF.

Table 5. 14: Normal Probability Density Function Adjustment for Building Cost

S/No	Sub.No	Data type	AF	Adjusted Mean	Adjusted LC	Adjusted UU	Adjusted SD
4	2	NPDF	1.1349	18,101.66	12,294.57	24,424.74	1,580.77

The objective is to transform the PDF data type to FMF in accordance with Table 3.13, the PDF data is first transformed into fuzzy data before integrating the two data sets. The transformation of the PDF data to fuzzy data is based on the transformation algorithm proposed by Klir and Perviz(1992). Figure 5.3 is a graphical presentation of the adjusted GFMF(X1), adjusted and transformed Normal PDF(X2) (see Appendix

10.0) and a GFMF(X3) which is a combination of X1 and X2. X3 represents the integrated FMF with a mean of 20,488.53 and a standard deviation of 1,580.77.

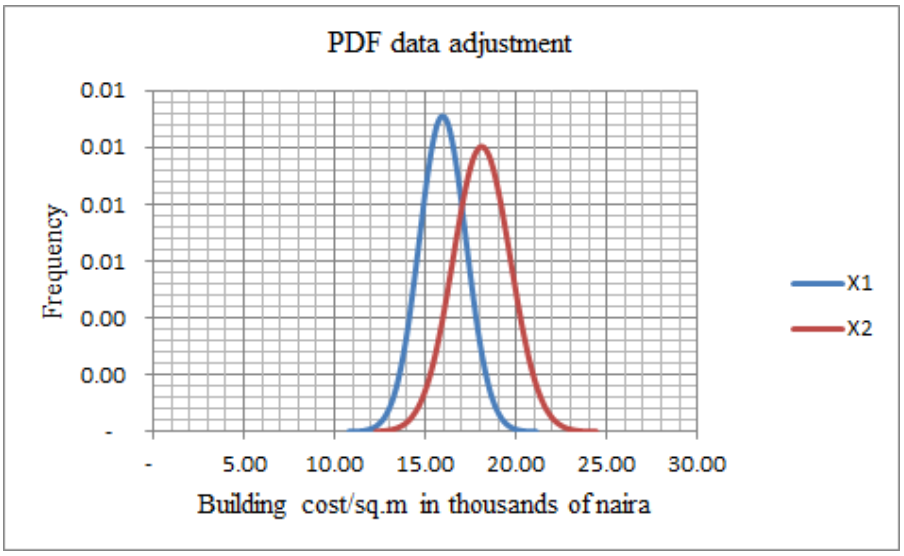


Figure 5. 2: Normal PDF Adjustment for Cost of Building

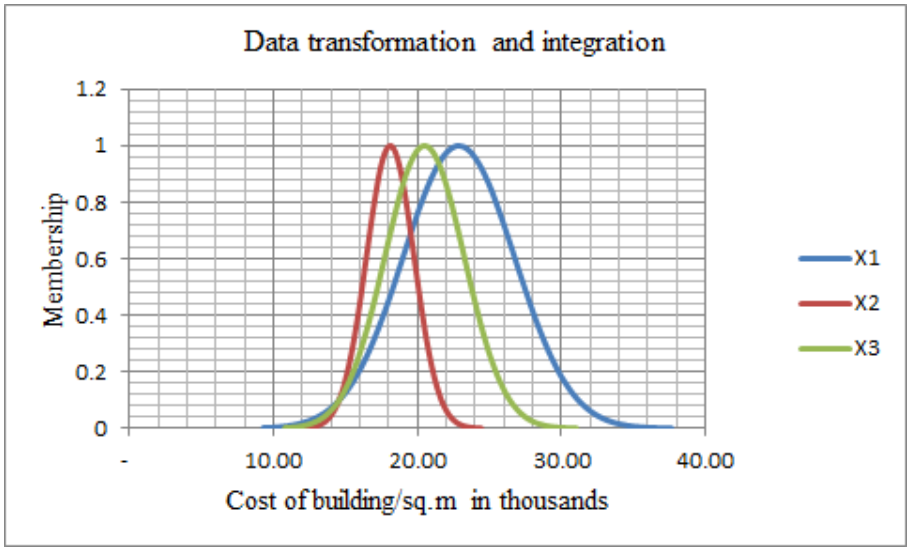


Figure 5. 3: PDF data Transformation and Integration

5.2.5 External Works

The dataset for cost of External works is shown on Table 6 of Appendix 9.1 and Table 9 of Appendix 9.2. The dataset consists of Uniform PDF and Triangular FMF. The objective is to first adjust both data types for time and location, convert the Fuzzy data

to stochastic data, and finally integrating the two to obtain a representative SPD. Table 5.15 shows the adjusted data for Uniform PDF for external works while Figure 5.4 shows the extent of adjustment from the original PDF function X1 to X2. The adjustment causes an increase in the standard deviation and a decrease in maximum probability of X2. This is expected since the total area underneath normalised PDF curve is constant.

Table 5. 15: Uniform PDF Data Adjustment for External Works

S/No	Sub.No	Data type	AF	Adjusted LBUC	Adjusted UBUC
5	1	RPDF	1.1543	2,943.47	5,598.36

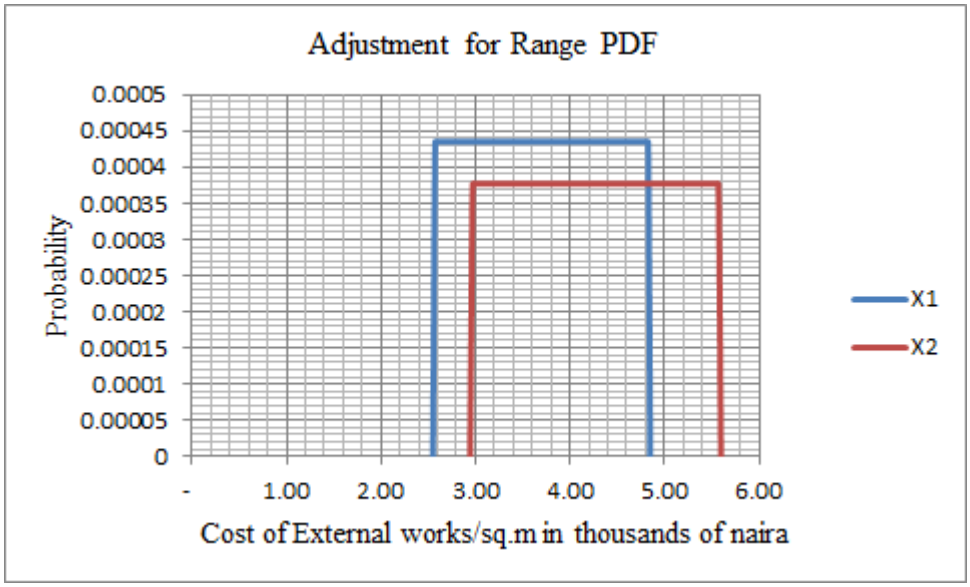


Figure 5. 4: Uniform PDF Data Adjustment for External Works

Table 5.16 shows both the adjustment factor and the adjusted Triangular fuzzy data for External works. Figure 5.5 shows the initial and adjusted membership functions labelled as X1 and X2 respectively. A shift to the right from X1 to X2 indicates an increase in the cost of External works resulting from the adjustment for time and location. It should be observed from the figure that, unlike a PDF, an increase in the

support of X2 does not generate a corresponding reduction in its maximum membership value as the total area underneath the two curves is no necessarily the same.

Table 5. 16: Triangular FMF Data Adjustment for External Works

S/No	Sub.No	Data type	AF	Adjusted LBUC	Adjusted MPUC	Adjusted UBUC
5	2	TFMF	1.1543	3,151.24	5,205.89	6,233.22

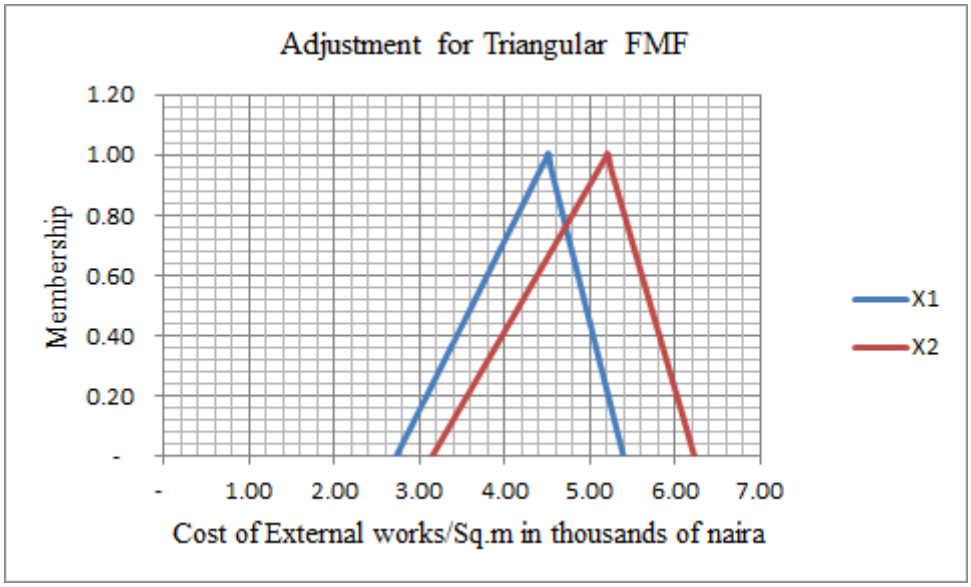


Figure 5. 5: Triangular FMF Data Adjustment for External Works

Figure 5.6 shows both the transformation (see Appendix 10.1) and integration result for External works. The Figure shows the adjusted uniform PDF(X1), transformed triangular PDF(X2) and a combined-irregular PDF(X3) that is representative of the two. The mean of X3 is 4,646.21 which represent its SPD equivalent.

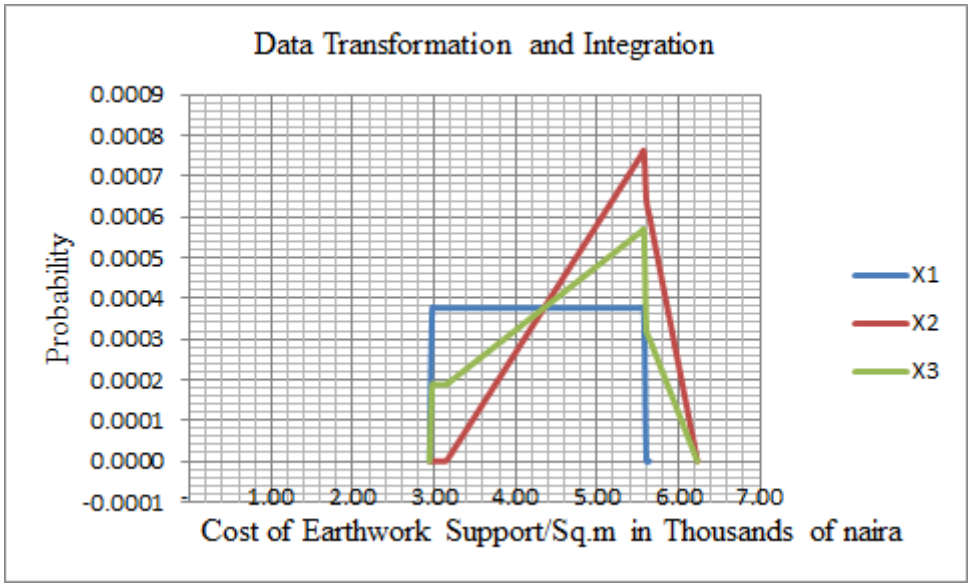


Figure 5. 6: Transformation and Integration of Costs of External Works

5.3.6 Preliminaries

The cost data for preliminaries is on Table 3 of Appendix 9.0 and Table 11 of Appendix 9.3. The objective is to first adjust the data sets for time and locational difference and then convert the MD to TPD data type since MD is at a higher level. Table 5.17 shows the adjusted MD. Each data item is first adjusted for time and location using the AF prior to the computation of an overall average. The range and mean of the MD set constitute the TPD to be used for the integration. Table 5.18 shows the adjusted TPD while Table 5.19 shows the converted and integrated data. The converted data is integrated by computing the averages of the lower, likely and upper values. The average of the likely values represents the SP data required.

Table 5. 17: Adjustment for Multi-data

S/No	Sub.No	Data type	Cost data	AF	Adjusted cost data
6	1	MD	1,240.00	1.14	1,417.32
6	1	MD	1,450.00	1.11	1,611.68
6	1	MD	1,810.00	1.16	2,104.13
6	1	MD	2,100.00	1.15	2,424.03
6	1	MD	2,250.00	1.19	2,670.30
				Total	10,227.45
			Average cost of preliminaries		2,045.49

Table 5. 18: Adjustment for Three-Point data

S/No	Sub.No	Data type	AF	Adjusted LUC	Adjusted LKUC	Adjusted UUC
6	2	TPD	1.16	1,347.34	1,569.38	1,830.94

Table 5. 19: Three-point Data Conversion and Integration

S/No	Sub.No	Data type	Adjusted LUC	Adjusted LKUC	Adjusted UUC
6	1	TPD	1,417.32	2,045.49	2,670.30
6	2	TPD	1,347.34	1,569.38	1,830.94
Average cost of preliminaries			1,382.33	**1,807.43**	2,250.62

5.3.7 Design Fees

The data for Design fees is presented on Table 6 of Appendix 9.1 and Table 8 of Appendix 9.2. The data set consists of Triangular FMF and Normal PDF. The objective is to transform the PDF to FMF after adjusting for time and location. Table 5.20 shows the data adjustment while Figure 5.7 shows both the initial and adjusted Triangular FMF X1 and X2 respectively. Table 5.21 on the other hand shows the data adjustment for the PDF. The data was first adjusted using AF and RF which causes the shift from the initial function X1 to X2.

Table 5. 20: Data Adjustment for Triangular FMF

S/No	Sub.No	Data type	AF	Adjusted LBUC	Adjusted MPUC	Adjusted UBUC
7	1	TFMF	1.143	2,343.15	3,314.70	4,171.95

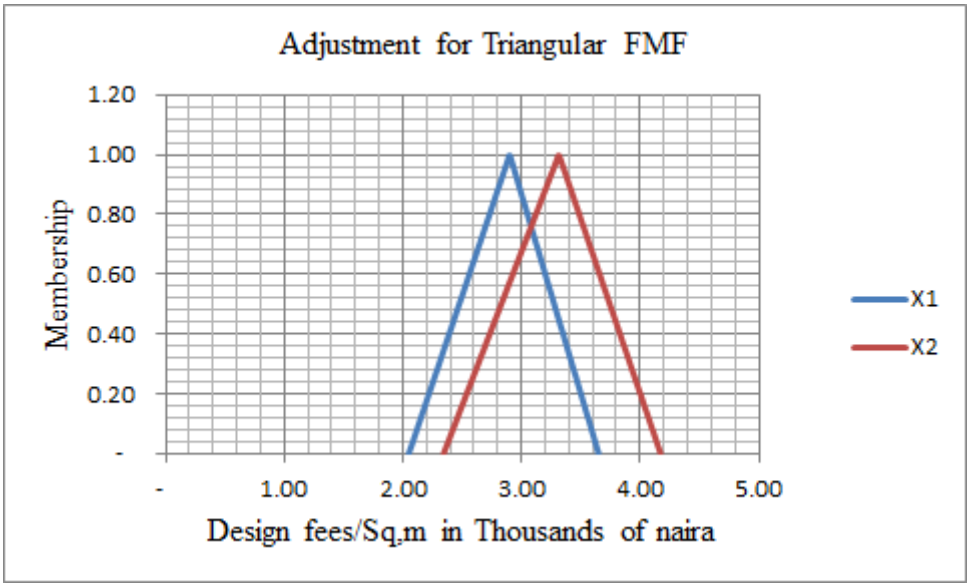


Figure 5. 7: Adjusted Triangular FMF for Design Fees

Table 5. 21:Data Adjustment for Normal PDF

S/No	Sub. No	Data type	AF	Adjusted mean	LC	UC	Adjusted SD
7	2	NPDF	1.16	4,068.75	2,584.24	5,688.11	404.84

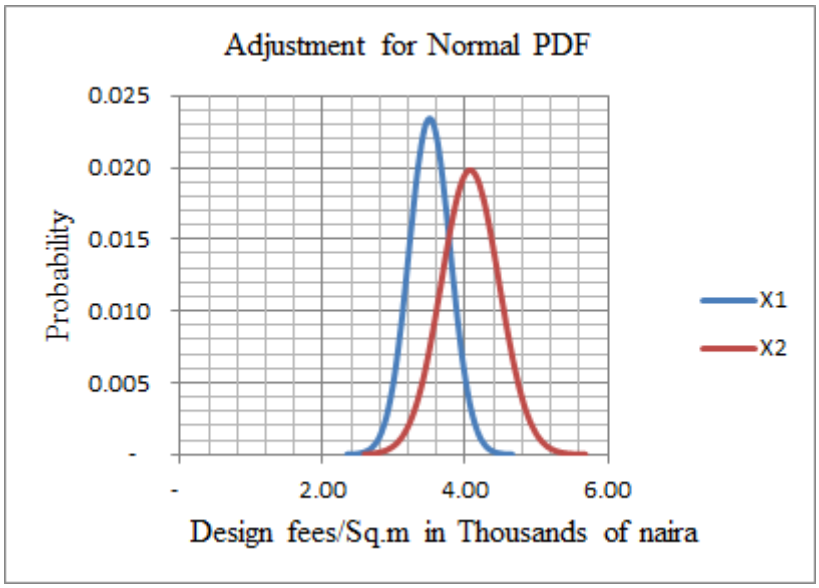


Figure 5. 8: Normal PDF Adjustment for Design Fees

Figure 5.9 shows the adjusted TFMF(X1), the FMF-transformed Normal PDF(X2)(see Appendix 10.2) and the integrated Fuzzy function(X3). The Integrated function takes both the characteristics of the triangular and Gaussian FMF with a mean of 3,694.40 that serves as its SPD equivalent.

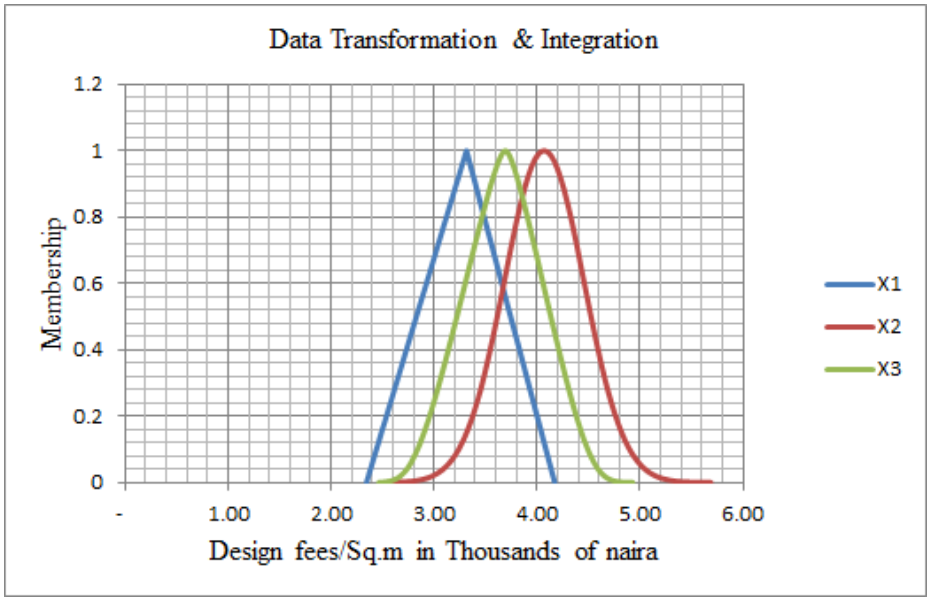


Figure 5. 9: Data Transformation and Integration for Design Fees

5.3.8 Operations Cost

The data for operations cost is contained on Table 5 of Appendix 9.1 and Table 11 of Appendix 9.3. The data set consists of a Multi-data, and Rectangular FMF data types. The objective is to adjust and transform MD format to Rectangular FMF for ease of integration. Table 5.22 shows the adjustment of the MD for time and location using the AF. The MD format is converted to RFMF through its range. The assumption is that each data item between the ranges has equal membership in the fuzzy set. The RFMF representation of the MD is shown on Figure 5.10

Table 5. 22: Data adjustment for Multi-data

S/No	Sub.No	Data type	Cost data(N)	AF	Adjusted cost data
8	1	MD	195.00	1.14	222.89
8	1	MD	260.00	1.11	288.99
8	1	MD	289.00	1.16	335.96
8	1	MD	340.00	1.15	392.46
8	1	MD	410.00	1.19	486.59

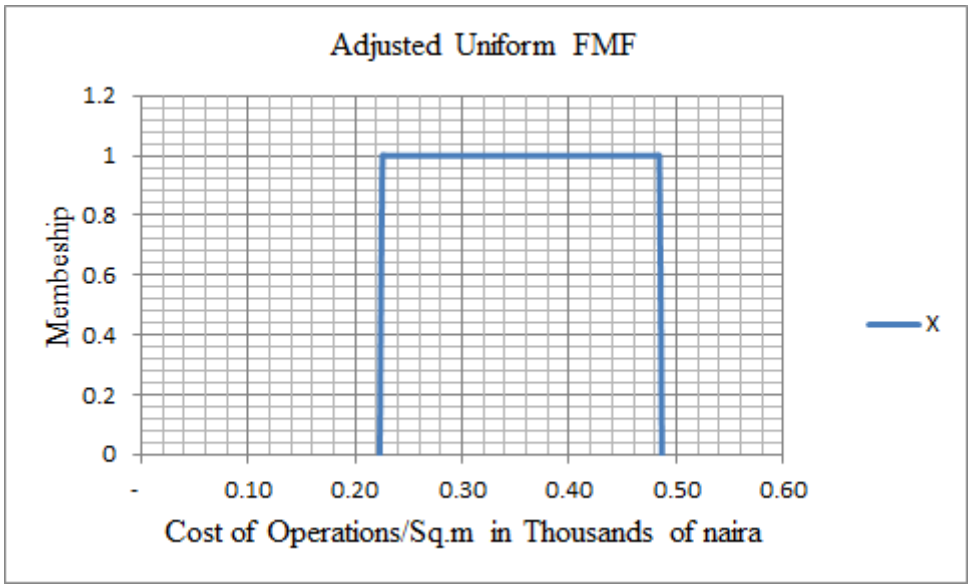


Figure 5. 10: Transformed MD to Rectangular FMF

Table 5.23 shows the data adjustment for the RFMF while Figure 5.11 shows both the initial and adjusted RFMF for the Operating cost. Figure 5.12 depicts the Integration of the RFMF X1 and X2 into X3. X3 has a centroid of 325.37.

Table 5. 23: Data Adjustment for Rectangular FMF

S/No	Sub. No	Data type	Lower Bound unit cost	Upper bound unit cost	AF	Adjusted LBUC	Adjusted UBUC
8	2	RFMF	210.00	295.00	1.1625	231.92	360.0844

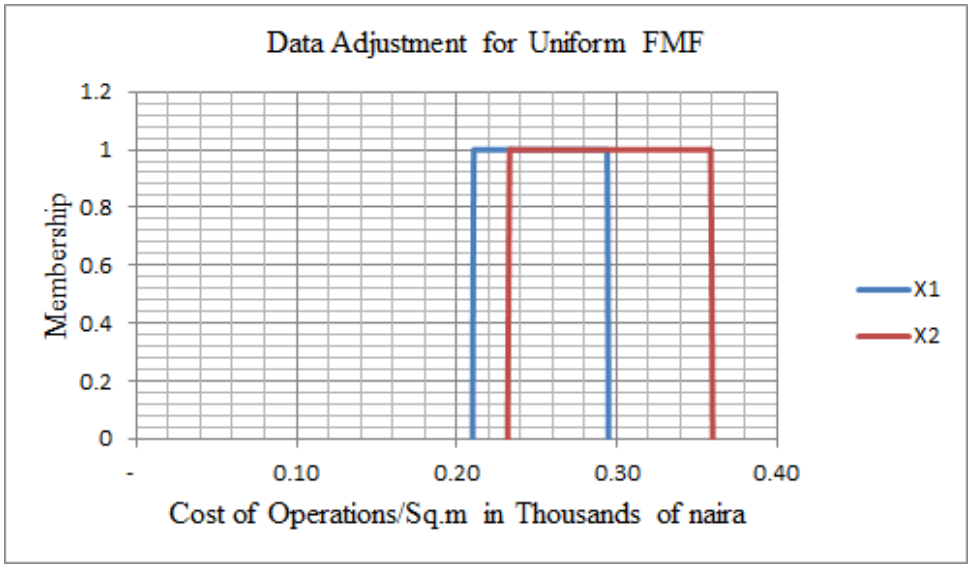


Figure 5. 11: Adjusted Rectangular FMF for Operations Cost

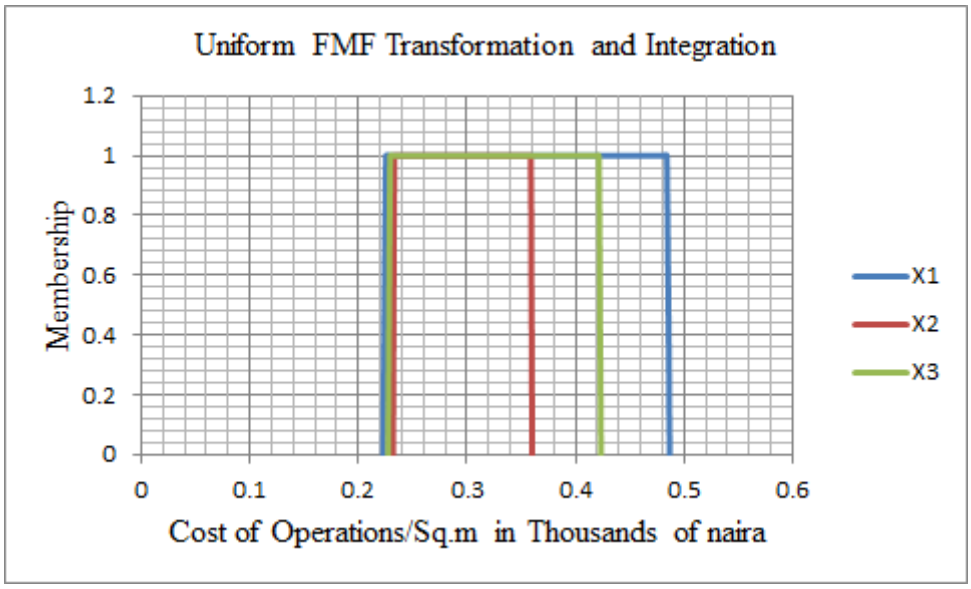


Figure 5. 12: Integration of RFMF for Cost of Operations

5.3.9 Maintenance

The data for maintenance cost is contained in Table 1 and Table 3 of Appendix 9.0. The data set consists of SPD and TPD. The objective is to first adjust the data set for time and location then transform the TPD into a SPD. Table 5.24 shows the adjustment for SPD, Table 5.25 presents the data adjustment for the TPD, and Table 5.26 summarises the Integration process. The average of the likely value of the TPD and the SPD yields the integrated Single point value of 311.78.

Table 5. 24: Data Adjustment for Single-point Data

S/No	Sub.No	Data type	Unit cost	AF	Adjusted values
9	1	SPD	310.00	1.11	344.57

Table 5. 25: Data Adjustment for Three-point Data

S/No	Sub.No	Data type	AF	Adjusted LUC	Adjusted LKUC	Adjusted UUC
9	2	TPD	1.16	231.92	279.00	317.36

Table 5. 26: Data integration for Maintenance Cost

S/No	Sub.No	Data type	Adjusted values
9	1	SPD	344.57
9	2	SPD	279.00
		Total	623.57
		Average	**311.78**

5.3.10 End-of-life

The End-of-life data is presented on Table 7 of Appendix 9.1 and Table 10 of Appendix 9.2. The data set comprises of Triangular PDF and Trapezoidal FMF. The goal is to adjust both data formats for time and locational difference and then convert the Trapezoidal FMF to a PDF so that both functions can easily be integrated. The adjustment for time and location on the TPDF using AF is shown on Table 5.27 and the adjusted function is on Figure 5.13. The function X1 completely shifts to the right to X2 indicating an increase in value due to time and locational differences.

Table 5. 27: Data Adjustment for Triangular PDF Data

S/No	Sub.No	Data type	AF	Adjusted LBUC	Adjusted MUC	Adjusted UBUC
10	1	TPDF	1.143	5,314.95	5,829.30	6,652.26

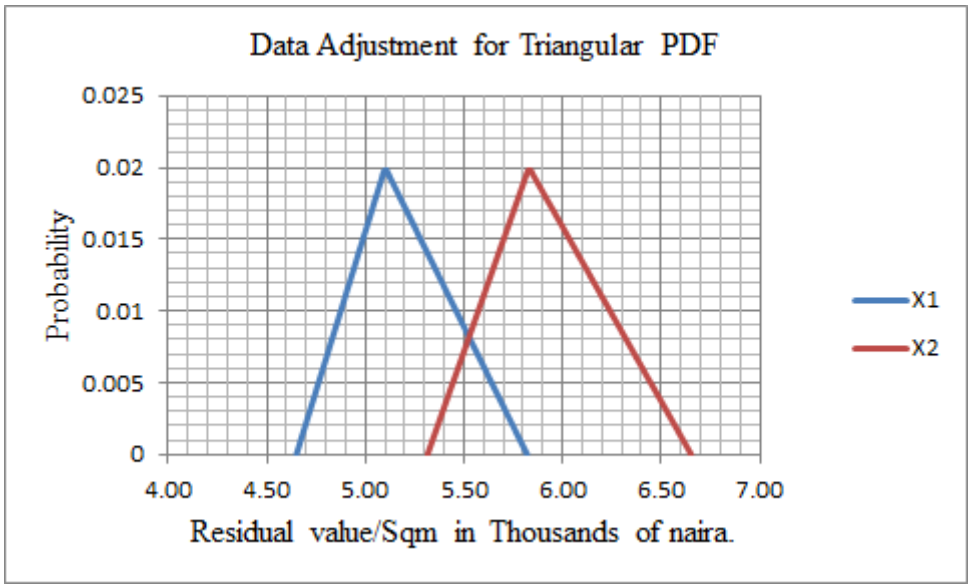


Figure 5. 13: Adjusted Triangular PDF for End-of-life Cost

The data adjustment for the Trapezoidal FMF is shown on Table 5.28. Figure 5.14 shows both the initial(X1) and adjusted Trapezoidal(X2) FMF. In this instance the X1 is completely contained within X2 indicating a low value for the RF (0.75) that causes a large increase in the support of the TrpzFMF.

Table 5. 28: Data adjustment for Trapezoidal FMF

S/No	Sub.No	Data type	AF	Adjusted LBUC	Adjusted MPUC1	Adjusted MPUC2	Adjusted UBUC
10	2	TrpzFMF	1.1625	3,731.63	4,036.78	8,108.44	8,675.16

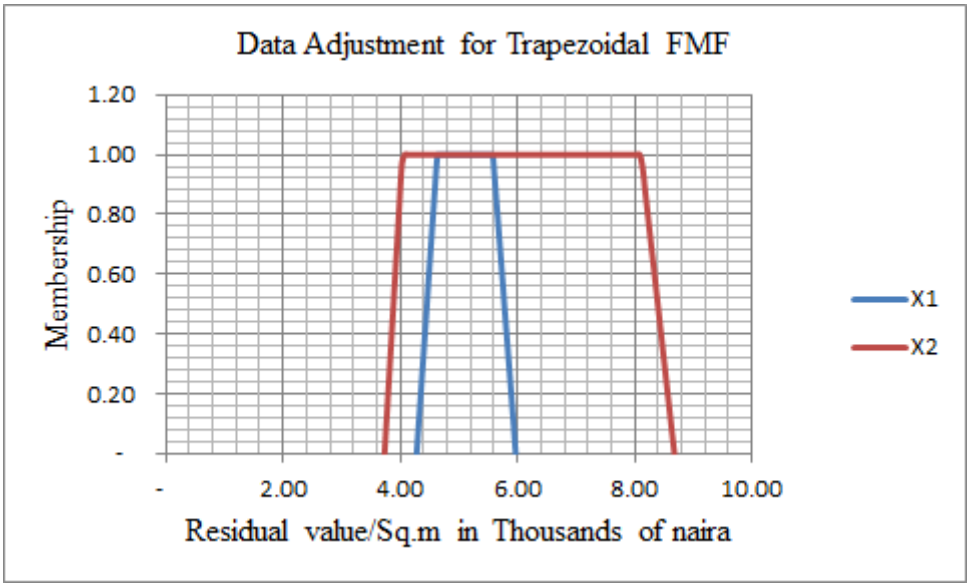


Figure 5. 14: Adjusted Trapezoidal FMF for End-of-life

The outcome of the transformation (see Appendix 10.3) and integration of the TPDF is shown on Figure 5.15. From the Figure, X1 is the initial Triangular PDF, X2 is the transformed TrpzFMF and X3 the resultant irregular PDF. Because the area underneath the three functions is equal, X2 with the largest spread has the lowest maximum probability while X2 that has the lowest spread has the largest maximum probability. The resultant function X3 has a mean of 6,060.27 which represents the SPD equivalent of the PDF.

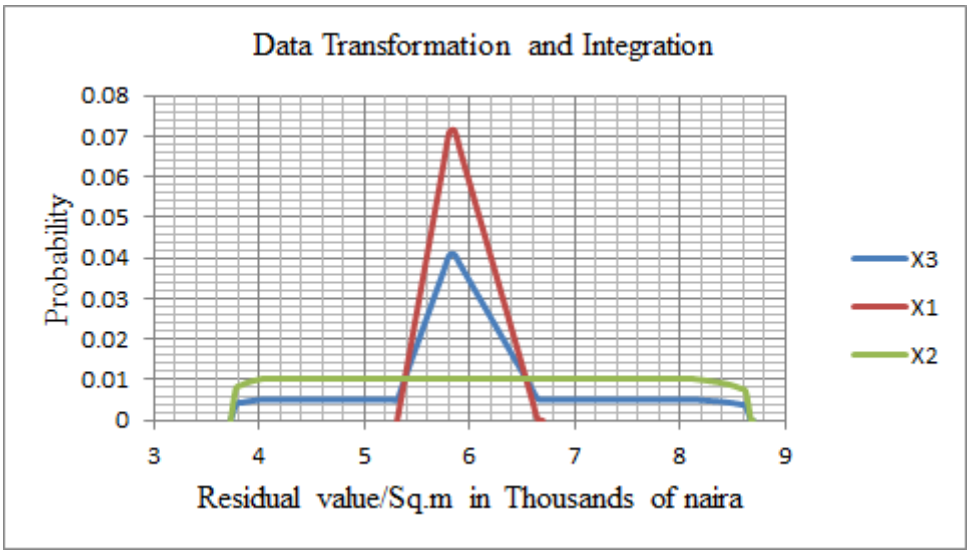


Figure 5. 15: Integration of PDF for Residual Value

5.3.11 Summary of the Data Adjustment, Transformation and Integration process

The data required for testing the transformation and integration process though obtained from multiple sources is mostly available. Building cost/price indices was not readily available in published form. It was however obtained by comparing past and current building costs in conjunction with construction materials price index published by the CBN.

The structure of the database used for the storage and retrieval of the data is quite effective as it enables the storage of such data in context. As demonstrated in section 5.1, the context information if used during data query ensures that only relevant information related to the proposed project is retrieved from the database. This is a unique fit as most existing databases either loses track of the context information, or the original data set from which a summary data is extracted.

Since the reliability of most data collected cannot be fully assured, the idea of Reliability Factor (RF) was introduced. RF enables the adjustment of cost data to

reflect the certainty level associated with both the data and its source. As demonstrated in section 5.2.1 to 5.2.10 RF can be used to adjust the interval of both RD and TPD, the standard deviation of PDF and the spread or support of a FMF thus adding flexibility to both the transformation and data level risk assessment.

In contrast with other WLC frameworks, and as demonstrated in sections 5.2.1 to 5.10, the transformation process is quite robust as it supports the conversion of higher level data to lower level. This fit reduces the burden of data scarcity by supporting the collection and use of any form of cost data within the same analysis framework. In this way, different data formats can be logically combined to produce a set of data that is useful for WLC analysis.

Table 5.29 presents the summary of the result for data adjustment, Transformation and Integration conducted in previous sections.

Table 5. 29: Summary of Data for WLC Analysis

S/No	Cost Centre	Data type	Incidence	Cost/ Value	Unit
1	Non-construction cost: Land	SPD	Initial	4,979.89	Sq.m of Land
2	Non-construction cost: Finance	SPD	Annual	8,049.24	Sq.m of GFA
3	Income	SPD	Annual	6,000.75	Sq.m of GFA
4	Building	SPD	Initial	20,488.53	Sq.m of GFA
5	External works	SPD	Initial	4,646.21	Sq.m
6	Preliminaries	SPD	Initial	1,807.43	Sq.m of GFA
7	Design fees	SPD	Initial	3,694.40	Sq.m of GFA
8	Operations	SPD	Annual	325.37	Sq.m of GFA
9	Maintenance	SPD	Annual	311.78	Sq.m of GFA
10	End-of-life	SPD	Terminal	6,060.27	Sq.m of GFA
Total				xxx	

5.4Model Testing

The purpose of this section is to implement and test the mathematical models formulated in sections 3.11. The models were tested using the cost data summarised on Tables 5.29 and 5.30. Table 5.30 shows the economic data used in the model evaluation. The testing was achieved in two separate stages of; Testing of modified traditional models;Testing of options-based model.

In all the cases, two scenarios were evaluated. The first investment scenario is financed with a bank loan therefore attracts interest as cost of finance, while the second investment scenario is financed through the investors personal savings so does not attract cost of finance. The investment scenarios would clarify the models' ability to identify the best from competing alternatives.

Table 5. 30: Summary of Economic Data

S/No	Data description	Value
1	Opportunity cost of capital	20%
2	Inflation rate	16.5%
3	Discount rate	3%
4	Analysis period	50 years
5	Cost of finance	22%
6	Volatility	50%

5.4.1 Testing of Modified Traditional Model

For the purpose of clarity, equation 15 was first evaluated using the FV and PV methods and the result presented in Appendixes 11.0, 11.1, 11.2 and 11.3 for Scenrio1 Scenario2 respectively. As a tradition, cost entries (cash outflows) are given positive values while income (cash inflows) is given negative values.

5.4.1.1 Future Worth Model

The analysis for Equation 21 is shown on Appendixes 12.0 and 12.1 while the graph of the cumulative annual values against time is shown on Figure 5.16.

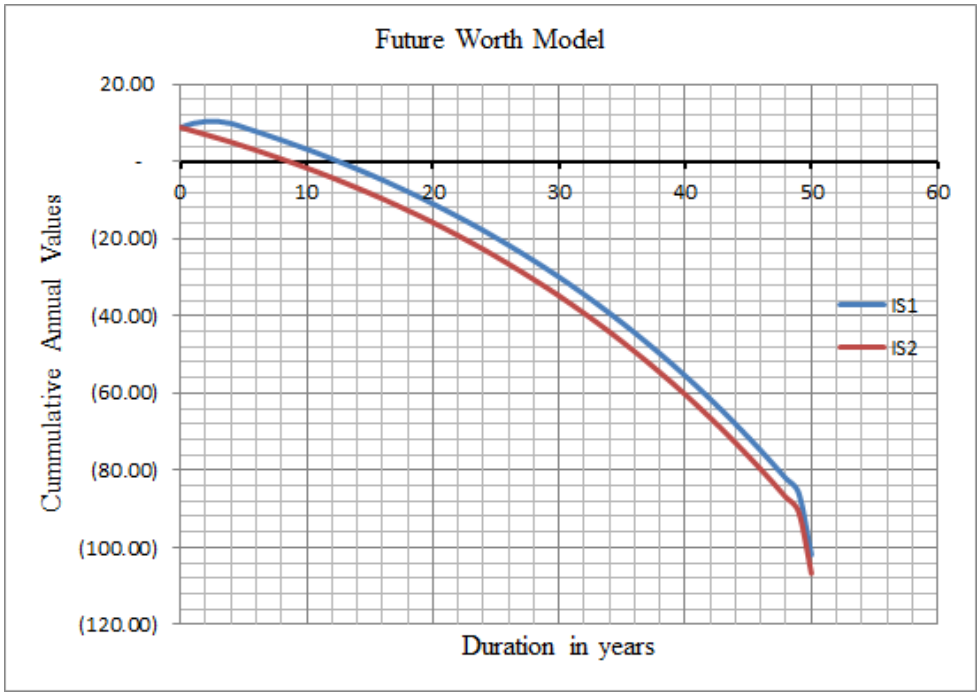


Figure 5. 16: Test Result for Future Worth Modified Traditional Model

From the Figure the vertical axis represents the cumulative annual values while the horizontal axis represents duration in years. The positive section of cumulative annual values is the region where costs outweigh income while the negative section marks the region where the income or benefit outweighs costs. The blue curve represents the first investment scenario (IS1) where the investment is financed through a bank loan, while the brown curve represents the second investment scenario (IS2) where the project is self-financed by the investor. The lower end of the curves is tailed-down indicating an increase in cumulative value due to the salvage value of the asset at the end of the investment life.

Conversely a tailed-up on the same graph would indicate a salvage cost. The point at which each curve strikes the X-axis marks the payback period. More so, the curve with the lowest CAV has the highest NFV. The area subtended between the curves and the X-axis on the positive side of the CAV is proportionate to the total cost of the investment, while the area subtended between the curves and the X-axis on the negative side of CAV is proportionate to the total income expected from the investment. From the foregoing, IS2 has a lower PBP of about 9years in comparison with IS1's 13years. Moreover, IS2 has a higher NFV of about ₦ 108M in comparison IS1's ₦102M. This is also proven by the smaller and larger area between IS2 and the X-axis on positive and negative sides of CAV respectively. Figures 5.17 and 5.18 are Income and Cost VS Time plots for IS1 and IS2 respectively.

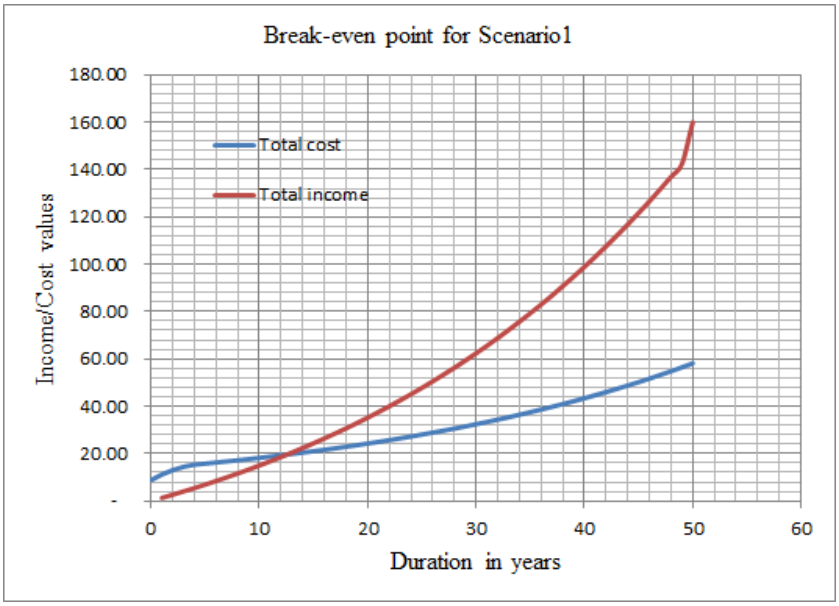


Figure 5. 17: Break-even Point for IS1 on Future Worth Method

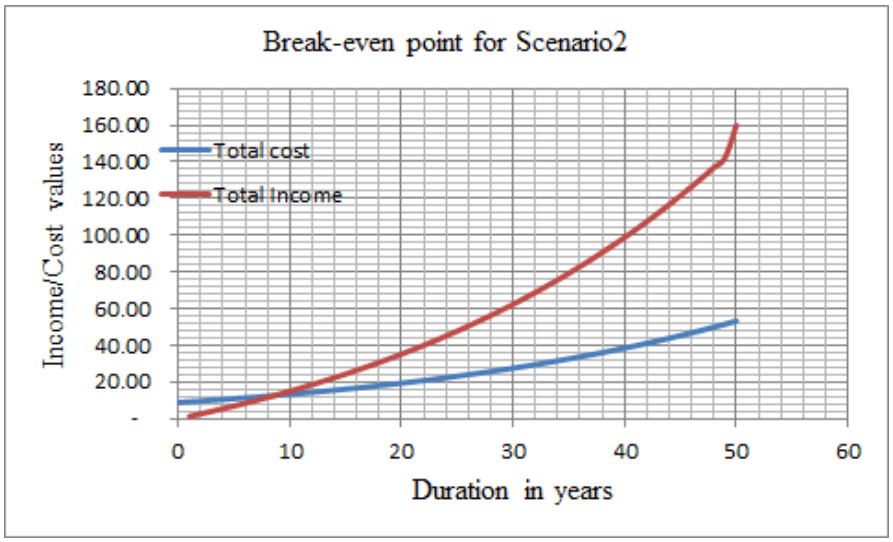


Figure 5. 18: Break-even Point for IS2 on Future Worth Method

From Figure 5.17 the break-even point which also corresponds to the payback period is about ₦20M for IS1 while that of IS2 is ₦12M. It can be reasonably concluded that, Using Equation 21 which is based on the future worth method IS2 is a better investment alternative on the basis of PBP, NFV, and Break-even point. Both options however are viable as they both have significant NFV on the income side.

5.4.1.2 Present Worth Model

The analysis for Equation 20 is shown on Appendixes 13.0 and 13.1. Figure 5.19 shows the CAV VS Time plot. From the Figure, IS1 has a PBP of about 21years while IS2 has a PBP of about 12years. IS1 has a NPV of about of N12M while IS2 has a NPV of 17M. Furthermore IS2 has a larger subtended area on the income region of CAV and a smaller area on the cost region confirming both the higher values of IS2 in terms of PBP and NPV. Figures 5.20 and 5.21 show the break-even points for IS1 and IS2 respectively.

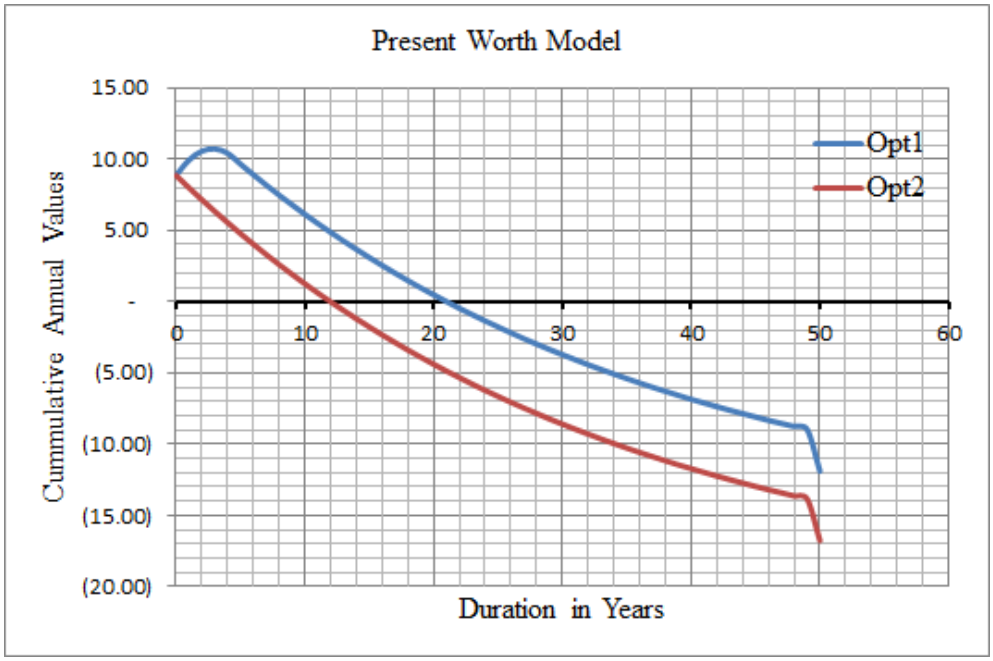


Figure 5. 19: Test Result for Present Worth Modified Traditional Model

From the Figures, the break-even point for IS1 and IS2 are N19.5M and N12.5M respectively. Based on the present worth method, scenario2 has better economic performance so should be preferred.

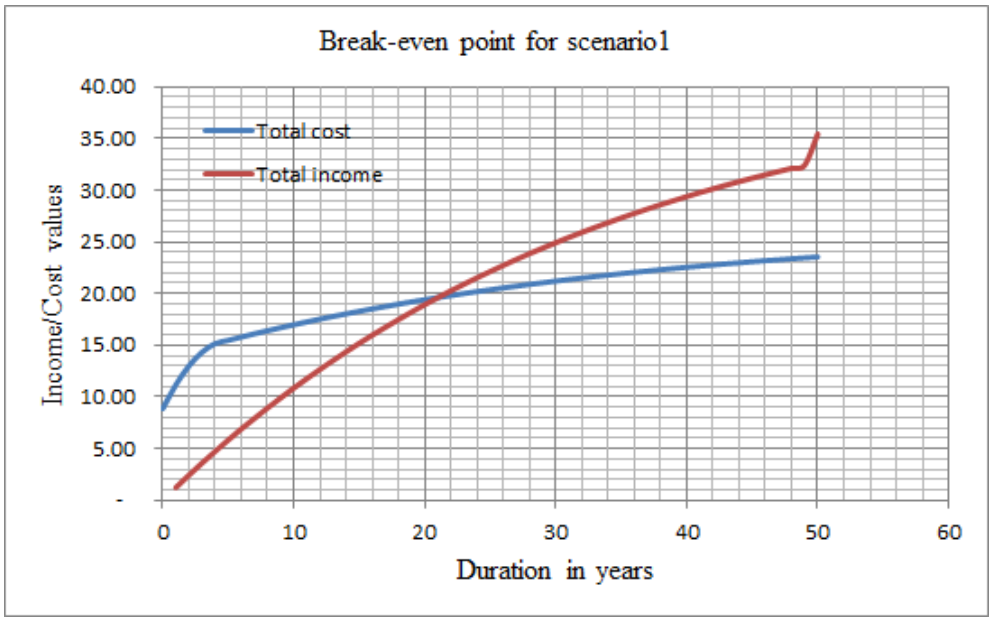


Figure 5. 20: Break-even Point for IS2 on Present Worth Method

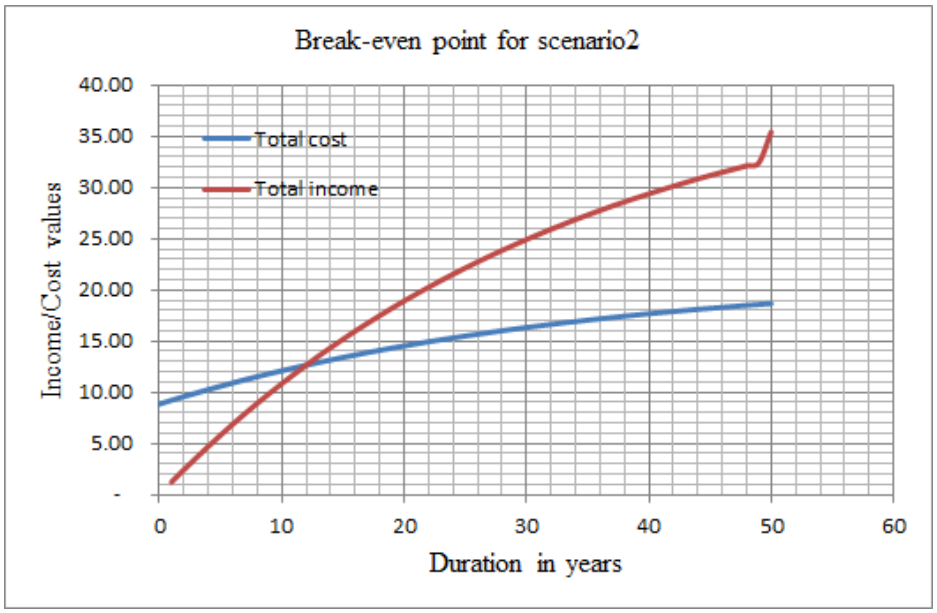


Figure 5. 21: Break-even point for IS2 on Present Worth Method

In comparison with the future worth model presented in section 5.3.1.2, the present worth model is more conservative on all the measured parameters. This can be confirmed from Tables 5.30 and 5.31 where the entries for IS1 and IS2 on the earlier Table are more favourable to those on the later with the exception of Break-even points. Besides, the present worth model is also more dichotomous as evidenced by the larger percentage difference between IS1 and IS2 across the tables. It is worthy of note that both methods produces very close result for the break-even point.

Table 5. 31: Summary of Future Worth Model Parameters

S/No	Parameter	Scenario1	Scenario2	Percentage difference
1	Pay-back period	12years	9years	-31%
2	Net future value	₦ 102M	₦108M	6%
3	Break-even point	₦ 20M	₦12M	-40%

Table 5. 32: Summary of Present Worth Model Parameters

S/No	Parameter	Scenario1	Scenario2	Percentage difference
1	Pay-back period	21years	12years	-43%
2	Net present value	₦ 12M	₦17M	42%
3	Break-even point	₦ 19.5M	₦12.5M	-36%

Based on the result for both the future worth and present worth models, it can be reasonably concluded that, the present worth method being both conservative and dichotomous, should be used when selecting between two or more investment alternatives, or when decision to either proceed or abandon an investment needs to be taken. Both methods can be used however to determine the break-even point of an investment. The future worth method on the hand should be for budgetary purpose as it has the ability to estimate the future values of costs and benefits.

5.4.2 Testing of Options Appraisal Model

This section evaluates the modified Black-Scholes options pricing model using test data. The evaluation checks the efficacy of the models in predicting the optimal investment times of proposed building projects. The evaluation result is presented in two separate sections ahead.

5.4.2.1 Present Worth Model

The analysis for Equations 25 to 34 and Equation 35 is shown on Appendix 14.0 and 14.1. Figure 5.22 shows the evaluation result for an option to develop (based on the present value method) using the same data used for testing the modified traditional model. The figure is a graph of options value VS duration in years. From the Figure, OD1 and NPV1 are scenario1 option to develop and net present value curves respectively while OD2 and NPV2 are scenario2 curves.

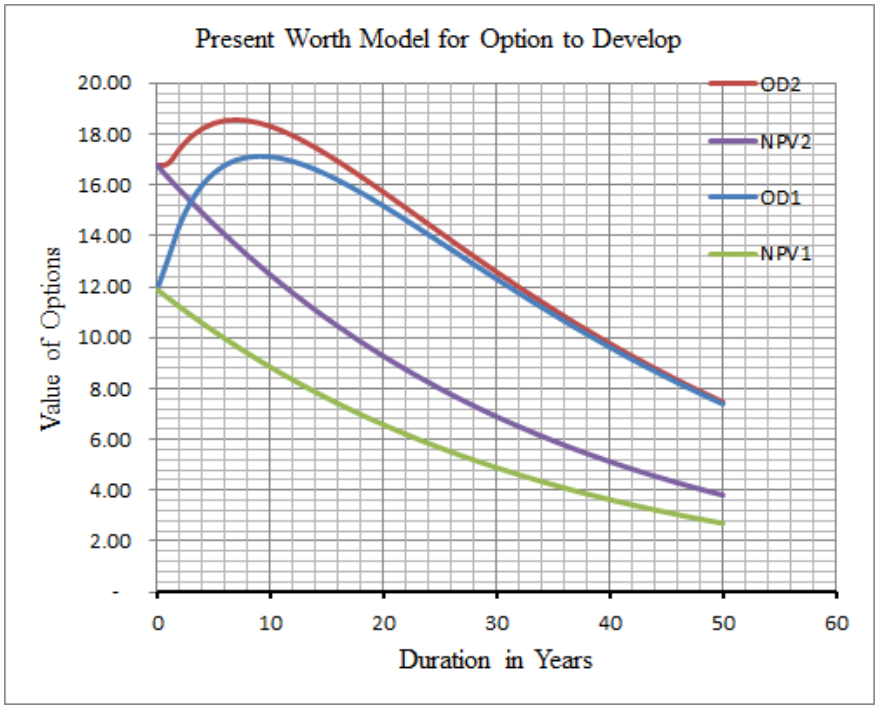


Figure 5. 22: Test Result for Option to Develop Present Worth Model

NPV1 and NPV2 curves trace the path of traditional NPV method which does not account for income volatility. OD1 and OD2 on the other hand trace the path of options to develop values in which volatility in income has been accounted for. Where volatility is zero, the NPV and OD curves would trace the same path. With volatility at 50% the OD curves rise to a maximum after some years and begins to fall exponentially towards their minimum value. The initial rise away from the traditional path is purely accounted for by the volatility. Both OD2 and NPV2 have higher values compared to ODI and NPV1 which implies that Scenario2 outperforms Scenario1 in terms of both NPV and the value of option to develop and so should be the preferred alternative. OD1 attains a maximum value of about N17M in 9years while OD2 attains a maximum of about N18.5M in 7years. The interpretation of the result for OD2 (the preferred option) is that;

the land should be purchased at 2.25M in order to create option to develop; construction should commence early enough to ensure completion by the seventh year when the option value is at its maximum. The interpretation of NPV2 on the other hand is; construct immediately and put to use as the value diminishes (exponentially) with time.

Figure 5.23 shows the economic performance indicators for both Scenario1 and 2. BCR1 and BCR2 represent the Benefit to Cost Ratios for Scenario1 and 2 respectively. PINPV1 and PINPV2 are the Profitability Index on the NPV for Scenario1 and 2 respectively. PIODV1 and PIODV2 are the Profitability Index on the options value for Scenario1 and 2 respectively. BCR1, BCR2, PINPV1, and PINPV2 all have constant values over time confirming the underlying assumption of the model. PIODV1 and PIODV unlike other parameters show a gradual rise to a maximum indicating a gradual increase in value over cost. This also confirms the increase in value due to the volatility accounted for by the model. It should be noted that all the indexes for Scenario2 are greater than those of Scenario1 confirming its economic performance superiority.

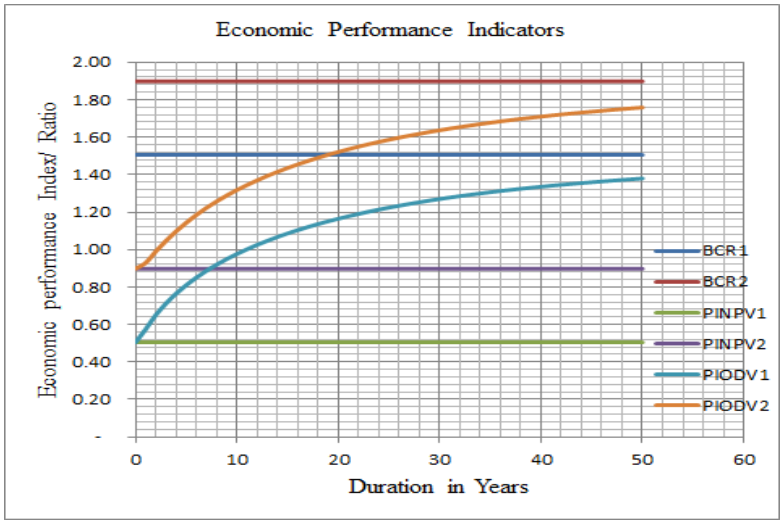


Figure 5. 23: Economic Performance Measures for Scenrio1 and 2

5.4.2.2 Future Worth Model

The analysis for Equations 25 to 34 in conjunction with Equations 36 is shown on Appendixes 15.0 and 15.1. Figure 5.24 shows the evaluation result for an option to develop using the future worth method. Unlike the present worth model, this model does not yield any vital result as all the curves rise exponentially without identifying the optimal investment time. The Black-Scholes model was formulated based on the present value technique which may explain why the Future Worth model did not behave as anticipated.

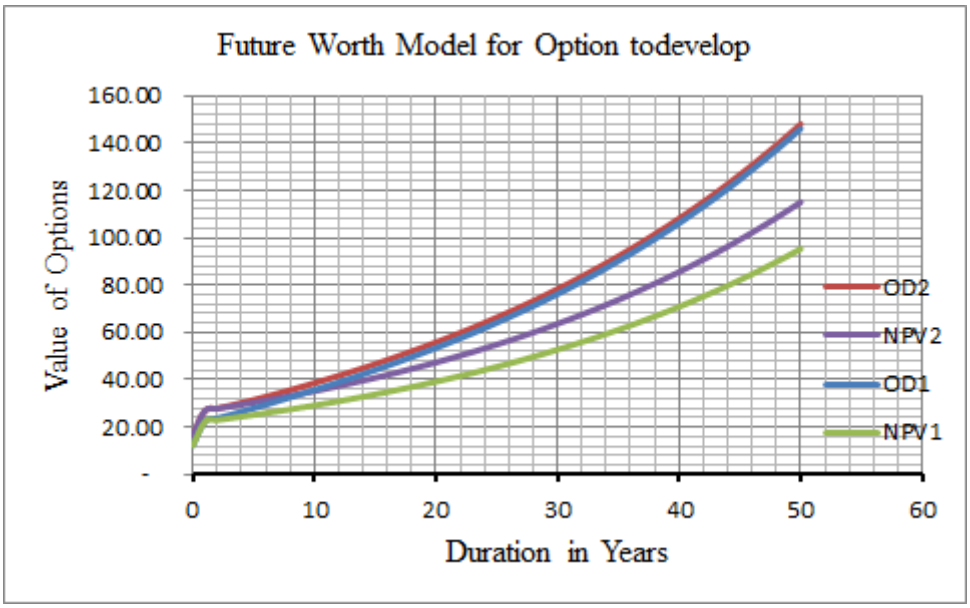


Figure 5. 24: Test Result for Option to Develop Future Worth Model

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

i. The legal requirement for the application of WLC in the Building sector of the Nigerian construction industry has been articulated. The articulation revealed that a legal framework for the application of WLC is in place. The public procurement Act, 2007 and the BPP through their publications (Public Procurement Manual, Public Procurement Regulations for goods and works) provides the platform upon which WLC could be used for the evaluation of design alternatives during the procurement of consultancy services, building systems, equipment and components at bidding stage. Moreover, the National policy on PPP in conjunction with PPP toolkit clearly requires the application of WLC in all PPP projects. The sources collectively defines; the types of projects in which WLC evaluations should be applied; the life-cycle stages at which WLC should be conducted the economic evaluation techniques to be used; the uncertainty and risk analysis techniques to use; approved sources of WLC data; CBS to adopt; WLC analysis and the situations under which they should be used; disposal methods and procedures; discounting techniques to be used; procedures to comply with and finally documentation and reporting formats.

ii. The evaluation of WLC implementation problems/ challenges indicates that, Client's lack of understanding/ demand, and data scarcity are the most significant challenges. Other problems include separation of capital from running cost, lack of understanding by the client, and lack of standard methodology.

iii. Existing frameworks have been evaluated to identify their strengths and weaknesses. Nine existing WLC frameworks and six evaluation criteria were identified from literature. The evaluation reveals that, on the overall, the frameworks adequately represent decision-making process, uncertainty and risk analysis, and iteration requirement. However, none of the existing frameworks fully satisfy all the identified criteria as all failed to adequately represent problem-solving process, and project life-cycle stages. This is not surprising since the target of most frameworks is to aid decision-making when selecting from competing design alternatives. As soon as the best alternative is identified, mission is presumed accomplished without a follow up to the construction and occupancy stages where real-life data is to be collected, analysed and performance evaluated. Thus, failure of frameworks to present WLC as a problem-solving process deemphasise the need for data collection, analysis, storage, and retrieval mechanism through which cost control and feedback of information to the early stages of building life-cycle are actualised. Furthermore, failure of the frameworks to reflect stages of building evolution negates the need for proper data structuring (into parametric, elemental, sub-elemental, unit rate, etc.) to fit the varying level of details of information across building life-cycle.

iv. A conceptual framework that satisfies the legal requirement for the application of WLC, addresses the major implementation challenges and limitations of existing frameworks was developed and transformed into a programme flowchart for possible coding into a computer language which will process complexity and enhance user friendliness. The framework is structured to clearly define and accommodate WLC activities at different life-cycle stages,

this was achieved by first classifying WLC activities into four broad groups of; data collection, analysis and storage; data preparation; WLC appraisal and uncertainty/risk analysis. A framework was then developed for each of the groups and combined to represent the WLC implementation framework. Each of the groups constitute of activities achieved at various levels and degrees depending on the life-cycle stage at which they occur. The activities for instance were achieved at building, group element, elemental, sub-elemental and component levels corresponding to the planning, concept design, developed design, technical design and post design stages respectively. This fit is particularly important as the potential for cost saving, risk impact and likelihood, types of decisions and data certainty and reliability and the modelling techniques to be used all vary with life-cycle stages.The framework also enables feedback of data/information between preceding and succeeding life-cycle stages. Data generated at the operating and end-of-life stages could be recycled through analysis and storage in preparation for use in the evaluation of proposed projects that could be entirely new, or retrofitting, renovation and refurbishment of existing asset. This was achieved through the design and implementation of a relational database that enables both the storage of data at different stages of project life-cycle and at varying level of details. The project life-cycle stages correspond to the RIBA stages while the levels of detail correspond with, building, group-element, element, sub-element, and component levels. The database was structured to house data that is both project and non-project related. To simplify the data storage and retrieval process, user-friendly dialogue boxes were used to guide the user in supplying the correct information. Each data entry form is associated with a database table that

captures and stores the input data. In all, thirty tables were assigned to thirty data entry forms to capture project related data while five tables and entry forms captures the non-project related data. Each dataset is stored alongside its context information to preserve data integrity. In line with this, the database ensures the association of each data entry with a general project information, and physical/performance data. Furthermore, the database facilitates data scoping which permits the inclusion and removal of data items within a particular storage or retrieval group as an important requirement of ISO 15686-5. In addition, the framework helps to identify and select an appropriate model to be used for both WLC evaluation and uncertainty/risk analysis. Both quantitative and qualitative assessments are supported by the framework depending on data type, and availability. It supports the use of deterministic, statistical, black-box, stochastic, fuzzy and weighted evaluation models for use with the appropriate set of data. Perhaps the most important pro of the framework is its ability to handle multiple data formats. The framework permits data entry in six different formats and the transformation of higher level to lower level formats. This was achieved through the data collection and analysis framework and the data preparation framework. The data analysis framework facilitates the collection and storage of physical, performance, economic and revenue/cost data in, crisp, range, three-point, PDF, FMF, or multiple data types. The data is stored in the relational database that was described earlier. The data preparation framework on the other hand facilitates data retrieval through a query system and the transformation of data from one form to the other and the processing of such data in preparation for use at the appraisal stage. This undoubtedly helps to mitigate the data scarcity problem as analysts do not have to focus on the data

format and model types they are conversant with but rather on an array of formats and models with all the attendant complex transformations, processes and computations handled at the framework's background.

v. In an attempt to improve client demand, two sets of mathematical models where developed to facilitate a breakaway from traditional practice to an option-based practice that supports building investors core decision needs. Each of the two models was subdivided into future worth and present worth method. The modified traditional model expresses cost in cumulative terms thereby enabling the identification of the best alternative based on Payback Period, net present/net future values, and break-even point. The Options appraisal model on the other hand was incorporated at various stages of project life cycle to facilitate the evaluation of embedded WLC opportunities. The present value options appraisal model enables the determination of the optimum investment time thereby improving the decision horizon from two-way to five-way. This has improved the decision horizon from the traditional 2-way decision of either to develop or abandon to: create option to develop vs defer option creation, develop now vs defer development, or abandon. It also provides estimate of benefit to cost ratios, profitability index on both the net present values and option value.

vi. Test result confirms the efficacy and robustness of: the transformation and integration algorithms in converting one data type to another, and the modified WLC and the options appraisal models. The duo models provides sufficient information that enables decision making when selecting from competing alternatives or when evaluating the viability of an investment on the basis of

net present values, payback period, profitability index, benefit to cost ratio and optimal options value.

vii. It is anticipated that the framework would improve the usability of WLC in the industry by providing both private and public sector with a robust analysis tool that would facilitate long term property investment decision making.

6.2 Conclusions

i. The legal requirement for the application of WLC in the procurement of public buildings, systems and components is clearly enshrined in the Nigerian legislations, standards, rules, regulations and guidelines. The legal provisions have already put in place platform upon which WLC could be used for the evaluation of design alternatives during the procurement of consultancy services, and building systems, equipment and components at bidding stage. Moreover, the legal provision also stipulates the application of WLC in all PPP.

ii. The major barriers to the application of WLC as identified by the study are: lack of demand and understanding by the client, and data scarcity.

iii. None of the existing frameworks satisfy all evaluation criteria. The frameworks performed poorly in terms of conformity with problem solving, project life-cycle, and feedback requirement.

iv. A conceptual framework that provides a bird's eye-view of WLC activities, process and satisfies all evaluation criteria was developed. The framework has the advantage of presenting WLC activities in a broad, rational and articulate manner. Thus the basic idea behind WLC planning, analysis and management has been fully covered. This represents a breakaway from traditional WLC decision-making to WLC problem-solving thereby mitigating the limitations of

existing frameworks and providing a sound basis upon which WLC decision support systems can be developed.

v. A model selection framework has been proposed. The framework assists an analyst to select a particular WLC model depending on the type and amount of data at his disposal. This mitigates the data scarcity problem by preventing model-data mismatch. It also facilitates the use of minimal subjective data in the form of fuzzy numbers so that expert judgement and opinion are fully integrated with other data formats. A robust relational database that facilitates the storage, retrieval, transformation and integration of the different data formats was developed. The main feature of the database is that it keeps data integrity intact by capturing its background information.

vi. A set of mathematical models for estimating the optimal development value and time for five different options was formulated. The models overcome the limitation of traditional NPV technique by expressing result in annual basis and capturing volatility in cash flows over an asset life. This enables the computation of the asset's true value at various times and also the identification of the optimal investment period. On the overall it increases the decision horizon by assisting the analyst to decide on whether to: abandon, defer development or sales, develop, reconfigure design, switch use and expand an investment. The model would undoubtedly assist investors to ascertain not just the viability of an investment option but also the time at which the investment is most viable thereby improving the profitability of proposed building projects. In addition, the models enables the decision maker to take informed decision on the viability of an investment on the basis of net present values, payback period, profitability index, benefit to cost ratio and optimal options value. This fit

undoubtedly provides the analyst with a tool that can serve the entire span of client's investment decision needs thereby improving his satisfaction and confidence.

6.3 Recommendations

i. Building professionals and consultants must be aware of the existence of legal provisions for WLC and also get prepared to take on the challenge placed upon them. They must understand that traditional procurement on the basis of initial cost alone is no more tenable and redirect their attention to the use of WLC as it gives the public better value for money and as such becomes imperative at especially the present times in which the country is experiencing recession.

ii. Stakeholders in the building industry should come together to agree on the circumstance of use of ISO 15686-5 standard and also to take steps towards making it a Nigerian Industrial Standard as SON will not hesitate to apply its provisions where national economic interest is of concern.

iii. Professionals should leverage on the models developed as a burden has been placed upon them by Sec. 56 of PP Act. to disburse public properties at a time when maximum economic gains can be achieved

iv. Investors in built assets should put to use the models developed so that they do not evaluate the viability of their investment on the basis of quantum of profit only but also the time at which the profit is optimal. This ensures that initial capital outlay works the hardest and an optimum value for money acquired. It will also boost client's confidence on the services received as his entire decision horizon has been fully covered.

v. In order to improve an overall client demand for WLC services, professionals in the industry must be ready to serve the client what he actually demands not

what they presume he needs. WLC brands from other industries may not necessarily appeal to building clients due to the diverse nature of the products.

6.4 Contribution to Knowledge

i. The study identified and documented the legal bases for WLC evaluation of public building projects in Nigeria; evaluated the performance of nine existing WLC frameworks and established that they performed below average in terms of conformity with problem solving, project life-cycle, and feedback requirement with average scores of 45%, 0% and 15% respectively.

ii. The study mitigates major WLC implementation challenges through the development of modified Black-Scholes model that makes possible the determination of the optimum investment/ disposal times of built assets; and a model selection framework that enables the selection of the most appropriate risk assessment technique based on data availability as well as a relational database that ensures data integrity and facilitates the storage and retrieval of data in multiple formats.

iii. The study developed a WLC conceptual framework that meets domestic legal requirements, mitigates the limitations of existing frameworks, addresses WLC implementation challenges; and provides the technical basis for the development of an industry level computer-based WLC application.

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Appendix 1:

Building and Group Element level data centres and their codes

Building and Group element level data centres and their codes

S/No.	DataCentreID	Data Centre
1	BLBR	Building related
2	BLBEEP	Building Embodied eco-points
3	BLOEEP	Opeations embodied eco-points
4	BLMEEP	Maintenance embodied eco-points
5	BLSR	Social related
6	BLSLD	Buildings estimated service life
7	BLNCC	Non-construction cost
8	BLI	Income
9	BLEX	Externalities
10	BLBC	Building
11	BLEW	External works
12	BLPC	Preliminaries
13	BLDF	Design fees
14	BLOC	Operations
15	BLMC	Maintenance
16	BLDC	End-of-life
17	GLBR	Building related
18	GLSR	Social related
19	GLBSSEEP	Substructure Embodied eco-points
20	GLBSSEEP	Superstructure Embodied eco-points
21	GLBIFEEP	Internal finishes Embodied eco-points
22	GLBFFEEP	Fittings furnishings and equipment Embodied eco-points
23	GLBSEEP	Services Embodied eco-points
24	GLBPPEEP	Prefabricated buildings and building unit Embodied eco-points
25	GLBWBEEP	Work to existing buildings Embodied eco-points
26	GLBEWEEP	External works Embodied eco-points
27	GLSSMEEP	Substructure Maintenance EEP
28	GLSuSMEEP	Superstructure maintenance EEP
29	GLIFMEEP	Internal finishes maintenance EEP
30	GLFFMEEP	Fittings furnishings and equipment maintenance EEP
31	GLSMEEP	Services maintenance EEP
32	GLPPMEEP	Prefabricated buildings and building unit maintenance EEP
33	GLWBMEEP	Work to existing buildings maintenance EEP
34	GLEWMEEP	External works maintenance EEP
35	GLSSSL	Substructure Service life
36	GLSuSSL	Superstructure Service life
37	GLIFSL	Internal finishes Service life
38	GLFFSL	Fittings furnishings and equipment Service life

39	GLSSL	Services Service life
40	GLPPSL	Prefabricated buildings and building unit Service life
41	GLWBSL	Work to existing buildings Service life
42	GLEWSL	External works Service life
43	GLNCLEW	Land and enabling works
44	GLNCFC	Finance cost
45	GLNCPM	User support cost: property management
46	GLNCUC	User support cost: Use charges
47	GLNCAC	User support cost: Administration cost
48	GLNCT	Taxes
49	GLNCOC	Other non-construction cost
50	GLIFS	Income from sales
51	GLTPI	Third party income
52	GLTOI	Taxes on income
53	GLDC	Disruption costs
54	GLOC	Other Income related costs
55	GLEXSC	Externalities-Social cost
56	GLEXEC	Externalities-Environmental cost
57	GLEXBC	Externalities-Business cost
58	GLEXSB	Externalities-Social benefits
59	GLEXEB	Externalities-Environmental benefits
60	GLEXBB	Externalities-Business benefits
61	GLCSS	Cost of Substructure
62	GLCSUS	Cost of Superstructure
63	GLCIF	Cost of Internal finishes
64	GLCFFE	Cost of Fittings furnishings and equipment cost
65	GLCS	Cost of Services
66	GLCPBU	Cost of Prefabricated buildings and building unit
67	GLCWEB	Cost of Work to existing buildings
68	GLCEW	Cost External works
69	GLCP	Cost of Preliminaries
70	GLOP	Contractor's Overhead and profit
71	GLDF	Design fees
72	GLOPC	Other development/ project costs
73	GLADSS	Adaptation of Substructure
74	GLADSUS	Adaptation of Superstructure
75	GLADIF	Adaptation of Internal finishes
76	GLADFFE	Adaptation of Fittings furnishings and equipment cost
77	GLADS	Adaptation of Services
78	GLADPBU	Adaptation of Prefabricated buildings and building unit
79	GLADWEB	Adaptation of Work to existing buildings
80	GLADEW	Adaptation of External works
81	GLRARSS	Repair & replacement of Substructure
82	GLRARSUS	Repair & replacement of Superstructure
83	GLRARIF	Repair & replacement of Internal finishes
84	GLRARFFE	Repair & replacement of Fittings furnishings and equipment

		cost
85	GLRARS	Repair & replacement of Services
86	GLRARPBU	Repair & replacement of Prefabricated buildings and building unit
87	GLRARWEB	Repair & replacement of Work to existing buildings
88	GLRAREW	Repair & replacement of External works
89	GLCLSS	Cleaning of Substructure
90	GLCLSUS	Cleaning of Superstructure
91	GLCLIF	Cleaning of Internal finishes
92	GLCLFFE	Cleaning of Fittings furnishings and equipment cost
93	GLCLS	Cleaning of Services
94	GLCLPBU	Cleaning of Prefabricated buildings and building unit
95	GLCLWEB	Cleaning of Work to existing buildings
96	GLCLEW	Cleaning of External works

Appendix 2:

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25	GLBWBEEP	Work to existing buildings Embodied eco-points
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27	GLSSMEEP	Substructure Maintenance EEP
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31	GLSMEEP	Services maintenance EEP
32	GLPPMEEP	Prefabricated buildings and building unit maintenance EEP
33	GLWBMEEP	Work to existing buildings maintenance EEP
34	GLEWMEEP	External works maintenance EEP
35	GLSSSL	Substructure Service life
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41	GLWBSL	Work to existing buildings Service life
42	GLEWSL	External works Service life
43	GLNCLEW	Land and enabling works

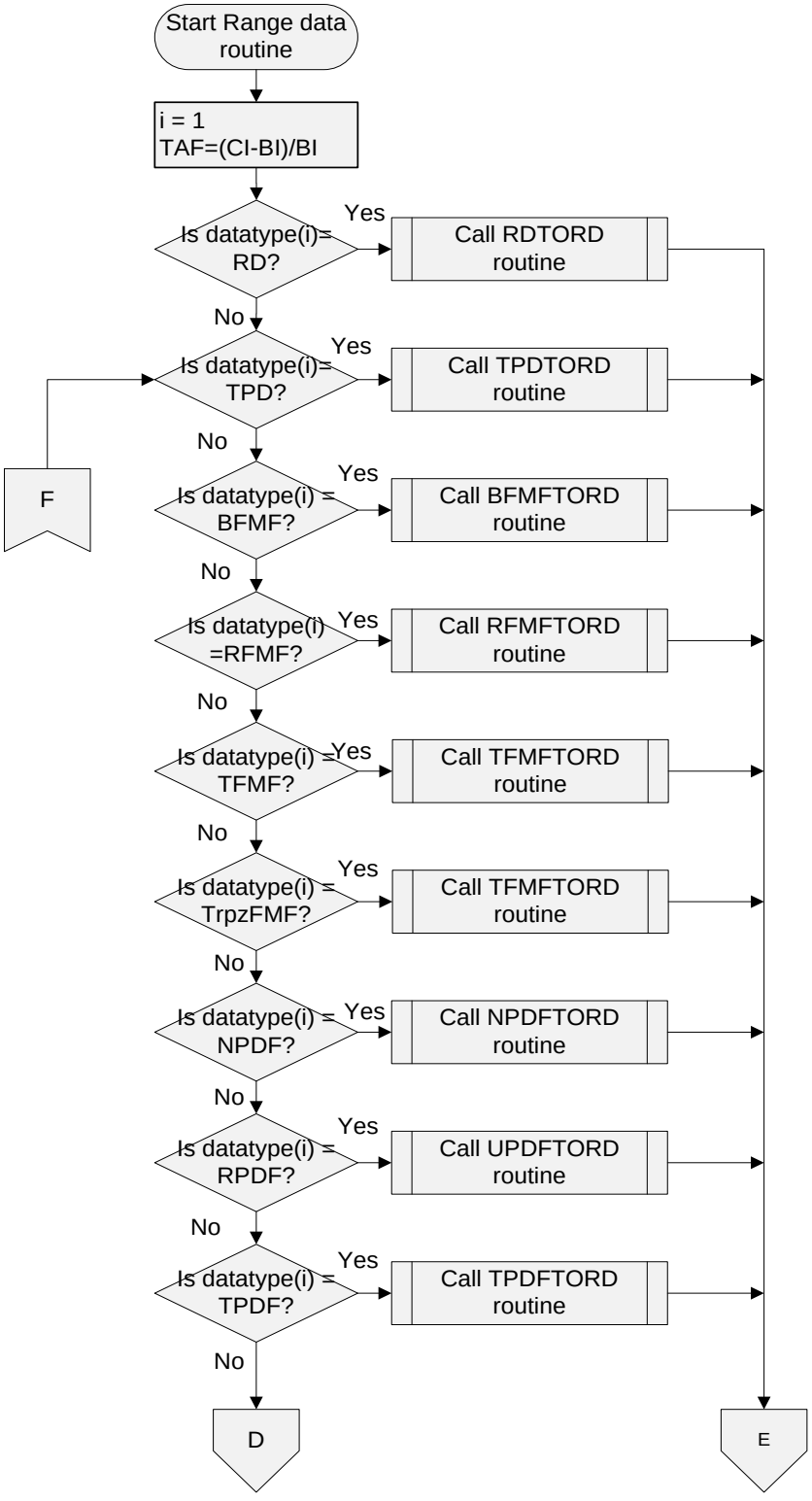
44	GLNCFC	Finance cost
45	GLNCPM	User support cost: property management
46	GLNCUC	User support cost: Use charges
47	GLNCAC	User support cost: Administration cost
48	GLNCT	Taxes
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50	GLIFS	Income from sales
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58	GLEXSB	Externalities-Social benefits
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76	GLADFFE	Adaptation of Fittings furnishings and equipment cost
77	GLADS	Adaptation of Services
78	GLADPBU	Adaptation of Prefabricated buildings and building unit
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80	GLADEW	Adaptation of External works
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84	GLRARFFE	Repair & replacement of Fittings furnishings and equipment cost
85	GLRARS	Repair & replacement of Services
86	GLRARPBU	Repair & replacement of Prefabricated buildings and building unit
87	GLRARWEB	Repair & replacement of Work to existing buildings

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93	GLCLS	Cleaning of Services
94	GLCLPBU	Cleaning of Prefabricated buildings and building unit
95	GLCLWEB	Cleaning of Work to existing buildings
96	GLCLEW	Cleaning of External works

Appendix 3:

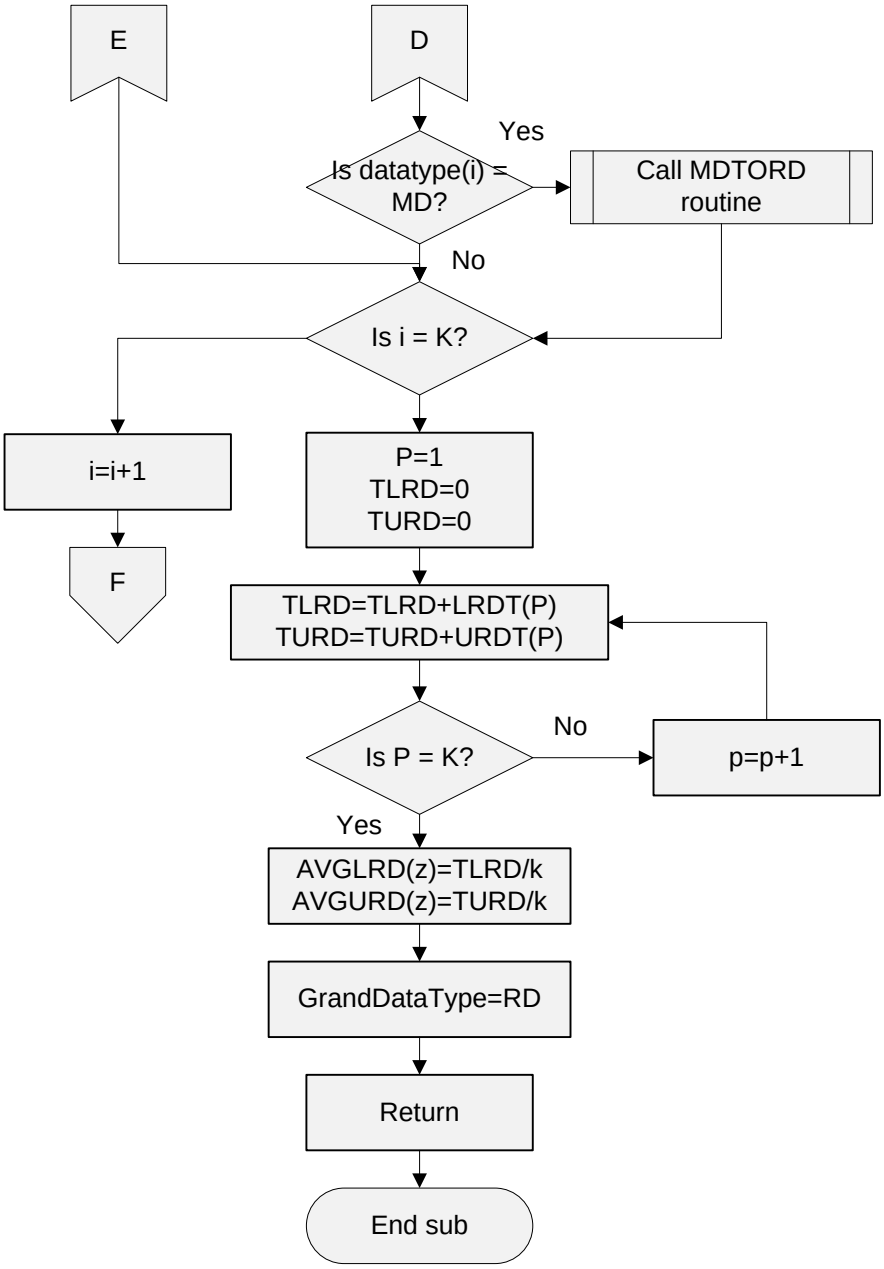
Transformation routines from other data formats to Range data

Appendix 3.0



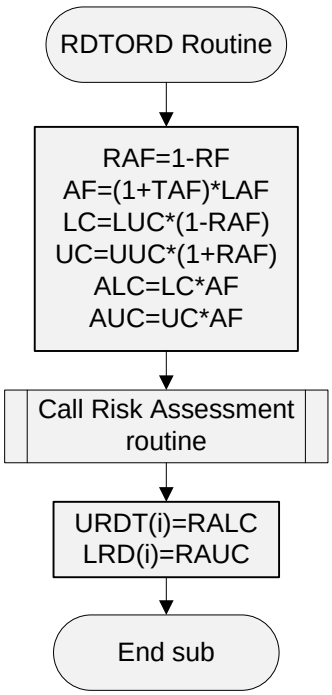
Flowchart representation of the conversion process from other data formats to Range data type

Appendix 3.0 Continues

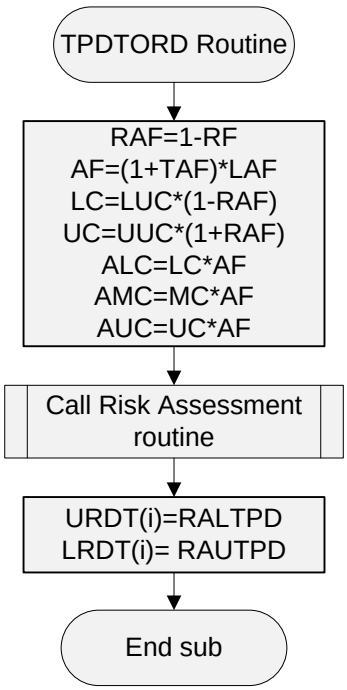


Flowchart representation of the conversion process from other data formats to Range data type Continues.

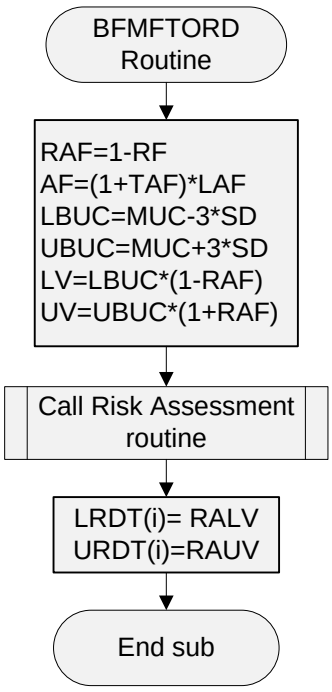
Appendix 3.1



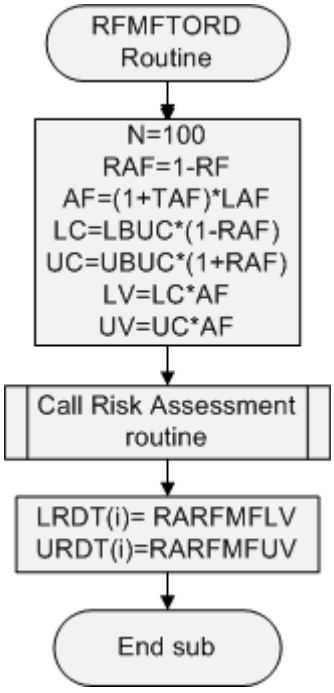
Range data to Range data



Three-point data to range data

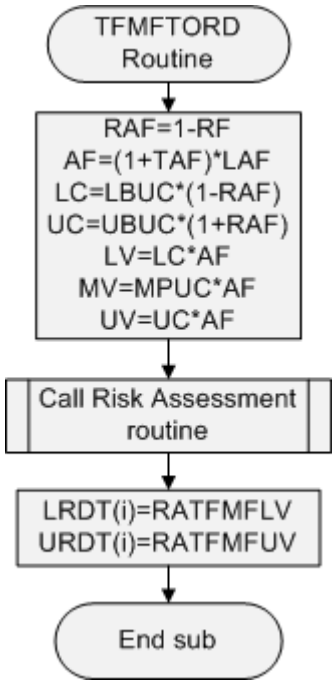


Bayesian FMF to Range data

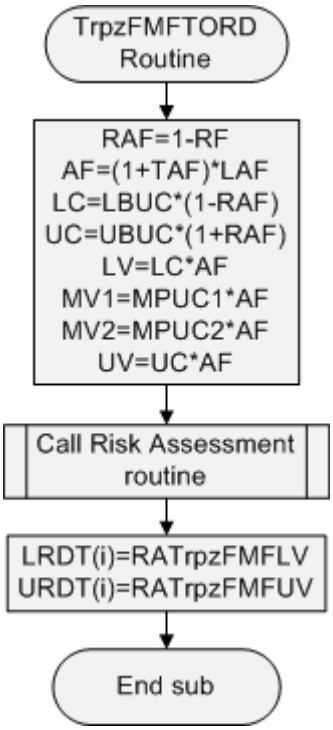


Rectangular FMF to Range data

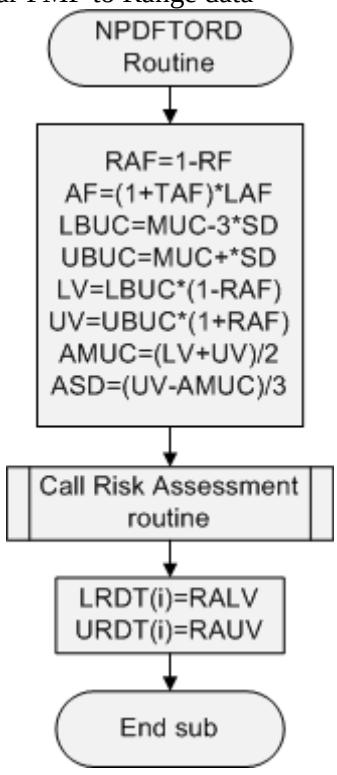
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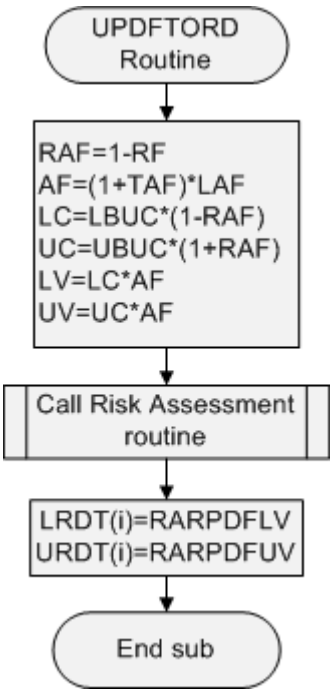
Triangular FMF to Range data



Trapezoidal FMF to Range data

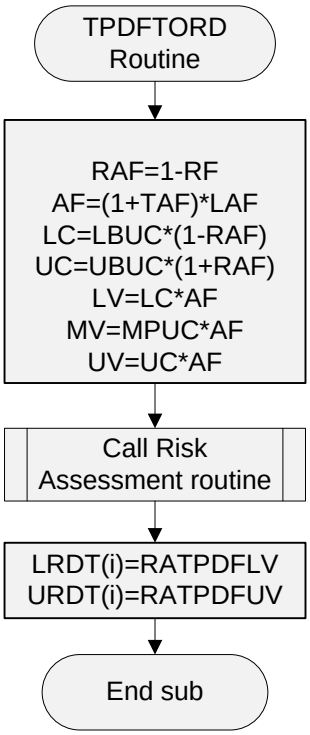


Normal probability density function to Range data



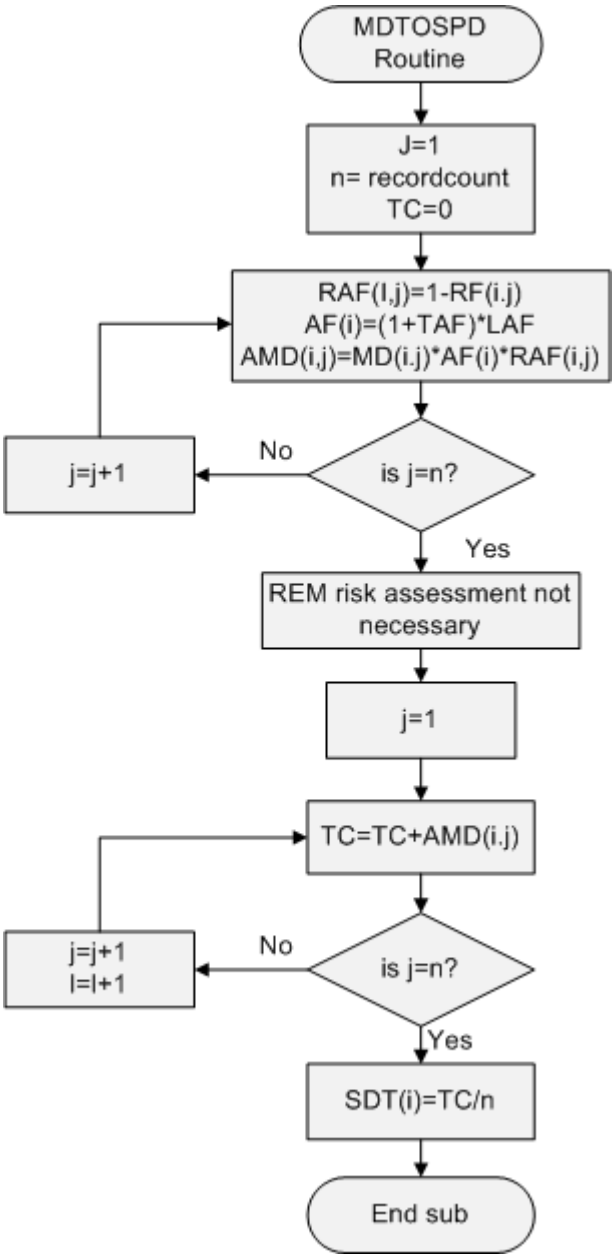
Uniform Probability Density function to Range data

Appendix 3.3



Triangular Probability Density function to Range data

Appendix 3.4

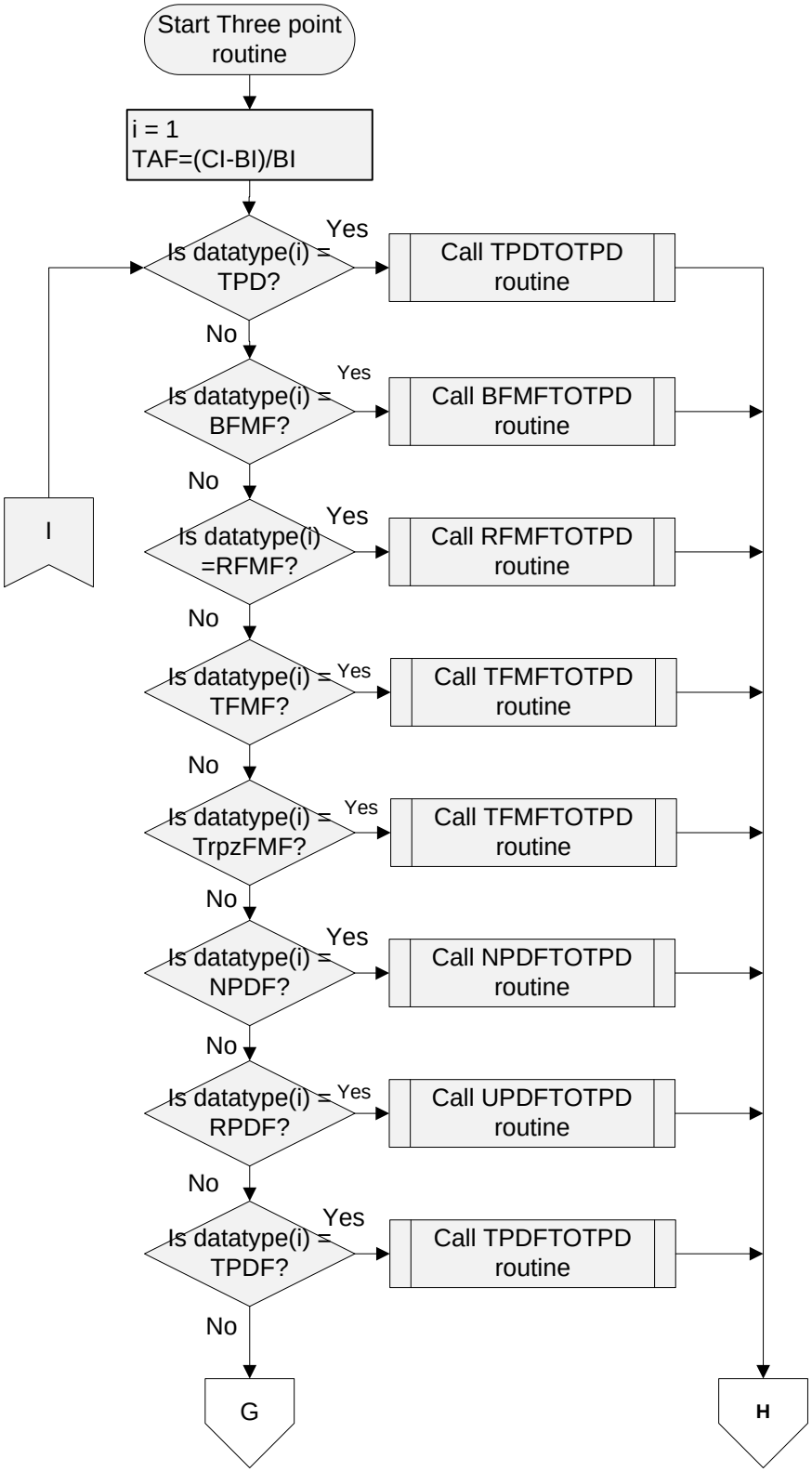


Multi-Data to Range Data

Appendix 4:

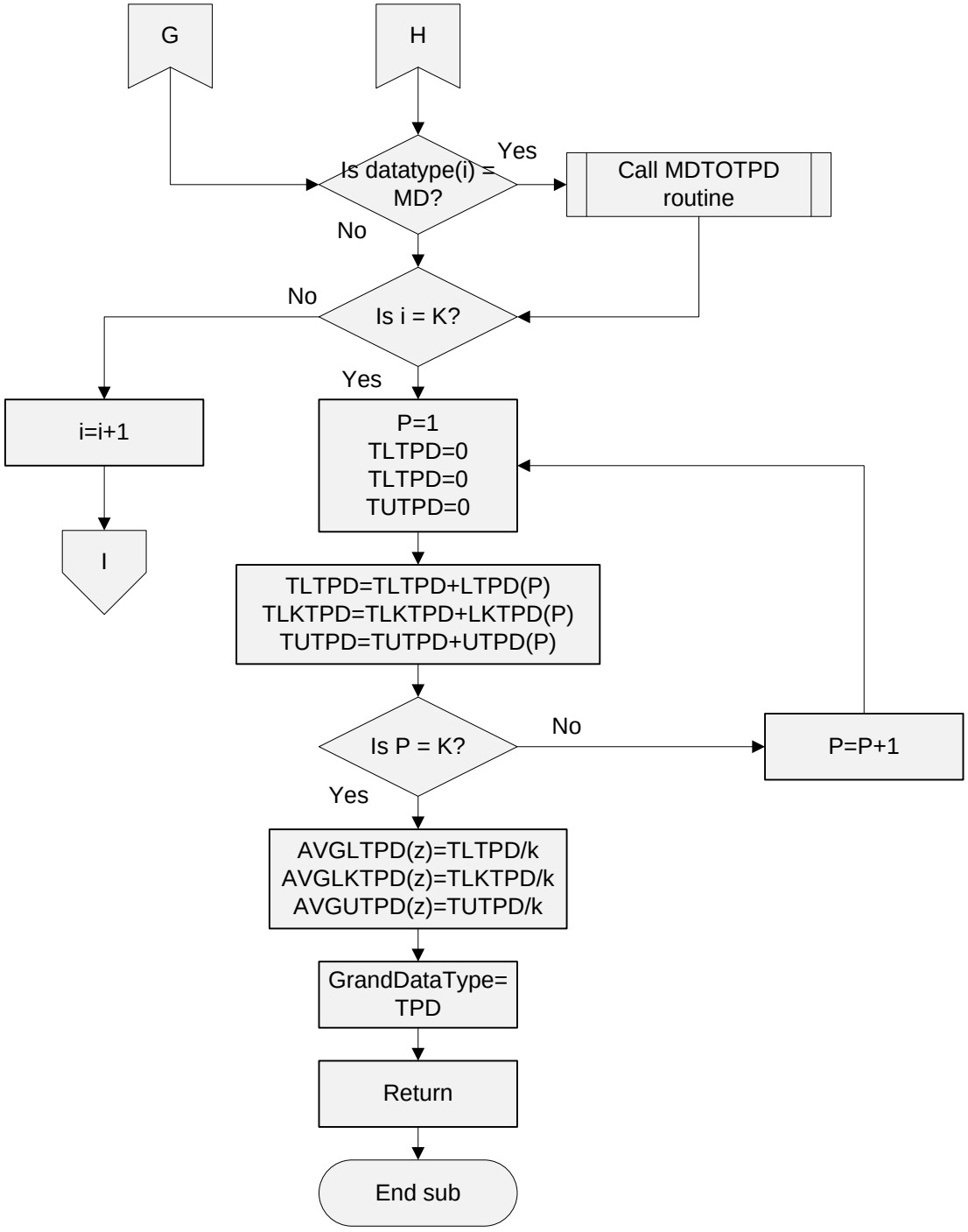
Transformation routines from other data formats to Three-point data

Appendix 4.0



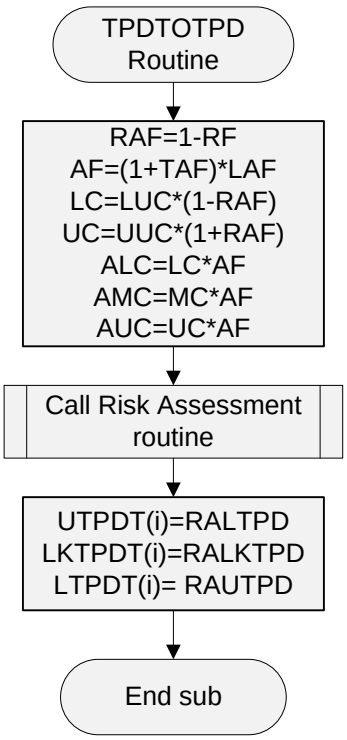
Flowchart representation of the conversion process from other data formats to Three-point data type

Appendix 4.0 Continues

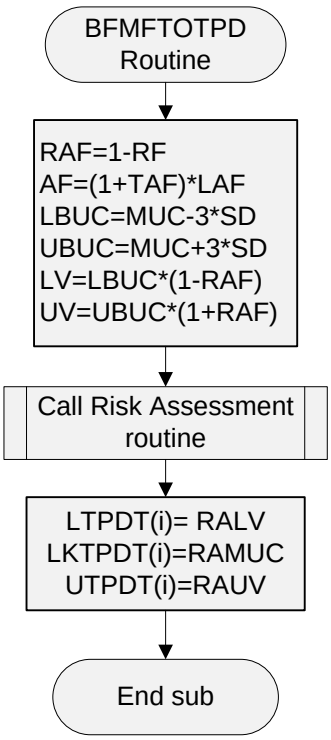


Flowchart representation of the conversion process from other data formats to Three-point data type Continues.

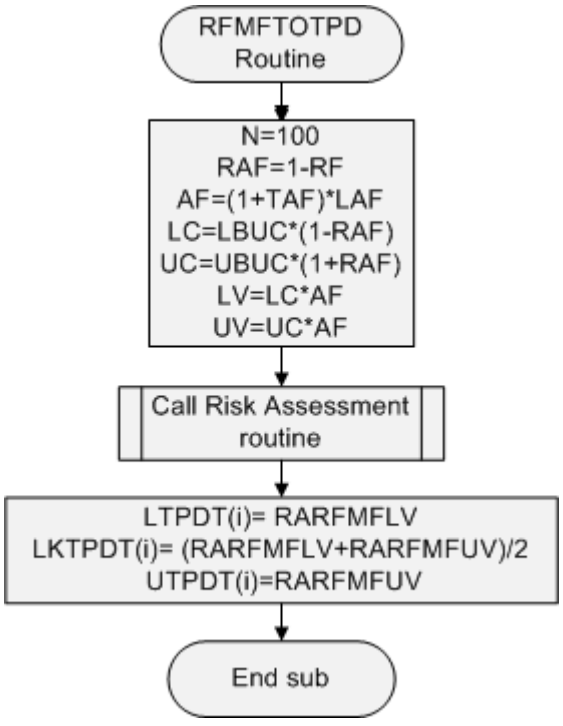
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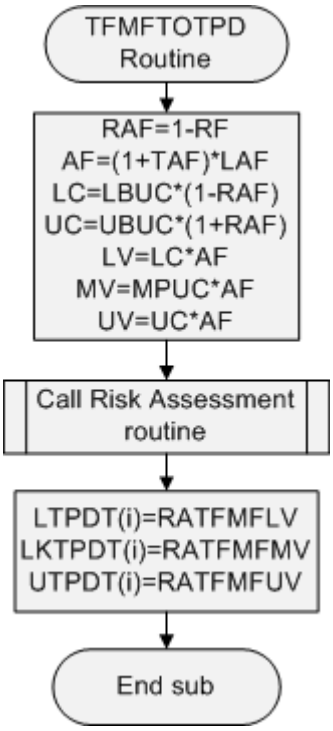
Three-point data to Three-point data



Bayesian FMF to Three-point data

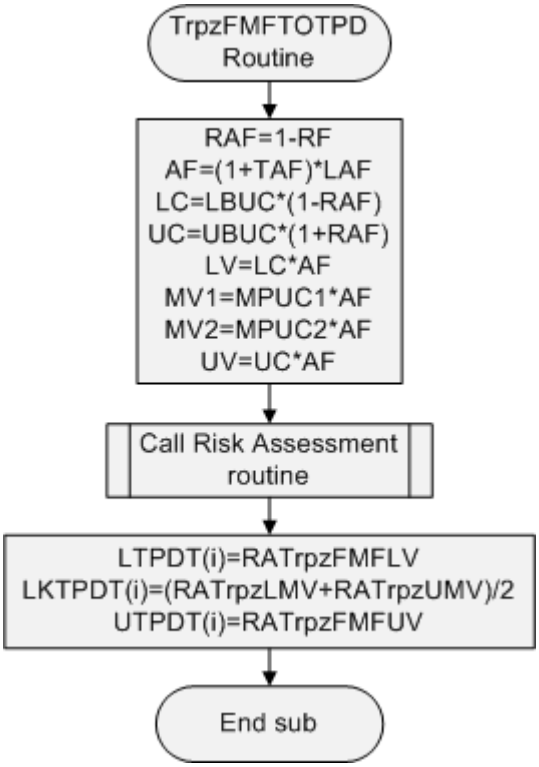


Range FMF to Three-point data

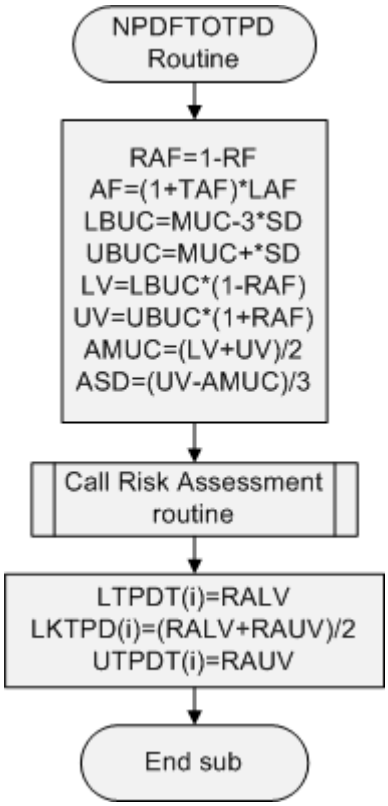


Triangular FMF to Three-point data

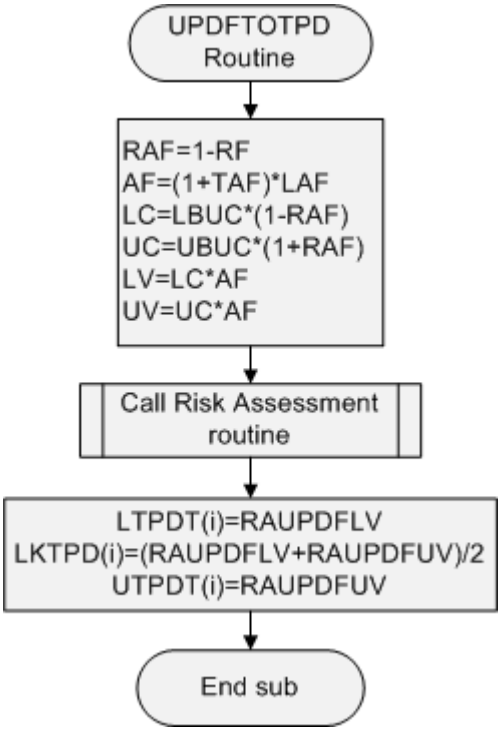
Appendix 4.2



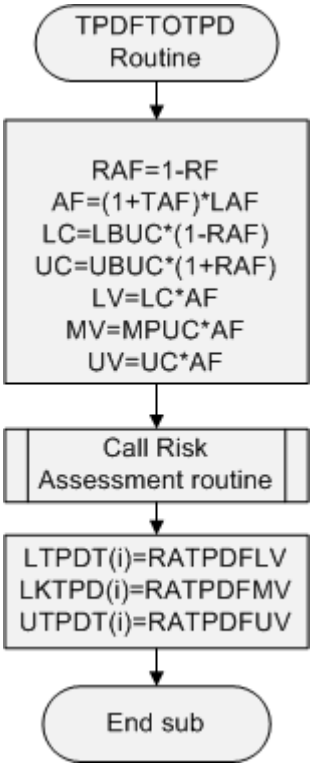
Trapezoidal FMF to Three-point data



Normal probability density function to Three-point data

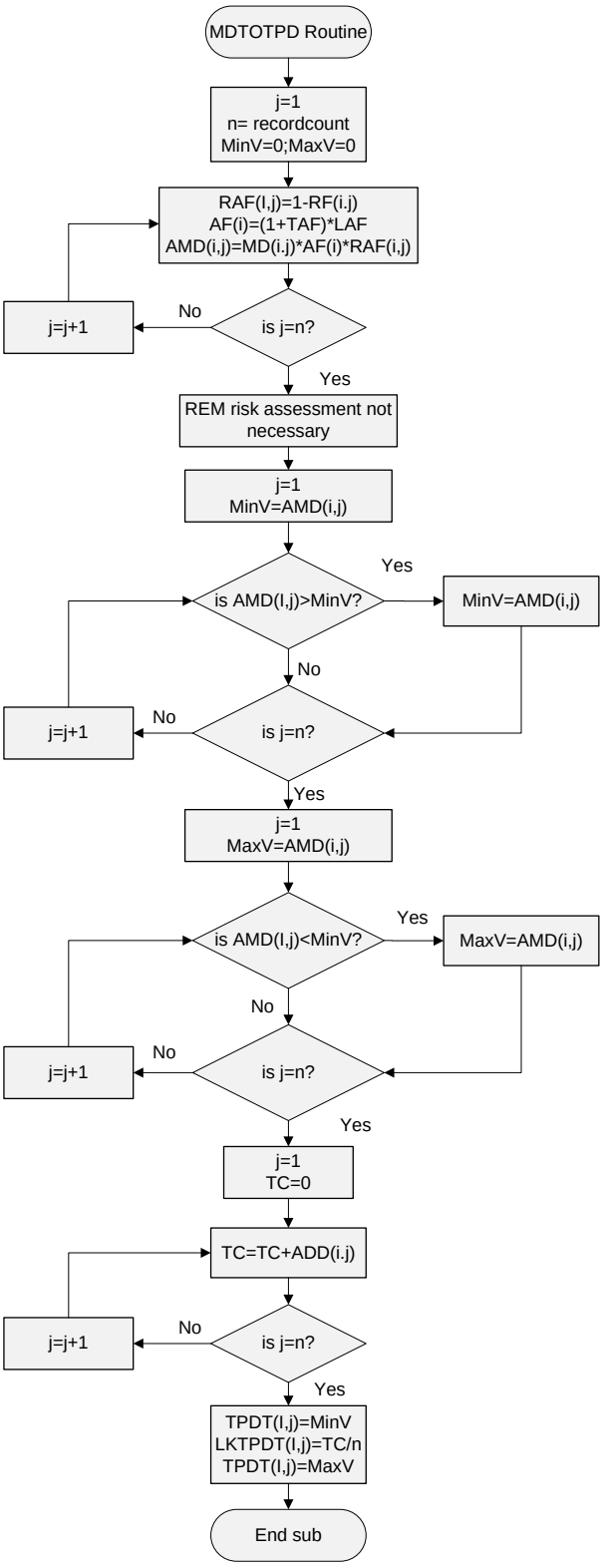


Uniform probability density function to Three-point data



Triangular Probability Density function to Three-point data

Appendix 4.3

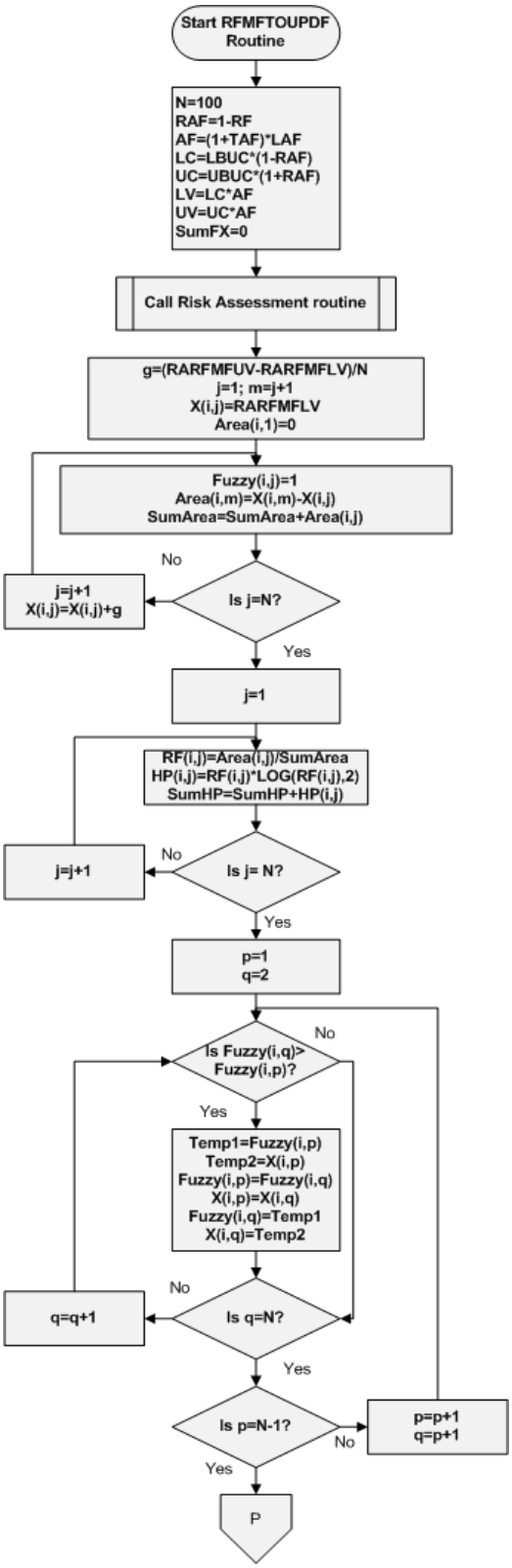


Multi-data to Three-point data

Appendix 5:

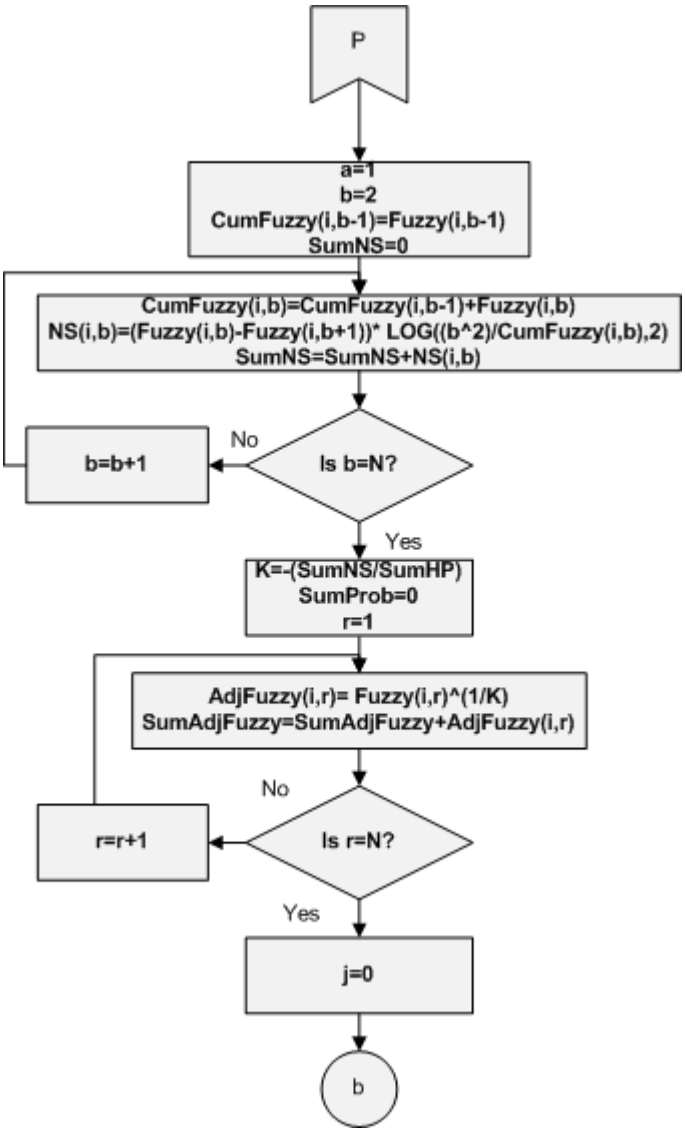
Transformation routines from other data formats to Probability Density Functions

Appendix 5.0



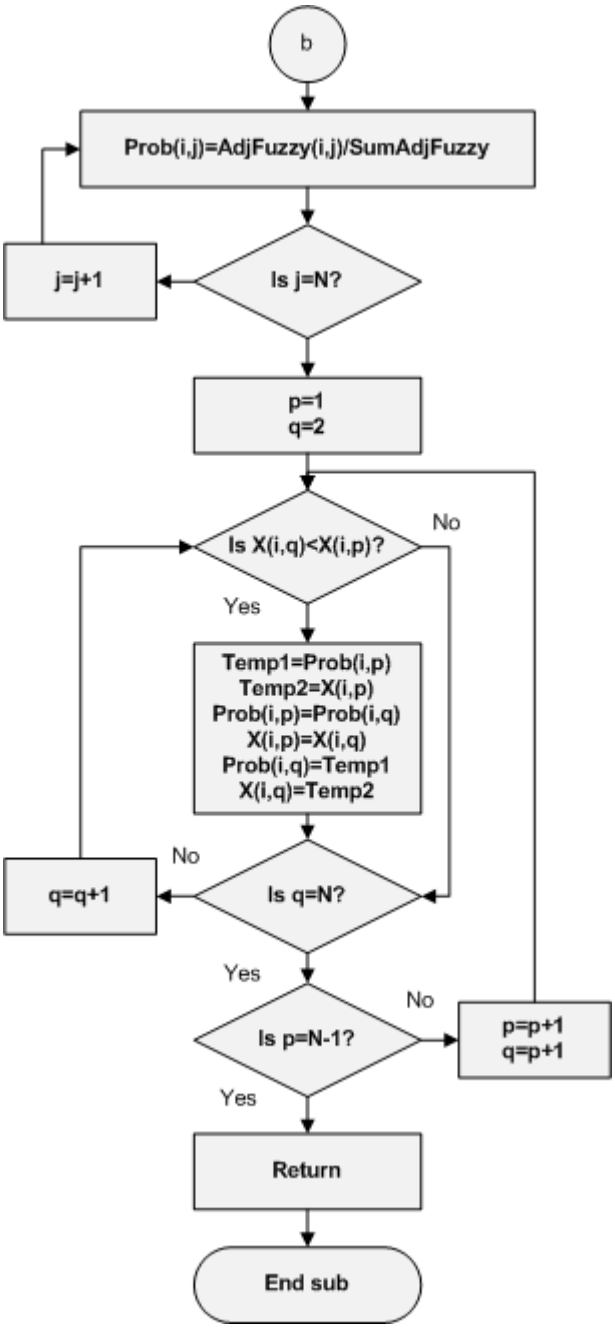
Flowchart representation of the conversion process from Rectangular FMF to Uniform PDF

Appendix 5.0 Continues



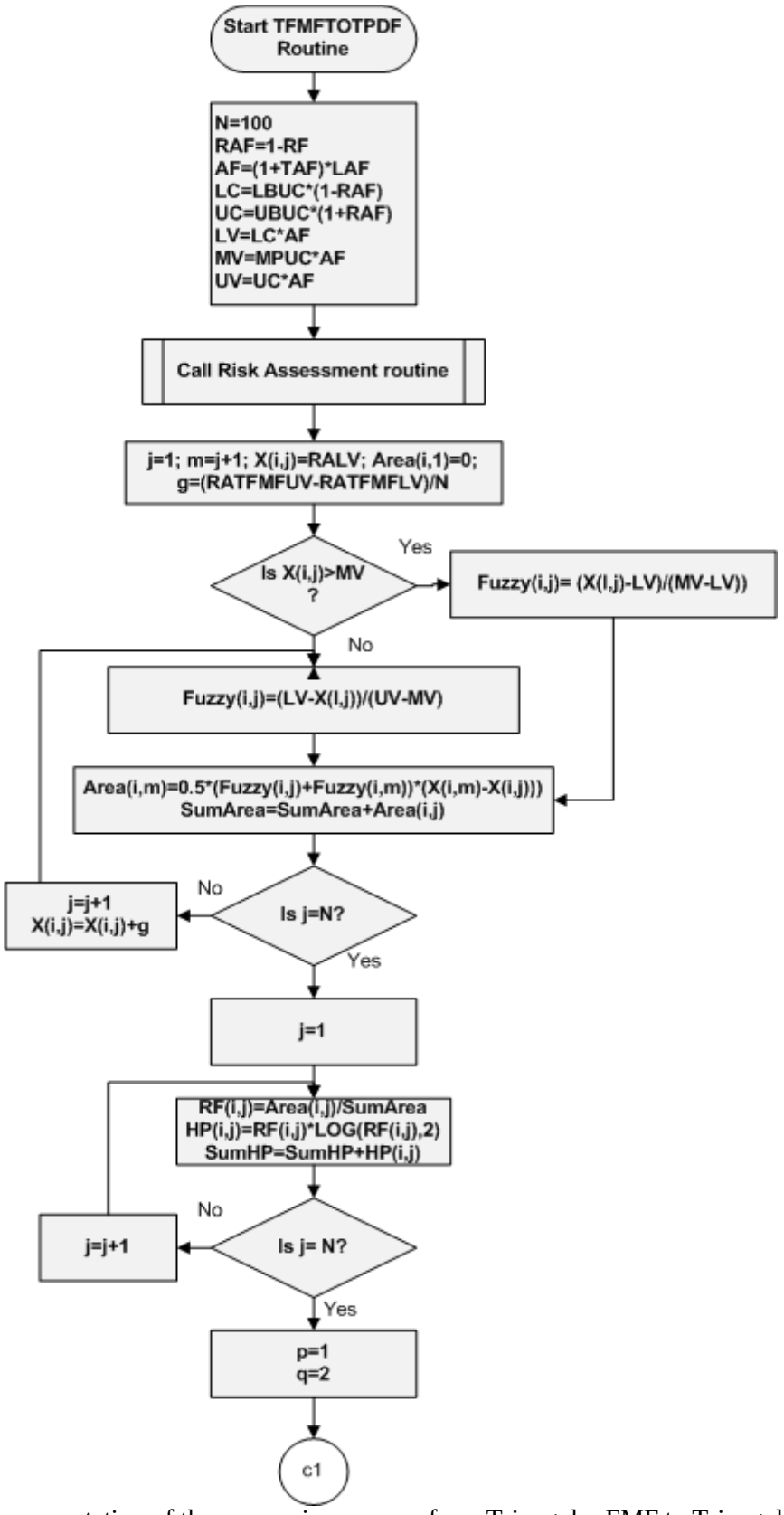
Flowchart representation of the conversion process from Rectangular FMF to Uniform PDF

Appendix 5.0 continues



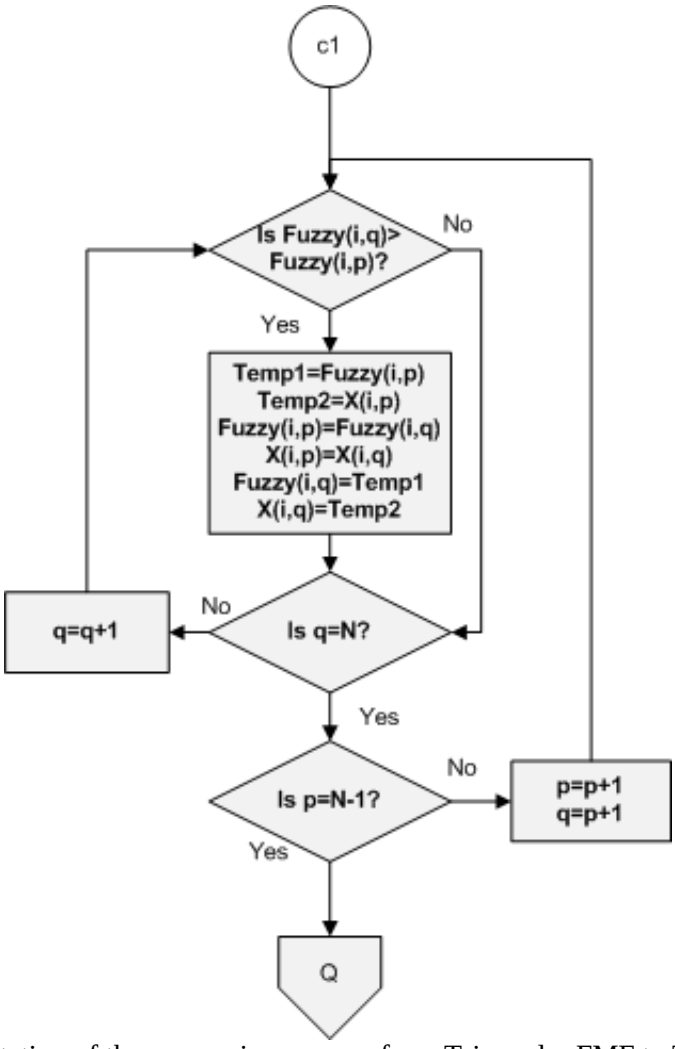
Flowchart representation of the conversion process from Rectangular FMF to Uniform PDF.

Appendix 5.1



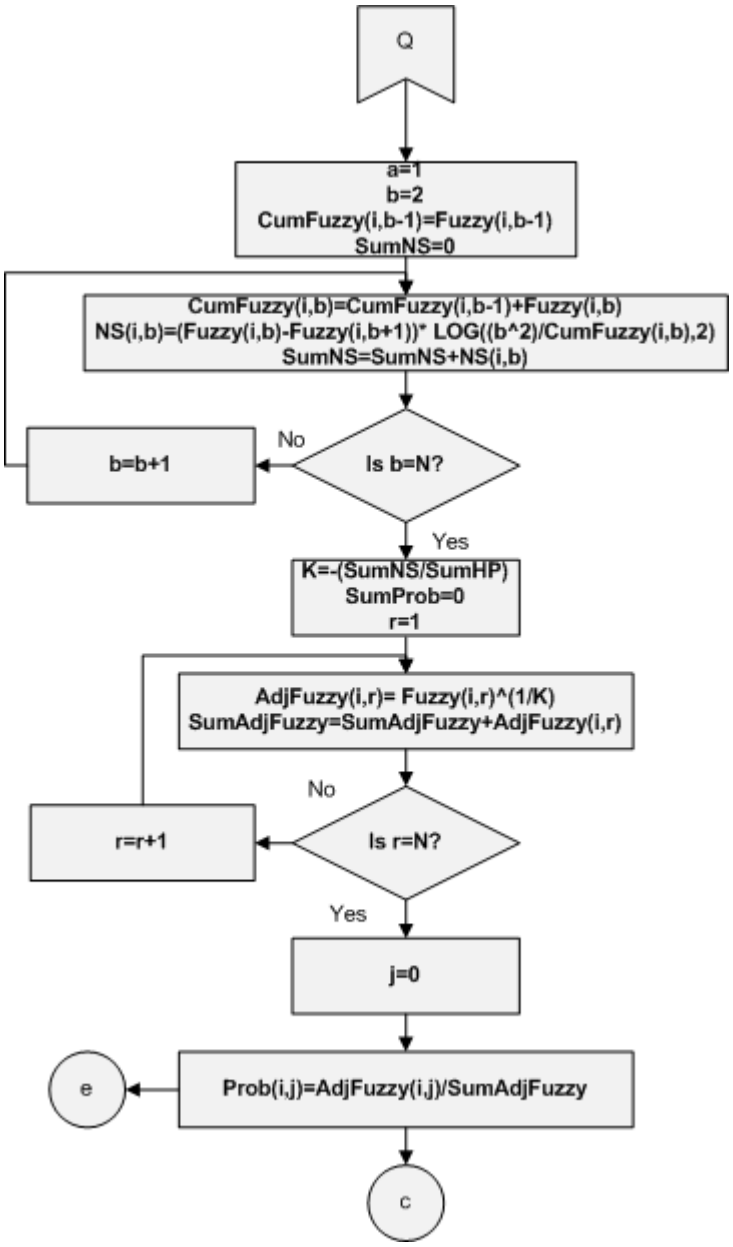
Flowchart representation of the conversion process from Triangular FMF to Triangular PDF.

Appendix 5.1 continues



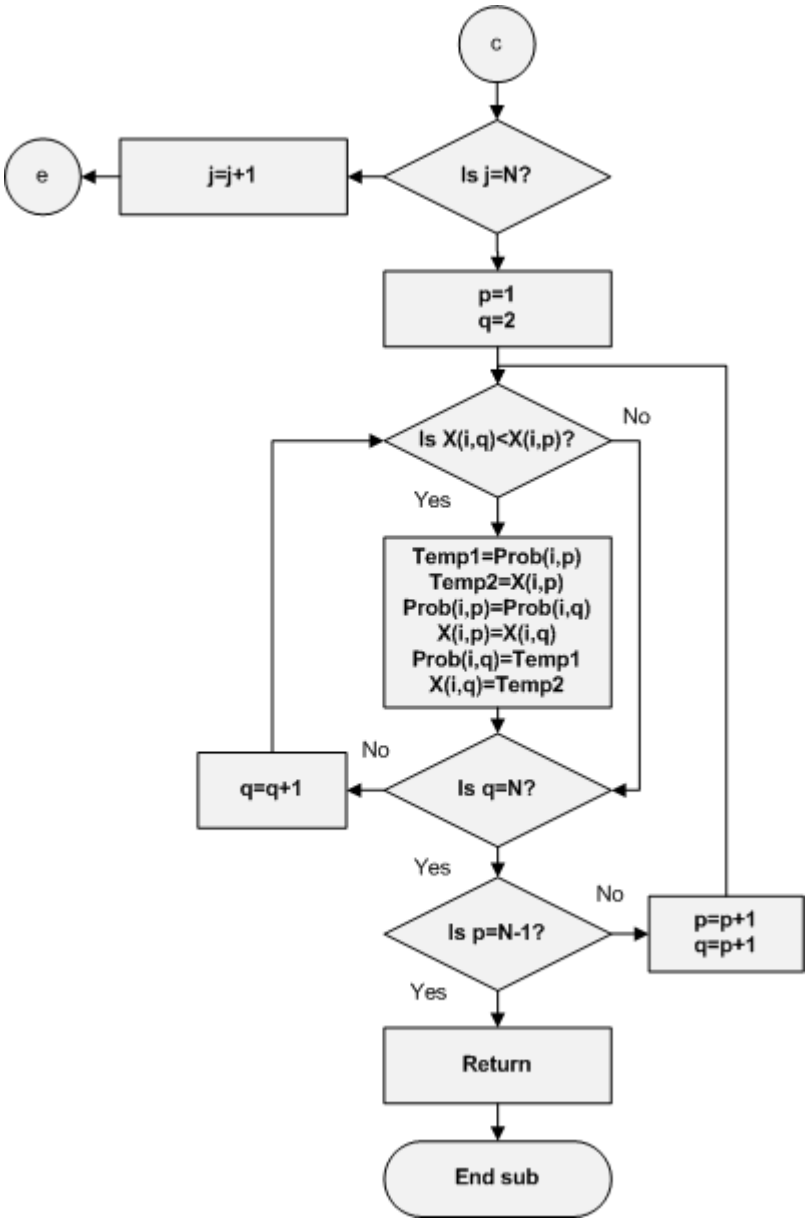
Flowchart representation of the conversion process from Triangular FMF to Triangular PDF.

Appendix 5.1 continues



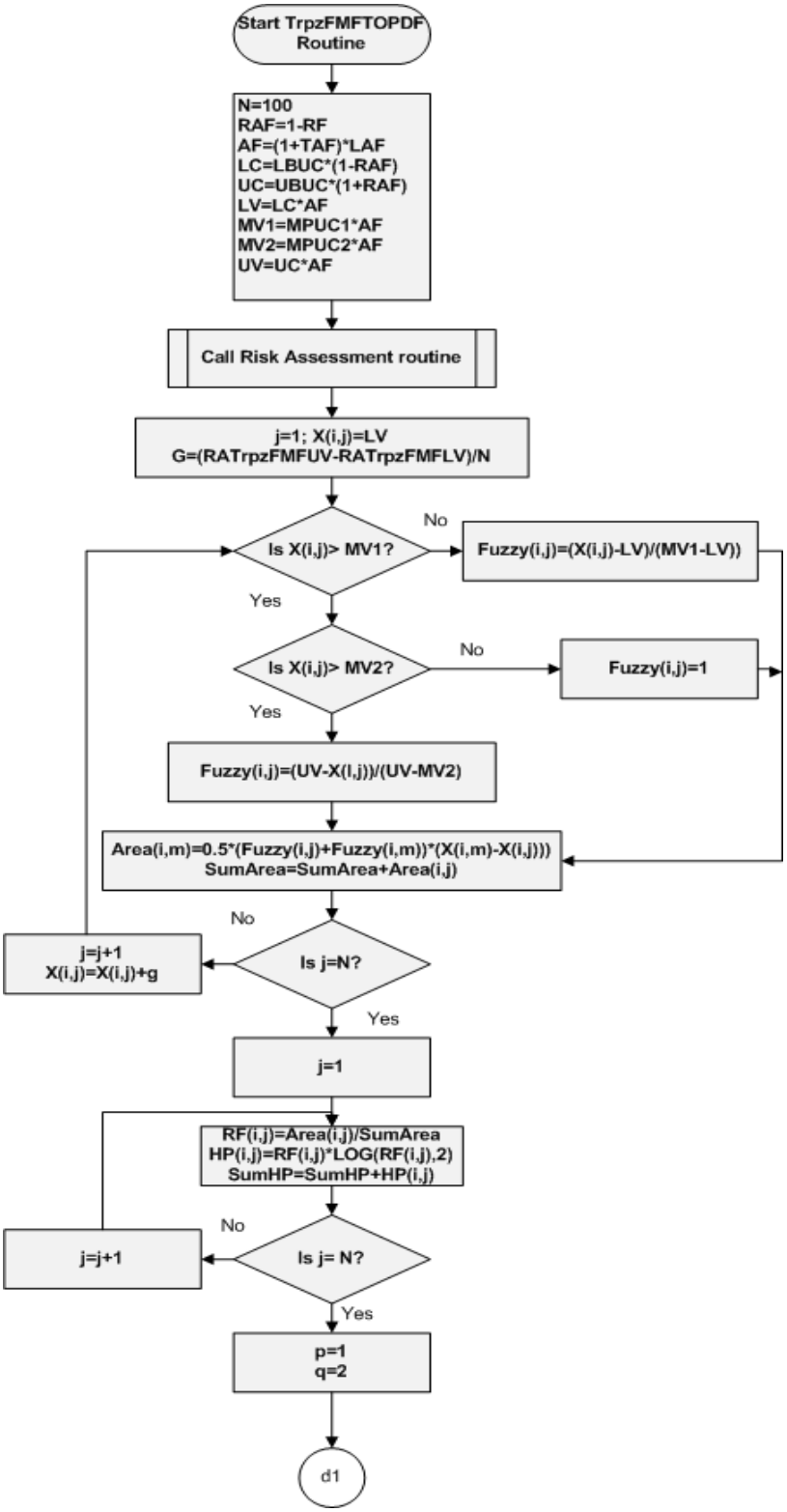
Flowchart representation of the conversion process from Triangular FMF to Triangular PDF.

Appendix 5.1 continues



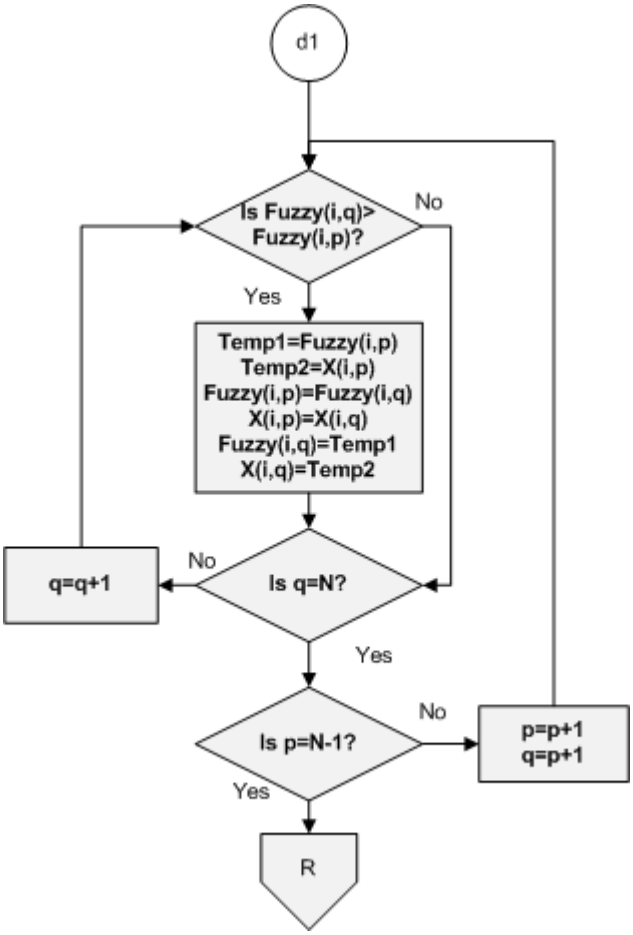
Flowchart representation of the conversion process from Triangular FMF to Triangular PDF.

Appendix 5.2



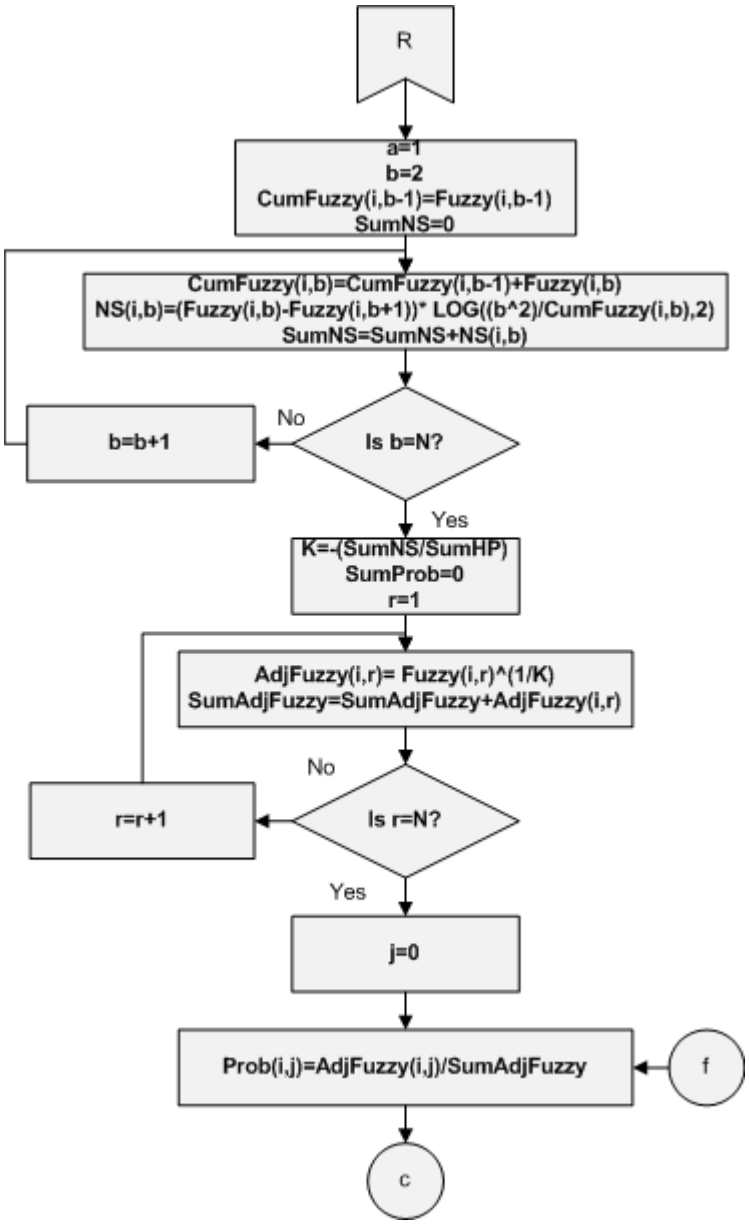
Flowchart representation of the conversion process from Trapezoidal FMF to PDF.

Appendix 5.2 continues



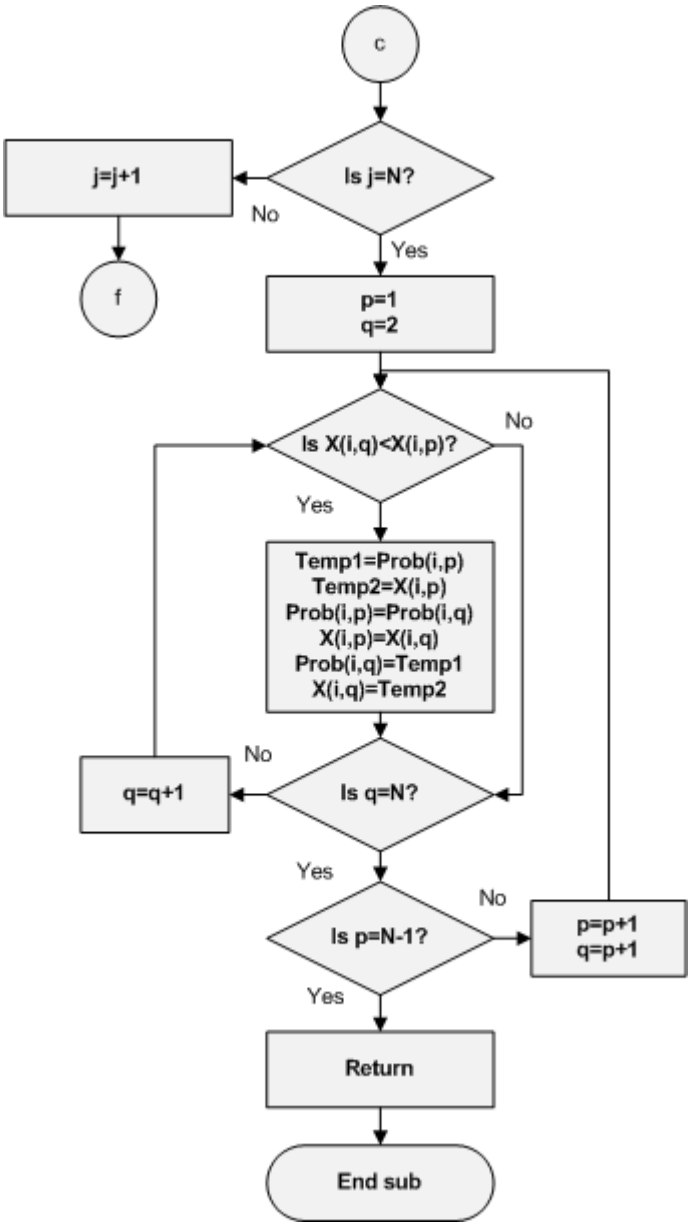
Flowchart representation of the conversion process from Trapezoidal FMF to PDF

Appendix 5.2 continues



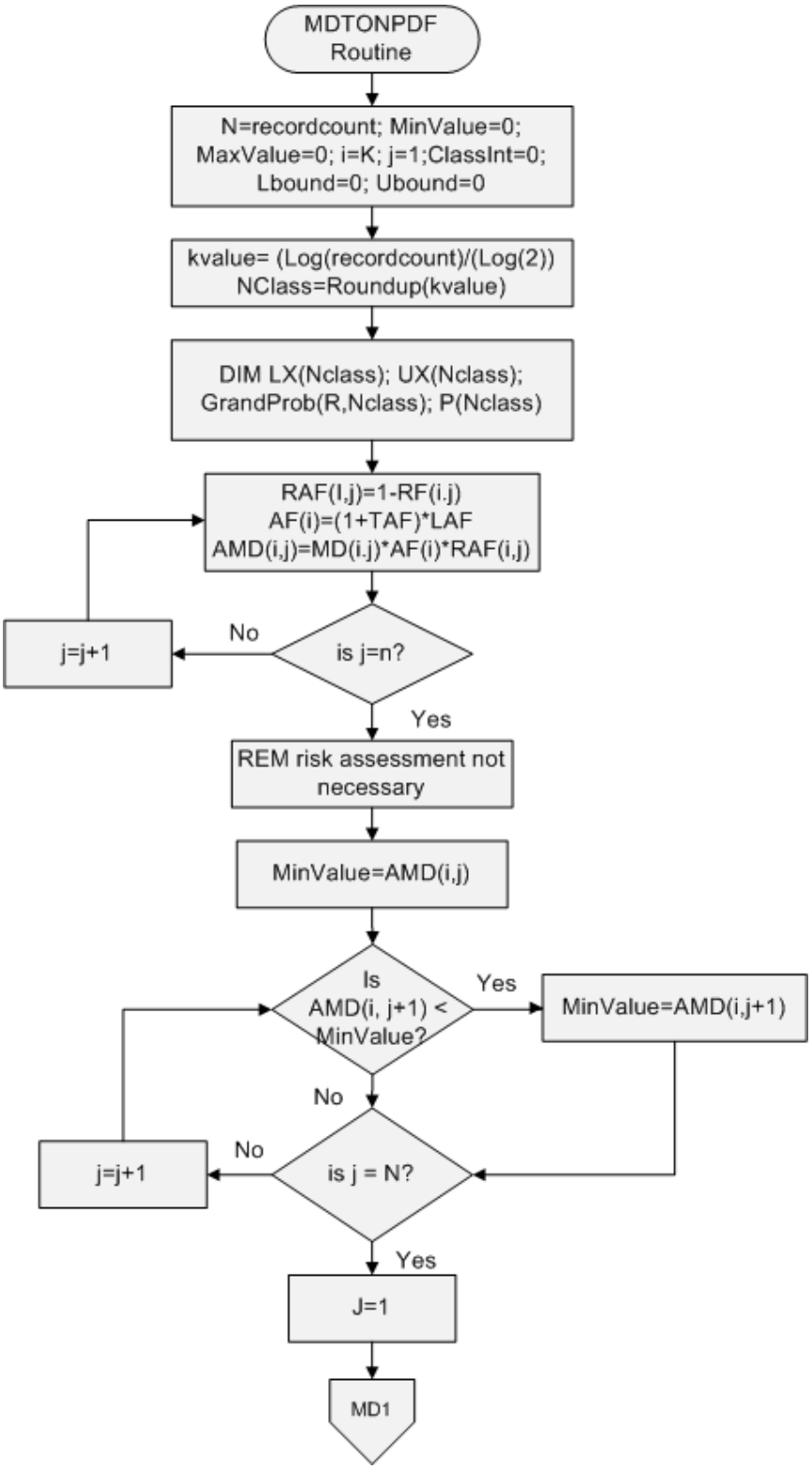
Flowchart representation of the conversion process from Trapezoidal FMF to PDF.

Appendix 5.2 continues



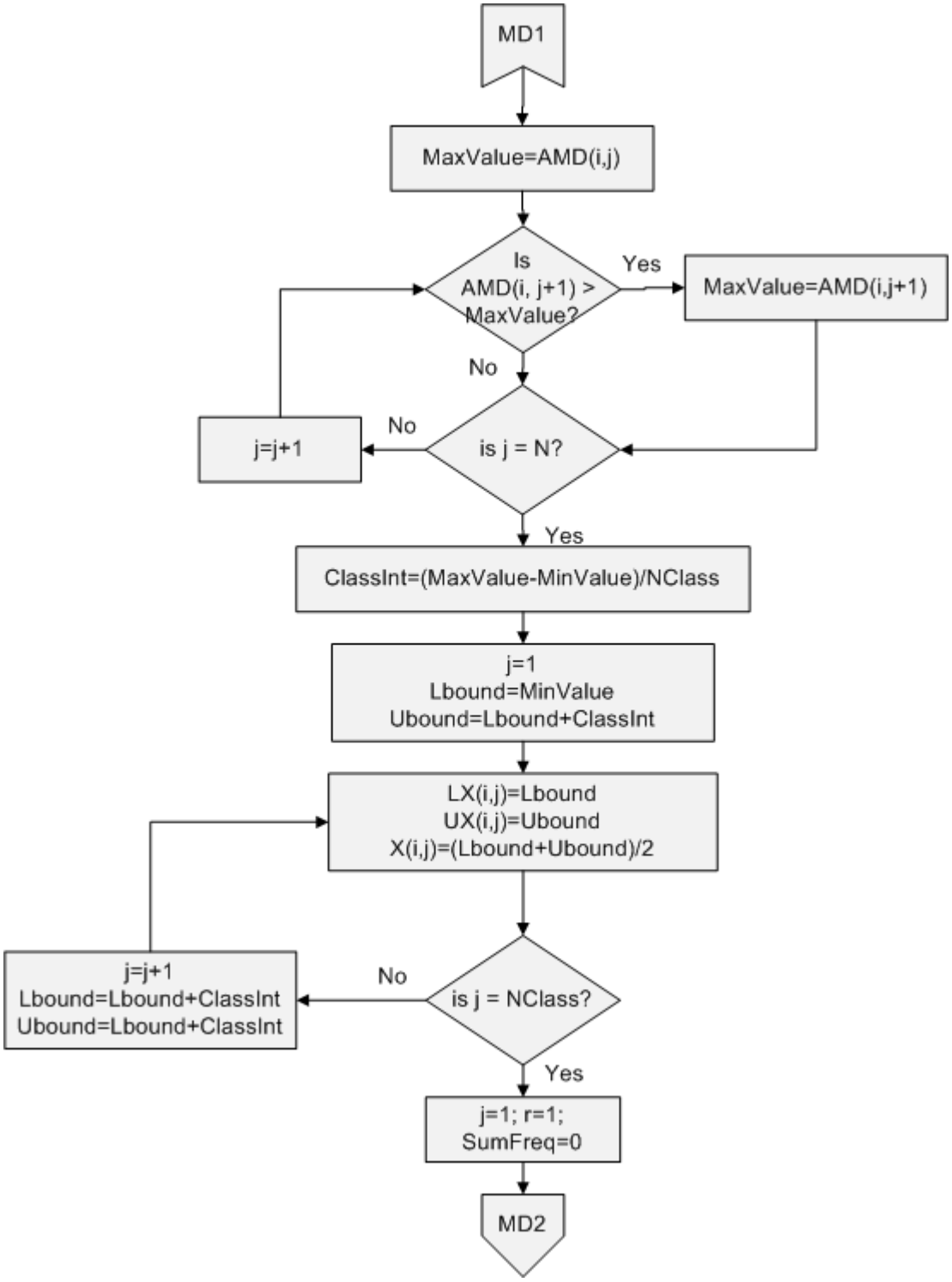
Flowchart representation of the conversion process from Trapezoidal FMF to PDF.

Appendix 5.3



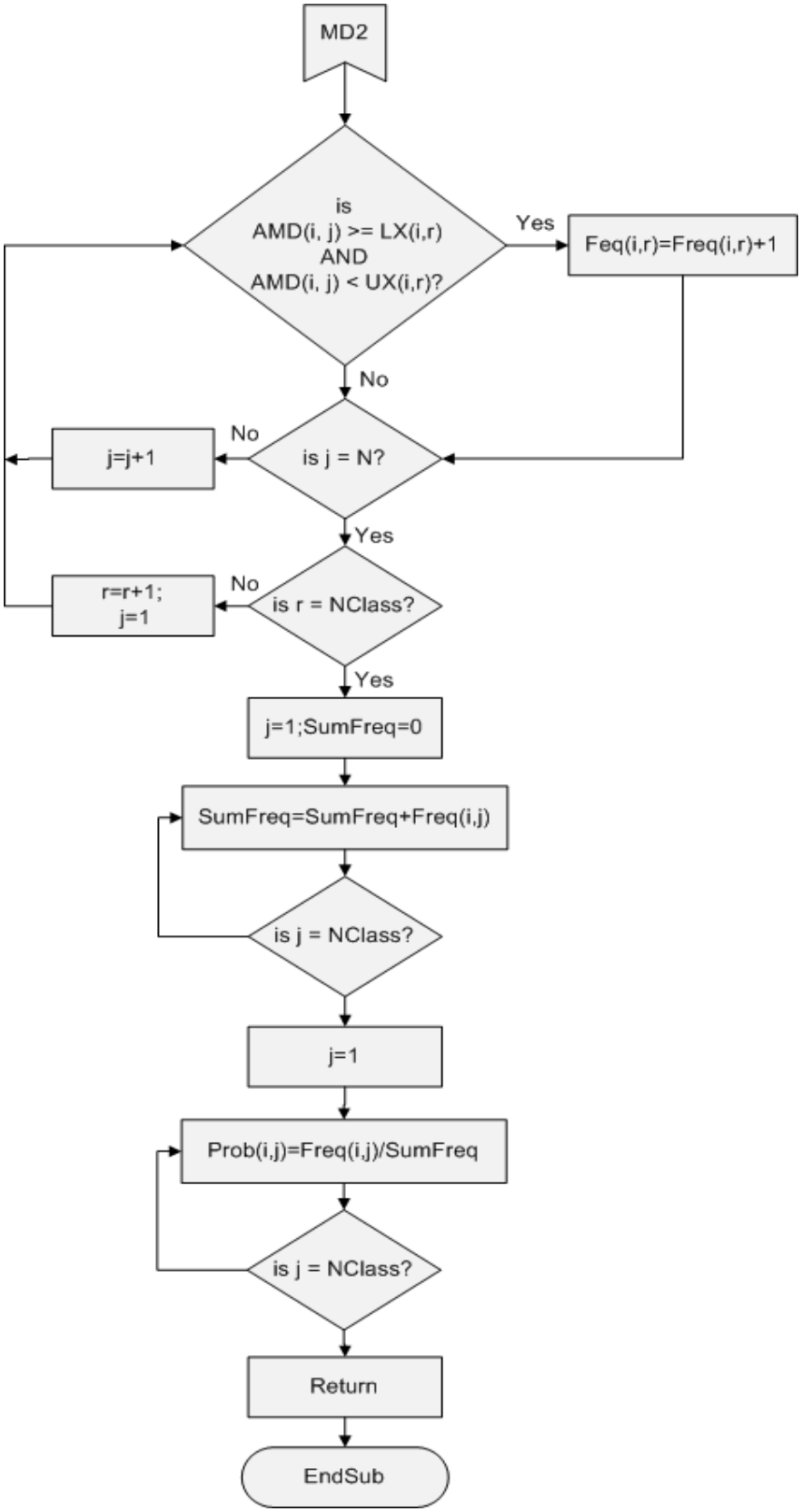
Flowchart representation of the conversion process from Muti-data to PDF.

Appendix 5.3 continues



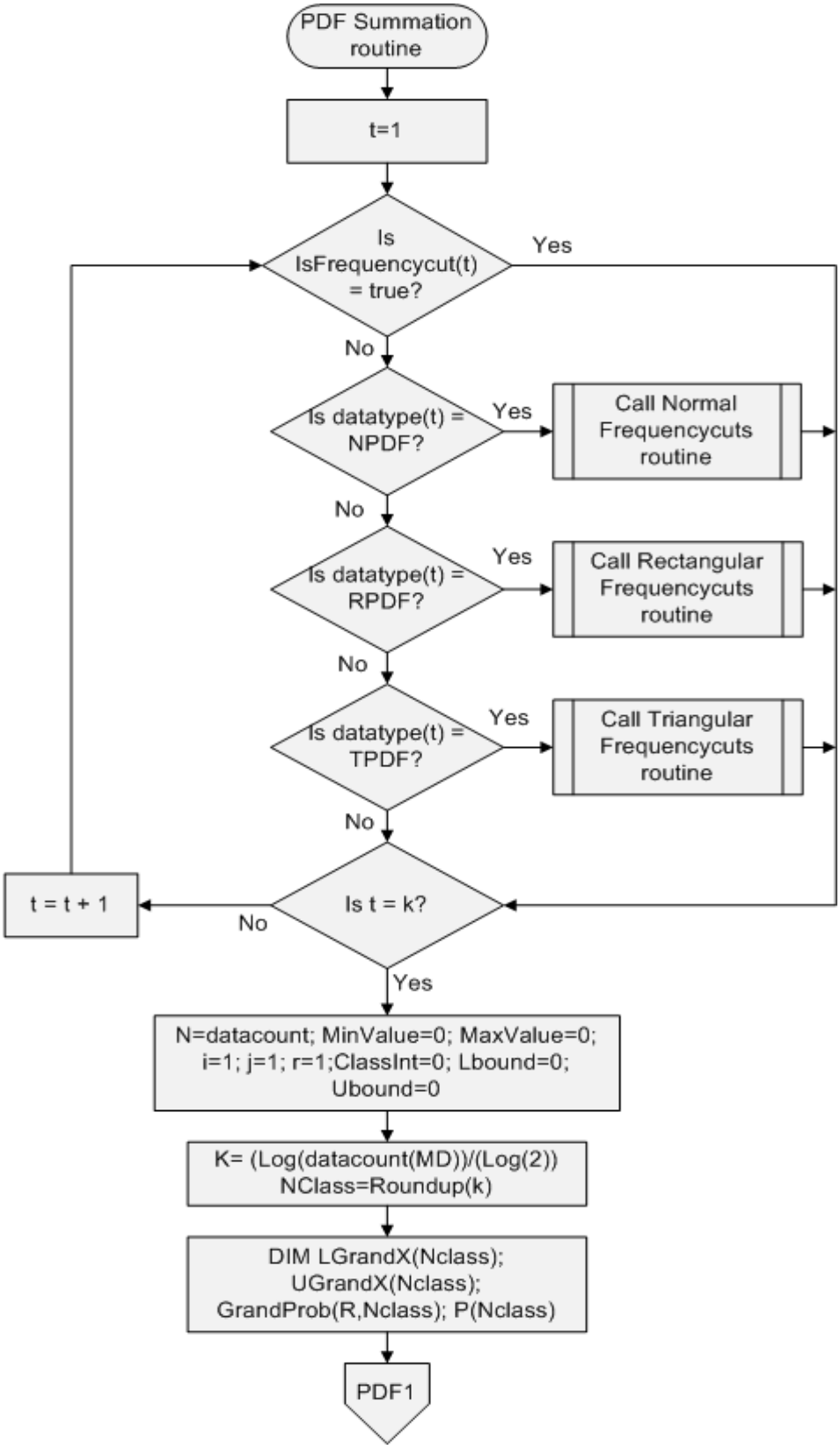
Flowchart representation of the conversion process from Muti-data to PDF.

Appendix 5.3 continues



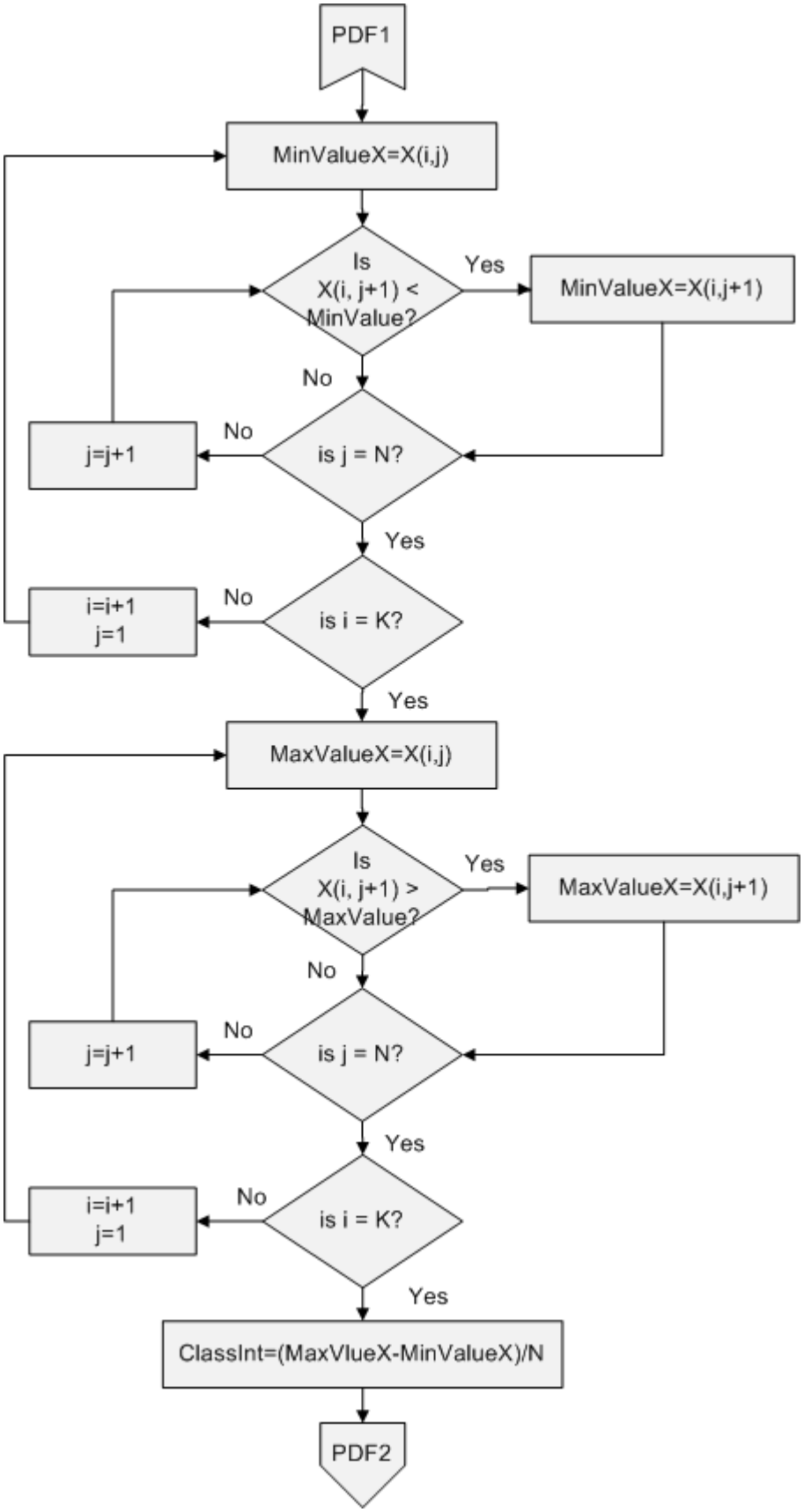
Flowchart representation of the conversion process from Multi-data to PDF.

Appendix 5.4



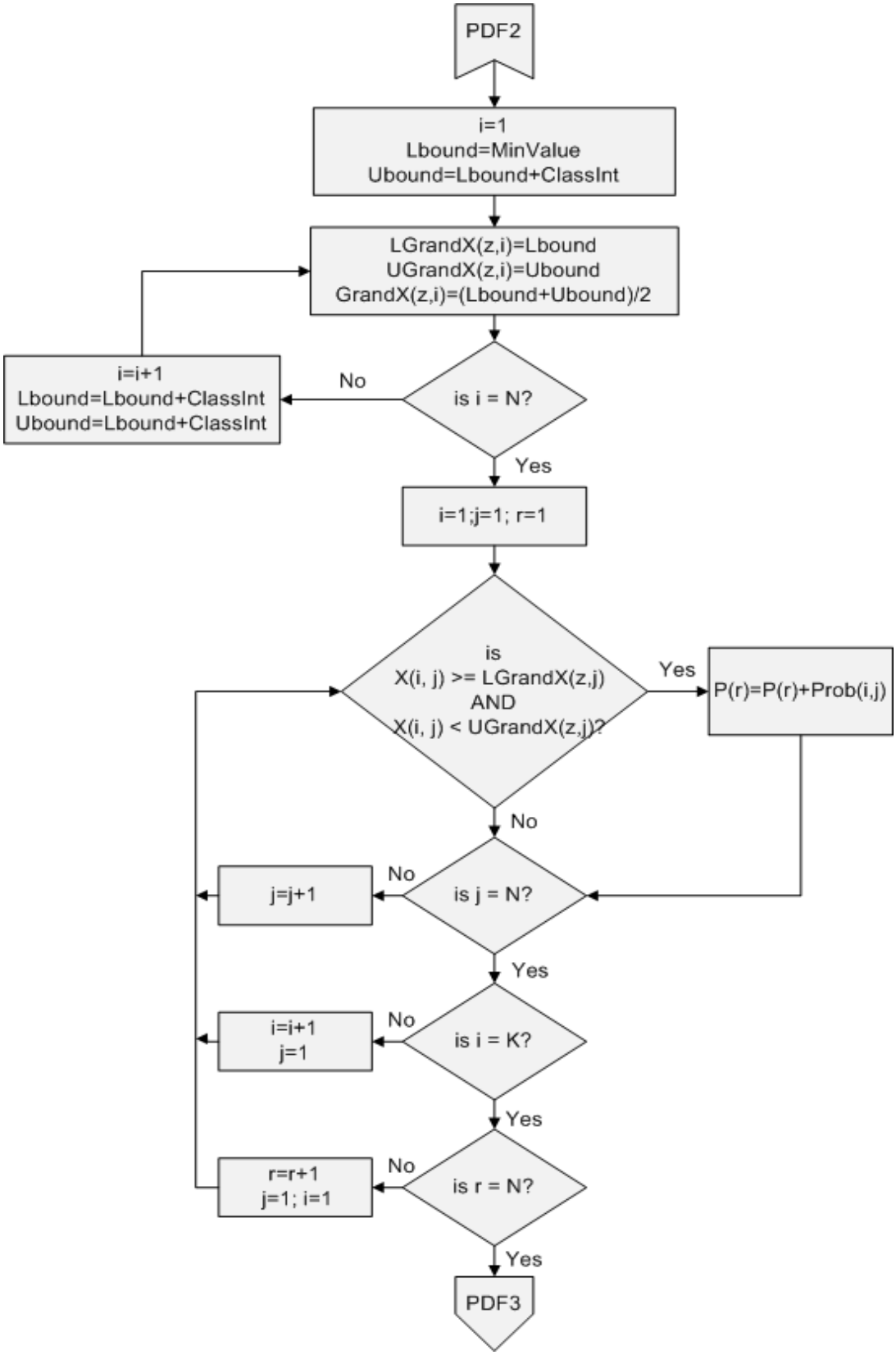
Flowchart representation of Probability Density function summation routine.

Appendix 5.4 Continues



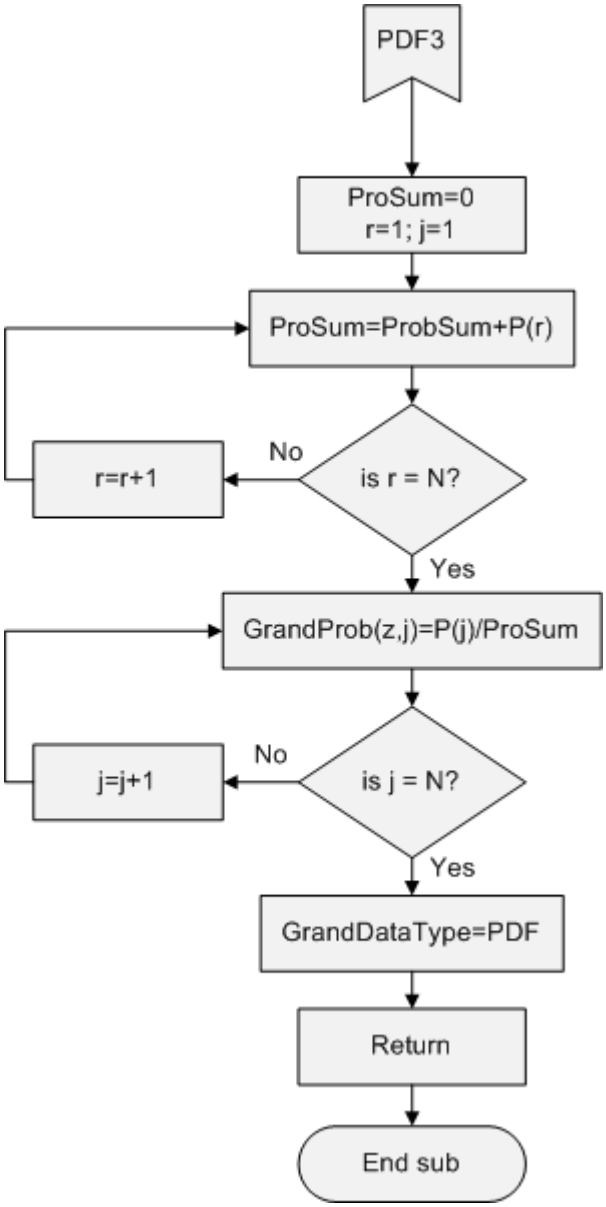
Flowchart representation of Probability Density function summation routine.

Appendix 5.4 Continues



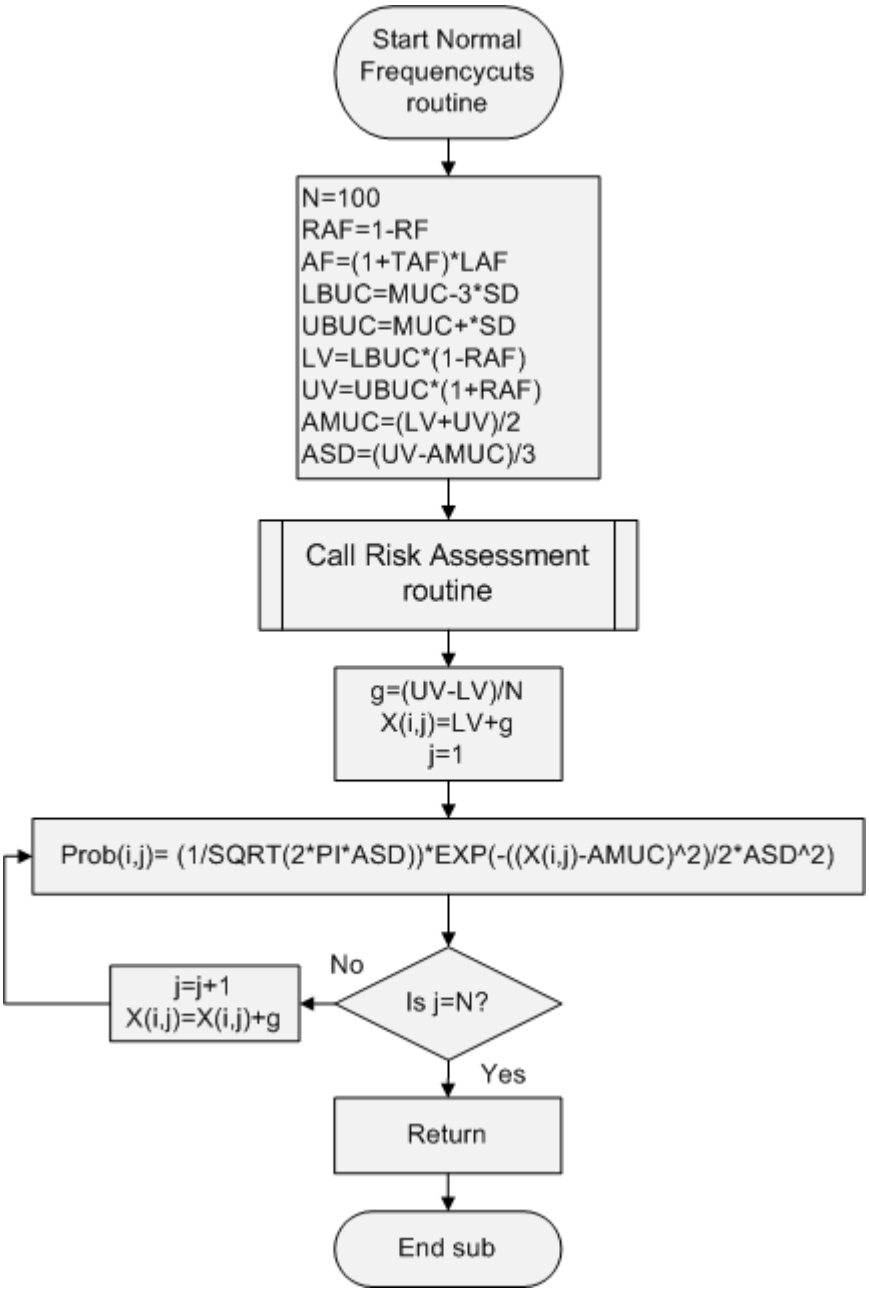
Flowchart representation of Probability Density function summation routine.

Appendix 5.4 Continues



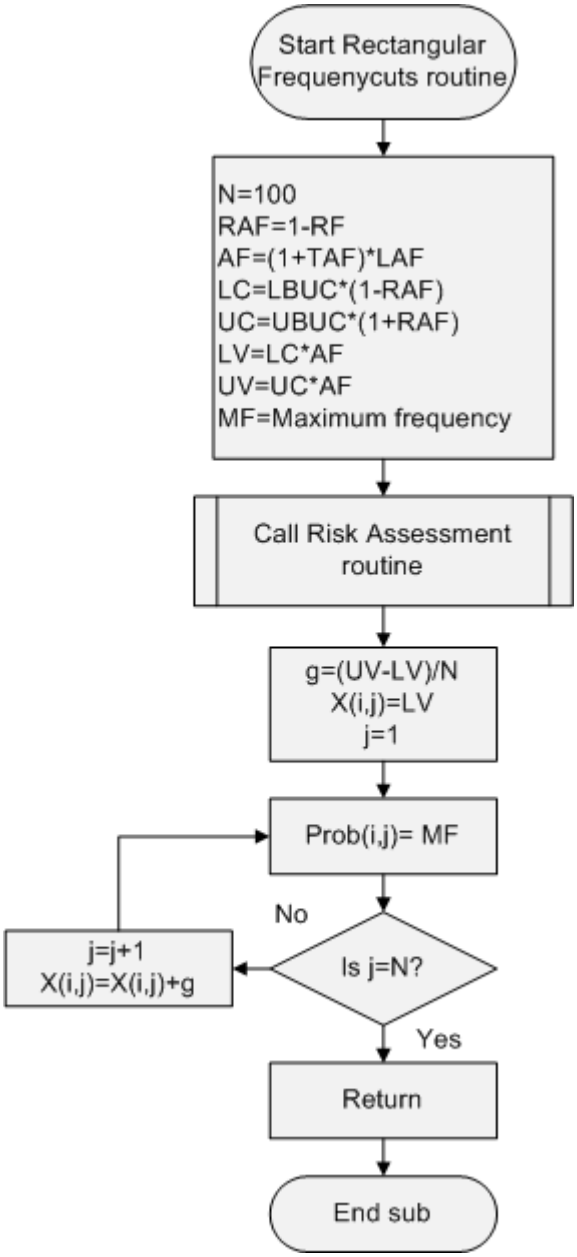
Flowchart representation of Probability Density function summation routine.

Appendix 5.5



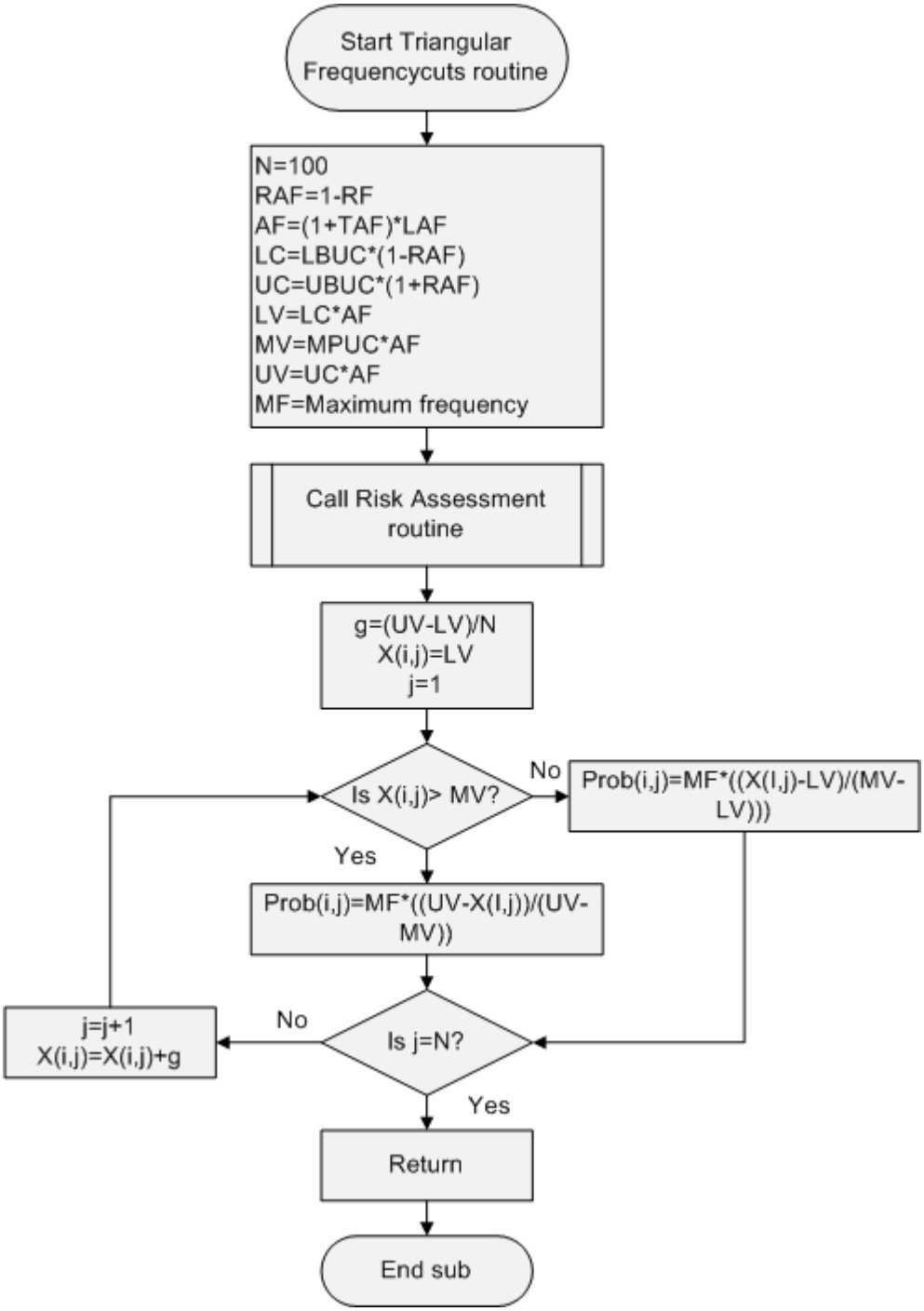
Flowchart representation of frequency-cuts routine for normal PDF.

Appendix 5.6



Flowchart representation of frequency-cuts routine for uniform PDF.

Appendix 5.7

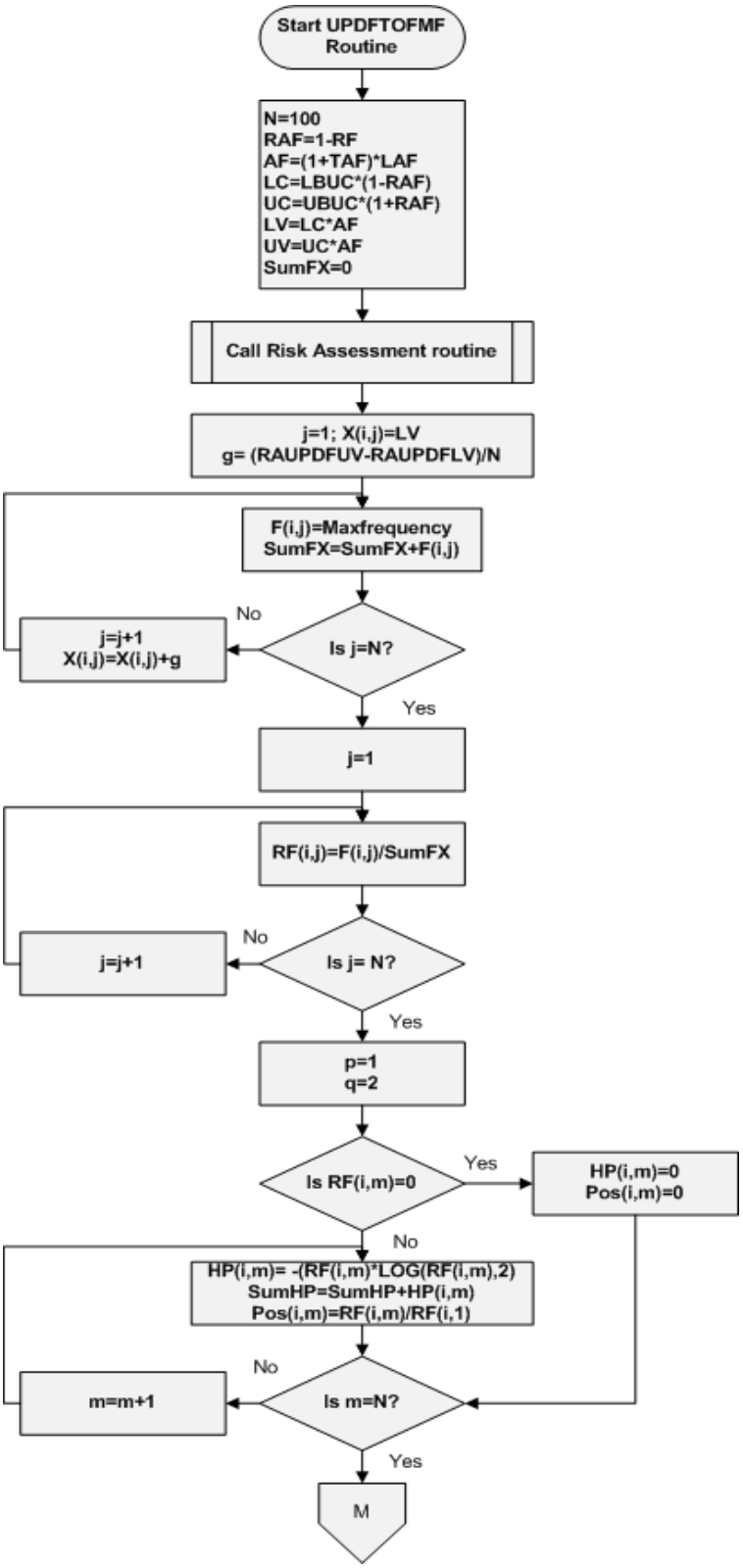


Flowchart representation of frequency-cuts routine for Triangular PDF.

Appendix 6:

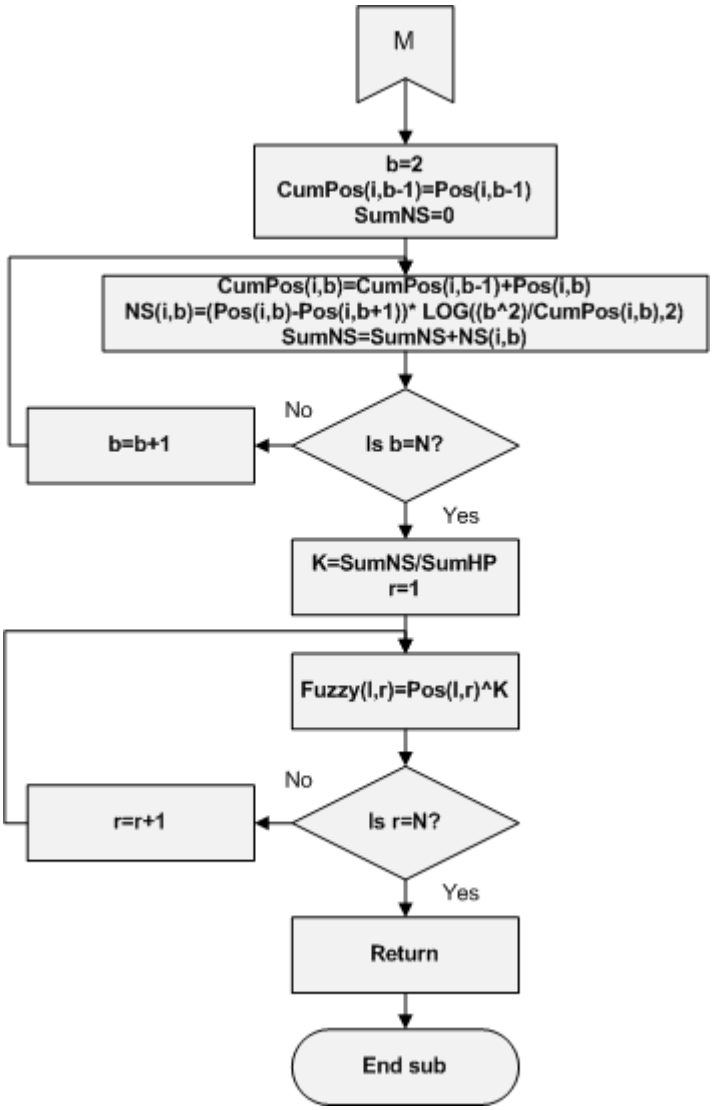
Transformation routines from other data format to Fuzzy Membership Function

Appendix 6.0



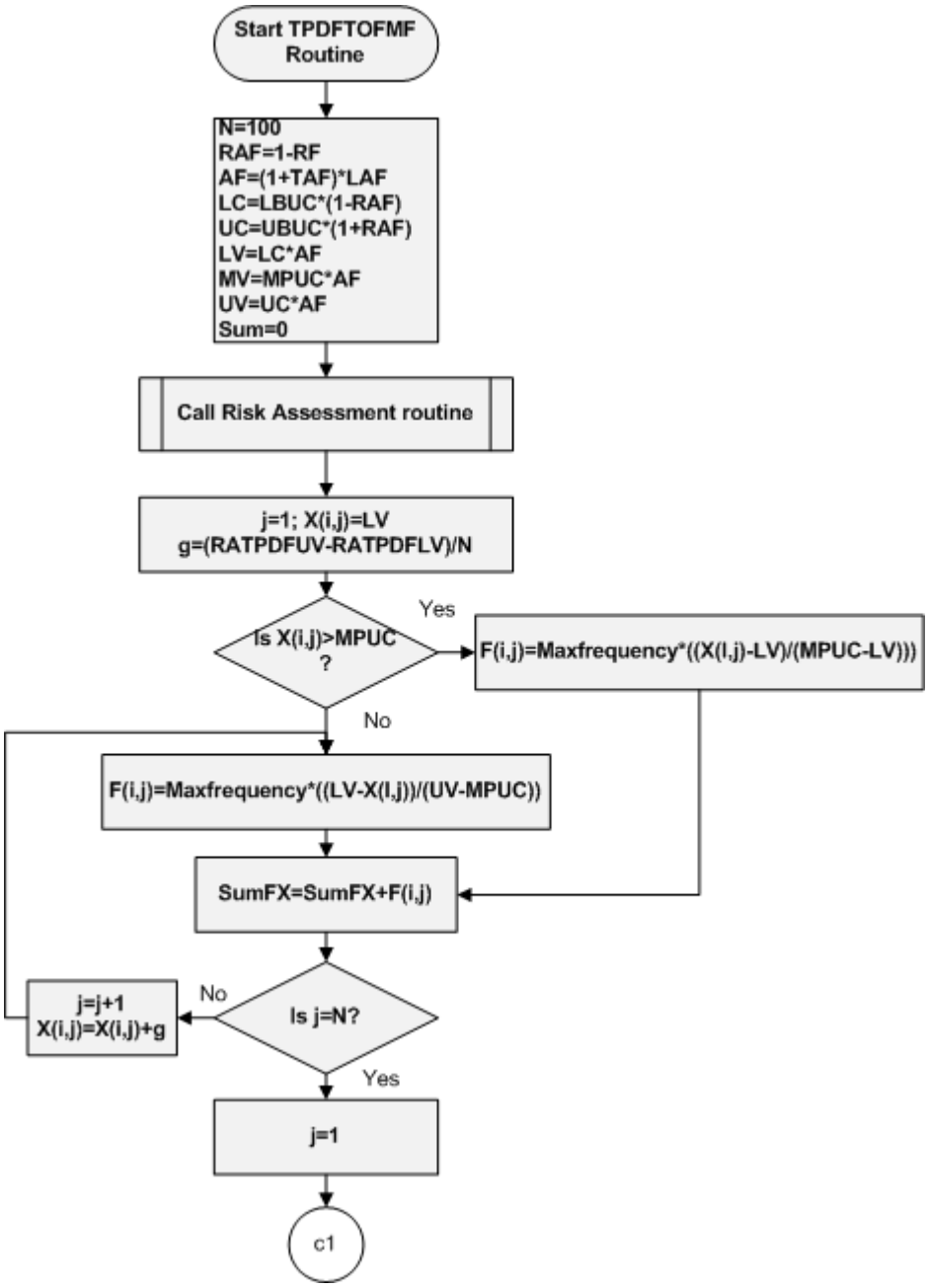
Flowchart representation of the conversion process from Uniform PDF to Rectangular FMF.

Appendix 6.0 Continues



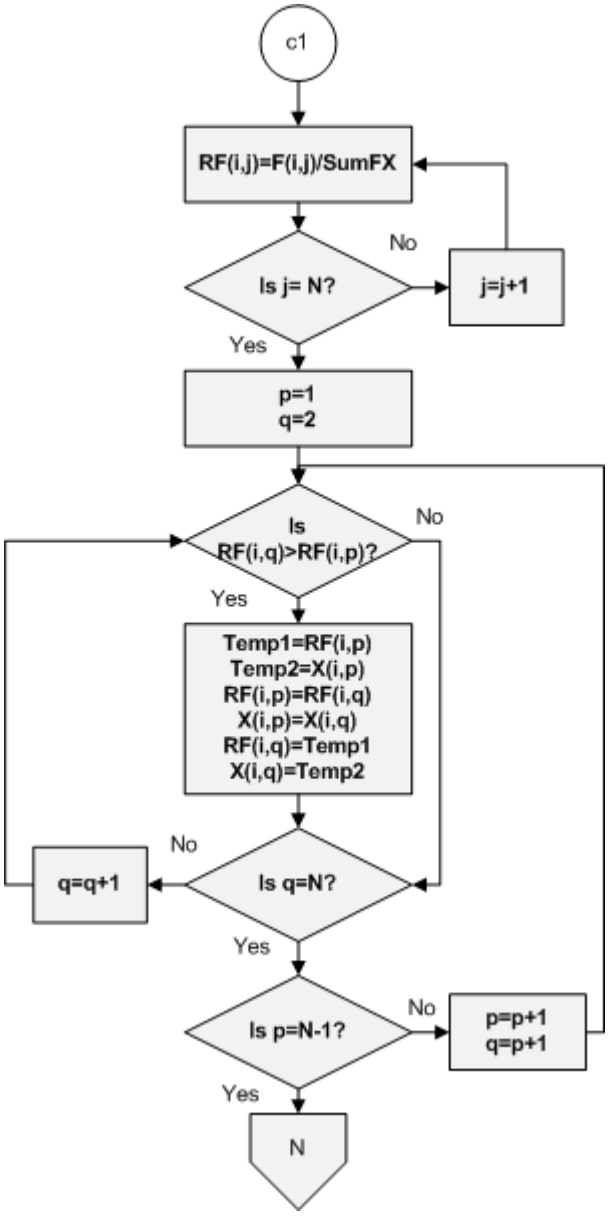
Flowchart representation of the conversion process from Uniform PDF to Rectangular FMF continues

Appendix 6.1



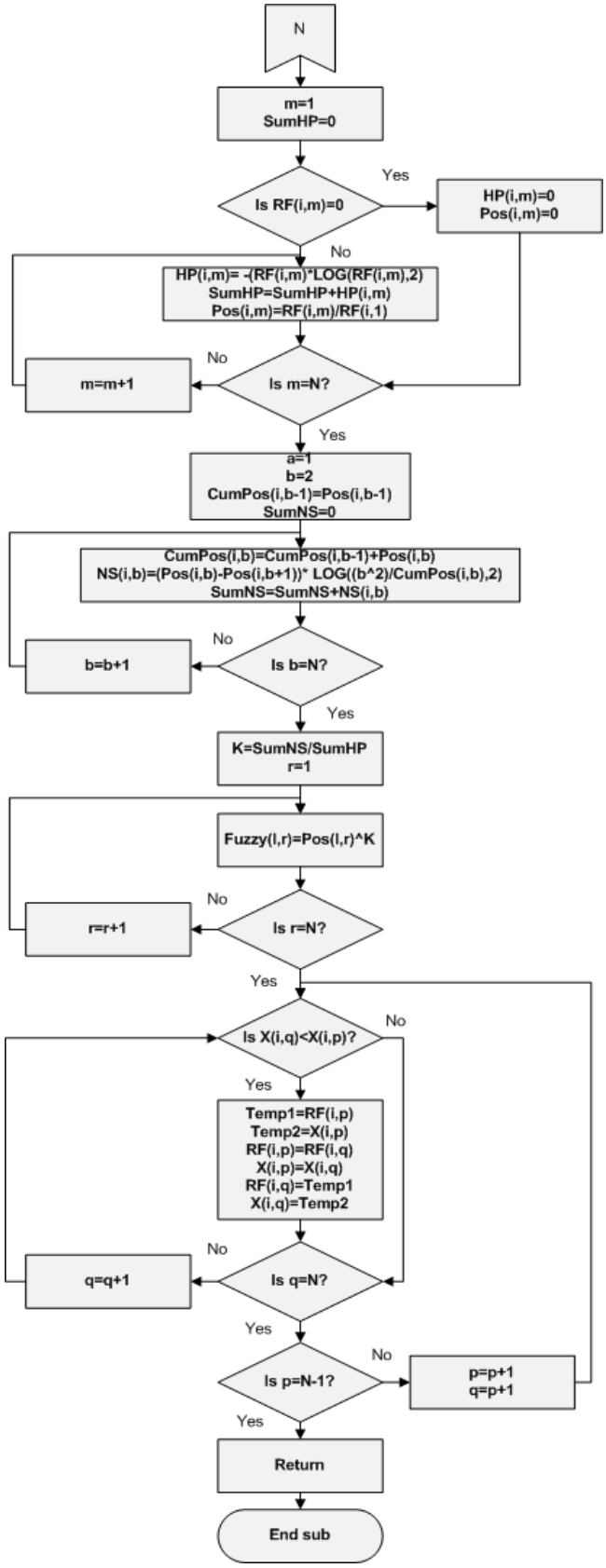
Flowchart representation of the conversion process from Triangular PDF to Triangular FMF

Appendix 6.1 continues



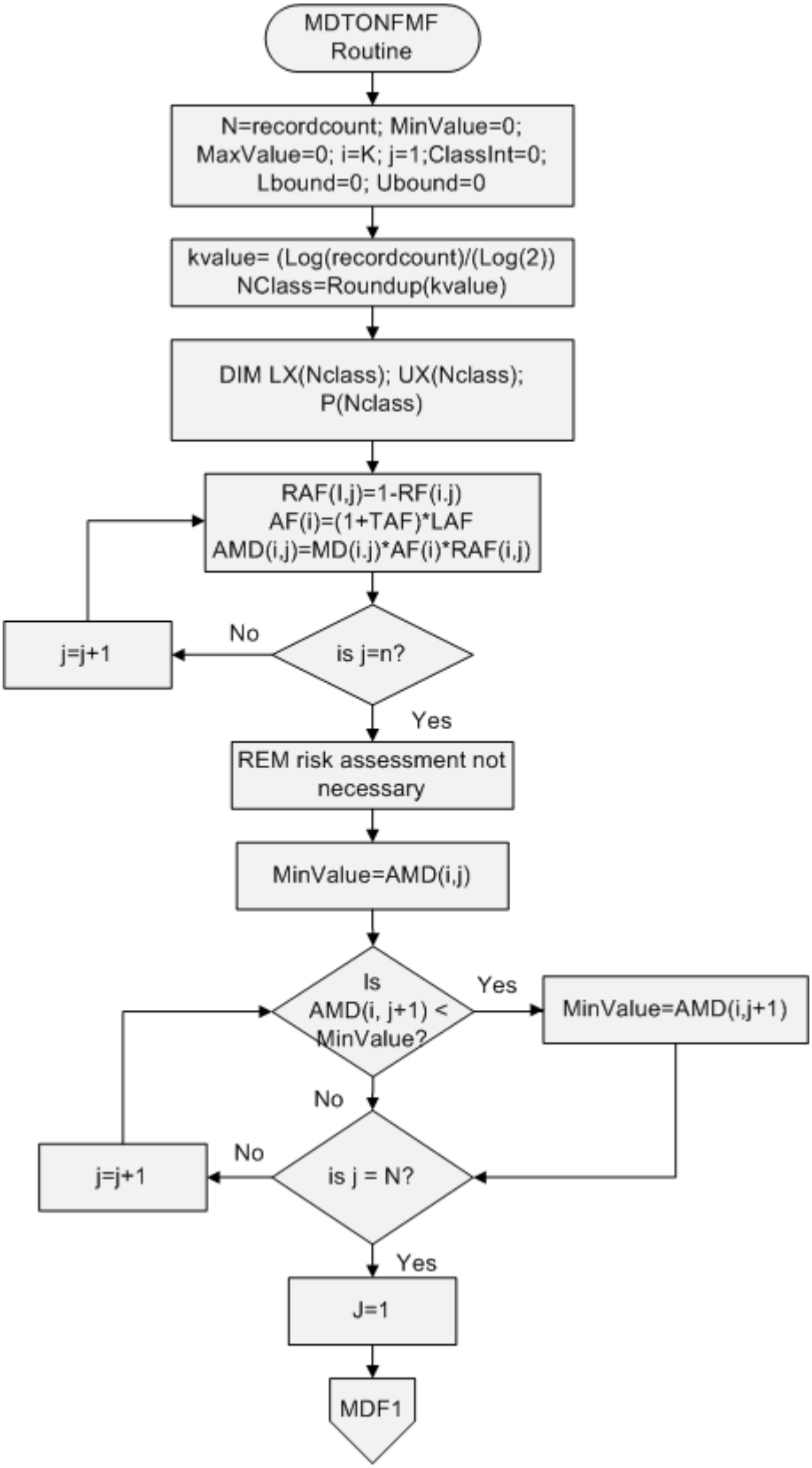
Flowchart representation of the conversion process from Triangular PDF to Triangular FMF continues

Appendix 6.1 continues



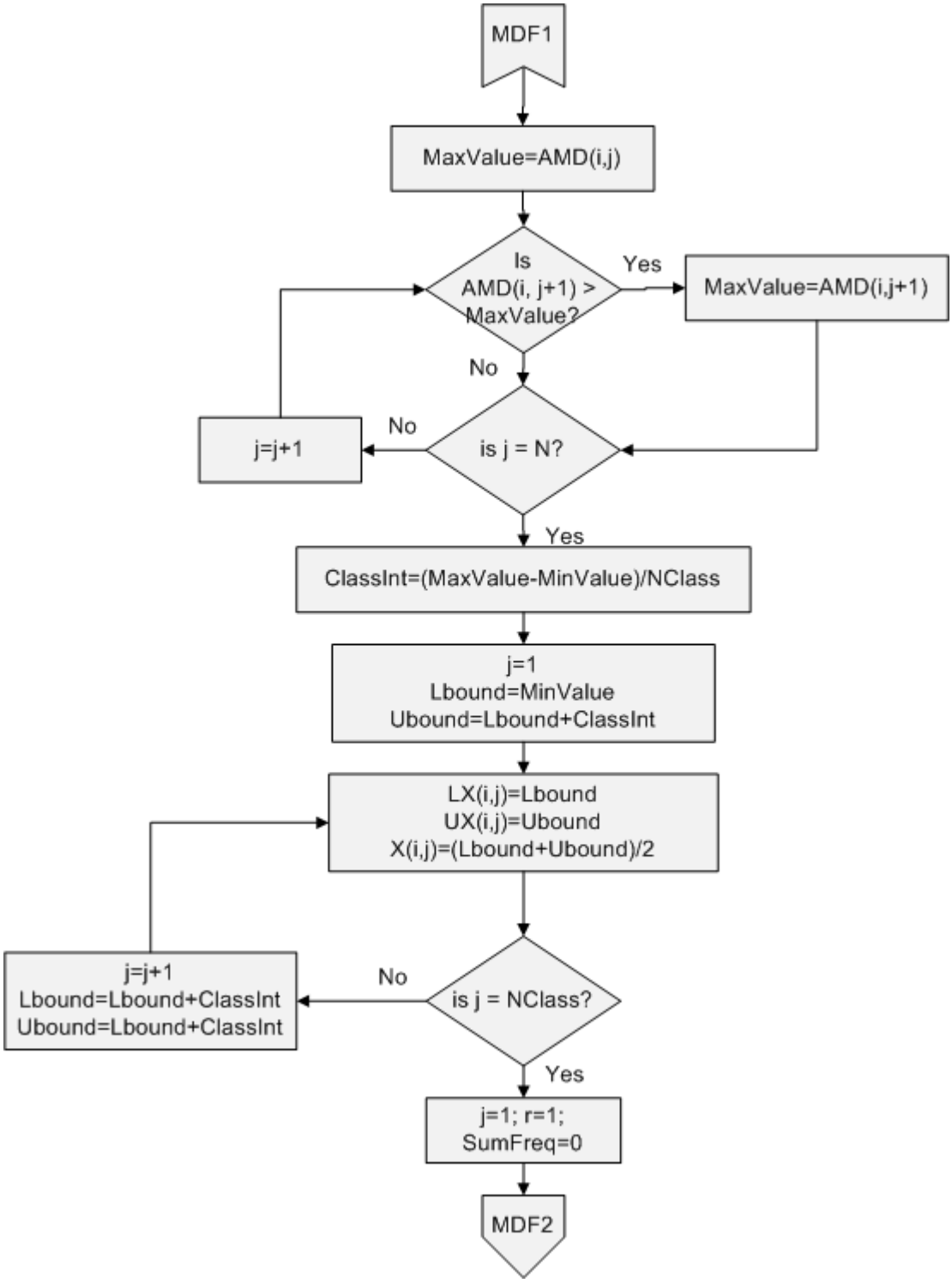
Flowchart representation of the conversion process from Triangular PDF to Triangular FMF continues

Appendix 6.2



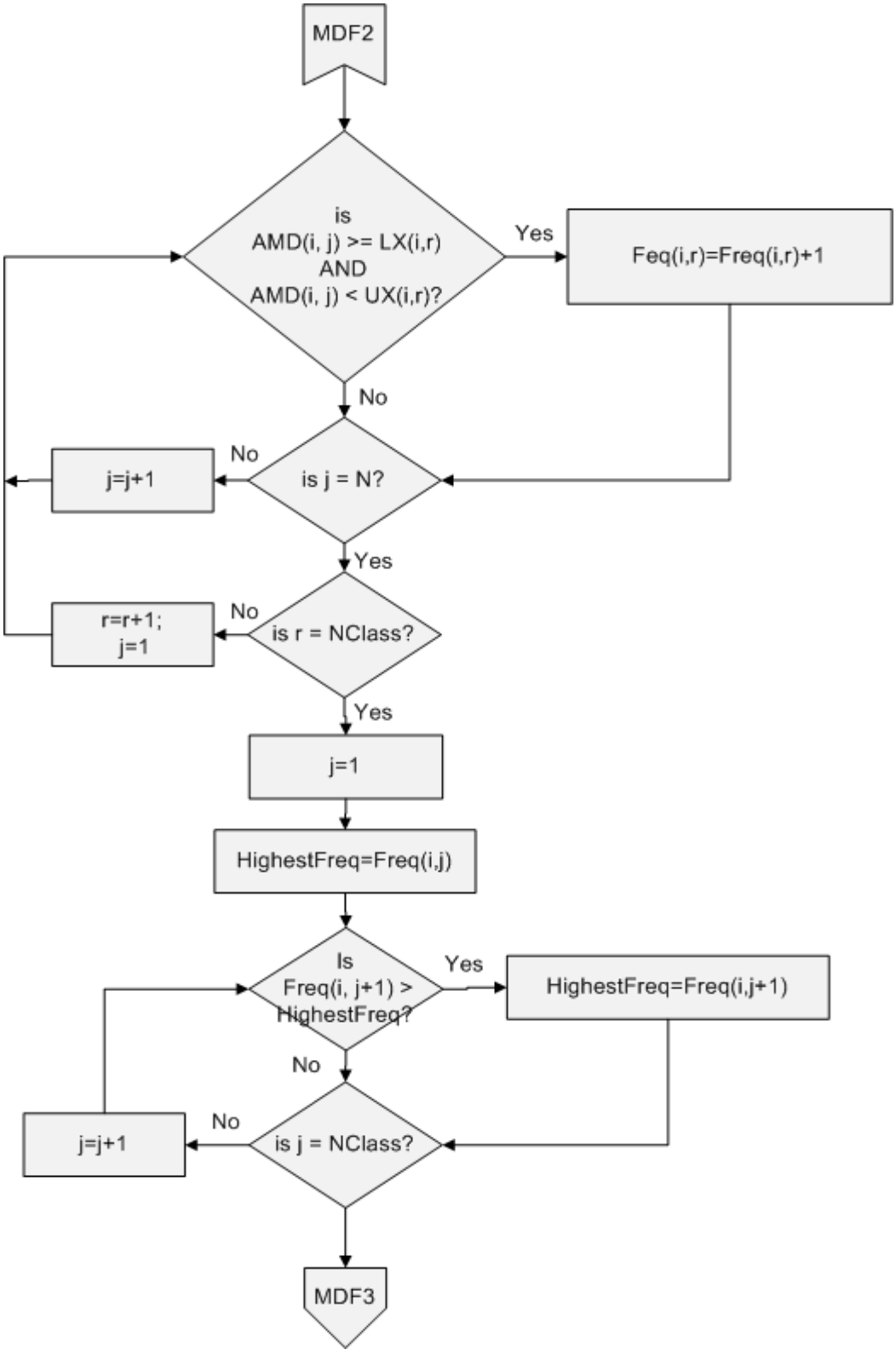
Flowchart representation of the conversion process from Multi-data to FMF

Appendix 6.2 continues



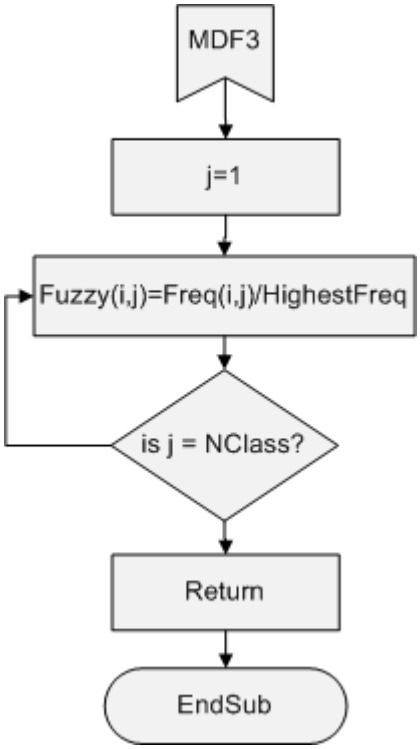
Flowchart representation of the conversion process from Multi-data to FMF

Appendix 6.2 continues



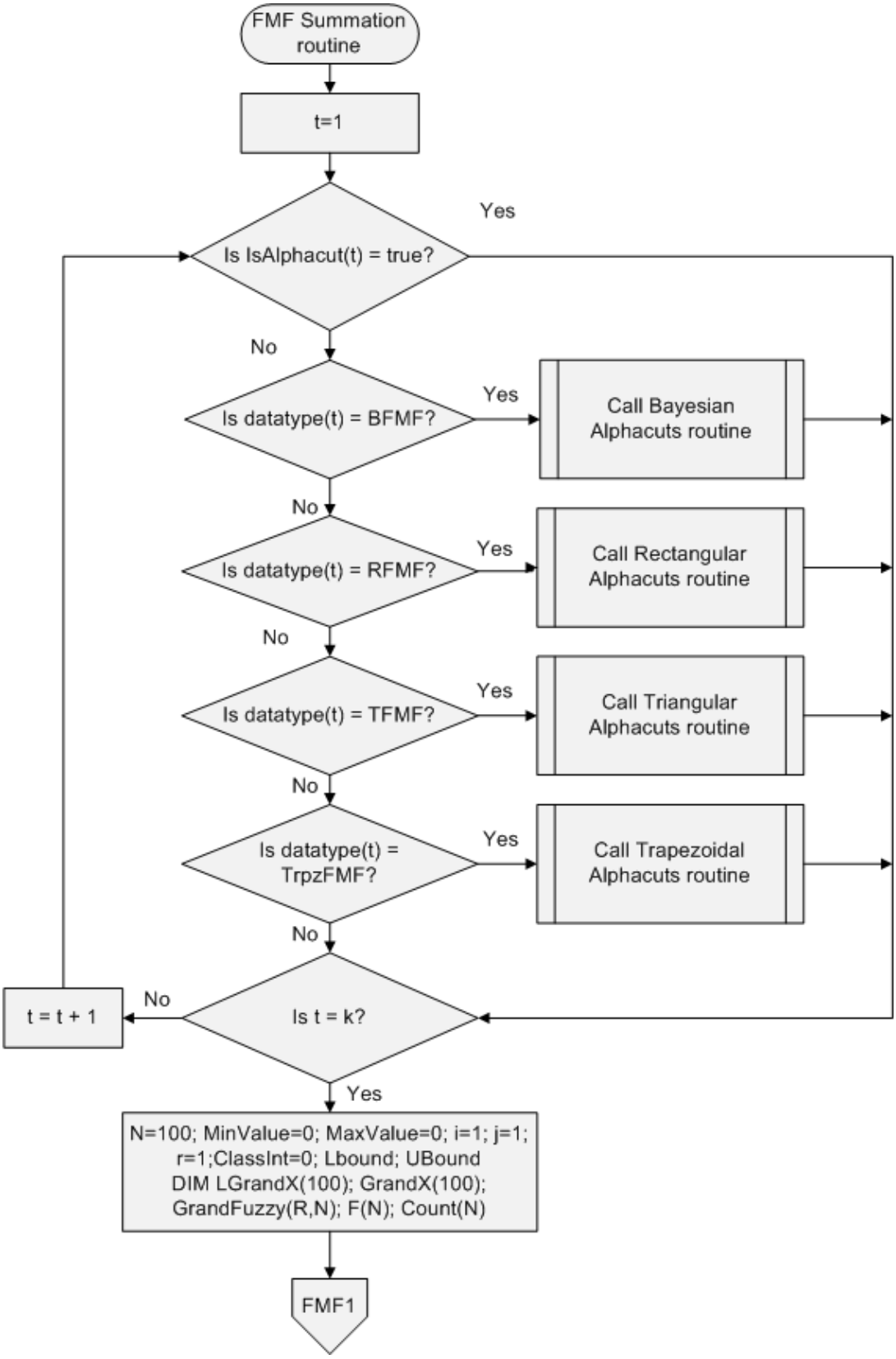
Flowchart representation of the conversion process from Multi-data to FMF.

Appendix 6.2 continues



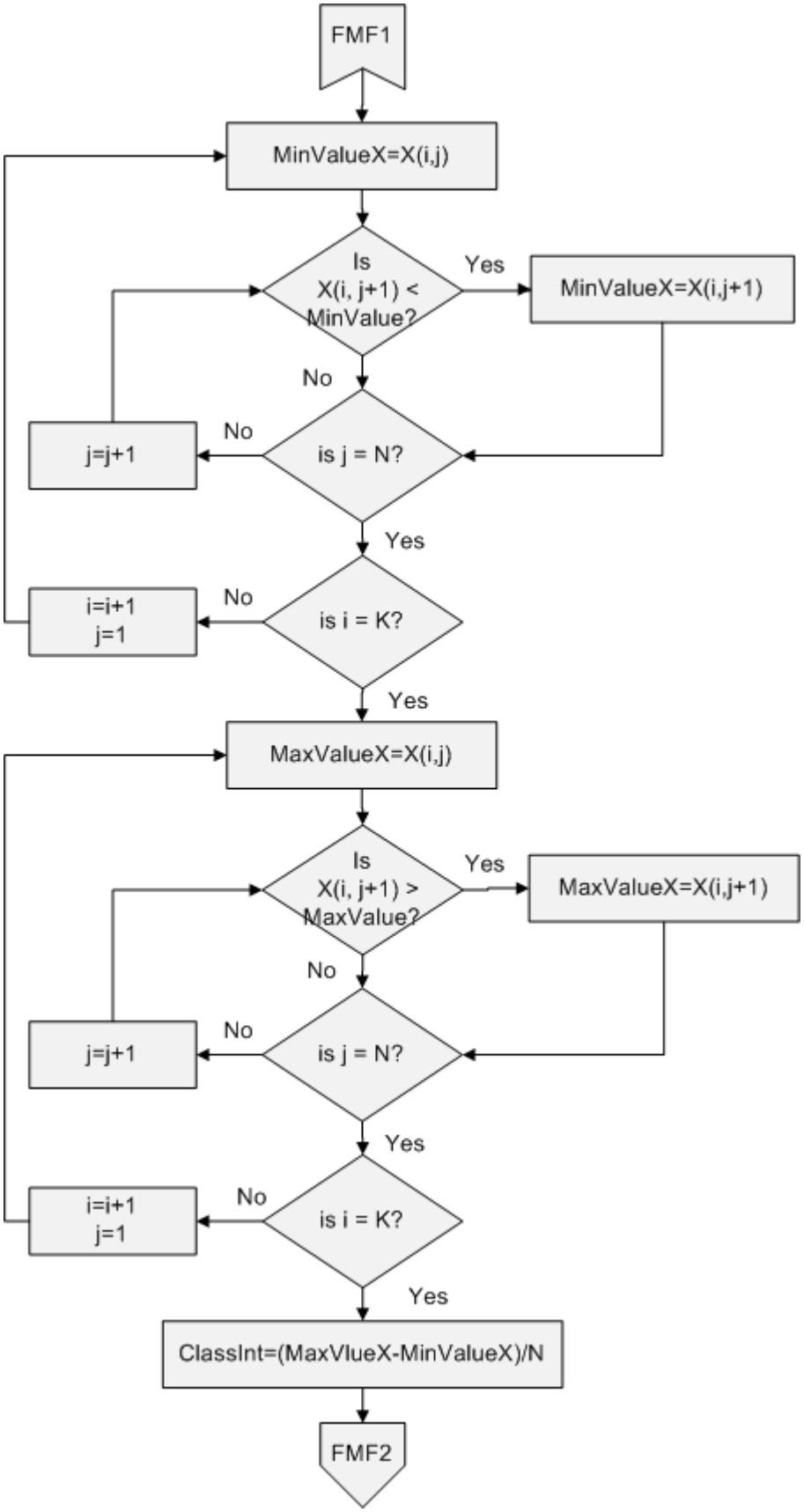
Flowchart representation of the conversion process from Multi-data to FMF

Appendix 6.3



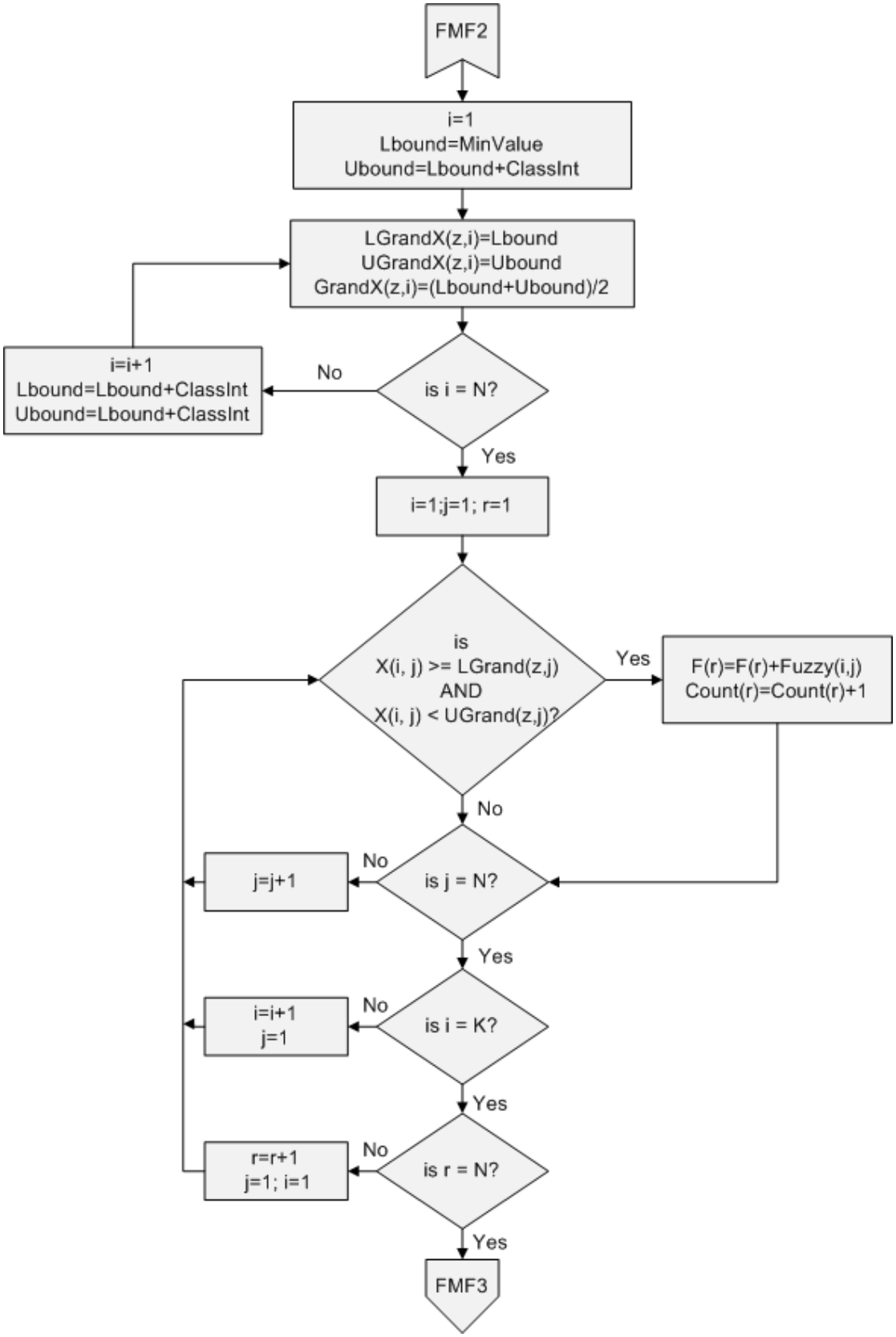
Flowchart representation of Fuzzy Membership Function Summation routine

Appendix 6.3 continues



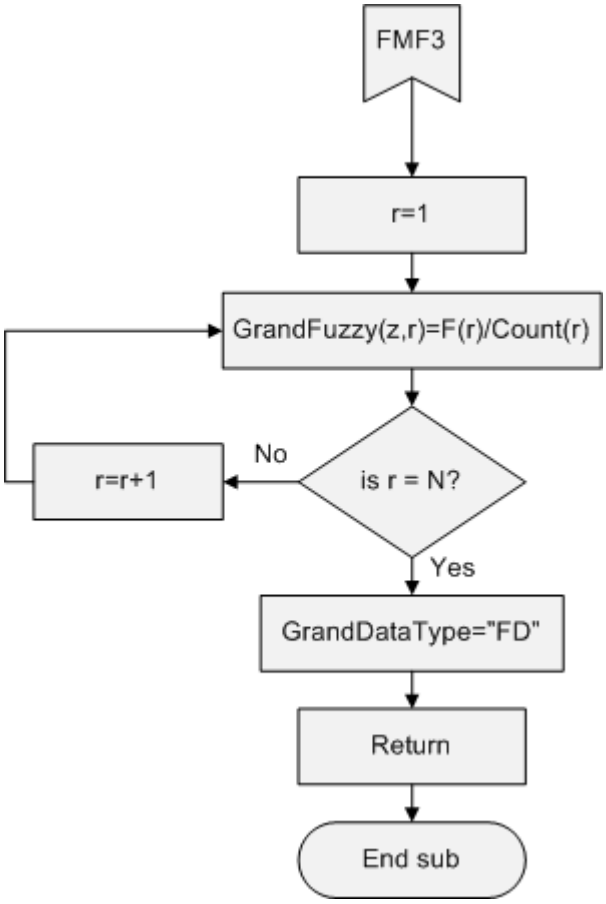
Flowchart representation of Fuzzy Membership Function Summation routine

Appendix 6.3 continues



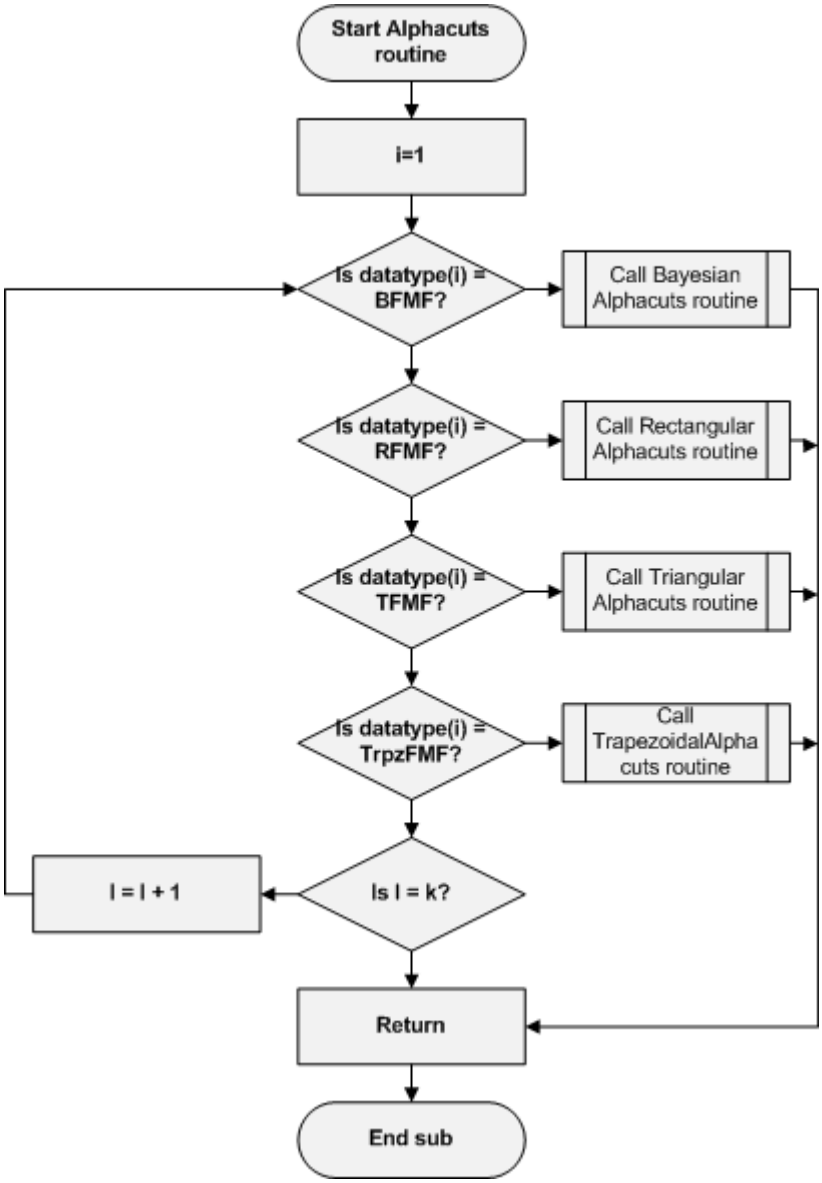
Flowchart representation of Fuzzy Membership Function Summation routine

Appendix 6.3 continues



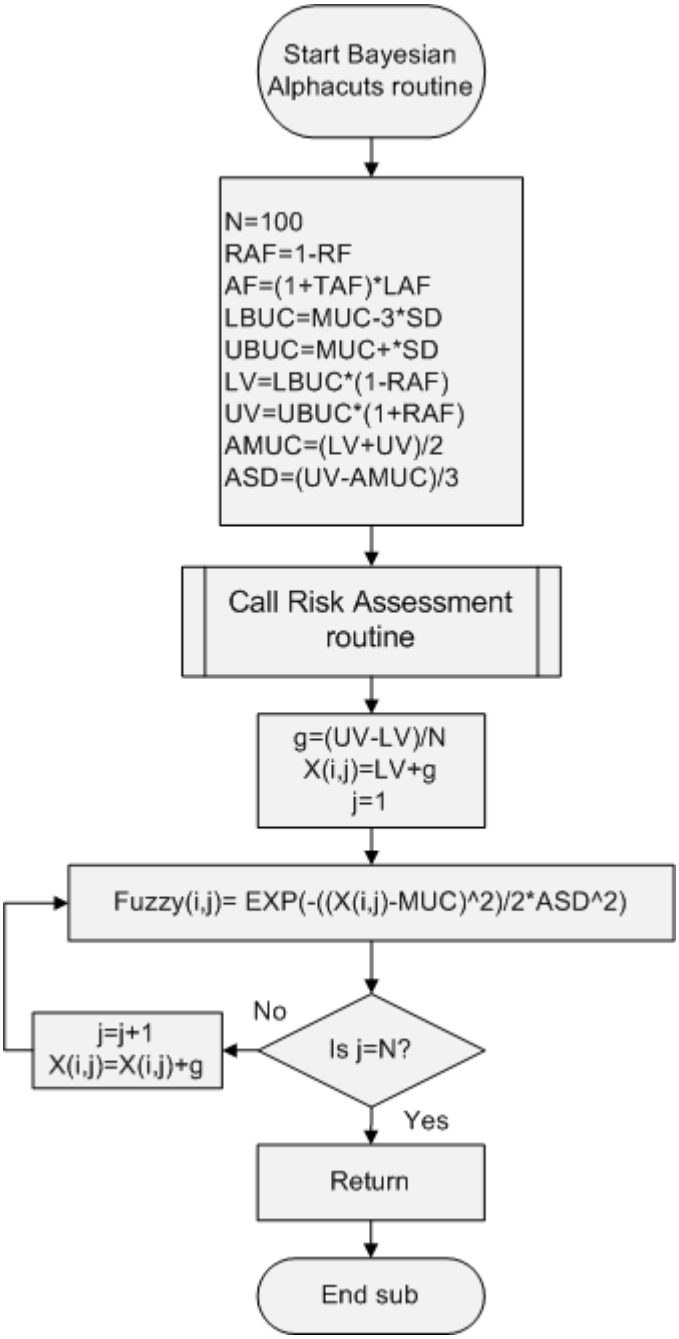
Flowchart representation of Fuzzy Membership Function Summation routine

Appendix 6.4



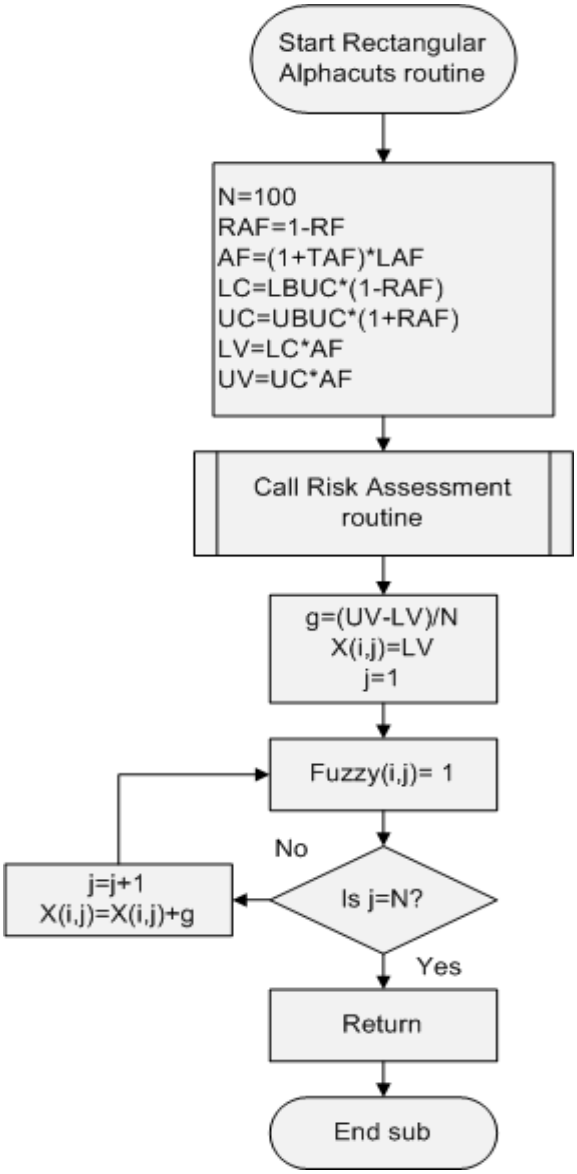
Flowchart representation of Alpha-cuts routine

Appendix 6.5



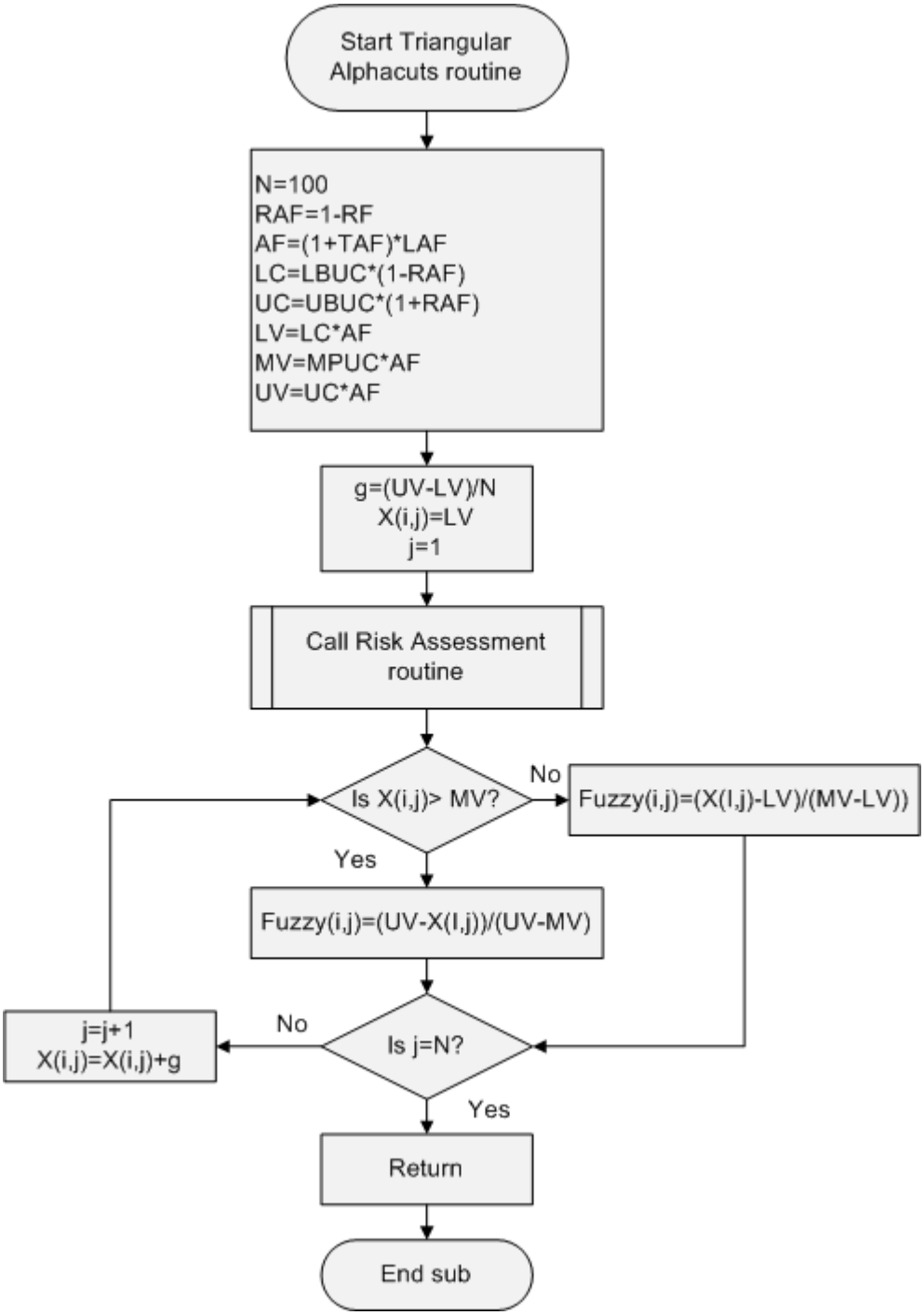
Flowchart representation of Bayesian Alpha-cuts routine.

Appendix 6.6



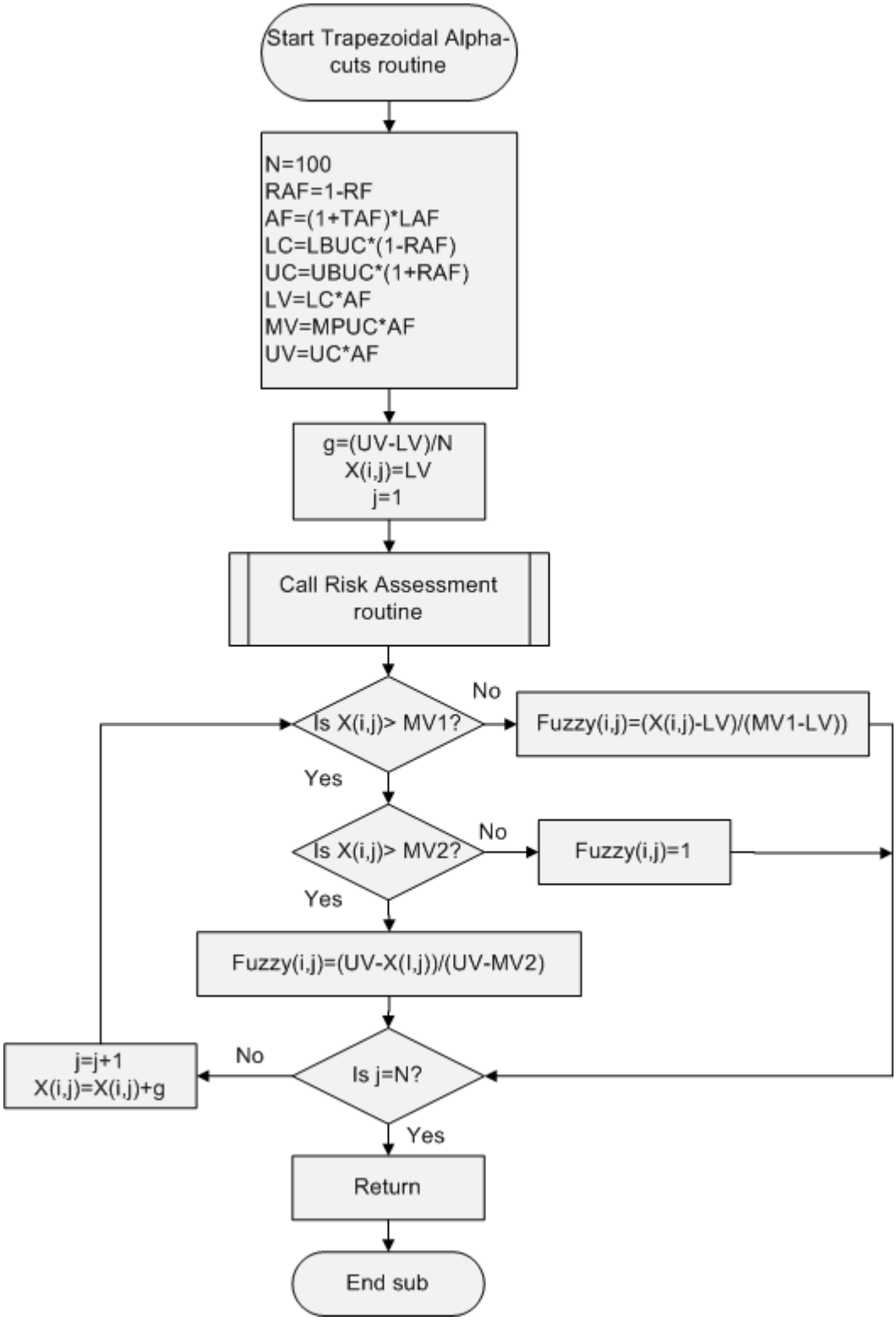
Flowchart representation of Rectangular Alpha-cuts routine.

Appendix 6.7



Flowchart representation of Triangular Alpha-cuts routine.

Appendix 6.8

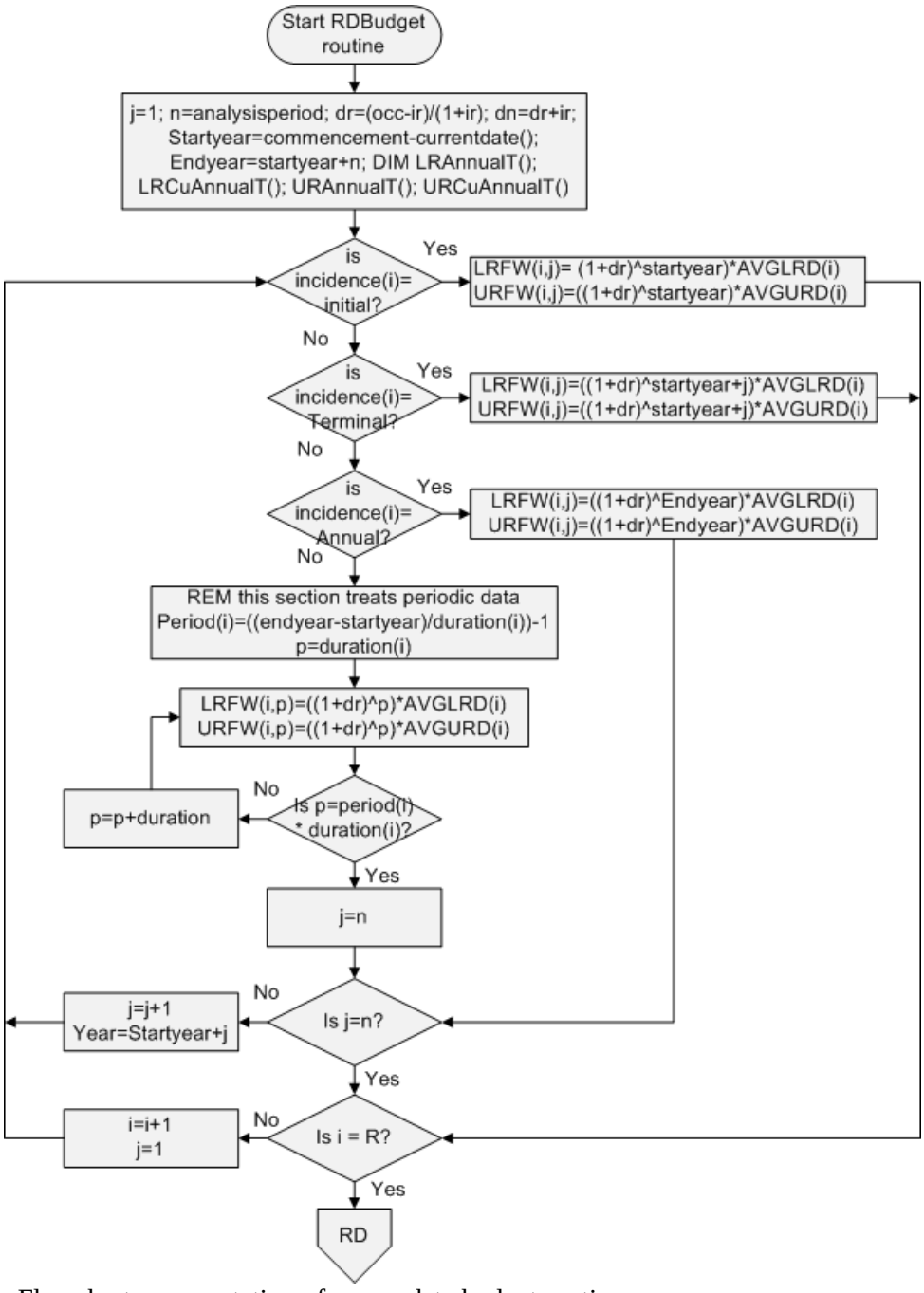


Flowchart representation of Trapezoidal Alpha-cuts routine.

Appendix 7:

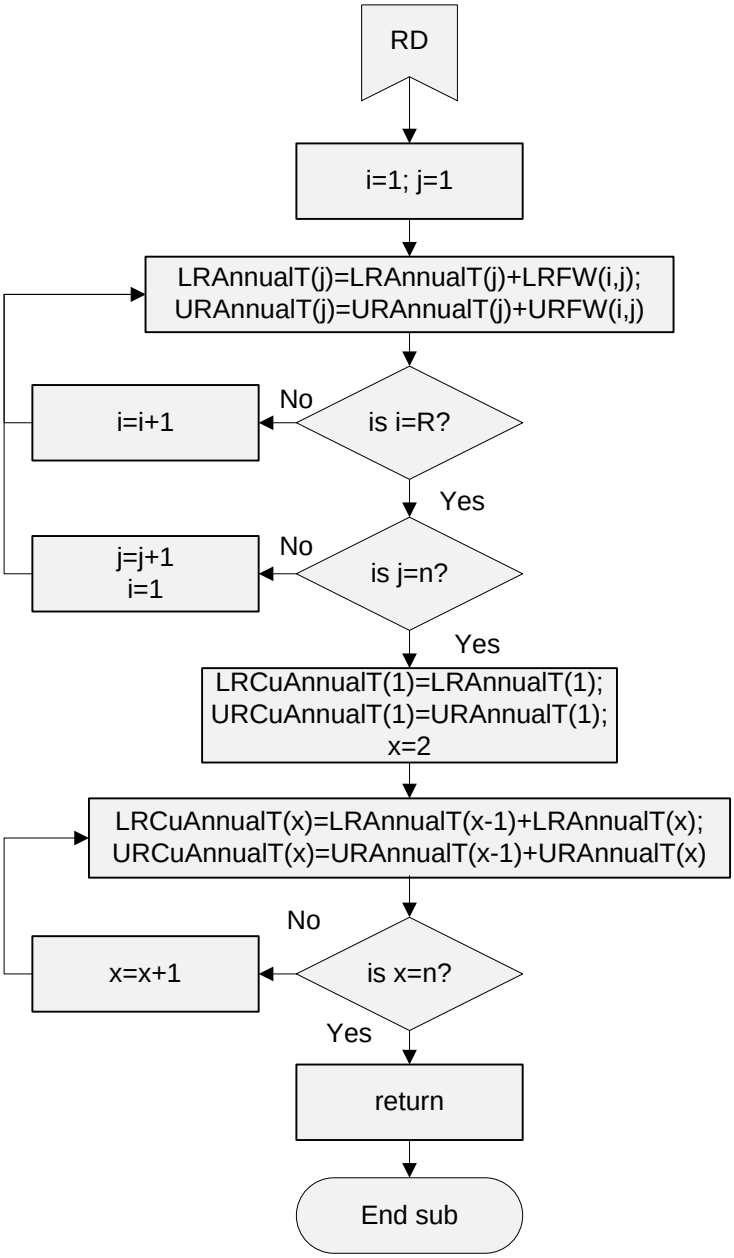
Flowchart representation of the WLC Budget routine

Appendix 7.0: Budget routines



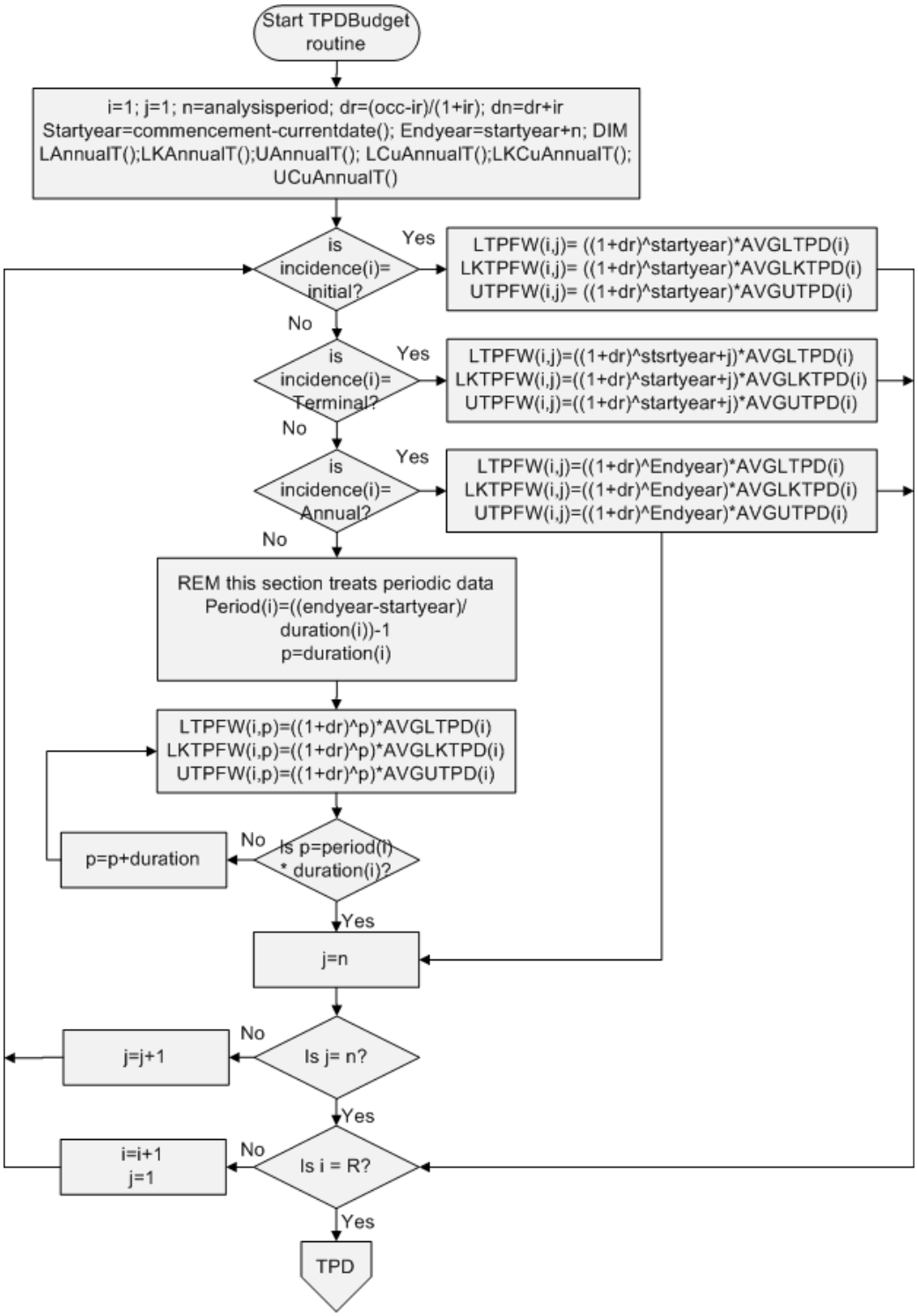
Flowchart representation of range data budget routine

Appendix 7.0 continues



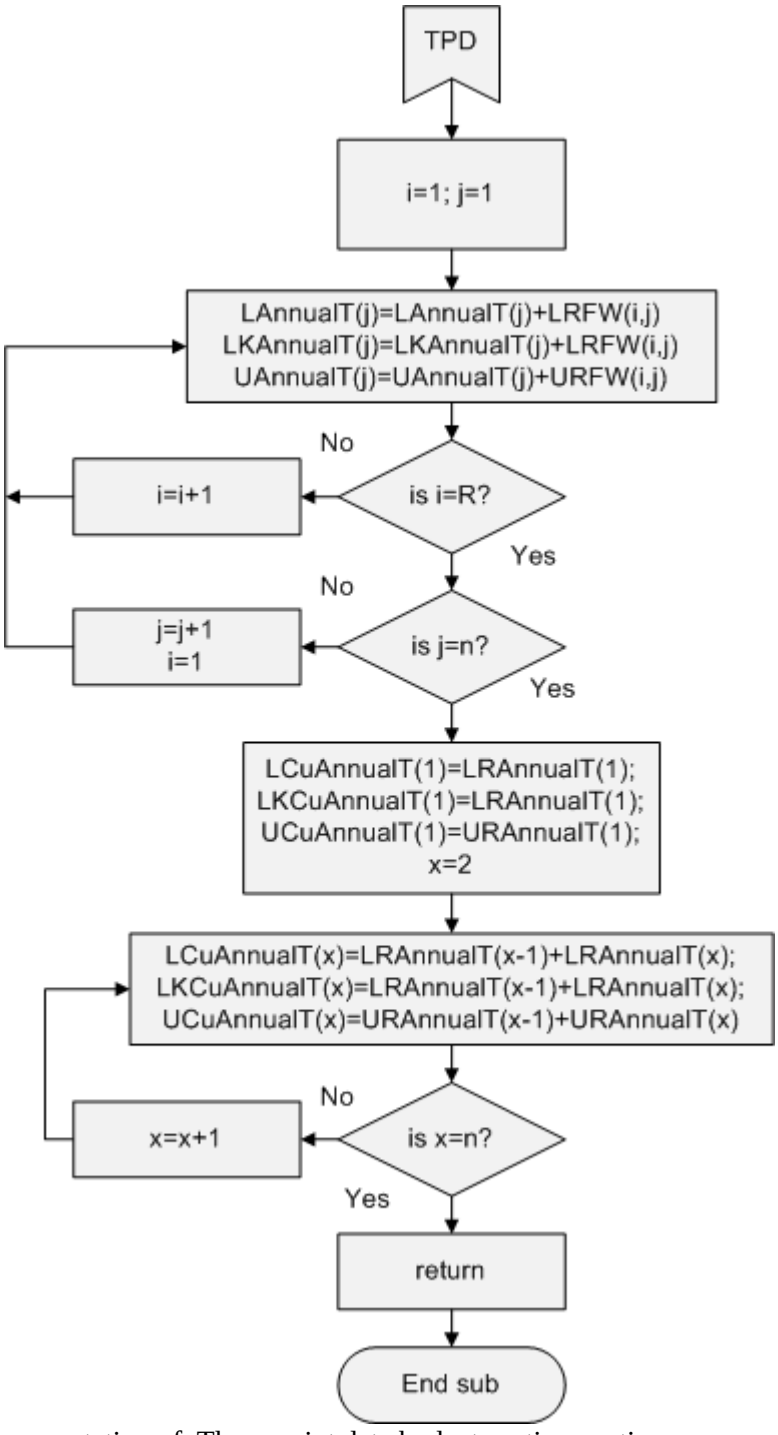
Flowchart representation of range data budget routine continues

Appendix 7.1: Three-point Budget routine



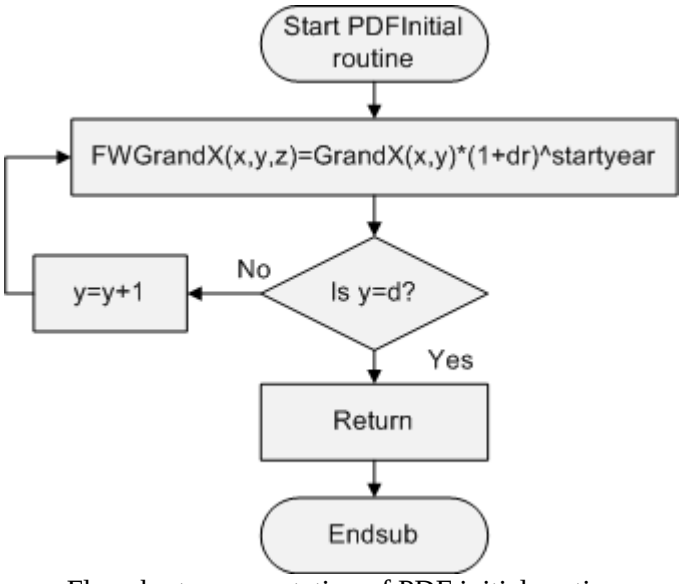
Flowchart representation of Three-point data budget routine

Appendix 7.1 continues

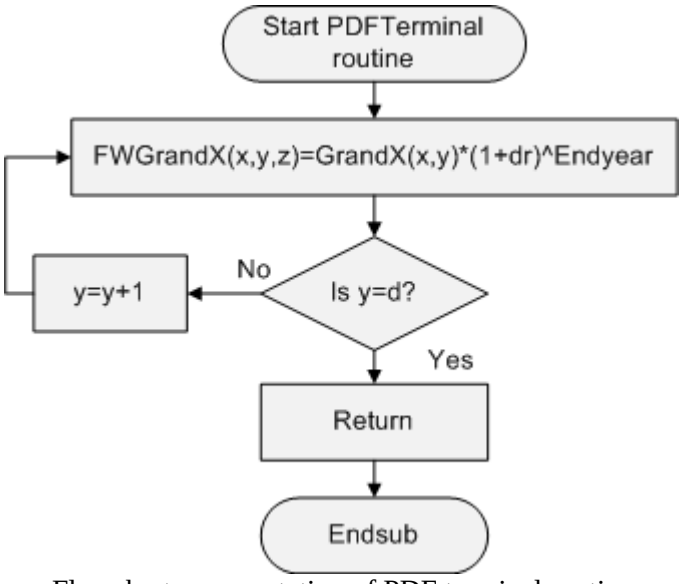


Flowchart representation of Three-point data budget routine continues

Appendix 7.2: PDF initial and terminal routine

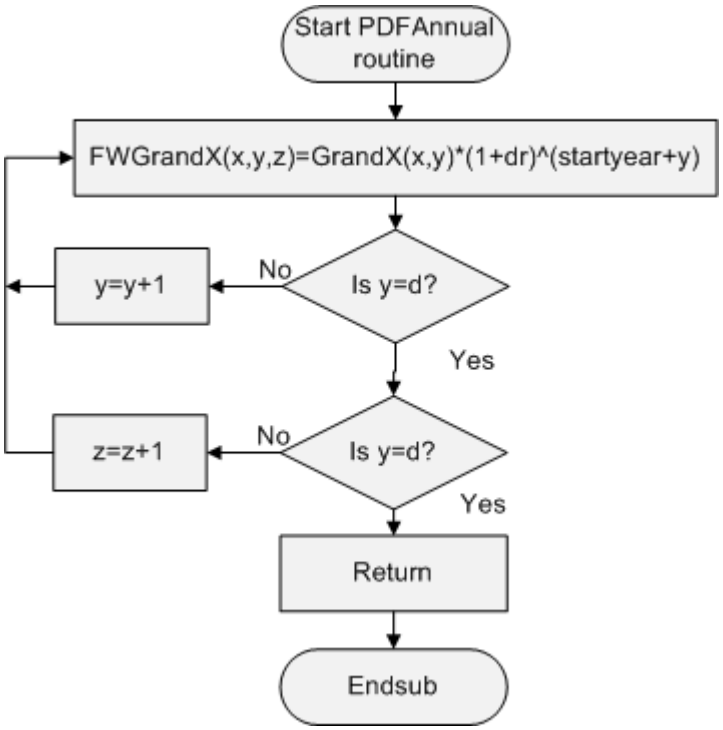


Flowchart representation of PDF initial routine

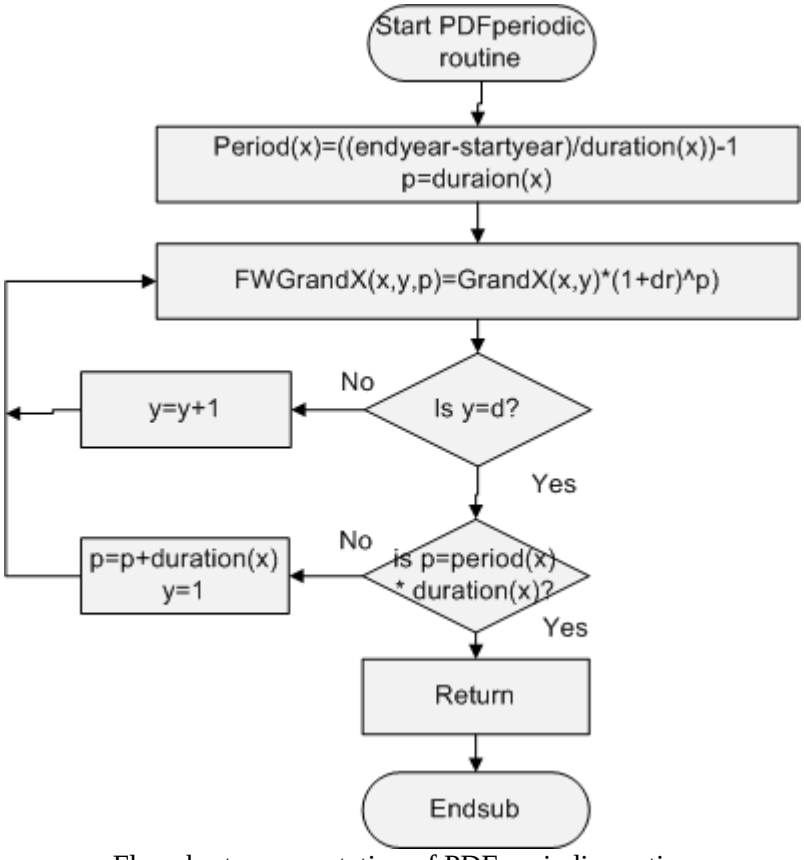


Flowchart representation of PDF terminal routine

Appendix 7.3: PDF annual and periodic routine

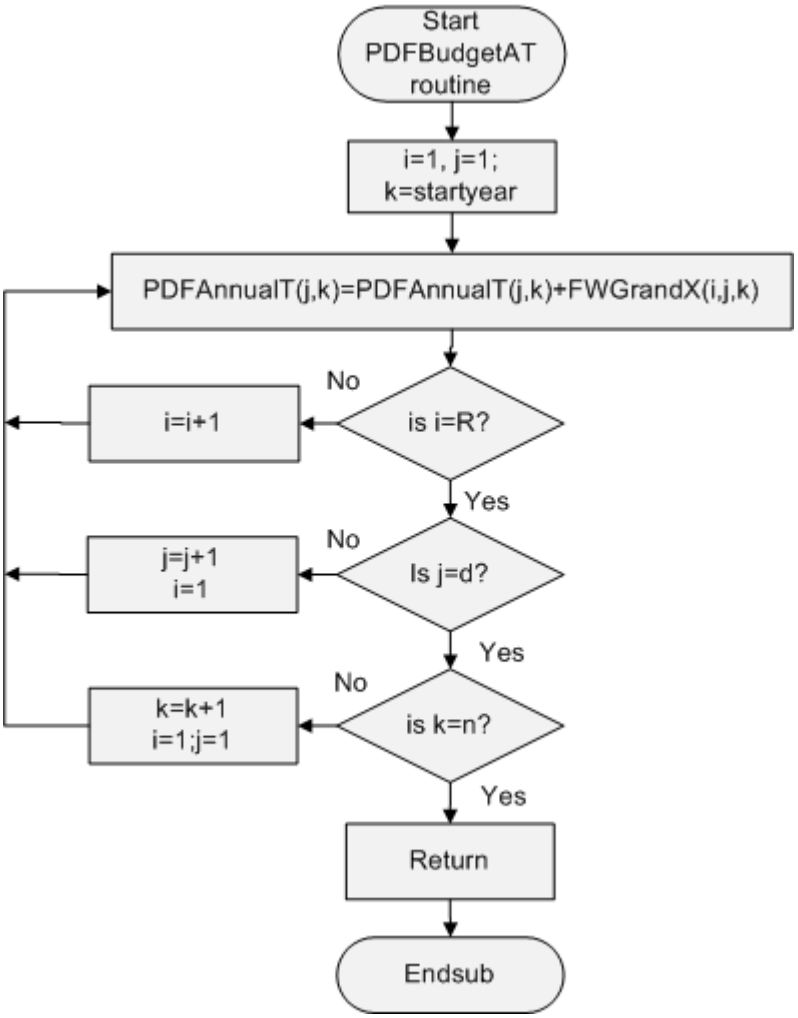


Flowchart representation of PDF annual routine



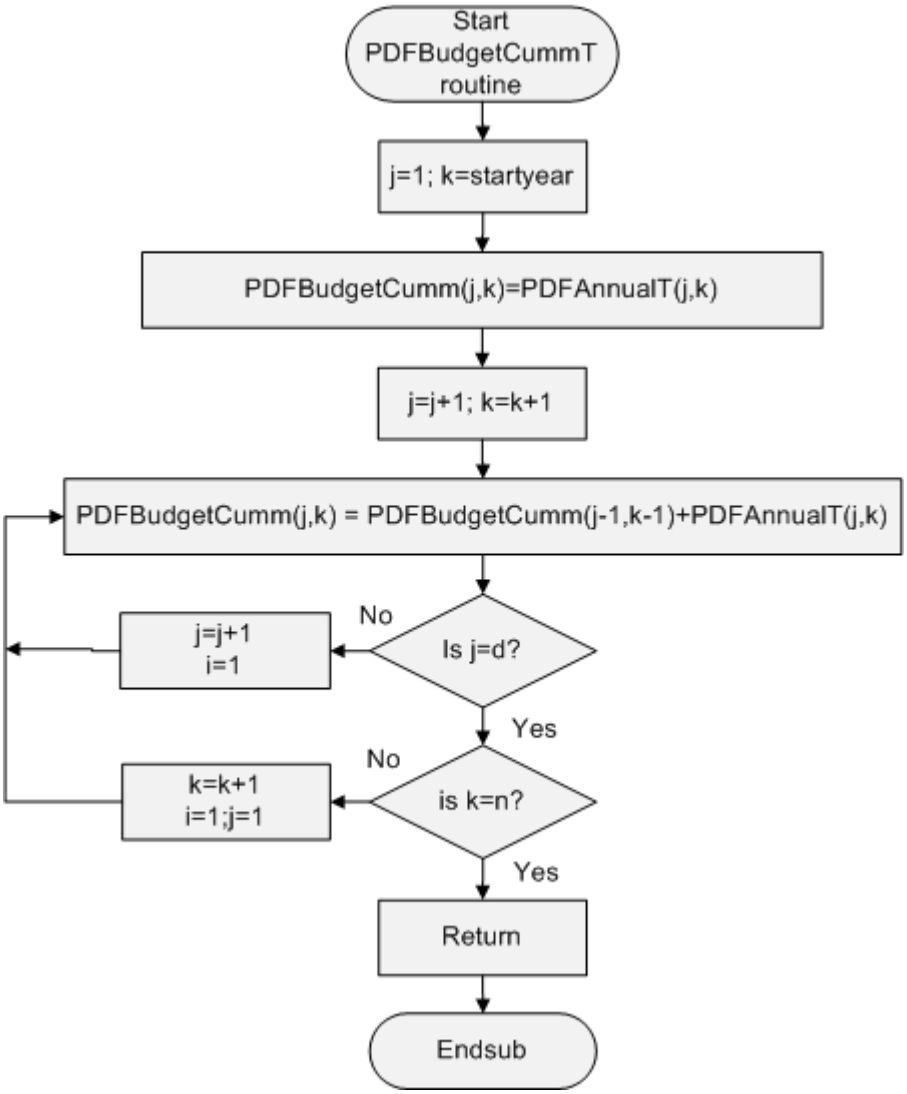
Flowchart representation of PDF periodic routine

Appendix 7.4: PDF annual totals routine



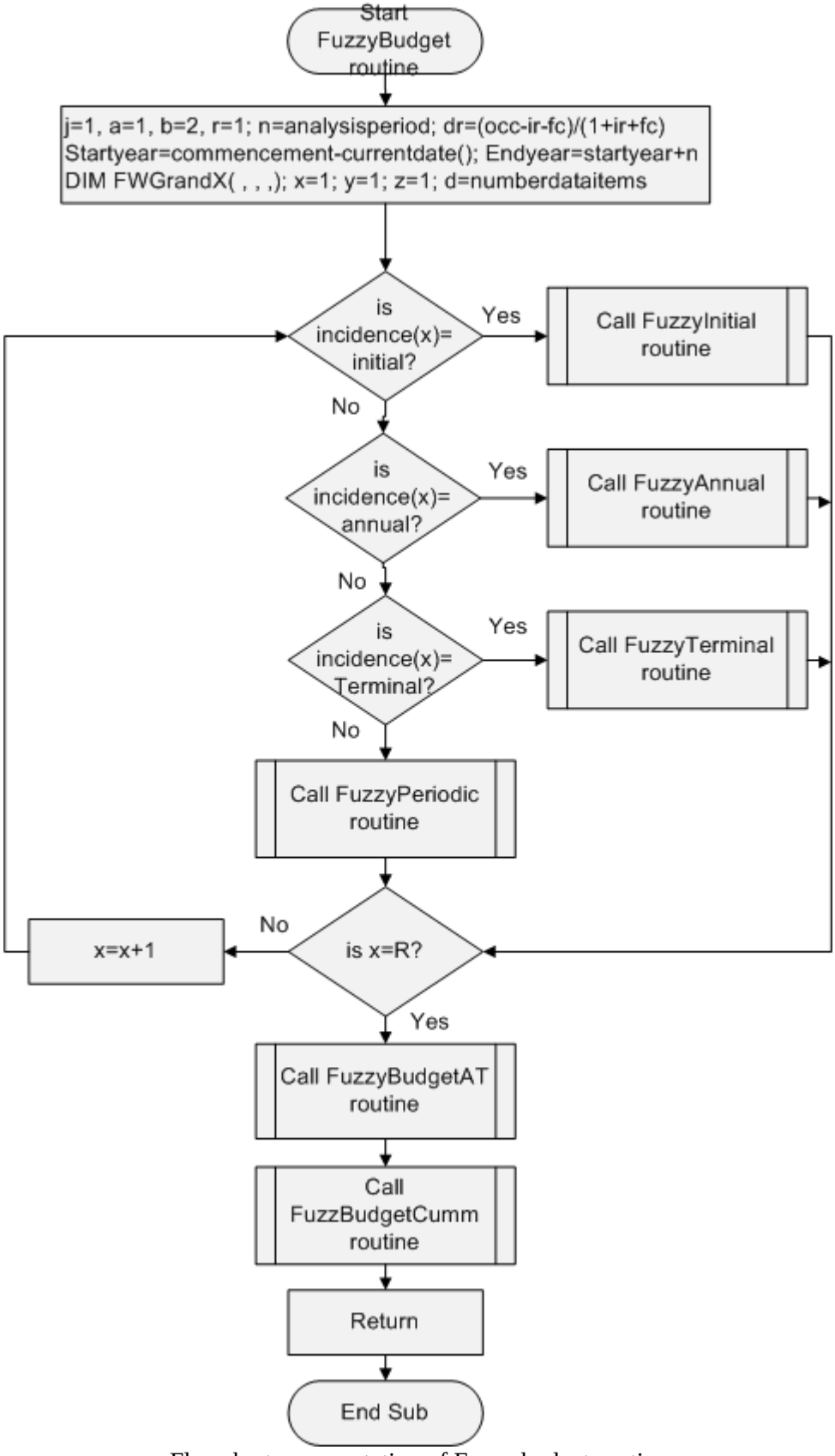
Flowchart representation of PDF Annual Total routine

Appendix 7.5: PDF cumulative total routine



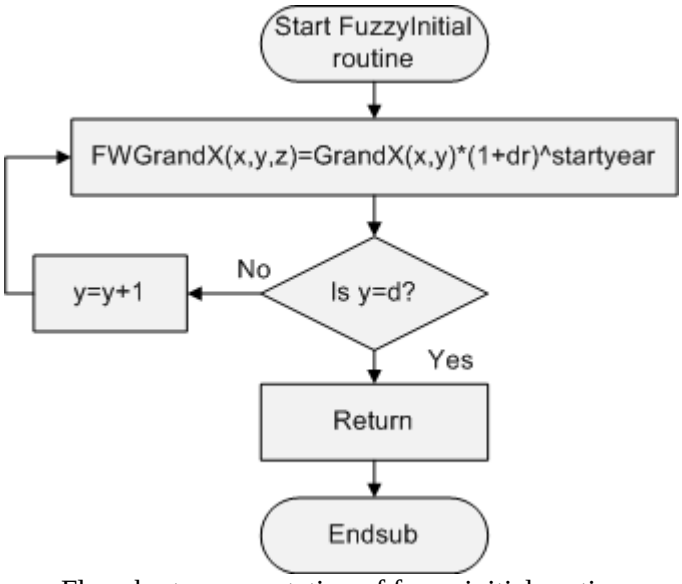
Flowchart representation of PDF Annual Total routine

Appendix 7.6: Fuzzy budget routine

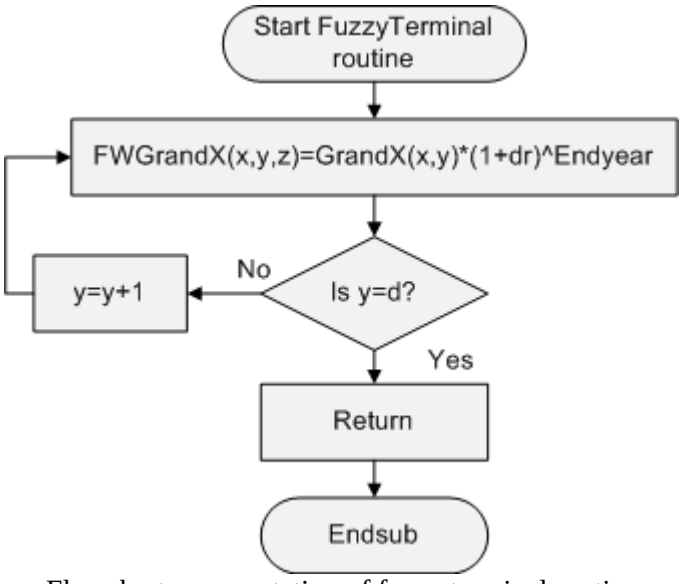


Flowchart representation of Fuzzy budget routine

Appendix 7.7: Fuzzy initial and terminal routines

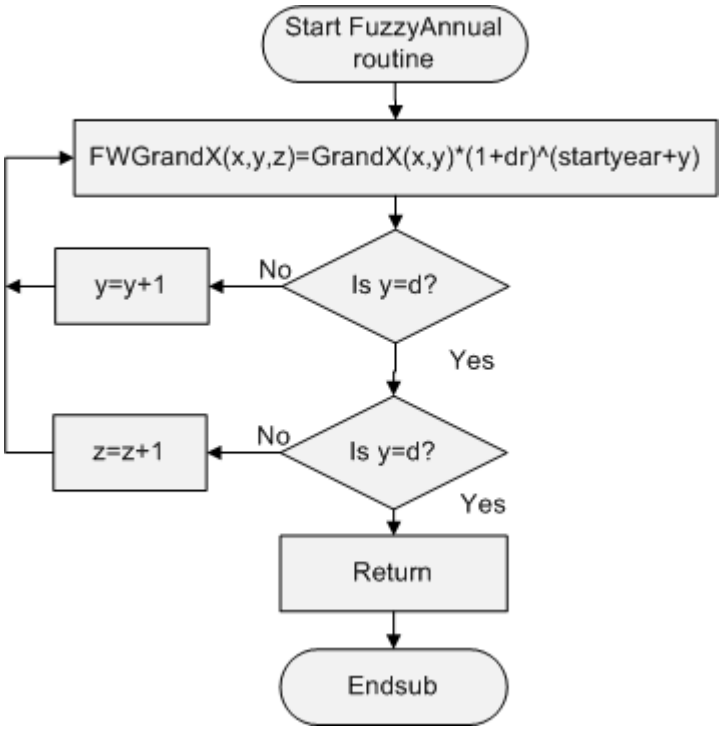


Flowchart representation of fuzzy initial routine

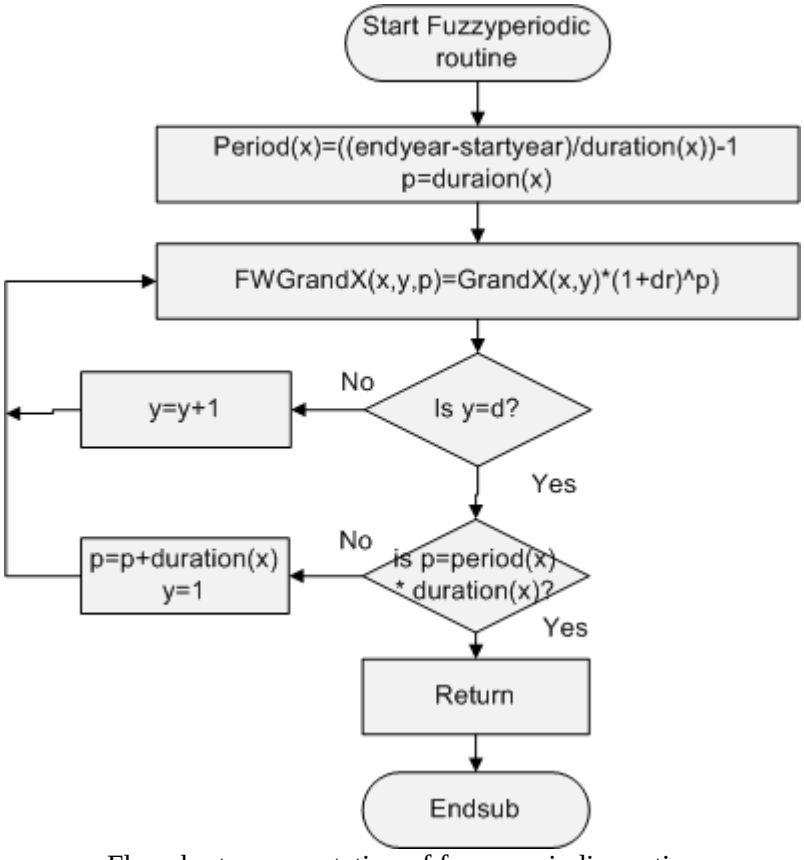


Flowchart representation of fuzzy terminal routine

Appendix 7.8: Fuzzy annual and periodic routines

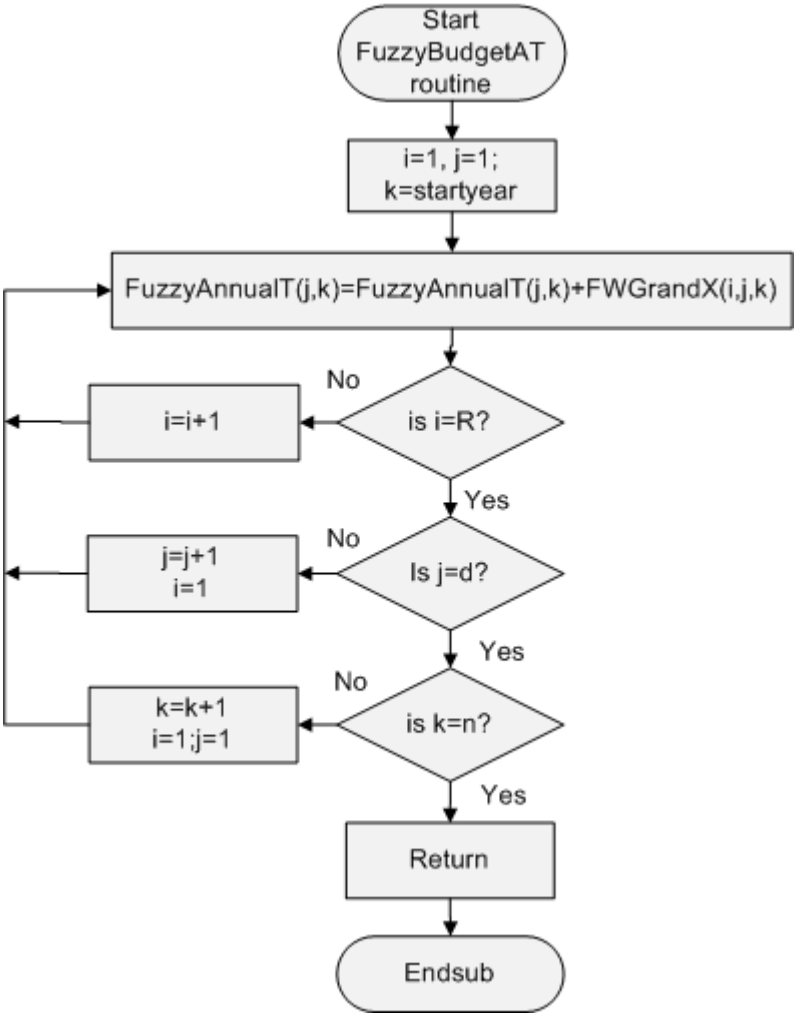


Flowchart representation of fuzzy annual routine



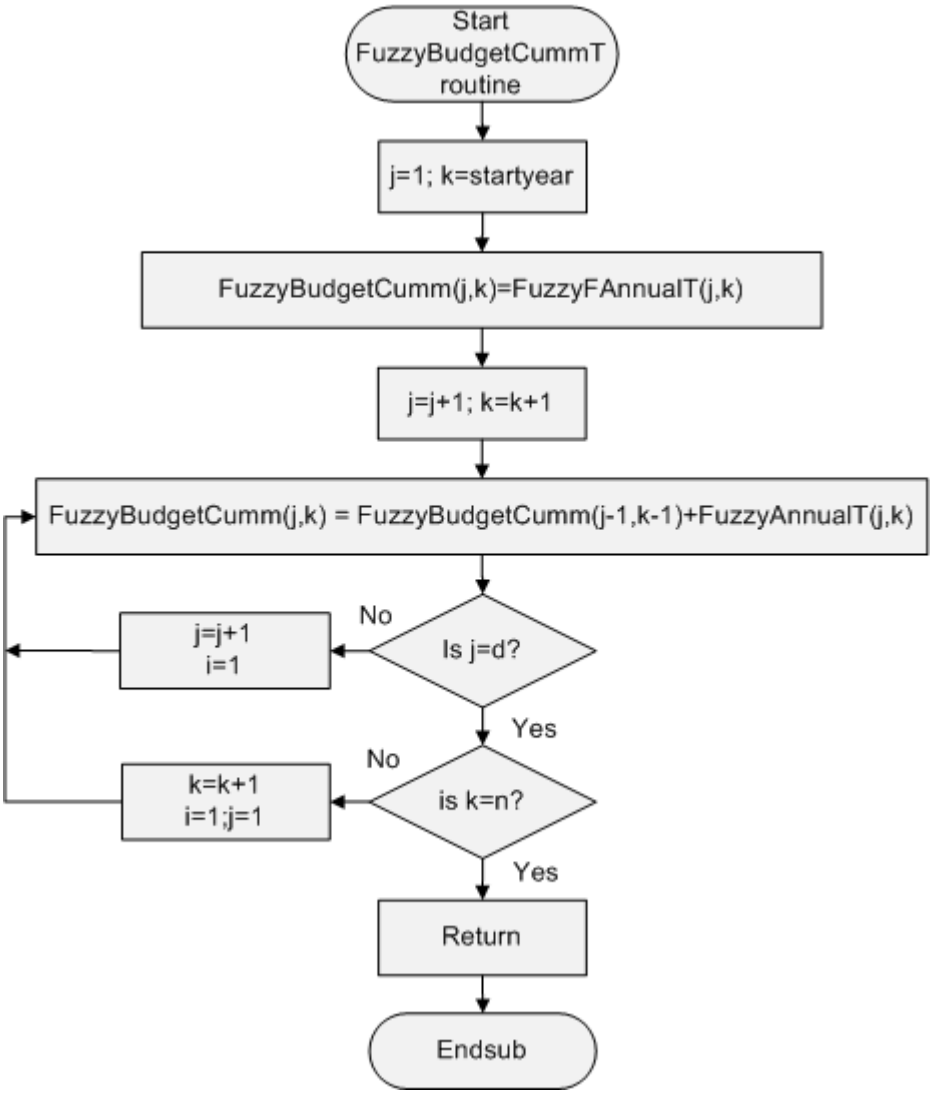
Flowchart representation of fuzzy periodic routine

Appendix 7.9: Fuzzy annual total routines



Flowchart representation of fuzzy annual total routine

Appendix 7.10: Fuzzy Cumulative annual total routines

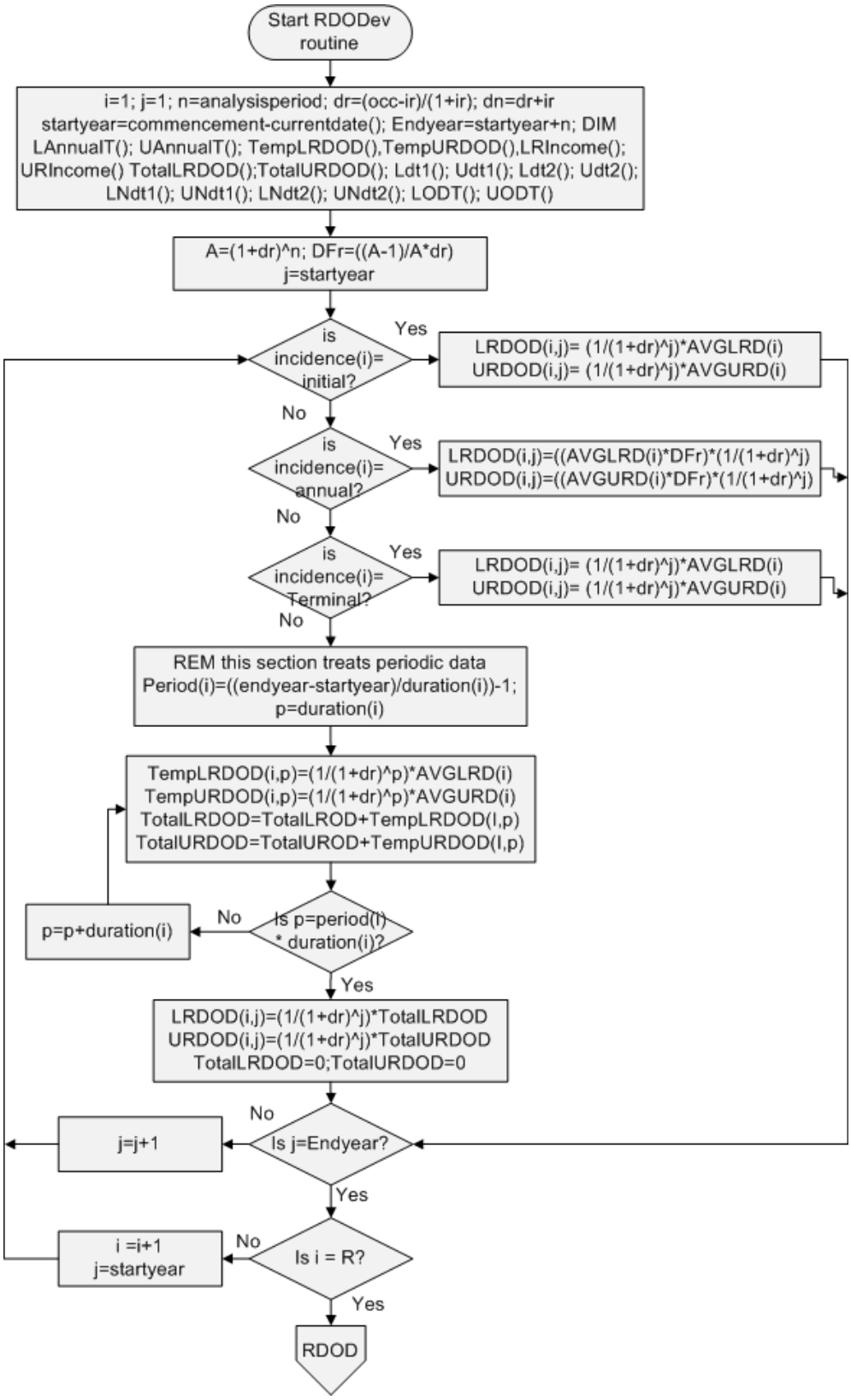


Flowchart representation of fuzzy cumulative annual total routine

Appendix 8:

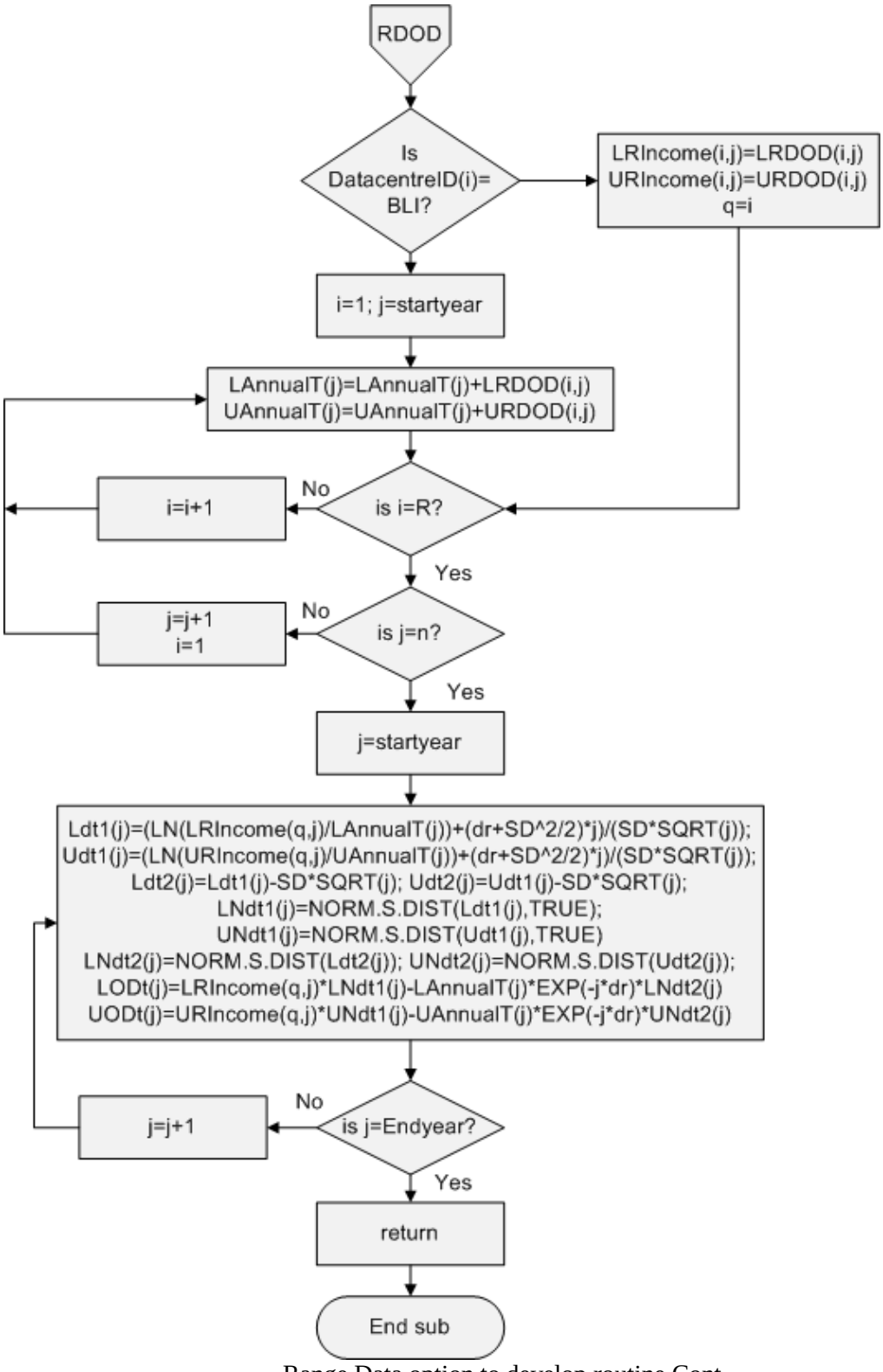
Flowchart representation of option to develop routine

Appendix 8.0



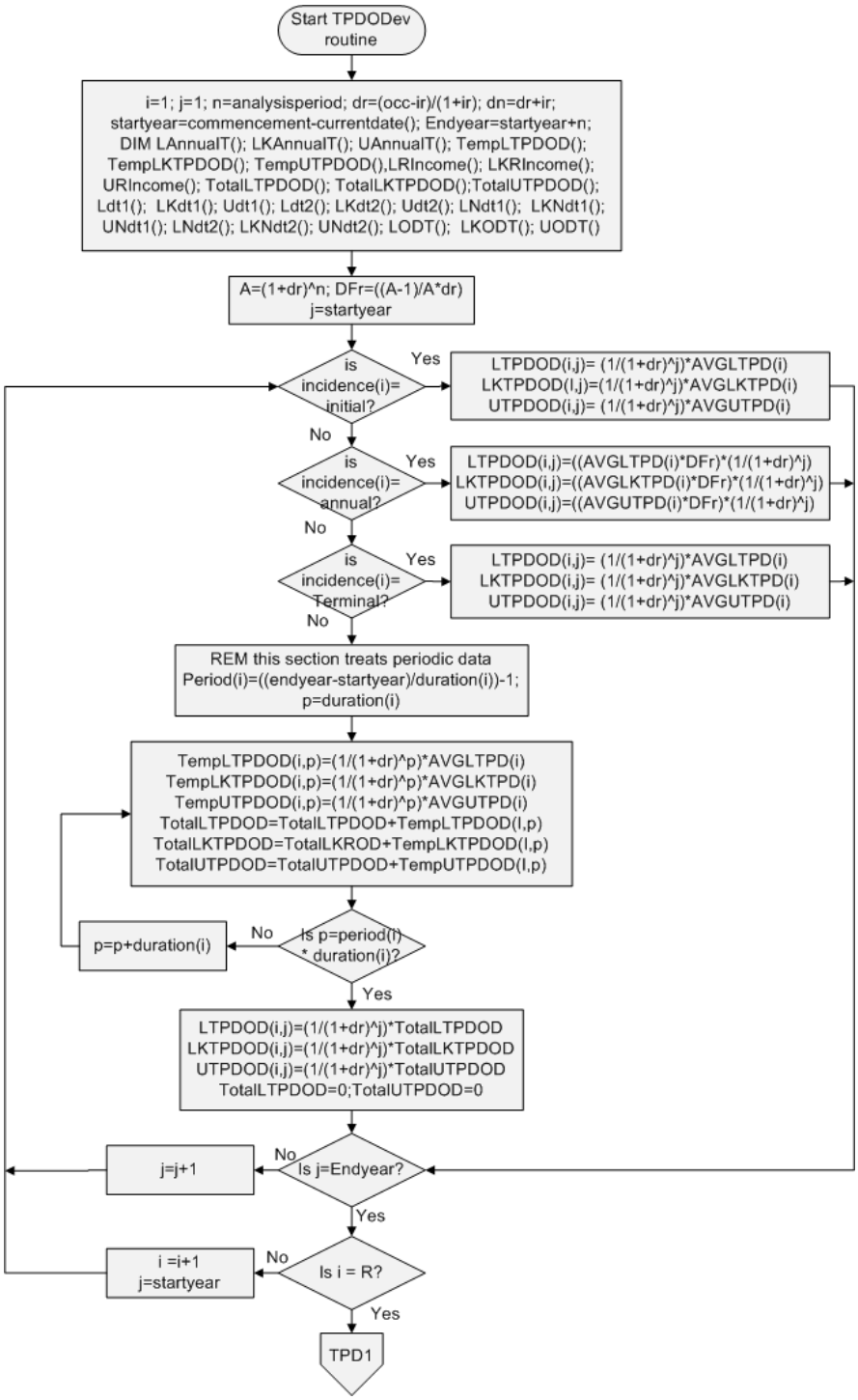
Range Data option to develop routine

Appendix 8.0 cont.



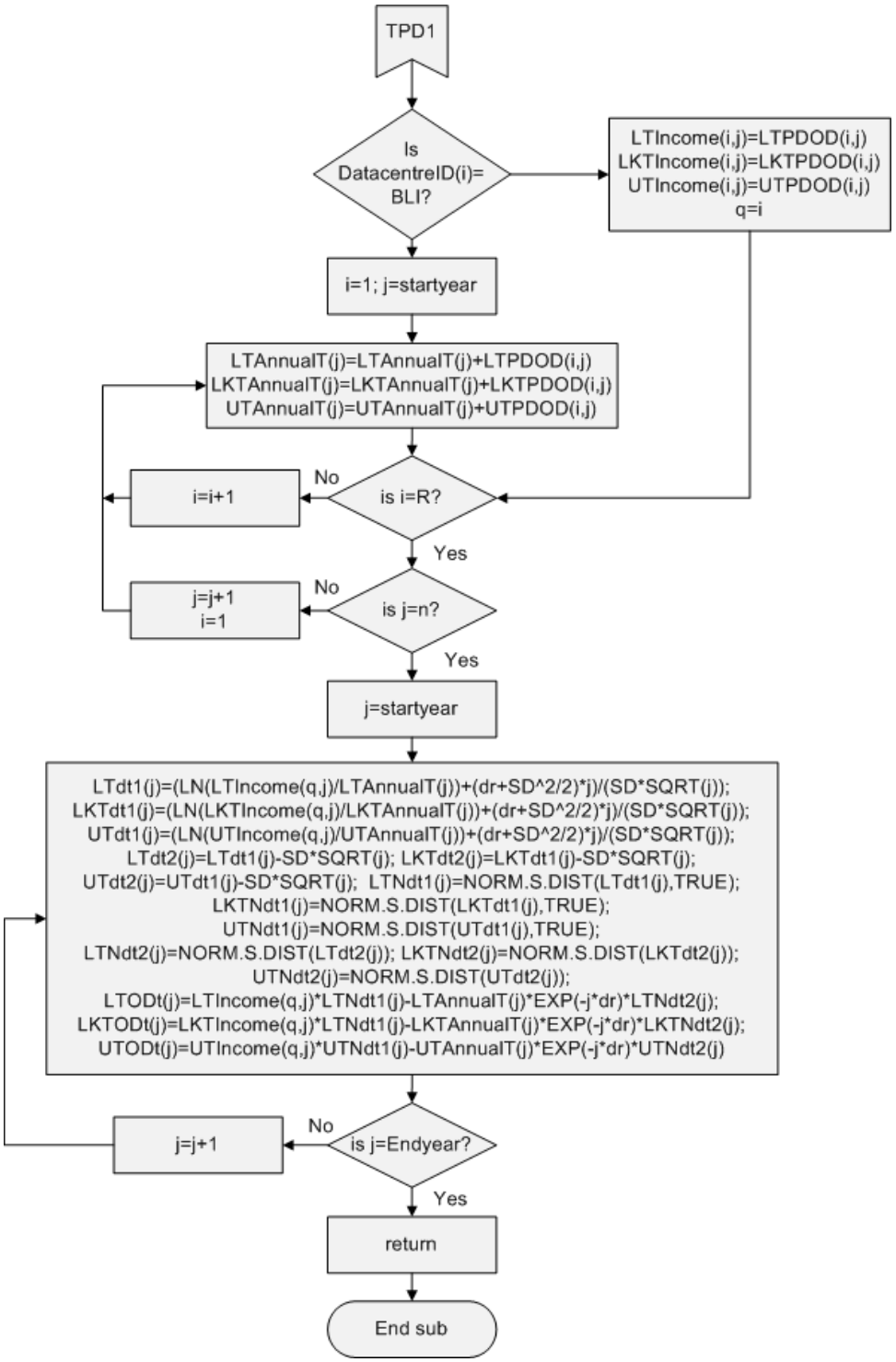
Range Data option to develop routine Cont.

Appendix 8.1



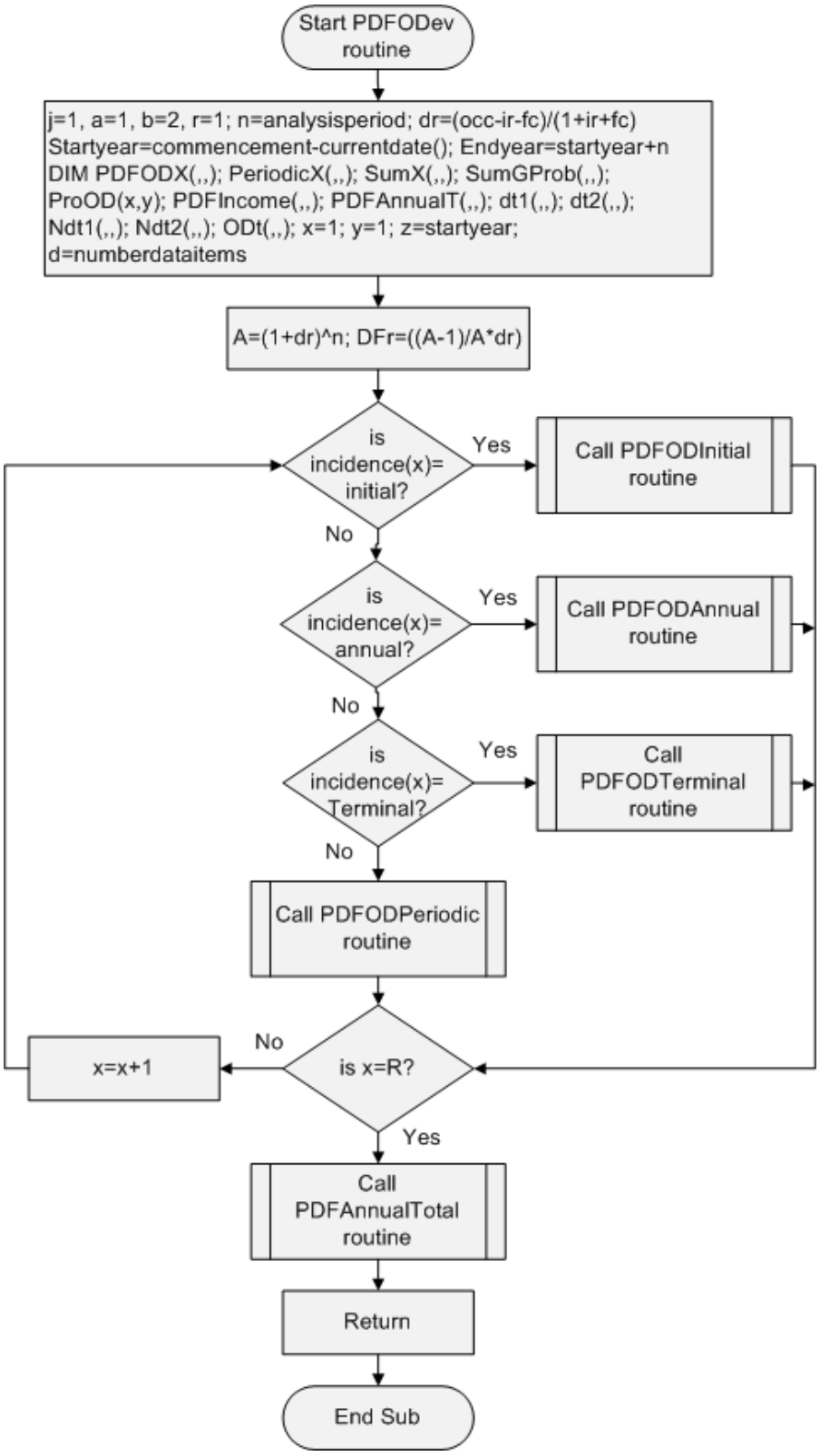
Three-point Data option to develop routine

Appendix 8.1 cont



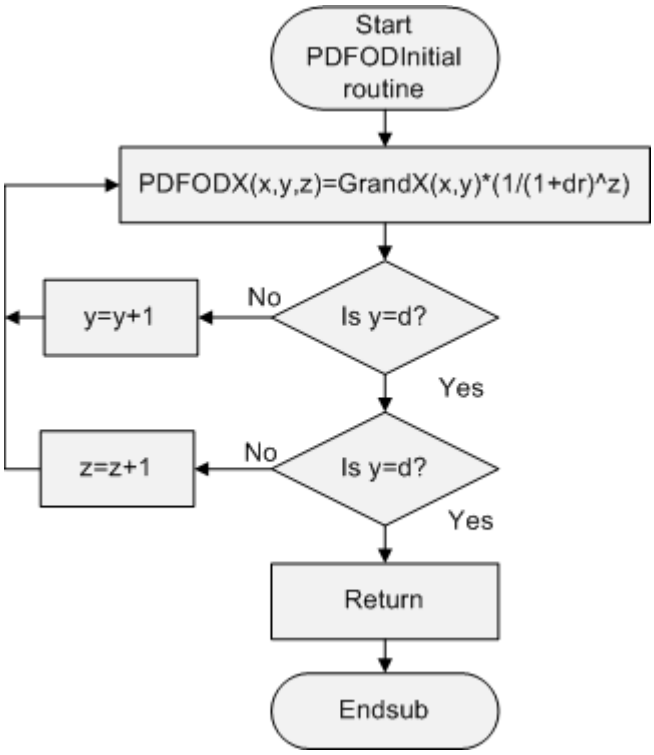
Three-point Data option to develop routine cont.

Appendix 8.2

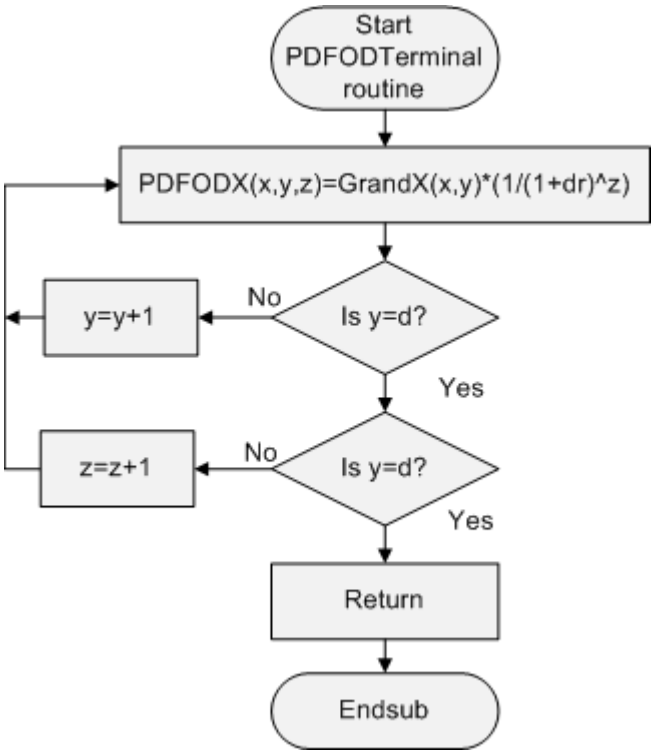


PDF Data option to develop routine

Appendix 8.3

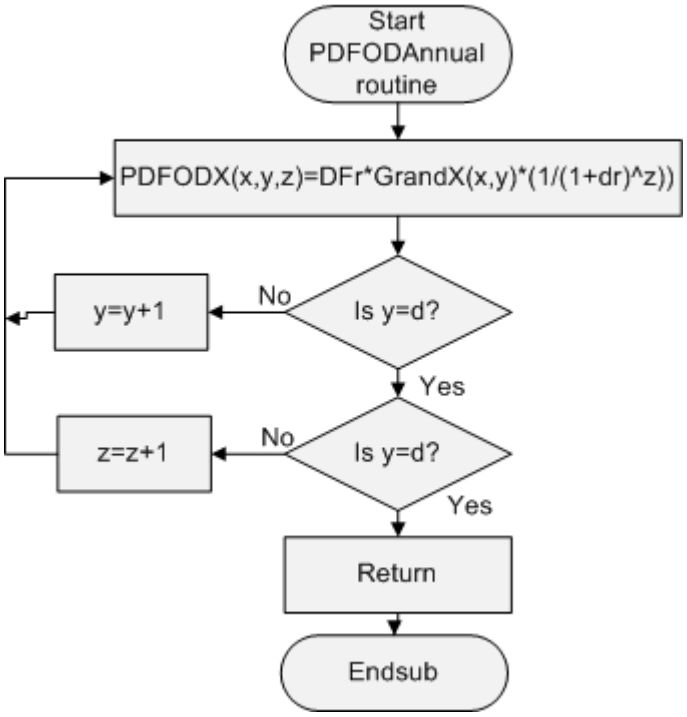


Initial cost routine for PDF Data option to develop.



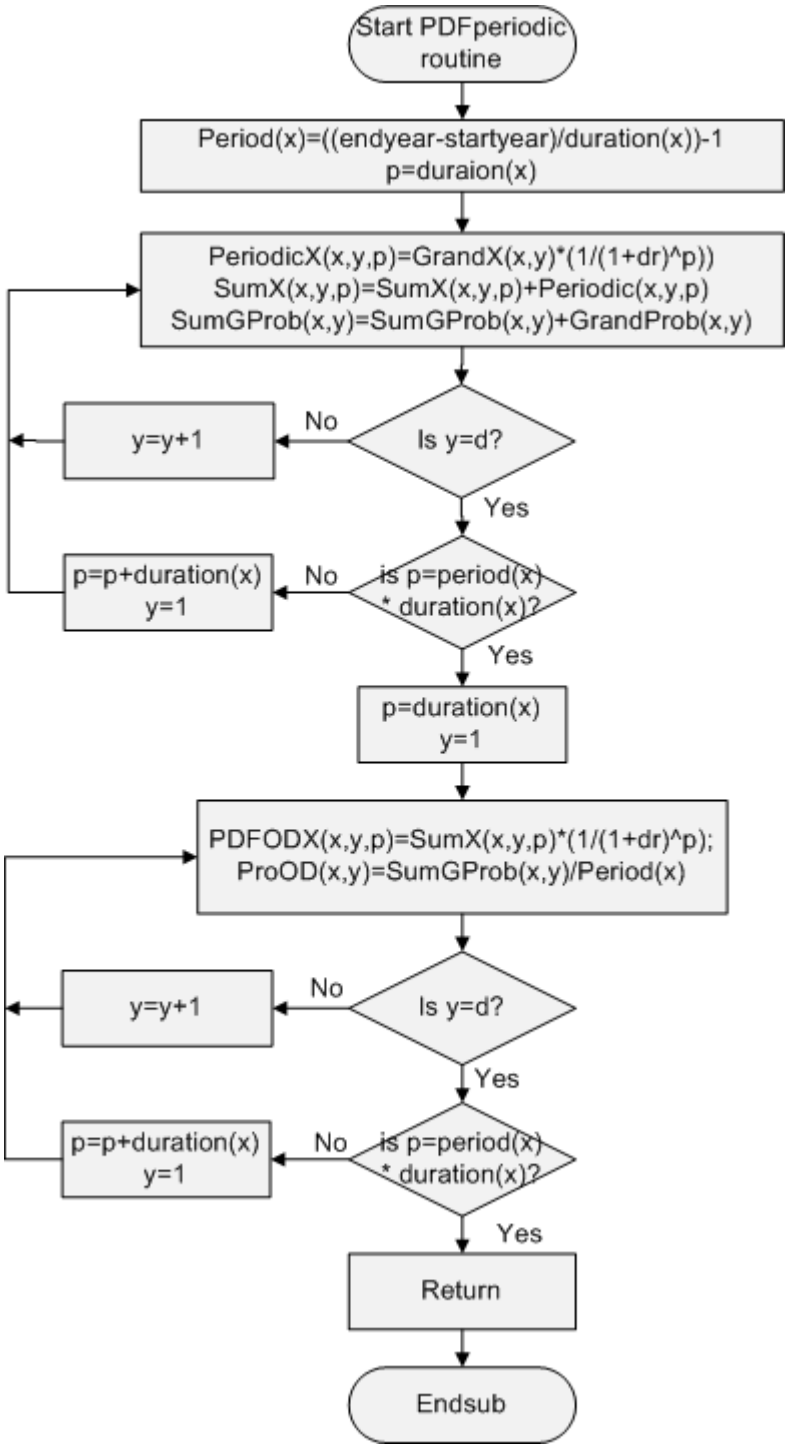
Terminal cost routine for PDF option to develop

Appendix 8.4



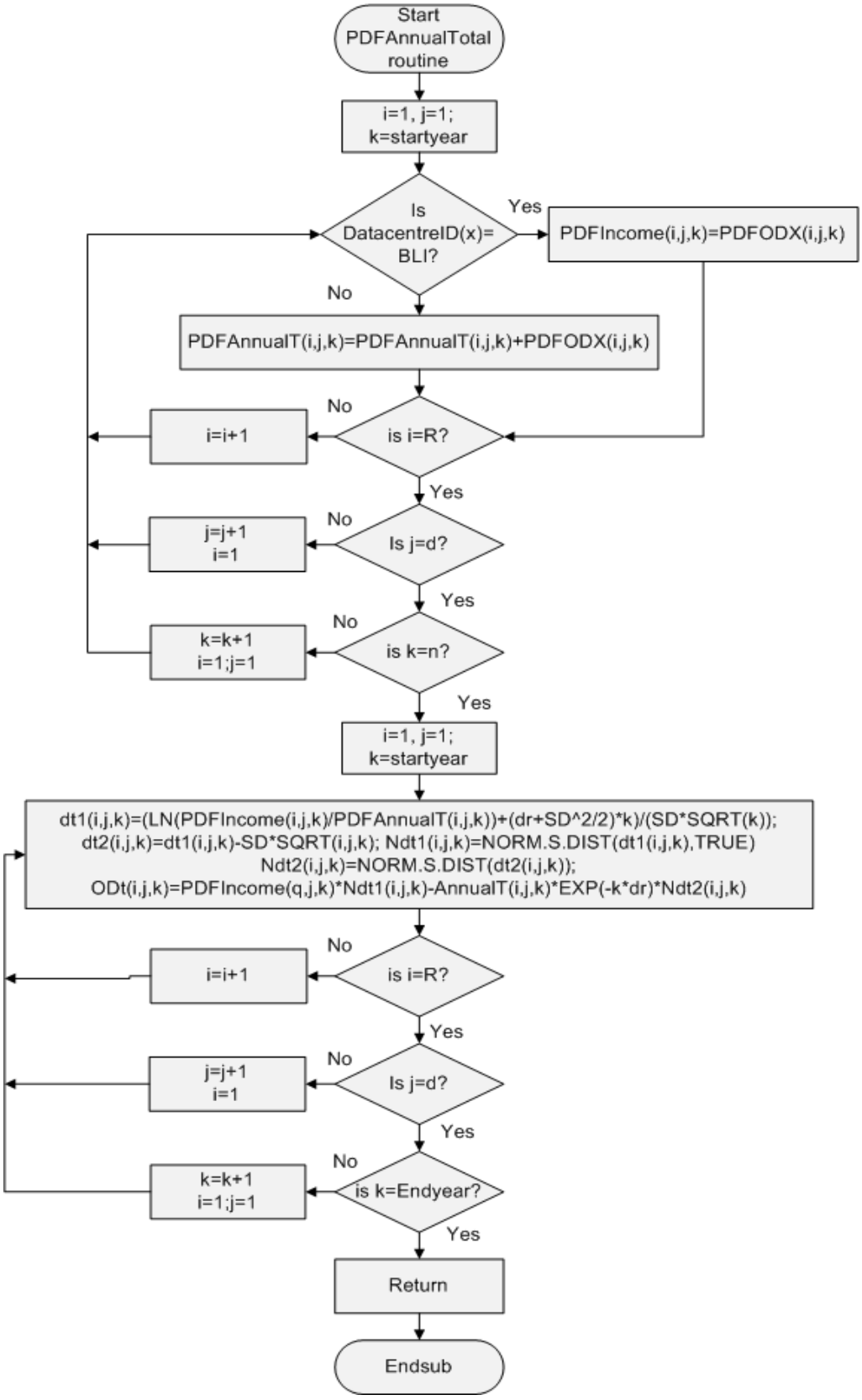
Annual cost routine for PDF Data option to develop

Appendix 8.5



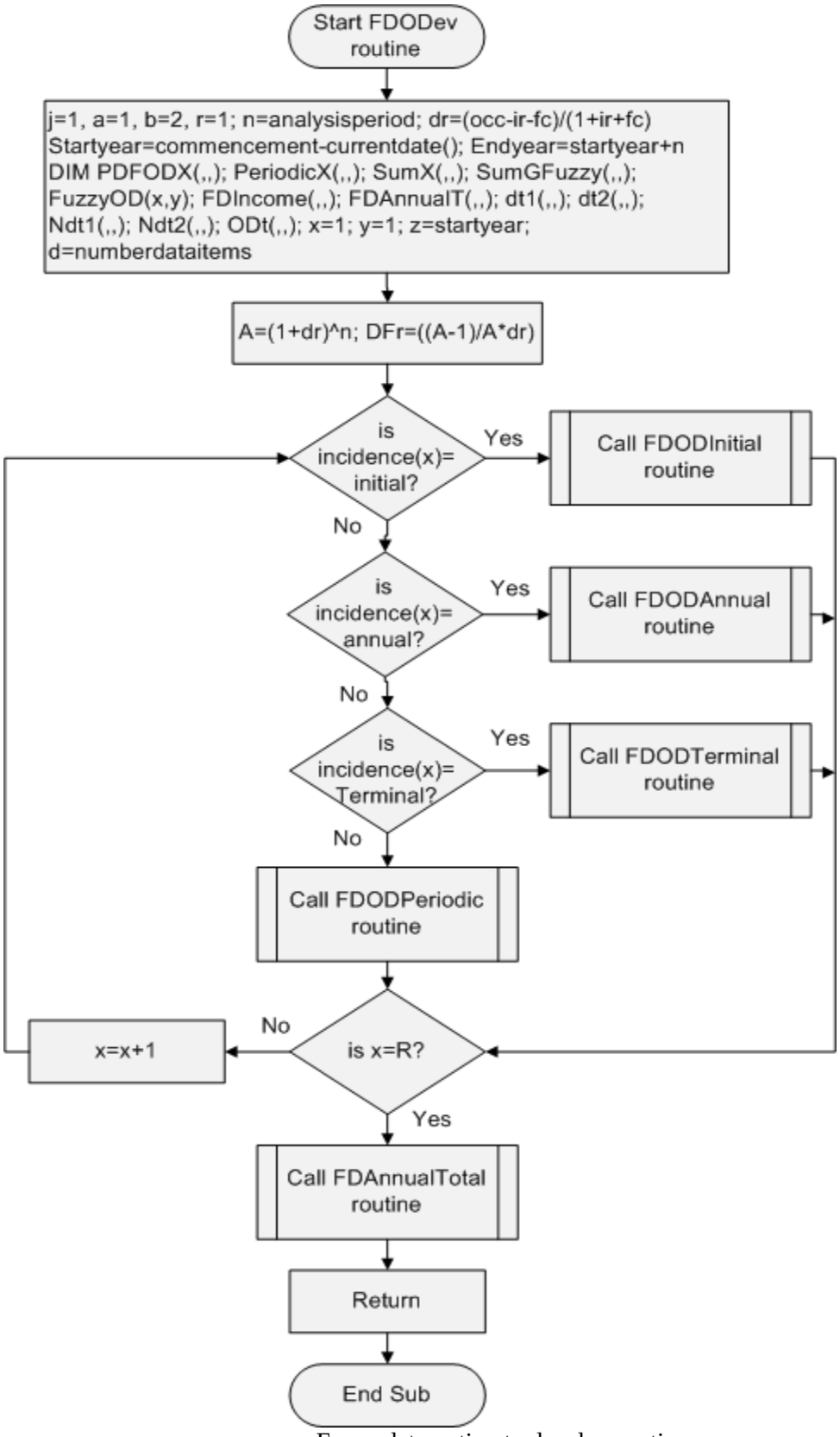
Periodic cost routine for PDF Data option to develop

Appendix 8.6



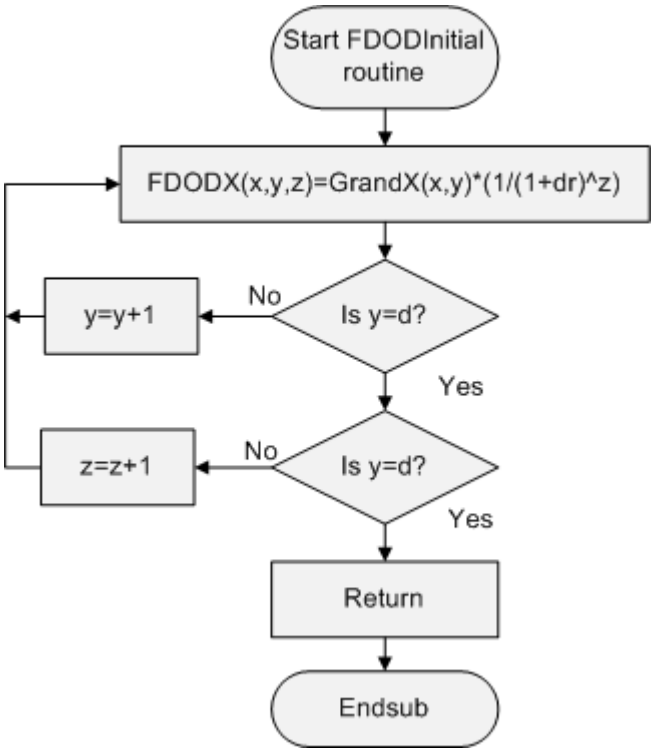
PDF Annual total routine for option to develop

Appendix 8.7

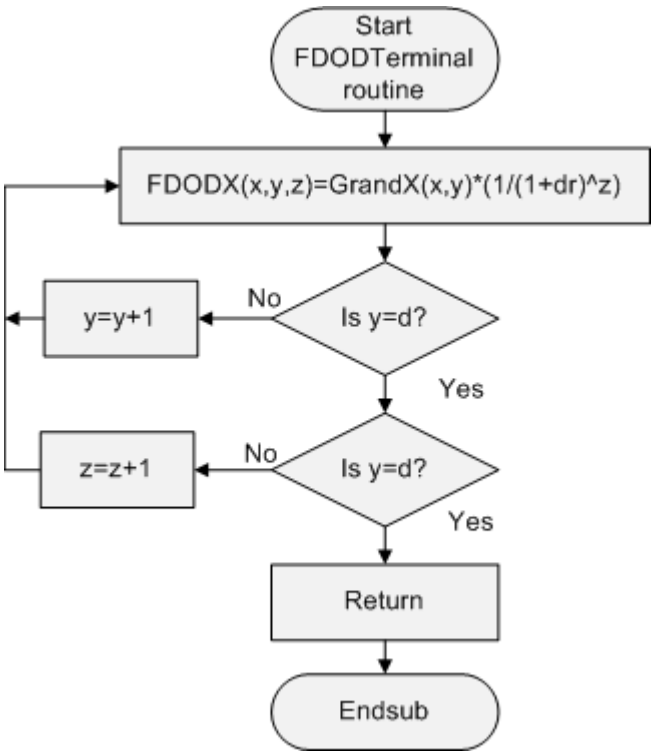


Fuzzy data option to develop routine

Appendix 8.8

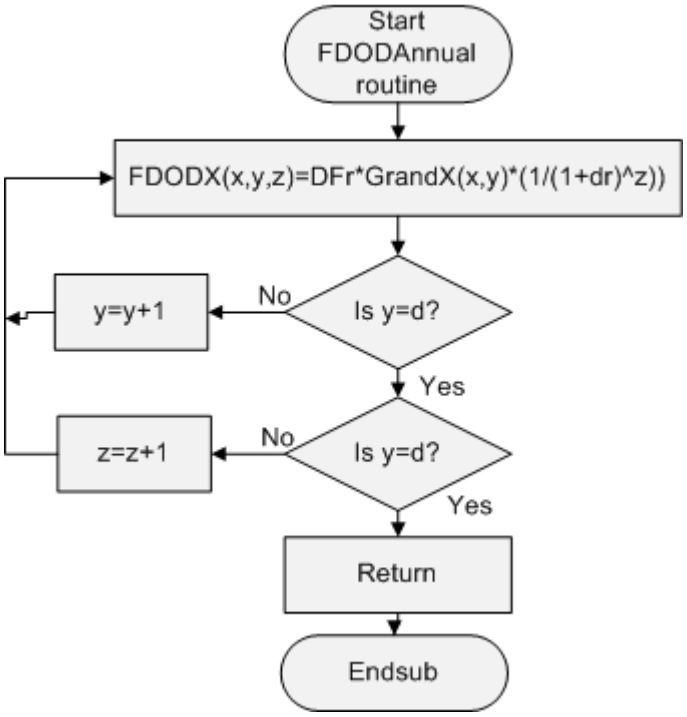


Initial cost routine for FD option to develop



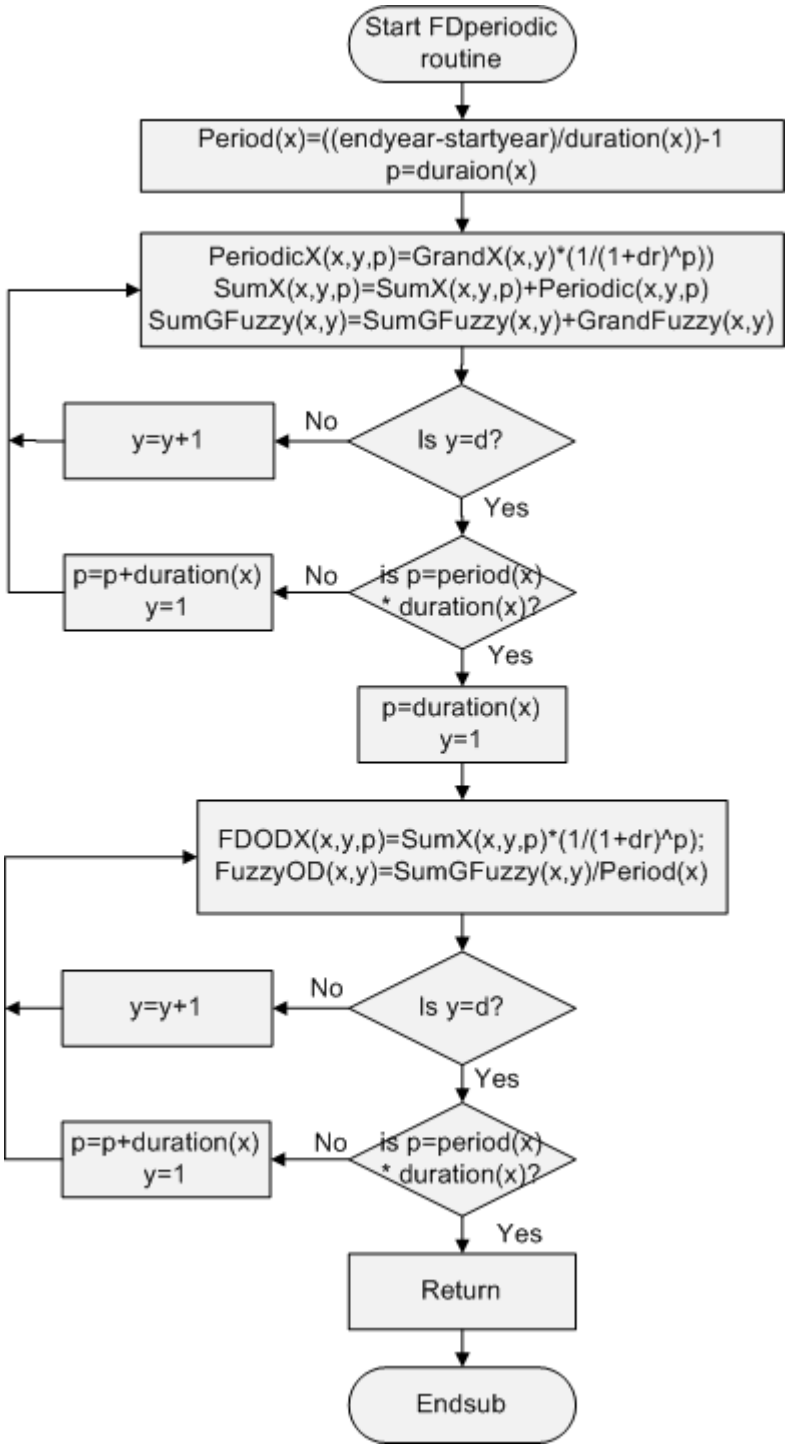
Terminal cost routine for FD option to develop

Appendix 8.9



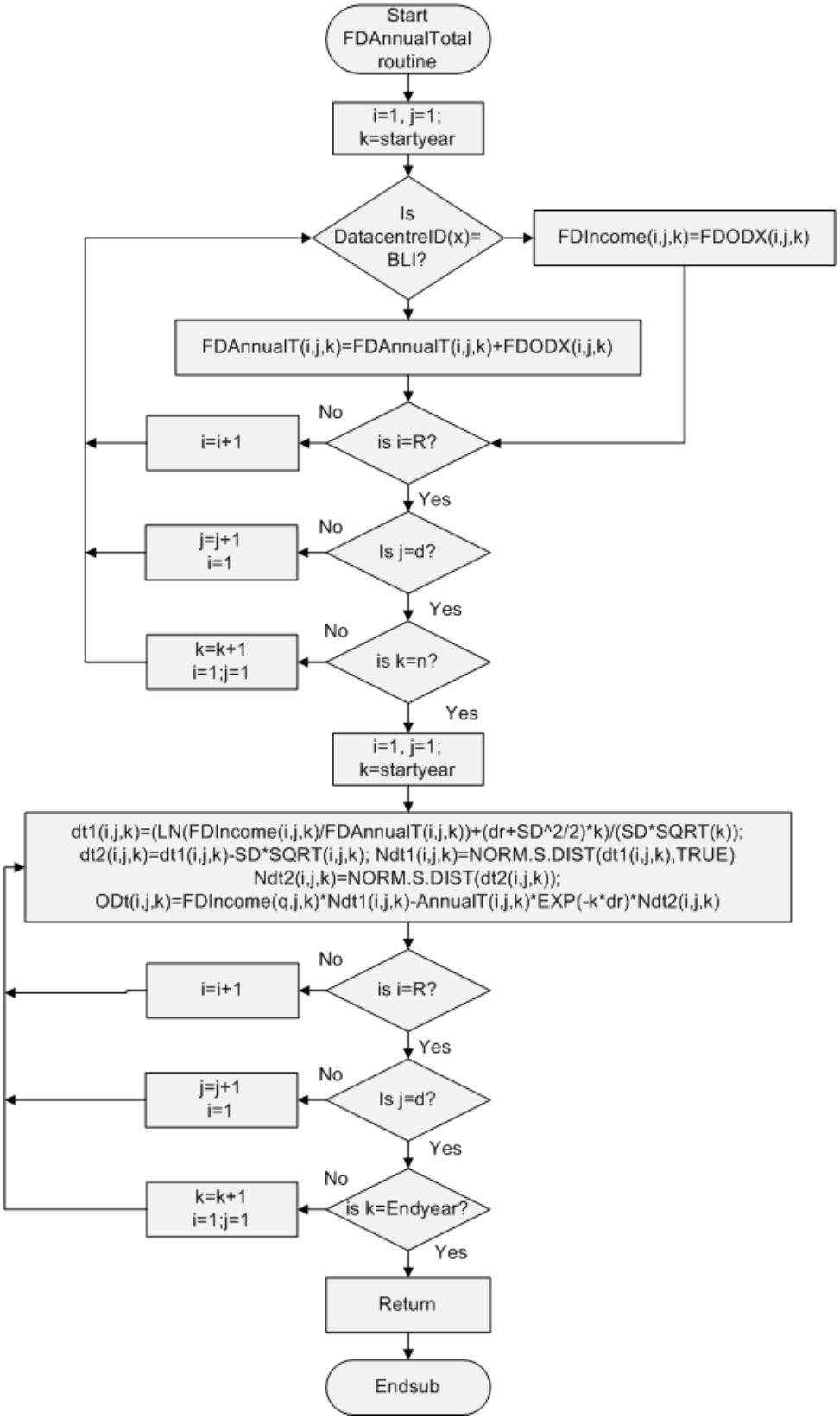
Annual cost routine for FD option to develop

Appendix 8.10



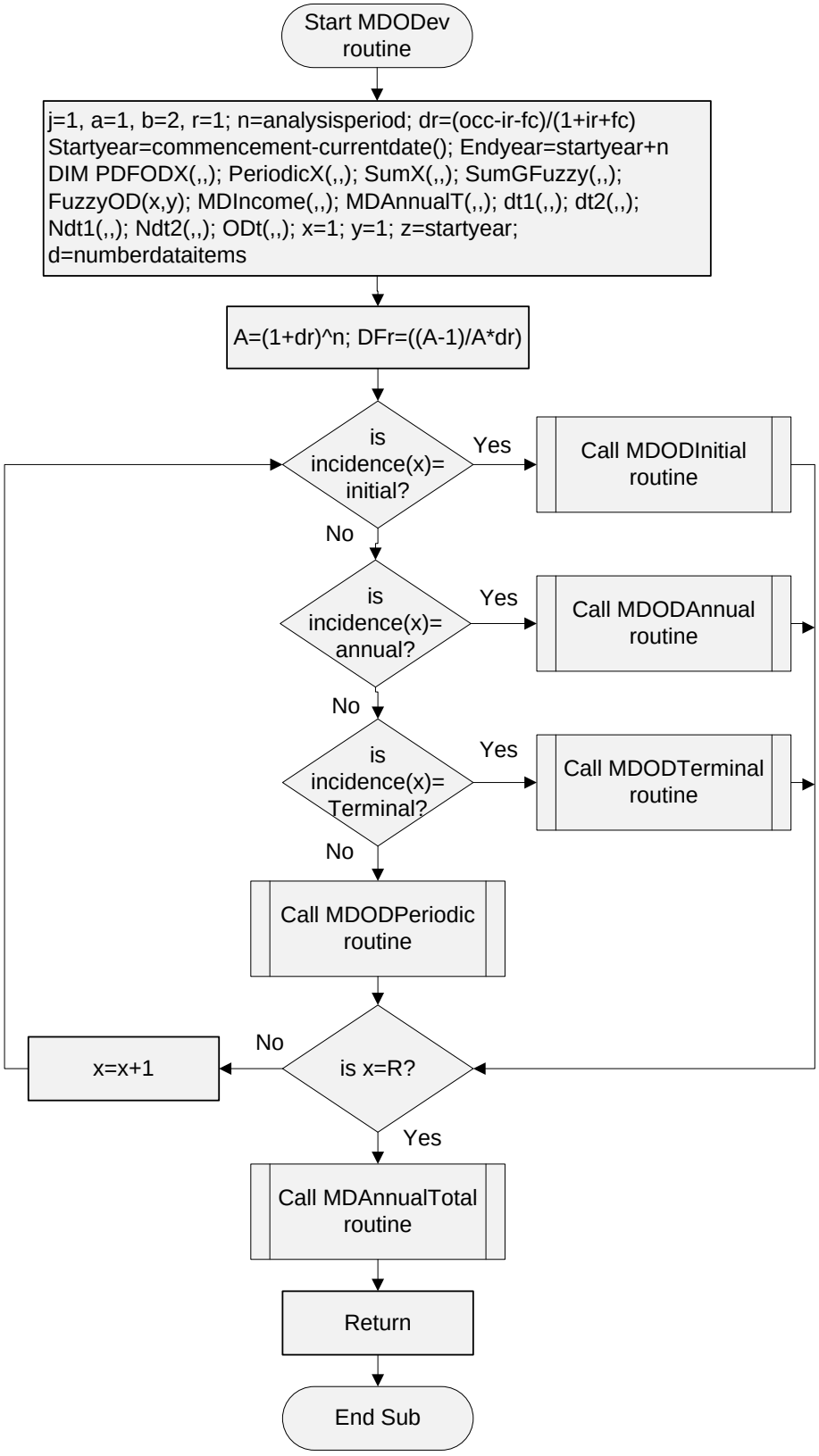
Periodic cost routine for FD option to develop

Appendix 8.12



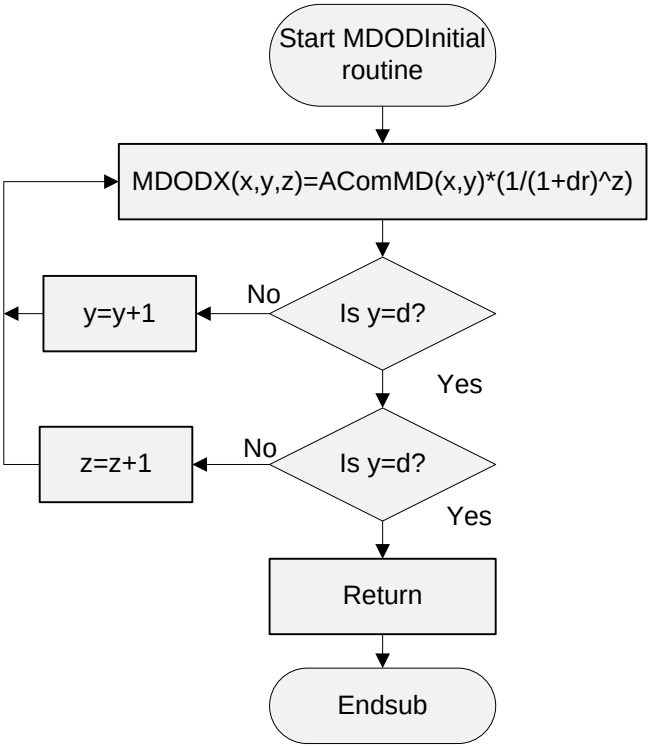
Fuzzy data annual total routine for option to develop

Appendix 8.13

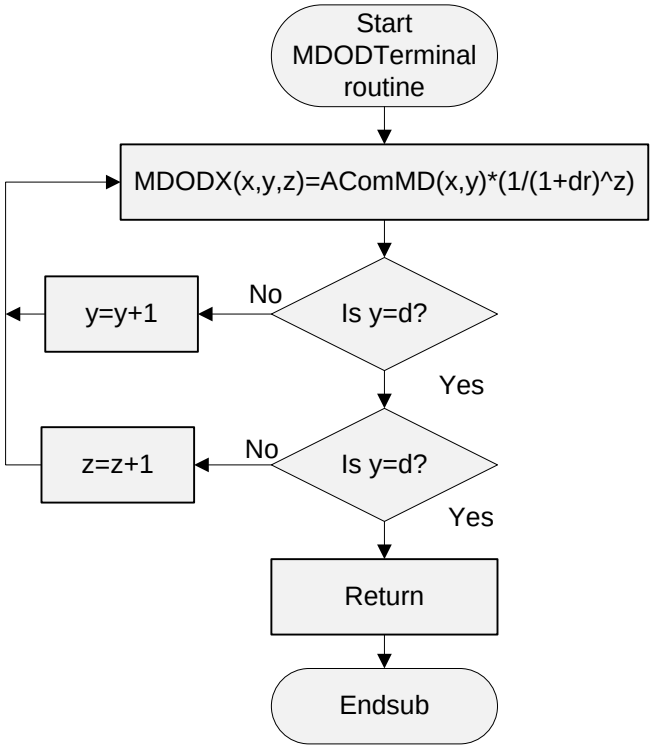


Multi-data routine for option to develop

Appendix 8.14

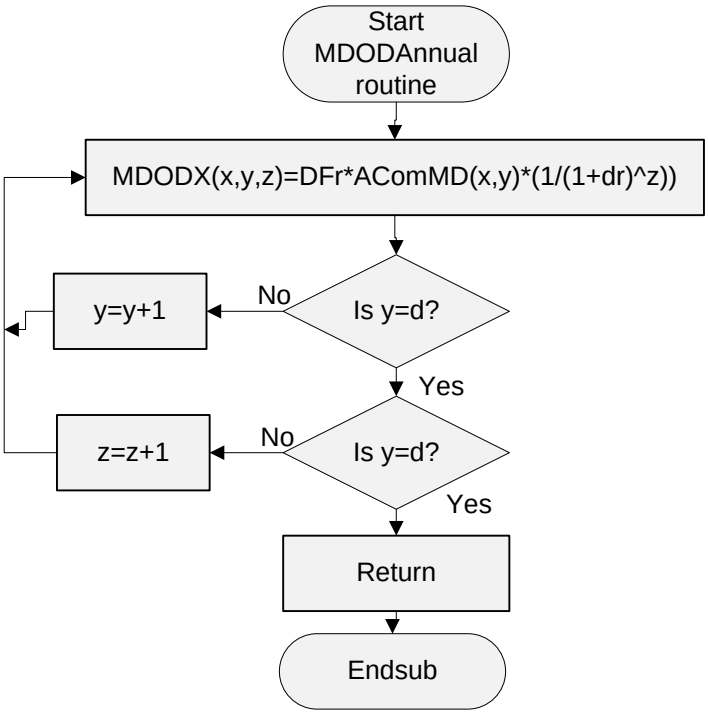


Initial cost routine for MD option to develop



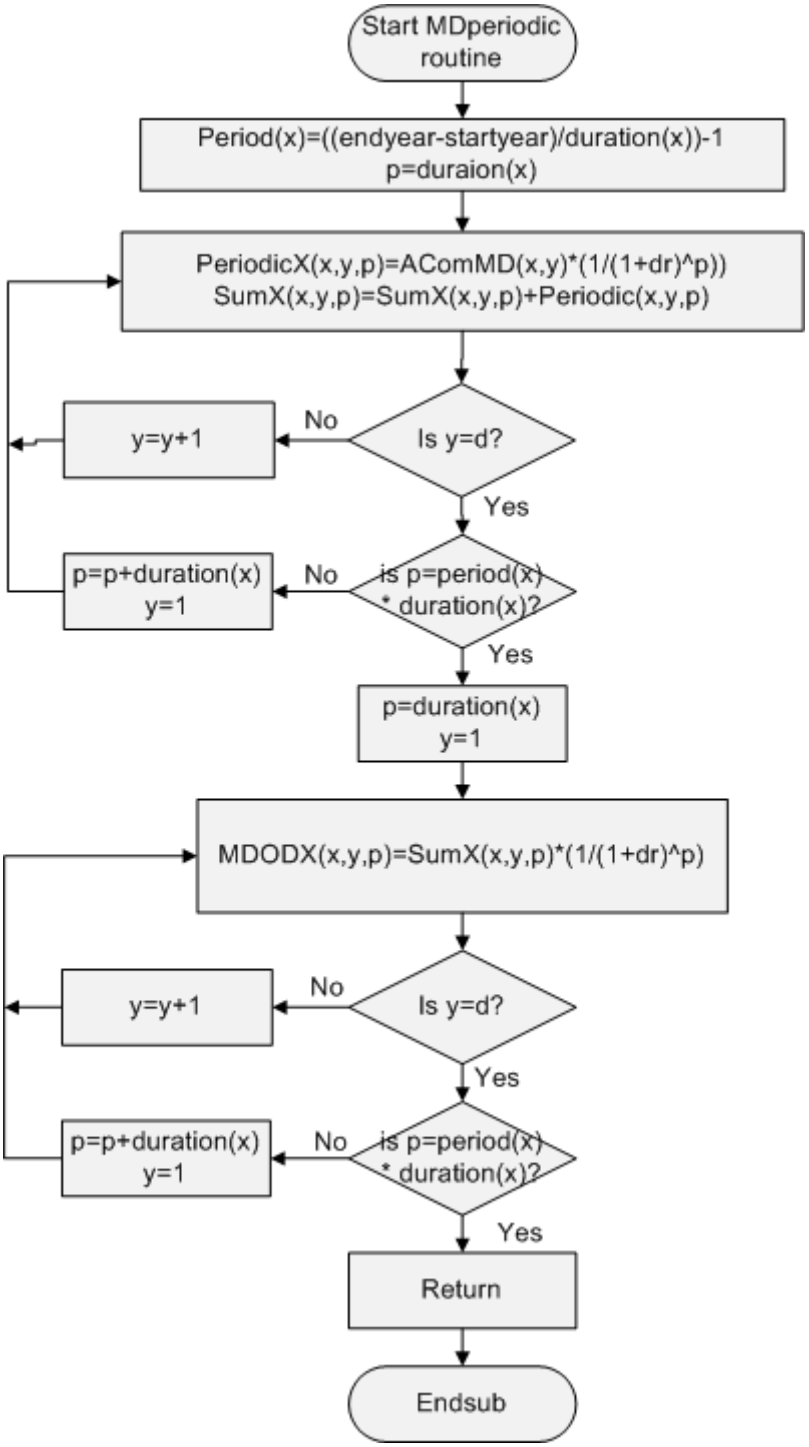
Terminal cost routine for MD option to develop

Appendix 8.15



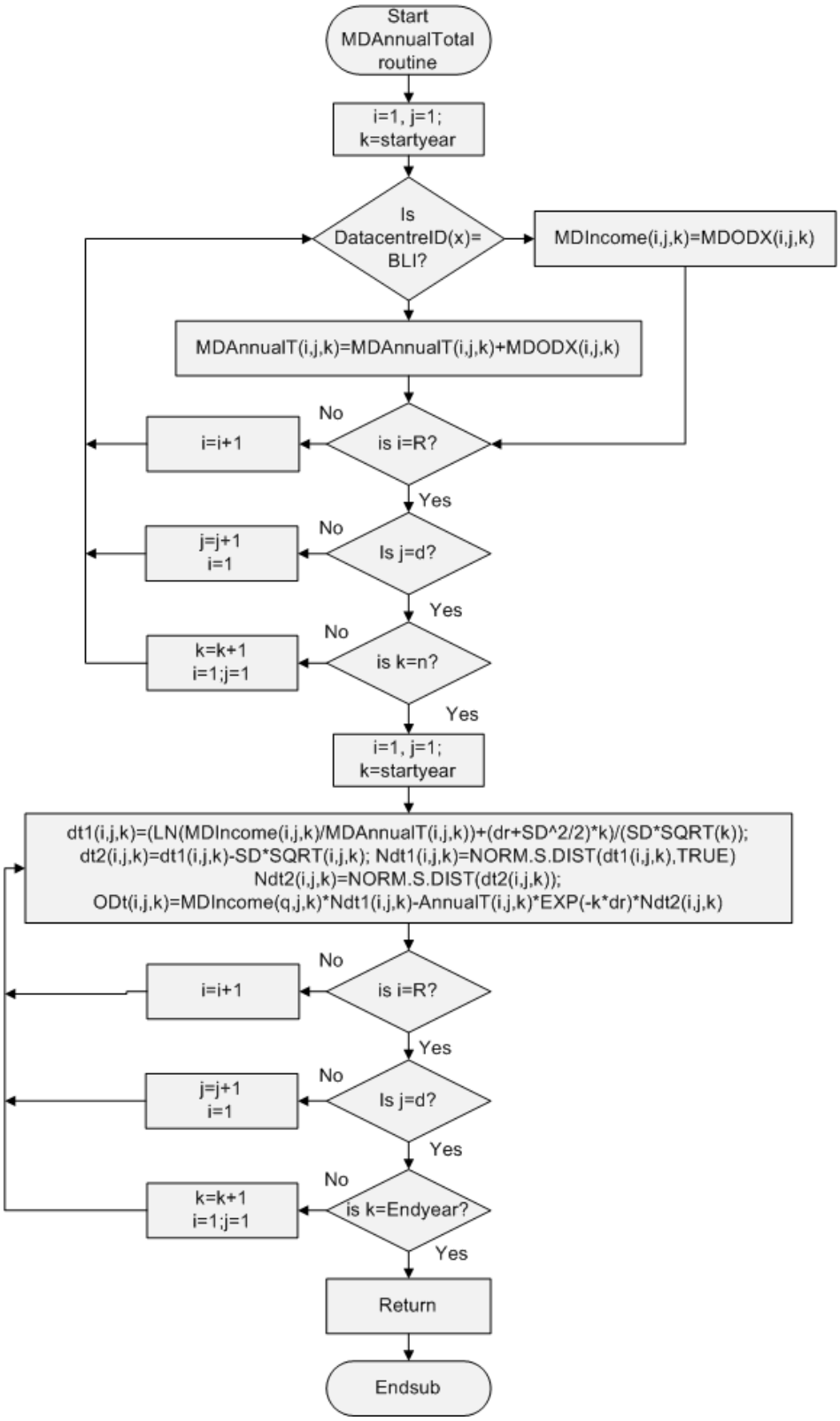
Annual cost routine for Multi-data option to develop

Appendix 8.16



Periodic cost routine for Multi-data option to develop

Appendix 8.17



Annual total routine for Multi-data option to develop

Appendix 9:

Test data

APPENDIX 9.0

Single-point data table

S/No	Sub.No	Cost Centre	Data type	Unit cost	Unit	Unit Quantity	Incidence	Duration	TAF	LAF	RF
1	1	Non construction: Land	SPD	4600.00	Area	250	Initial	0	0.19	0.97	1
1	2	Non construction: Land	SPD	4,000.00	Area	210	Initial	0	0.25	0.93	0.95
2	1	Non construction: Finance	SPD	7,771.60	GFA	175	Annual	1	0.17	0.95	1
9	1	Maintenance	SPD	310.00	GFA	175	Annual	1	0.17	0.95	1

Range data table

S/No	Sub.No	Cost Centre	Data type	Lower unit cost	Upper unit cost	Unit	Unit quantity	Incidence	Duration	TAF	LAF	RF
2	2	Finance	RD	6,050.00	6,750.00	GFA	210	Annual	1	0.25	0.93	0.95
3	1	Income	RD	4,250.00	5,600.00	GFA	170	Annual	1	0.27	0.9	1

Three-point data table

S/No	Sub.No	Cost Centre	Data type	Lower unit cost	Likely unit cost	Upper unit cost	Unit	Unit quantity	Incidence	Duration	TAF	LAF	RF
3	2	Income	TPD	4,450.00	5,900.00	6,200.00	GFA	170	Annual	1	0.27	0.9	0.9
6	2	Preliminaries	TPD	1,220.00	1,350.00	1,500.00	GFA	210	Initial	0	0.25	0.93	0.95
9	2	Maintenance	TPD	210.00	240.00	260.00	GFA	210	Annual	1	0.25	0.93	0.95

Data table for Gaussian Fuzzy Membership function

S/No	Sub.No	Cost Centre	Data type	Centroid unit cost	Deviation	Unit	Unit quantity	Incidence	TAF	LAF	Duration	RF
4	1	Building	GFMF	20,000.00	1,650.00	GFA	170	Initial	0.27	0.9	0	1

Appendix 9.1

Data table for Uniform Fuzzy Membership function

S/No	Sub.No	Cost Centre	Data type	Lower Bound unit cost	Upper bound unit cost	Unit	Unit quantity	Incidence	Duration	TAF	LAF	RF
8	2	Operations	RFMF	210.00	295.00	GFA	210	Annual	1	0.25	0.93	0.95

Data table for Triangular Fuzzy Membership function

S/No	Sub.No	Cost Centre	Data type	Lower bound unit cost	Mid-point unit cost	Upper bound unit cost	Unit	Unit quantity	Incidence	Duration	TAF	LAF	RF
5	2	External works	TFMF	2,730.00	4,510.00	5,400.00	GFA	250	Initial	0	0.19	0.97	1
7	1	Design fees	TFMF	2,050.00	4,300.00	5,120.00	GFA	170	Initial	0	0.27	0.9	1

Data table for Trapezoidal Fuzzy Membership function

S/No	Sub.No	Cost Centre	Data type	Lower bound unit cost	Mid-point1 unit cost	Mid-point2 unit cost	Upper bound unit cost	Unit	Unit quantity	Incidence	Duration	TAF	LAF	RF
10	2	End-of-life	TrpzFMF	1,200.00	1,410.00	1,450.00	2,100.00	GFA	210	Termial	1	0.25	0.93	0.75

Appendix 9.2

Data table for Normal Probability Density Function

S/No	Sub.No	Cost Centre	Data type	Mean unit cost	SD	Unit	Unit quantity	Incidence	Duration	TAF	LAF	RF
7	2	Design fees	NPDF	3,500.00	290.00	GFA	210	Initial	0	0.25	0.93	0.95
4	2	Building	NPDF	15,950.00	1,290.00	GFA	250	Initial	0	0.17	0.97	0.95

Data table for Uniform Probability Density Function

S/No	Sub.No	Cost Centre	Data type	Lower bound unit cost	Upper bound unit cost	Max. Frequency	Unit	Unit quantity	Incidence	Duration	TAF	LAF	RF
5	1	External works	RPDF	2,550.00	4,850.00	0.00043478	GFA	250	Initial	0	0.19	0.97	1

Data table for Triangular Probability Density function

S/No	Sub.No	Cost Centre	Data type	Lower bound unit cost	Mean unit cost	Upper bound unit cost	Unit	Unit quantity	Incidence	Duration	TAF	LAF	RF
10	1	End-of-life	TPDF	1,600.00	2,010.00	2,440.00	GFA	170	Terminal	0	0.27	0.9	1

Appendix 9.3:Data table for Multi-data

S/No	Sub.No	Cost Centre	Data type	Cost data	Unit	Unit Quantity	Incidence	Duration	TAF	LAF	RF
6	1	Preliminaries	MD	1,240.00	GFA	170	Initial	0	0.27	0.9	1
6	1	Preliminaries	MD	1,450.00	GFA	175	Initial	0	0.17	0.95	1
6	1	Preliminaries	MD	1,810.00	GFA	210	Initial	0	0.25	0.93	0.95
6	1	Preliminaries	MD	2,100.00	GFA	250	Initial	0	0.19	0.97	1
6	1	Preliminaries	MD	2,250.00	GFA	280	Initial	0	0.29	0.92	0.85
8	1	Operations	MD	195.00	GFA	170	Annual	1	0.27	0.9	1
8	1	Operations	MD	260.00	GFA	175	Annual	1	0.17	0.95	1
8	1	Operations	MD	289.00	GFA	210	Annual	1	0.25	0.93	0.95
8	1	Operations	MD	340.00	GFA	250	Annual	1	0.19	0.97	1
8	1	Operations	MD	410.00	GFA	280	Annual	1	0.29	0.92	0.85

Appendix 10:

Data Transformation Tables

Appendix 10.0: Normal PDF Transformation to Gaussian FMF for Cost of building

N	X2-values	F	RF	Pos	HP	Sorted N	Sorted Pos	Pos1-Pos2	Cum Pos	NS	Fuzzy	Resorted N	Fuzzy
1	12,294.57	0.000012	0.000036	0.001174	-0.0005306	49	1.000				1	1	0.002
2	12,415.87	0.000016	0.000047	0.001551	-0.0006822	48	0.998	0.0022	2.00	0.00	1.00	2	0.003
3	12,537.18	0.000020	0.000062	0.002039	-0.0008717	50	0.996	0.0015	2.99	0.00	1.00	3	0.004
4	12,658.48	0.000027	0.000082	0.002663	-0.0011073	47	0.990	0.0065	3.98	0.01	0.99	4	0.004
5	12,779.78	0.000035	0.000106	0.003458	-0.001398	51	0.987	0.0030	4.97	0.01	0.99	5	0.006
6	12,901.08	0.000045	0.000137	0.004464	-0.0017545	46	0.976	0.0108	5.95	0.03	0.98	6	0.007
7	13,022.38	0.000057	0.000175	0.005729	-0.0021886	52	0.972	0.0044	6.92	0.01	0.97	7	0.009
8	13,143.68	0.000073	0.000224	0.007310	-0.0027136	45	0.957	0.0148	7.88	0.04	0.96	8	0.011
9	13,264.99	0.000093	0.000284	0.009272	-0.0033445	53	0.951	0.0057	8.83	0.02	0.96	9	0.014
10	13,386.29	0.000117	0.000358	0.011691	-0.0040975	44	0.933	0.0186	9.76	0.06	0.94	10	0.017
11	13,507.59	0.000147	0.000449	0.014655	-0.00499	54	0.926	0.0069	10.68	0.02	0.93	11	0.021
12	13,628.89	0.000183	0.000559	0.018262	-0.0060408	43	0.903	0.0221	11.59	0.08	0.91	12	0.026
13	13,750.19	0.000227	0.000693	0.022624	-0.0072696	55	0.895	0.0081	12.48	0.03	0.90	13	0.032
14	13,871.49	0.000280	0.000853	0.027863	-0.0086967	42	0.870	0.0252	13.35	0.10	0.88	14	0.038
15	13,992.80	0.000342	0.001044	0.034113	-0.0103428	56	0.861	0.0091	14.21	0.04	0.87	15	0.046
16	14,114.10	0.000417	0.001271	0.041521	-0.0122283	41	0.833	0.0279	15.05	0.11	0.85	16	0.055
17	14,235.40	0.000504	0.001538	0.050241	-0.0143734	57	0.823	0.0099	15.87	0.04	0.84	17	0.065
18	14,356.70	0.000606	0.001850	0.060434	-0.0167966	40	0.793	0.0302	16.66	0.13	0.81	18	0.077
19	14,478.00	0.000725	0.002213	0.072270	-0.0195151	58	0.783	0.0106	17.45	0.05	0.80	19	0.091
20	14,599.30	0.000862	0.002630	0.085916	-0.0225436	39	0.751	0.0320	18.20	0.14	0.77	20	0.107
21	14,720.61	0.001019	0.003109	0.101539	-0.0258936	59	0.739	0.0111	18.94	0.05	0.76	21	0.124
22	14,841.91	0.001197	0.003652	0.119298	-0.0295731	38	0.706	0.0333	19.64	0.15	0.73	22	0.144
23	14,963.21	0.001398	0.004266	0.139340	-0.0335857	60	0.695	0.0115	20.34	0.05	0.72	23	0.166
24	15,084.51	0.001623	0.004953	0.161794	-0.0379301	37	0.660	0.0342	21.00	0.16	0.68	24	0.190

25	15,205.81	0.001874	0.005718	0.186763	-0.0425999	61	0.649	0.0117	21.65	0.06	0.67	25	0.216
26	15,327.11	0.002150	0.006562	0.214320	-0.0475827	36	0.614	0.0347	22.26	0.17	0.64	26	0.245
27	15,448.42	0.002453	0.007485	0.244499	-0.0528602	62	0.602	0.0118	22.86	0.06	0.63	27	0.277
28	15,569.72	0.002782	0.008489	0.277290	-0.0584082	35	0.567	0.0347	23.43	0.18	0.60	28	0.310
29	15,691.02	0.003137	0.009571	0.312632	-0.0641961	63	0.556	0.0118	23.99	0.06	0.59	29	0.346
30	15,812.32	0.003516	0.010728	0.350410	-0.0701878	34	0.521	0.0343	24.51	0.18	0.55	30	0.384
31	15,933.62	0.003918	0.011954	0.390447	-0.0763415	64	0.510	0.0116	25.02	0.06	0.54	31	0.424
32	16,054.92	0.004340	0.013241	0.432504	-0.0826103	33	0.476	0.0336	25.49	0.18	0.51	32	0.466
33	16,176.23	0.004779	0.014582	0.476278	-0.0889433	65	0.465	0.0113	25.96	0.06	0.50	33	0.508
34	16,297.53	0.005232	0.015963	0.521403	-0.0952856	32	0.433	0.0325	26.39	0.18	0.47	34	0.552
35	16,418.83	0.005694	0.017373	0.567453	-0.1015798	66	0.422	0.0109	26.81	0.06	0.45	35	0.596
36	16,540.13	0.006160	0.018796	0.613944	-0.1077668	31	0.390	0.0312	27.20	0.17	0.42	36	0.641
37	16,661.43	0.006626	0.020217	0.660344	-0.1137865	67	0.380	0.0104	27.58	0.06	0.41	37	0.685
38	16,782.73	0.007085	0.021617	0.706081	-0.1195791	30	0.350	0.0297	27.93	0.17	0.38	38	0.728
39	16,904.04	0.007531	0.022979	0.750553	-0.1250858	68	0.341	0.0098	28.27	0.06	0.37	39	0.770
40	17,025.34	0.007958	0.024283	0.793142	-0.1302501	29	0.313	0.0280	28.59	0.16	0.35	40	0.809
41	17,146.64	0.008360	0.025510	0.833227	-0.1350184	69	0.303	0.0092	28.89	0.05	0.34	41	0.847
42	17,267.94	0.008731	0.026642	0.870199	-0.1393406	28	0.277	0.0261	29.17	0.15	0.31	42	0.881
43	17,389.24	0.009065	0.027660	0.903475	-0.1431715	70	0.269	0.0086	29.44	0.05	0.30	43	0.912
44	17,510.54	0.009356	0.028550	0.932517	-0.1464705	27	0.244	0.0242	29.68	0.15	0.28	44	0.938
45	17,631.85	0.009601	0.029294	0.956842	-0.1492029	71	0.237	0.0079	29.92	0.05	0.27	45	0.961
46	17,753.15	0.009793	0.029882	0.976036	-0.1513397	26	0.214	0.0223	30.13	0.14	0.25	46	0.978
47	17,874.45	0.009931	0.030302	0.989771	-0.1528584	72	0.207	0.0072	30.34	0.04	0.24	47	0.991
48	17,995.75	0.010012	0.030548	0.997806	-0.153743	25	0.187	0.0203	30.53	0.13	0.22	48	0.998
49	18,117.05	0.010034	0.030616	1.000000	-0.1539841	73	0.180	0.0066	30.71	0.04	0.21	49	1.000
50	18,238.35	0.009997	0.030503	0.996315	-0.1535791	24	0.162	0.0184	30.87	0.12	0.19	50	0.997
51	18,359.66	0.009901	0.030212	0.986816	-0.1525324	74	0.156	0.0059	31.02	0.04	0.18	51	0.988
52	18,480.96	0.009749	0.029748	0.971669	-0.150855	23	0.139	0.0165	31.16	0.11	0.17	52	0.974

53	18,602.26	0.009543	0.029120	0.951137	-0.1485646	75	0.134	0.0053	31.30	0.03	0.16	53	0.955
54	18,723.56	0.009287	0.028337	0.925573	-0.1456854	22	0.119	0.0147	31.42	0.10	0.14	54	0.932
55	18,844.86	0.008984	0.027414	0.895408	-0.1422479	76	0.115	0.0047	31.53	0.03	0.14	55	0.904
56	18,966.16	0.008640	0.026364	0.861141	-0.1382882	21	0.102	0.0130	31.63	0.09	0.12	56	0.873
57	19,087.46	0.008261	0.025207	0.823322	-0.1338482	77	0.097	0.0042	31.73	0.03	0.12	57	0.837
58	19,208.77	0.007852	0.023958	0.782543	-0.1289746	20	0.086	0.0115	31.82	0.08	0.11	58	0.800
59	19,330.07	0.007419	0.022638	0.739417	-0.1237181	78	0.082	0.0036	31.90	0.02	0.10	59	0.759
60	19,451.37	0.006969	0.021265	0.694566	-0.1181333	19	0.072	0.0100	31.97	0.07	0.09	60	0.717
61	19,572.67	0.006508	0.019857	0.648605	-0.1122775	79	0.069	0.0032	32.04	0.02	0.09	61	0.674
62	19,693.97	0.006041	0.018435	0.602129	-0.1062097	18	0.060	0.0087	32.10	0.06	0.08	62	0.630
63	19,815.27	0.005576	0.017013	0.555701	-0.0999898	80	0.058	0.0027	32.16	0.02	0.07	63	0.585
64	19,936.58	0.005116	0.015609	0.509842	-0.0936778	17	0.050	0.0075	32.21	0.05	0.07	64	0.541
65	20,057.88	0.004666	0.014237	0.465022	-0.0873325	81	0.048	0.0023	32.26	0.02	0.06	65	0.497
66	20,179.18	0.004231	0.012909	0.421651	-0.0810108	16	0.042	0.0064	32.30	0.05	0.05	66	0.455
67	20,300.48	0.003814	0.011636	0.380081	-0.0747665	82	0.040	0.0020	32.34	0.01	0.05	67	0.414
68	20,421.78	0.003417	0.010428	0.340598	-0.0686497	15	0.034	0.0054	32.37	0.04	0.05	68	0.374
69	20,543.08	0.003044	0.009290	0.303424	-0.062706	83	0.032	0.0017	32.40	0.01	0.04	69	0.337
70	20,664.39	0.002696	0.008227	0.268721	-0.0569757	14	0.028	0.0046	32.43	0.03	0.04	70	0.302
71	20,785.69	0.002374	0.007243	0.236589	-0.0514938	84	0.026	0.0014	32.46	0.01	0.04	71	0.268
72	20,906.99	0.002078	0.006340	0.207077	-0.046289	13	0.023	0.0038	32.48	0.03	0.03	72	0.238
73	21,028.29	0.001808	0.005516	0.180181	-0.0413842	85	0.021	0.0012	32.50	0.01	0.03	73	0.209
74	21,149.59	0.001564	0.004772	0.155859	-0.0367961	12	0.018	0.0032	32.52	0.02	0.03	74	0.183
75	21,270.89	0.001345	0.004103	0.134028	-0.0325355	86	0.017	0.0010	32.54	0.01	0.02	75	0.160
76	21,392.20	0.001150	0.003508	0.114579	-0.0286075	11	0.015	0.0026	32.55	0.02	0.02	76	0.139
77	21,513.50	0.000977	0.002981	0.097376	-0.0250122	87	0.014	0.0008	32.57	0.01	0.02	77	0.119
78	21,634.80	0.000825	0.002519	0.082271	-0.0217448	10	0.012	0.0022	32.58	0.02	0.02	78	0.102
79	21,756.10	0.000693	0.002116	0.069101	-0.0187962	88	0.011	0.0007	32.59	0.01	0.02	79	0.087
80	21,877.40	0.000579	0.001766	0.057698	-0.0161541	9	0.009	0.0018	32.60	0.01	0.01	80	0.074

81	21,998.70	0.000481	0.001466	0.047894	-0.0138032	89	0.009	0.0005	32.61	0.00	0.01	81	0.063
82	22,120.01	0.000397	0.001210	0.039522	-0.0117259	8	0.007	0.0014	32.61	0.01	0.01	82	0.052
83	22,241.31	0.000325	0.000993	0.032423	-0.009903	90	0.007	0.0004	32.62	0.00	0.01	83	0.044
84	22,362.61	0.000265	0.000810	0.026442	-0.0083145	7	0.006	0.0011	32.63	0.01	0.01	84	0.036
85	22,483.91	0.000215	0.000656	0.021438	-0.0069397	91	0.005	0.0003	32.63	0.00	0.01	85	0.030
86	22,605.21	0.000173	0.000529	0.017279	-0.005758	6	0.004	0.0009	32.64	0.01	0.01	86	0.025
87	22,726.51	0.000139	0.000424	0.013845	-0.0047492	92	0.004	0.0003	32.64	0.00	0.01	87	0.020
88	22,847.82	0.000111	0.000338	0.011029	-0.0038938	5	0.003	0.0007	32.64	0.01	0.01	88	0.016
89	22,969.12	0.000088	0.000267	0.008733	-0.0031735	93	0.003	0.0002	32.65	0.00	0.01	89	0.013
90	23,090.42	0.000069	0.000210	0.006875	-0.0025709	4	0.003	0.0006	32.65	0.00	0.00	90	0.011
91	23,211.72	0.000054	0.000165	0.005381	-0.0020703	94	0.002	0.0002	32.65	0.00	0.00	91	0.009
92	23,333.02	0.000042	0.000128	0.004186	-0.0016571	3	0.002	0.0005	32.65	0.00	0.00	92	0.007
93	23,454.32	0.000032	0.000099	0.003238	-0.0013185	95	0.002	0.0001	32.66	0.00	0.00	93	0.005
94	23,575.63	0.000025	0.000076	0.002490	-0.0010427	2	0.002	0.0004	32.66	0.00	0.00	94	0.004
95	23,696.93	0.000019	0.000058	0.001903	-0.0008196	96	0.001	0.0001	32.66	0.00	0.00	95	0.003
96	23,818.23	0.000015	0.000044	0.001446	-0.0006404	1	0.001	0.0003	32.66	0.00	0.00	96	0.003
97	23,939.53	0.000011	0.000033	0.001092	-0.0004973	97	0.001	0.0001	32.66	0.00	0.00	97	0.002
98	24,060.83	0.000008	0.000025	0.000820	-0.0003838	98	0.001	0.0003	32.66	0.00	0.00	98	0.002
99	24,182.13	0.000006	0.000019	0.000613	-0.0002945	99	0.001	0.0002	32.66	0.00	0.00	99	0.001
100	24,303.44	0.000005	0.000014	0.000455	-0.0002246	100	0.000	0.0002	32.66	0.00	0.00	100	0.001
101	24,424.74	0.000003	0.000010	0.000335	-0.0001702	101	0.000	0.0001	32.66	0.00	0.00	101	0.001
	Sum	**0.327727**	1.000000		-5.7494475					**5.2449**			

Appendix 10.1: Triangular FMF transformation to Triangular PDF for external works

N	X2	MF	Area (X1-X2)	RF	HP	Sorted X2	Sorted MF	PI2-PI1	Cumm Fuzzy	LOG	NS	Adjusted Fuzzy	Prob	Resorted Prob
1	3,151.24	0.000	0.000	0.000	0.000	5,216.17	1.01					1.01	0.02	0.00
2	3,182.06	0.015	0.231	0.000	-0.002	5,185.35	0.99	0.02	2.00	1.00	0.02	0.99	0.02	0.00
3	3,212.88	0.030	0.693	0.000	-0.005	5,154.53	0.97	0.02	2.97	1.60	0.02	0.97	0.02	0.00
4	3,243.70	0.045	1.156	0.001	-0.008	5,246.99	0.96	0.01	3.93	2.03	0.03	0.96	0.02	0.00
5	3,274.52	0.060	1.618	0.001	-0.010	5,123.71	0.96	0.00	4.89	2.35	0.00	0.96	0.02	0.00
6	3,305.34	0.075	2.080	0.001	-0.013	5,092.89	0.94	0.01	5.84	2.63	0.04	0.94	0.02	0.00
7	3,336.16	0.090	2.543	0.002	-0.015	5,277.81	0.93	0.01	6.77	2.86	0.04	0.92	0.02	0.00
8	3,366.98	0.105	3.005	0.002	-0.018	5,062.07	0.93	0.00	7.70	3.06	0.00	0.92	0.02	0.00
9	3,397.80	0.120	3.467	0.002	-0.020	5,031.25	0.91	0.02	8.61	3.23	0.05	0.91	0.02	0.00
10	3,428.62	0.135	3.930	0.003	-0.022	5,308.63	0.90	0.01	9.51	3.39	0.05	0.89	0.02	0.00
11	3,459.44	0.150	4.392	0.003	-0.024	5,000.43	0.90	0.00	10.41	3.54	0.00	0.89	0.02	0.00
12	3,490.26	0.165	4.854	0.003	-0.026	4,969.61	0.88	0.01	11.30	3.67	0.06	0.87	0.02	0.00
13	3,521.08	0.180	5.316	0.003	-0.028	5,339.45	0.87	0.01	12.17	3.80	0.06	0.86	0.02	0.00
14	3,551.90	0.195	5.779	0.004	-0.030	4,938.79	0.87	0.00	13.04	3.91	0.00	0.86	0.02	0.00
15	3,582.72	0.210	6.241	0.004	-0.032	4,907.97	0.85	0.02	13.89	4.02	0.06	0.84	0.02	0.00
16	3,613.54	0.225	6.703	0.004	-0.034	5,370.27	0.84	0.01	14.73	4.12	0.06	0.82	0.02	0.00
17	3,644.36	0.240	7.166	0.005	-0.036	4,877.15	0.84	0.00	15.57	4.21	0.00	0.82	0.02	0.00
18	3,675.18	0.255	7.628	0.005	-0.038	4,846.33	0.82	0.01	16.40	4.30	0.06	0.81	0.02	0.00
19	3,706.00	0.270	8.090	0.005	-0.040	5,401.09	0.81	0.01	17.21	4.39	0.07	0.79	0.02	0.00
20	3,736.82	0.285	8.552	0.006	-0.042	4,815.51	0.81	0.00	18.02	4.47	0.00	0.79	0.02	0.01
21	3,767.64	0.300	9.015	0.006	-0.043	4,784.69	0.79	0.02	18.81	4.55	0.07	0.78	0.02	0.01
22	3,798.46	0.315	9.477	0.006	-0.045	5,431.90	0.78	0.01	19.59	4.63	0.07	0.76	0.02	0.01
23	3,829.27	0.330	9.939	0.006	-0.047	4,753.87	0.78	0.00	20.37	4.70	0.00	0.76	0.02	0.01
24	3,860.09	0.345	10.402	0.007	-0.049	4,723.05	0.76	0.02	21.14	4.77	0.07	0.74	0.02	0.01

25	3,890.91	0.360	10.864	0.007	-0.050	5,462.72	0.75	0.01	21.89	4.84	0.07	0.73	0.02	0.01
26	3,921.73	0.375	11.326	0.007	-0.052	4,692.23	0.75	0.00	22.64	4.90	0.00	0.73	0.02	0.01
27	3,952.55	0.390	11.789	0.008	-0.054	4,661.41	0.73	0.02	23.37	4.96	0.07	0.71	0.01	0.01
28	3,983.37	0.405	12.251	0.008	-0.055	5,493.54	0.72	0.01	24.09	5.02	0.08	0.69	0.01	0.01
29	4,014.19	0.420	12.713	0.008	-0.057	4,630.59	0.72	0.00	24.81	5.08	0.00	0.69	0.01	0.01
30	4,045.01	0.435	13.175	0.009	-0.059	4,599.77	0.70	0.02	25.52	5.14	0.08	0.68	0.01	0.01
31	4,075.83	0.450	13.638	0.009	-0.060	5,524.36	0.69	0.01	26.21	5.20	0.08	0.66	0.01	0.01
32	4,106.65	0.465	14.100	0.009	-0.062	4,568.95	0.69	0.00	26.90	5.25	0.00	0.66	0.01	0.01
33	4,137.47	0.480	14.562	0.009	-0.064	4,538.13	0.67	0.02	27.57	5.30	0.08	0.65	0.01	0.01
34	4,168.29	0.495	15.025	0.010	-0.065	5,555.18	0.66	0.01	28.23	5.36	0.08	0.63	0.01	0.01
35	4,199.11	0.510	15.487	0.010	-0.067	4,507.31	0.66	0.00	28.89	5.41	0.00	0.63	0.01	0.01
36	4,229.93	0.525	15.949	0.010	-0.068	4,476.49	0.64	0.02	29.54	5.46	0.08	0.62	0.01	0.01
37	4,260.75	0.540	16.412	0.011	-0.070	5,586.00	0.63	0.01	30.17	5.50	0.08	0.60	0.01	0.01
38	4,291.57	0.555	16.874	0.011	-0.071	4,445.67	0.63	0.00	30.80	5.55	0.00	0.60	0.01	0.01
39	4,322.39	0.570	17.336	0.011	-0.073	4,414.85	0.61	0.02	31.41	5.60	0.08	0.58	0.01	0.01
40	4,353.21	0.585	17.798	0.012	-0.074	5,616.82	0.60	0.01	32.01	5.64	0.08	0.57	0.01	0.01
41	4,384.03	0.600	18.261	0.012	-0.076	4,384.03	0.60	0.00	32.61	5.69	0.00	0.57	0.01	0.01
42	4,414.85	0.615	18.723	0.012	-0.077	4,353.21	0.58	0.02	33.20	5.73	0.09	0.55	0.01	0.01
43	4,445.67	0.630	19.185	0.012	-0.079	5,647.64	0.57	0.01	33.77	5.78	0.09	0.54	0.01	0.01
44	4,476.49	0.645	19.648	0.013	-0.080	4,322.39	0.57	0.00	34.34	5.82	0.00	0.54	0.01	0.01
45	4,507.31	0.660	20.110	0.013	-0.082	4,291.57	0.55	0.02	34.89	5.86	0.09	0.52	0.01	0.01
46	4,538.13	0.675	20.572	0.013	-0.083	5,678.46	0.54	0.01	35.43	5.90	0.09	0.51	0.01	0.01
47	4,568.95	0.690	21.035	0.014	-0.085	4,260.75	0.54	0.00	35.97	5.94	0.00	0.51	0.01	0.01
48	4,599.77	0.705	21.497	0.014	-0.086	4,229.93	0.52	0.02	36.50	5.98	0.09	0.49	0.01	0.01
49	4,630.59	0.720	21.959	0.014	-0.087	5,709.28	0.51	0.01	37.01	6.02	0.09	0.47	0.01	0.01
50	4,661.41	0.735	22.421	0.015	-0.089	4,199.11	0.51	0.00	37.52	6.06	0.00	0.47	0.01	0.01
51	4,692.23	0.750	22.884	0.015	-0.090	4,168.29	0.49	0.02	38.01	6.10	0.09	0.46	0.01	0.02
52	4,723.05	0.765	23.346	0.015	-0.092	5,740.10	0.48	0.01	38.49	6.13	0.09	0.44	0.01	0.02

53	4,753.87	0.780	23.808	0.015	-0.093	4,137.47	0.48	0.00	38.97	6.17	0.00	0.44	0.01	0.02
54	4,784.69	0.795	24.271	0.016	-0.094	4,106.65	0.47	0.02	39.44	6.21	0.09	0.43	0.01	0.02
55	4,815.51	0.810	24.733	0.016	-0.096	5,770.92	0.45	0.01	39.89	6.24	0.09	0.41	0.01	0.02
56	4,846.33	0.825	25.195	0.016	-0.097	4,075.83	0.45	0.00	40.34	6.28	0.00	0.41	0.01	0.02
57	4,877.15	0.840	25.657	0.017	-0.098	4,045.01	0.44	0.02	40.77	6.32	0.09	0.40	0.01	0.02
58	4,907.97	0.855	26.120	0.017	-0.100	5,801.74	0.42	0.01	41.19	6.35	0.10	0.38	0.01	0.02
59	4,938.79	0.870	26.582	0.017	-0.101	4,014.19	0.42	0.00	41.61	6.39	0.00	0.38	0.01	0.02
60	4,969.61	0.885	27.044	0.018	-0.102	3,983.37	0.41	0.02	42.02	6.42	0.10	0.37	0.01	0.02
61	5,000.43	0.900	27.507	0.018	-0.104	5,832.56	0.39	0.01	42.41	6.46	0.10	0.35	0.01	0.02
62	5,031.25	0.915	27.969	0.018	-0.105	3,952.55	0.39	0.00	42.80	6.49	0.00	0.35	0.01	0.02
63	5,062.07	0.930	28.431	0.018	-0.106	3,921.73	0.38	0.02	43.17	6.52	0.10	0.34	0.01	0.02
64	5,092.89	0.945	28.894	0.019	-0.108	5,863.38	0.36	0.01	43.53	6.56	0.10	0.32	0.01	0.02
65	5,123.71	0.960	29.356	0.019	-0.109	3,890.91	0.36	0.00	43.89	6.59	0.00	0.32	0.01	0.02
66	5,154.53	0.975	29.818	0.019	-0.110	3,860.09	0.35	0.02	44.24	6.62	0.10	0.31	0.01	0.02
67	5,185.35	0.990	30.280	0.020	-0.111	5,894.20	0.33	0.01	44.57	6.65	0.10	0.29	0.01	0.02
68	5,216.17	1.005	30.743	0.020	-0.113	3,829.27	0.33	0.00	44.90	6.69	0.00	0.29	0.01	0.02
69	5,246.99	0.960	30.280	0.020	-0.111	3,798.46	0.32	0.02	45.21	6.72	0.10	0.28	0.01	0.02
70	5,277.81	0.930	29.125	0.019	-0.108	5,925.02	0.30	0.01	45.51	6.75	0.10	0.26	0.01	0.02
71	5,308.63	0.900	28.200	0.018	-0.106	3,767.64	0.30	0.00	45.81	6.78	0.00	0.26	0.01	0.02
72	5,339.45	0.870	27.276	0.018	-0.103	3,736.82	0.29	0.02	46.10	6.81	0.10	0.25	0.01	0.02
73	5,370.27	0.840	26.351	0.017	-0.100	5,955.84	0.27	0.01	46.37	6.84	0.10	0.23	0.00	0.02
74	5,401.09	0.810	25.426	0.016	-0.098	3,706.00	0.27	0.00	46.64	6.88	0.00	0.23	0.00	0.02
75	5,431.90	0.780	24.502	0.016	-0.095	3,675.18	0.26	0.02	46.89	6.91	0.10	0.22	0.00	0.02
76	5,462.72	0.750	23.577	0.015	-0.092	5,986.66	0.24	0.01	47.13	6.94	0.10	0.21	0.00	0.02
77	5,493.54	0.720	22.653	0.015	-0.089	3,644.36	0.24	0.00	47.37	6.97	0.00	0.21	0.00	0.01
78	5,524.36	0.690	21.728	0.014	-0.087	3,613.54	0.23	0.02	47.60	7.00	0.10	0.19	0.00	0.01
79	5,555.18	0.660	20.803	0.013	-0.084	6,017.48	0.21	0.01	47.81	7.03	0.11	0.18	0.00	0.01
80	5,586.00	0.630	19.879	0.013	-0.081	3,582.72	0.21	0.00	48.02	7.06	0.00	0.18	0.00	0.01

81	5,616.82	0.600	18.954	0.012	-0.078	3,551.90	0.20	0.02	48.21	7.09	0.11	0.16	0.00	0.01
82	5,647.64	0.570	18.030	0.012	-0.075	6,048.30	0.18	0.01	48.39	7.12	0.11	0.15	0.00	0.01
83	5,678.46	0.540	17.105	0.011	-0.072	3,521.08	0.18	0.00	48.57	7.15	0.00	0.15	0.00	0.01
84	5,709.28	0.510	16.180	0.010	-0.069	3,490.26	0.17	0.02	48.74	7.18	0.11	0.14	0.00	0.01
85	5,740.10	0.480	15.256	0.010	-0.066	6,079.12	0.15	0.01	48.89	7.21	0.11	0.12	0.00	0.01
86	5,770.92	0.450	14.331	0.009	-0.063	3,459.44	0.15	0.00	49.04	7.24	0.00	0.12	0.00	0.01
87	5,801.74	0.420	13.407	0.009	-0.060	3,428.62	0.14	0.02	49.17	7.27	0.11	0.11	0.00	0.01
88	5,832.56	0.390	12.482	0.008	-0.056	6,109.94	0.12	0.01	49.29	7.30	0.11	0.10	0.00	0.01
89	5,863.38	0.360	11.557	0.007	-0.053	3,397.80	0.12	0.00	49.41	7.32	0.00	0.10	0.00	0.01
90	5,894.20	0.330	10.633	0.007	-0.050	3,366.98	0.11	0.02	49.52	7.35	0.11	0.08	0.00	0.01
91	5,925.02	0.300	9.708	0.006	-0.046	6,140.76	0.09	0.01	49.61	7.38	0.11	0.07	0.00	0.01
92	5,955.84	0.270	8.784	0.006	-0.042	3,336.16	0.09	0.00	49.70	7.41	0.00	0.07	0.00	0.00
93	5,986.66	0.240	7.859	0.005	-0.039	3,305.34	0.07	0.02	49.77	7.44	0.11	0.06	0.00	0.00
94	6,017.48	0.210	6.934	0.004	-0.035	6,171.58	0.06	0.01	49.83	7.47	0.11	0.04	0.00	0.00
95	6,048.30	0.180	6.010	0.004	-0.031	3,274.52	0.06	0.00	49.89	7.50	0.00	0.04	0.00	0.00
96	6,079.12	0.150	5.085	0.003	-0.027	3,243.70	0.05	0.02	49.94	7.53	0.11	0.03	0.00	0.00
97	6,109.94	0.120	4.161	0.003	-0.023	6,202.40	0.03	0.01	49.97	7.56	0.11	0.02	0.00	0.00
98	6,140.76	0.090	3.236	0.002	-0.019	3,212.88	0.03	0.00	50.00	7.59	0.00	0.02	0.00	0.00
99	6,171.58	0.060	2.311	0.001	-0.014	3,182.06	0.02	0.02	50.01	7.61	0.11	0.01	0.00	0.00
100	6,202.40	0.030	1.387	0.001	-0.009	6,233.22	0.00	0.01	50.01	7.64	0.11	0.00	0.00	0.00
101	6,233.22	0.000	0.462	0.000	-0.004	3,151.24	0.00	0.00	50.01	7.67	0.00	0.00	0.00	0.00
			1541.299	1.000	-6.365						**5.74**	47.45		0.02
				HP	6.365									
				K=	0.903									

Appendix 10.2: Normal PDF Transformation to Gaussian FMF for Design fees

N	X2-values	F	RF	Pos	HP	Sorted X2	Sorted Pos	Pos1-Pos2	Cum Pos	NS	MF	Resorted X2	Resorted MF
1	2,584.24	0.00	0.00	0.00	(0.00)	4,074.10	1.00				1.00	2,584.24	0.00
2	2,615.28	0.00	0.00	0.00	(0.00)	4,043.06	1.00	0.00	2.00	0.00	1.00	2,615.28	0.00
3	2,646.32	0.00	0.00	0.00	(0.00)	4,105.14	1.00	0.00	2.99	0.00	1.00	2,646.32	0.00
4	2,677.35	0.00	0.00	0.00	(0.00)	4,012.02	0.99	0.01	3.98	0.01	0.99	2,677.35	0.00
5	2,708.39	0.00	0.00	0.00	(0.00)	4,136.18	0.99	0.00	4.97	0.01	0.99	2,708.39	0.00
6	2,739.43	0.00	0.00	0.00	(0.00)	3,980.98	0.98	0.01	5.95	0.02	0.97	2,739.43	0.00
7	2,770.47	0.00	0.00	0.01	(0.00)	4,167.21	0.97	0.01	6.92	0.02	0.97	2,770.47	0.00
8	2,801.51	0.00	0.00	0.01	(0.00)	3,949.94	0.96	0.01	7.88	0.04	0.95	2,801.51	0.00
9	2,832.55	0.00	0.00	0.01	(0.00)	4,198.25	0.95	0.01	8.83	0.02	0.95	2,832.55	0.01
10	2,863.59	0.00	0.00	0.01	(0.00)	3,918.90	0.93	0.02	9.76	0.05	0.93	2,863.59	0.01
11	2,894.63	0.00	0.00	0.01	(0.01)	4,229.29	0.92	0.01	10.69	0.03	0.92	2,894.63	0.01
12	2,925.66	0.00	0.00	0.02	(0.01)	3,887.87	0.91	0.02	11.59	0.07	0.90	2,925.66	0.01
13	2,956.70	0.00	0.00	0.02	(0.01)	4,260.33	0.89	0.01	12.48	0.04	0.88	2,956.70	0.02
14	2,987.74	0.00	0.00	0.03	(0.01)	3,856.83	0.87	0.02	13.36	0.09	0.86	2,987.74	0.02
15	3,018.78	0.00	0.00	0.03	(0.01)	4,291.37	0.86	0.01	14.22	0.05	0.85	3,018.78	0.03
16	3,049.82	0.00	0.00	0.04	(0.01)	3,825.79	0.84	0.02	15.05	0.10	0.82	3,049.82	0.03
17	3,080.86	0.00	0.00	0.05	(0.01)	4,322.41	0.82	0.01	15.87	0.06	0.81	3,080.86	0.04
18	3,111.90	0.00	0.00	0.06	(0.02)	3,794.75	0.80	0.03	16.67	0.11	0.78	3,111.90	0.05
19	3,142.94	0.00	0.00	0.07	(0.02)	4,353.45	0.78	0.01	17.45	0.06	0.76	3,142.94	0.06
20	3,173.97	0.00	0.00	0.09	(0.02)	3,763.71	0.75	0.03	18.20	0.13	0.73	3,173.97	0.07
21	3,205.01	0.00	0.00	0.10	(0.03)	4,384.49	0.74	0.02	18.94	0.07	0.72	3,205.01	0.08
22	3,236.05	0.00	0.00	0.12	(0.03)	3,732.67	0.71	0.03	19.65	0.14	0.69	3,236.05	0.10
23	3,267.09	0.00	0.00	0.14	(0.03)	4,415.52	0.69	0.02	20.34	0.07	0.67	3,267.09	0.12
24	3,298.13	0.00	0.00	0.16	(0.04)	3,701.63	0.66	0.03	21.00	0.14	0.64	3,298.13	0.14

25	3,329.17	0.00	0.01	0.19	(0.04)	4,446.56	0.65	0.02	21.65	0.08	0.62	3,329.17	0.16
26	3,360.21	0.00	0.01	0.22	(0.05)	3,670.59	0.62	0.03	22.27	0.15	0.59	3,360.21	0.19
27	3,391.25	0.00	0.01	0.25	(0.05)	4,477.60	0.60	0.02	22.87	0.08	0.57	3,391.25	0.22
28	3,422.28	0.01	0.01	0.28	(0.06)	3,639.56	0.57	0.03	23.44	0.15	0.54	3,422.28	0.25
29	3,453.32	0.01	0.01	0.31	(0.06)	4,508.64	0.55	0.02	23.99	0.08	0.52	3,453.32	0.28
30	3,484.36	0.01	0.01	0.35	(0.07)	3,608.52	0.52	0.03	24.52	0.16	0.49	3,484.36	0.32
31	3,515.40	0.01	0.01	0.39	(0.08)	4,539.68	0.51	0.02	25.03	0.08	0.48	3,515.40	0.36
32	3,546.44	0.01	0.01	0.44	(0.08)	3,577.48	0.48	0.03	25.50	0.16	0.45	3,546.44	0.40
33	3,577.48	0.01	0.01	0.48	(0.09)	4,570.72	0.46	0.02	25.97	0.08	0.43	3,577.48	0.45
34	3,608.52	0.01	0.02	0.52	(0.10)	3,546.44	0.44	0.03	26.40	0.16	0.40	3,608.52	0.49
35	3,639.56	0.01	0.02	0.57	(0.10)	4,601.76	0.42	0.01	26.82	0.08	0.39	3,639.56	0.54
36	3,670.59	0.01	0.02	0.62	(0.11)	3,515.40	0.39	0.03	27.22	0.15	0.36	3,670.59	0.59
37	3,701.63	0.01	0.02	0.66	(0.11)	4,632.80	0.38	0.01	27.60	0.08	0.35	3,701.63	0.64
38	3,732.67	0.01	0.02	0.71	(0.12)	3,484.36	0.35	0.03	27.95	0.15	0.32	3,732.67	0.69
39	3,763.71	0.01	0.02	0.75	(0.13)	4,663.83	0.34	0.01	28.29	0.08	0.31	3,763.71	0.73
40	3,794.75	0.02	0.02	0.80	(0.13)	3,453.32	0.31	0.02	28.60	0.14	0.28	3,794.75	0.78
41	3,825.79	0.02	0.03	0.84	(0.14)	4,694.87	0.30	0.01	28.91	0.07	0.27	3,825.79	0.82
42	3,856.83	0.02	0.03	0.87	(0.14)	3,422.28	0.28	0.02	29.18	0.14	0.25	3,856.83	0.86
43	3,887.87	0.02	0.03	0.91	(0.14)	4,725.91	0.27	0.01	29.45	0.07	0.24	3,887.87	0.90
44	3,918.90	0.02	0.03	0.93	(0.15)	3,391.25	0.25	0.02	29.70	0.13	0.22	3,918.90	0.93
45	3,949.94	0.02	0.03	0.96	(0.15)	4,756.95	0.24	0.01	29.94	0.07	0.21	3,949.94	0.95
46	3,980.98	0.02	0.03	0.98	(0.15)	3,360.21	0.22	0.02	30.15	0.12	0.19	3,980.98	0.97
47	4,012.02	0.02	0.03	0.99	(0.15)	4,787.99	0.21	0.01	30.36	0.06	0.18	4,012.02	0.99
48	4,043.06	0.02	0.03	1.00	(0.15)	3,329.17	0.19	0.02	30.55	0.11	0.16	4,043.06	1.00
49	4,074.10	0.02	0.03	1.00	(0.15)	4,819.03	0.18	0.01	30.73	0.06	0.15	4,074.10	1.00
50	4,105.14	0.02	0.03	1.00	(0.15)	3,298.13	0.16	0.02	30.89	0.10	0.14	4,105.14	1.00
51	4,136.18	0.02	0.03	0.99	(0.15)	4,850.07	0.16	0.01	31.04	0.05	0.13	4,136.18	0.99
52	4,167.21	0.02	0.03	0.97	(0.15)	3,267.09	0.14	0.01	31.19	0.09	0.12	4,167.21	0.97

53	4,198.25	0.02	0.03	0.95	(0.15)	4,881.11	0.13	0.01	31.32	0.05	0.11	4,198.25	0.95
54	4,229.29	0.02	0.03	0.92	(0.15)	3,236.05	0.12	0.01	31.44	0.08	0.10	4,229.29	0.92
55	4,260.33	0.02	0.03	0.89	(0.14)	4,912.14	0.11	0.01	31.55	0.04	0.09	4,260.33	0.88
56	4,291.37	0.02	0.03	0.86	(0.14)	3,205.01	0.10	0.01	31.66	0.08	0.08	4,291.37	0.85
57	4,322.41	0.02	0.03	0.82	(0.13)	4,943.18	0.10	0.01	31.75	0.04	0.08	4,322.41	0.81
58	4,353.45	0.02	0.02	0.78	(0.13)	3,173.97	0.09	0.01	31.84	0.07	0.07	4,353.45	0.76
59	4,384.49	0.01	0.02	0.74	(0.12)	4,974.22	0.08	0.00	31.92	0.03	0.06	4,384.49	0.72
60	4,415.52	0.01	0.02	0.69	(0.12)	3,142.94	0.07	0.01	32.00	0.06	0.06	4,415.52	0.67
61	4,446.56	0.01	0.02	0.65	(0.11)	5,005.26	0.07	0.00	32.06	0.03	0.05	4,446.56	0.62
62	4,477.60	0.01	0.02	0.60	(0.11)	3,111.90	0.06	0.01	32.13	0.05	0.05	4,477.60	0.57
63	4,508.64	0.01	0.02	0.55	(0.10)	5,036.30	0.06	0.00	32.18	0.03	0.04	4,508.64	0.52
64	4,539.68	0.01	0.02	0.51	(0.09)	3,080.86	0.05	0.01	32.23	0.05	0.04	4,539.68	0.48
65	4,570.72	0.01	0.01	0.46	(0.09)	5,067.34	0.05	0.00	32.28	0.02	0.04	4,570.72	0.43
66	4,601.76	0.01	0.01	0.42	(0.08)	3,049.82	0.04	0.01	32.32	0.04	0.03	4,601.76	0.39
67	4,632.80	0.01	0.01	0.38	(0.07)	5,098.38	0.04	0.00	32.36	0.02	0.03	4,632.80	0.35
68	4,663.83	0.01	0.01	0.34	(0.07)	3,018.78	0.03	0.00	32.40	0.03	0.03	4,663.83	0.31
69	4,694.87	0.01	0.01	0.30	(0.06)	5,129.42	0.03	0.00	32.43	0.02	0.02	4,694.87	0.27
70	4,725.91	0.01	0.01	0.27	(0.06)	2,987.74	0.03	0.00	32.46	0.03	0.02	4,725.91	0.24
71	4,756.95	0.00	0.01	0.24	(0.05)	5,160.45	0.03	0.00	32.48	0.01	0.02	4,756.95	0.21
72	4,787.99	0.00	0.01	0.21	(0.05)	2,956.70	0.02	0.00	32.51	0.02	0.02	4,787.99	0.18
73	4,819.03	0.00	0.01	0.18	(0.04)	5,191.49	0.02	0.00	32.53	0.01	0.01	4,819.03	0.15
74	4,850.07	0.00	0.00	0.16	(0.04)	2,925.66	0.02	0.00	32.55	0.02	0.01	4,850.07	0.13
75	4,881.11	0.00	0.00	0.13	(0.03)	5,222.53	0.02	0.00	32.57	0.01	0.01	4,881.11	0.11
76	4,912.14	0.00	0.00	0.11	(0.03)	2,894.63	0.01	0.00	32.58	0.02	0.01	4,912.14	0.09
77	4,943.18	0.00	0.00	0.10	(0.02)	5,253.57	0.01	0.00	32.59	0.01	0.01	4,943.18	0.08
78	4,974.22	0.00	0.00	0.08	(0.02)	2,863.59	0.01	0.00	32.61	0.01	0.01	4,974.22	0.06
79	5,005.26	0.00	0.00	0.07	(0.02)	5,284.61	0.01	0.00	32.62	0.01	0.01	5,005.26	0.05
80	5,036.30	0.00	0.00	0.06	(0.02)	2,832.55	0.01	0.00	32.63	0.01	0.01	5,036.30	0.04

81	5,067.34	0.00	0.00	0.05	(0.01)	5,315.65	0.01	0.00	32.63	0.01	0.01	5,067.34	0.04
82	5,098.38	0.00	0.00	0.04	(0.01)	2,801.51	0.01	0.00	32.64	0.01	0.00	5,098.38	0.03
83	5,129.42	0.00	0.00	0.03	(0.01)	5,346.69	0.01	0.00	32.65	0.00	0.00	5,129.42	0.02
84	5,160.45	0.00	0.00	0.03	(0.01)	2,770.47	0.01	0.00	32.66	0.01	0.00	5,160.45	0.02
85	5,191.49	0.00	0.00	0.02	(0.01)	5,377.73	0.01	0.00	32.66	0.00	0.00	5,191.49	0.01
86	5,222.53	0.00	0.00	0.02	(0.01)	2,739.43	0.00	0.00	32.66	0.01	0.00	5,222.53	0.01
87	5,253.57	0.00	0.00	0.01	(0.00)	5,408.76	0.00	0.00	32.67	0.00	0.00	5,253.57	0.01
88	5,284.61	0.00	0.00	0.01	(0.00)	2,708.39	0.00	0.00	32.67	0.01	0.00	5,284.61	0.01
89	5,315.65	0.00	0.00	0.01	(0.00)	5,439.80	0.00	0.00	32.68	0.00	0.00	5,315.65	0.01
90	5,346.69	0.00	0.00	0.01	(0.00)	2,677.35	0.00	0.00	32.68	0.00	0.00	5,346.69	0.00
91	5,377.73	0.00	0.00	0.01	(0.00)	5,470.84	0.00	0.00	32.68	0.00	0.00	5,377.73	0.00
92	5,408.76	0.00	0.00	0.00	(0.00)	2,646.32	0.00	0.00	32.68	0.00	0.00	5,408.76	0.00
93	5,439.80	0.00	0.00	0.00	(0.00)	5,501.88	0.00	0.00	32.69	0.00	0.00	5,439.80	0.00
94	5,470.84	0.00	0.00	0.00	(0.00)	2,615.28	0.00	0.00	32.69	0.00	0.00	5,470.84	0.00
95	5,501.88	0.00	0.00	0.00	(0.00)	5,532.92	0.00	0.00	32.69	0.00	0.00	5,501.88	0.00
96	5,532.92	0.00	0.00	0.00	(0.00)	2,584.24	0.00	0.00	32.69	0.00	0.00	5,532.92	0.00
97	5,563.96	0.00	0.00	0.00	(0.00)	5,563.96	0.00	0.00	32.69	0.00	0.00	5,563.96	0.00
98	5,595.00	0.00	0.00	0.00	(0.00)	5,595.00	0.00	0.00	32.69	0.00	0.00	5,595.00	0.00
99	5,626.03	0.00	0.00	0.00	(0.00)	5,626.03	0.00	0.00	32.69	0.00	0.00	5,626.03	0.00
100	5,657.07	0.00	0.00	0.00	(0.00)	5,657.07	0.00	0.00	32.69	0.00	0.00	5,657.07	0.00
101	5,688.11	0.00	0.00	0.00	(0.00)	5,688.11	0.00	0.00	32.69	0.00	0.00	5,688.11	0.00
	Sum	**0.65**	1.00		- 5.751					**5.2463**			
	Maximum		**0.03**										
	SumHP		5.75										
	K		1.10										

Appendix 10.3: Trapezoidal FMF transformation to PDF for End-of-life cost

N	X2	MF	Area (X1-X2)	RF	HP	Sorted X2	Sorted MF	PI2-PI1	Cumm. Fuzzy	LOG	NS	Adjusted Fuzzy	Prob	Resorted X2	Resorted Prob
1	3,731.63	0.00	0.00	0.00	0.00	4,077.67	1.00					1.00	0.01	3,731.63	0.000
2	3,781.06	0.16	4.00	0.00	-0.01	4,127.11	1.00	0.00	2.00	1.00	0.00	1.00	0.01	3,781.06	0.008
3	3,830.50	0.32	12.01	0.00	-0.02	4,176.54	1.00	0.00	3.00	1.58	0.00	1.00	0.01	3,830.50	0.009
4	3,879.93	0.49	20.02	0.00	-0.03	4,225.98	1.00	0.00	4.00	2.00	0.00	1.00	0.01	3,879.93	0.009
5	3,929.37	0.65	28.03	0.01	-0.05	4,275.41	1.00	0.00	5.00	2.32	0.00	1.00	0.01	3,929.37	0.010
6	3,978.80	0.81	36.04	0.01	-0.06	4,324.85	1.00	0.00	6.00	2.58	0.00	1.00	0.01	3,978.80	0.010
7	4,028.24	0.97	44.05	0.01	-0.07	4,374.28	1.00	0.00	7.00	2.81	0.00	1.00	0.01	4,028.24	0.010
8	4,077.67	1.00	48.74	0.01	-0.07	4,423.72	1.00	0.00	8.00	3.00	0.00	1.00	0.01	4,077.67	0.010
9	4,127.11	1.00	49.44	0.01	-0.07	4,473.15	1.00	0.00	9.00	3.17	0.00	1.00	0.01	4,127.11	0.010
10	4,176.54	1.00	49.44	0.01	-0.07	4,522.59	1.00	0.00	10.00	3.32	0.00	1.00	0.01	4,176.54	0.010
11	4,225.98	1.00	49.44	0.01	-0.07	4,572.03	1.00	0.00	11.00	3.46	0.00	1.00	0.01	4,225.98	0.010
12	4,275.41	1.00	49.44	0.01	-0.07	4,621.46	1.00	0.00	12.00	3.58	0.00	1.00	0.01	4,275.41	0.010
13	4,324.85	1.00	49.44	0.01	-0.07	4,670.90	1.00	0.00	13.00	3.70	0.00	1.00	0.01	4,324.85	0.010
14	4,374.28	1.00	49.44	0.01	-0.07	4,720.33	1.00	0.00	14.00	3.81	0.00	1.00	0.01	4,374.28	0.010
15	4,423.72	1.00	49.44	0.01	-0.07	4,769.77	1.00	0.00	15.00	3.91	0.00	1.00	0.01	4,423.72	0.010
16	4,473.15	1.00	49.44	0.01	-0.07	4,819.20	1.00	0.00	16.00	4.00	0.00	1.00	0.01	4,473.15	0.010
17	4,522.59	1.00	49.44	0.01	-0.07	4,868.64	1.00	0.00	17.00	4.09	0.00	1.00	0.01	4,522.59	0.010
18	4,572.03	1.00	49.44	0.01	-0.07	4,918.07	1.00	0.00	18.00	4.17	0.00	1.00	0.01	4,572.03	0.010
19	4,621.46	1.00	49.44	0.01	-0.07	4,967.51	1.00	0.00	19.00	4.25	0.00	1.00	0.01	4,621.46	0.010
20	4,670.90	1.00	49.44	0.01	-0.07	5,016.94	1.00	0.00	20.00	4.32	0.00	1.00	0.01	4,670.90	0.010
21	4,720.33	1.00	49.44	0.01	-0.07	5,066.38	1.00	0.00	21.00	4.39	0.00	1.00	0.01	4,720.33	0.010
22	4,769.77	1.00	49.44	0.01	-0.07	5,115.81	1.00	0.00	22.00	4.46	0.00	1.00	0.01	4,769.77	0.010
23	4,819.20	1.00	49.44	0.01	-0.07	5,165.25	1.00	0.00	23.00	4.52	0.00	1.00	0.01	4,819.20	0.010
24	4,868.64	1.00	49.44	0.01	-0.07	5,214.68	1.00	0.00	24.00	4.58	0.00	1.00	0.01	4,868.64	0.010

25	4,918.07	1.00	49.44	0.01	-0.07	5,264.12	1.00	0.00	25.00	4.64	0.00	1.00	0.01	4,918.07	0.010
26	4,967.51	1.00	49.44	0.01	-0.07	5,313.56	1.00	0.00	26.00	4.70	0.00	1.00	0.01	4,967.51	0.010
27	5,016.94	1.00	49.44	0.01	-0.07	5,362.99	1.00	0.00	27.00	4.75	0.00	1.00	0.01	5,016.94	0.010
28	5,066.38	1.00	49.44	0.01	-0.07	5,412.43	1.00	0.00	28.00	4.81	0.00	1.00	0.01	5,066.38	0.010
29	5,115.81	1.00	49.44	0.01	-0.07	5,461.86	1.00	0.00	29.00	4.86	0.00	1.00	0.01	5,115.81	0.010
30	5,165.25	1.00	49.44	0.01	-0.07	5,511.30	1.00	0.00	30.00	4.91	0.00	1.00	0.01	5,165.25	0.010
31	5,214.68	1.00	49.44	0.01	-0.07	5,560.73	1.00	0.00	31.00	4.95	0.00	1.00	0.01	5,214.68	0.010
32	5,264.12	1.00	49.44	0.01	-0.07	5,610.17	1.00	0.00	32.00	5.00	0.00	1.00	0.01	5,264.12	0.010
33	5,313.56	1.00	49.44	0.01	-0.07	5,659.60	1.00	0.00	33.00	5.04	0.00	1.00	0.01	5,313.56	0.010
34	5,362.99	1.00	49.44	0.01	-0.07	5,709.04	1.00	0.00	34.00	5.09	0.00	1.00	0.01	5,362.99	0.010
35	5,412.43	1.00	49.44	0.01	-0.07	5,758.47	1.00	0.00	35.00	5.13	0.00	1.00	0.01	5,412.43	0.010
36	5,461.86	1.00	49.44	0.01	-0.07	5,807.91	1.00	0.00	36.00	5.17	0.00	1.00	0.01	5,461.86	0.010
37	5,511.30	1.00	49.44	0.01	-0.07	5,857.34	1.00	0.00	37.00	5.21	0.00	1.00	0.01	5,511.30	0.010
38	5,560.73	1.00	49.44	0.01	-0.07	5,906.78	1.00	0.00	38.00	5.25	0.00	1.00	0.01	5,560.73	0.010
39	5,610.17	1.00	49.44	0.01	-0.07	5,956.21	1.00	0.00	39.00	5.29	0.00	1.00	0.01	5,610.17	0.010
40	5,659.60	1.00	49.44	0.01	-0.07	6,005.65	1.00	0.00	40.00	5.32	0.00	1.00	0.01	5,659.60	0.010
41	5,709.04	1.00	49.44	0.01	-0.07	6,055.08	1.00	0.00	41.00	5.36	0.00	1.00	0.01	5,709.04	0.010
42	5,758.47	1.00	49.44	0.01	-0.07	6,104.52	1.00	0.00	42.00	5.39	0.00	1.00	0.01	5,758.47	0.010
43	5,807.91	1.00	49.44	0.01	-0.07	6,153.96	1.00	0.00	43.00	5.43	0.00	1.00	0.01	5,807.91	0.010
44	5,857.34	1.00	49.44	0.01	-0.07	6,203.39	1.00	0.00	44.00	5.46	0.00	1.00	0.01	5,857.34	0.010
45	5,906.78	1.00	49.44	0.01	-0.07	6,252.83	1.00	0.00	45.00	5.49	0.00	1.00	0.01	5,906.78	0.010
46	5,956.21	1.00	49.44	0.01	-0.07	6,302.26	1.00	0.00	46.00	5.52	0.00	1.00	0.01	5,956.21	0.010
47	6,005.65	1.00	49.44	0.01	-0.07	6,351.70	1.00	0.00	47.00	5.55	0.00	1.00	0.01	6,005.65	0.010
48	6,055.08	1.00	49.44	0.01	-0.07	6,401.13	1.00	0.00	48.00	5.58	0.00	1.00	0.01	6,055.08	0.010
49	6,104.52	1.00	49.44	0.01	-0.07	6,450.57	1.00	0.00	49.00	5.61	0.00	1.00	0.01	6,104.52	0.010
50	6,153.96	1.00	49.44	0.01	-0.07	6,500.00	1.00	0.00	50.00	5.64	0.00	1.00	0.01	6,153.96	0.010
51	6,203.39	1.00	49.44	0.01	-0.07	6,549.44	1.00	0.00	51.00	5.67	0.00	1.00	0.01	6,203.39	0.010
52	6,252.83	1.00	49.44	0.01	-0.07	6,598.87	1.00	0.00	52.00	5.70	0.00	1.00	0.01	6,252.83	0.010

53	6,302.26	1.00	49.44	0.01	-0.07	6,648.31	1.00	0.00	53.00	5.73	0.00	1.00	0.01	6,302.26	0.010
54	6,351.70	1.00	49.44	0.01	-0.07	6,697.74	1.00	0.00	54.00	5.75	0.00	1.00	0.01	6,351.70	0.010
55	6,401.13	1.00	49.44	0.01	-0.07	6,747.18	1.00	0.00	55.00	5.78	0.00	1.00	0.01	6,401.13	0.010
56	6,450.57	1.00	49.44	0.01	-0.07	6,796.61	1.00	0.00	56.00	5.81	0.00	1.00	0.01	6,450.57	0.010
57	6,500.00	1.00	49.44	0.01	-0.07	6,846.05	1.00	0.00	57.00	5.83	0.00	1.00	0.01	6,500.00	0.010
58	6,549.44	1.00	49.44	0.01	-0.07	6,895.48	1.00	0.00	58.00	5.86	0.00	1.00	0.01	6,549.44	0.010
59	6,598.87	1.00	49.44	0.01	-0.07	6,944.92	1.00	0.00	59.00	5.88	0.00	1.00	0.01	6,598.87	0.010
60	6,648.31	1.00	49.44	0.01	-0.07	6,994.36	1.00	0.00	60.00	5.91	0.00	1.00	0.01	6,648.31	0.010
61	6,697.74	1.00	49.44	0.01	-0.07	7,043.79	1.00	0.00	61.00	5.93	0.00	1.00	0.01	6,697.74	0.010
62	6,747.18	1.00	49.44	0.01	-0.07	7,093.23	1.00	0.00	62.00	5.95	0.00	1.00	0.01	6,747.18	0.010
63	6,796.61	1.00	49.44	0.01	-0.07	7,142.66	1.00	0.00	63.00	5.98	0.00	1.00	0.01	6,796.61	0.010
64	6,846.05	1.00	49.44	0.01	-0.07	7,192.10	1.00	0.00	64.00	6.00	0.00	1.00	0.01	6,846.05	0.010
65	6,895.48	1.00	49.44	0.01	-0.07	7,241.53	1.00	0.00	65.00	6.02	0.00	1.00	0.01	6,895.48	0.010
66	6,944.92	1.00	49.44	0.01	-0.07	7,290.97	1.00	0.00	66.00	6.04	0.00	1.00	0.01	6,944.92	0.010
67	6,994.36	1.00	49.44	0.01	-0.07	7,340.40	1.00	0.00	67.00	6.07	0.00	1.00	0.01	6,994.36	0.010
68	7,043.79	1.00	49.44	0.01	-0.07	7,389.84	1.00	0.00	68.00	6.09	0.00	1.00	0.01	7,043.79	0.010
69	7,093.23	1.00	49.44	0.01	-0.07	7,439.27	1.00	0.00	69.00	6.11	0.00	1.00	0.01	7,093.23	0.010
70	7,142.66	1.00	49.44	0.01	-0.07	7,488.71	1.00	0.00	70.00	6.13	0.00	1.00	0.01	7,142.66	0.010
71	7,192.10	1.00	49.44	0.01	-0.07	7,538.14	1.00	0.00	71.00	6.15	0.00	1.00	0.01	7,192.10	0.010
72	7,241.53	1.00	49.44	0.01	-0.07	7,587.58	1.00	0.00	72.00	6.17	0.00	1.00	0.01	7,241.53	0.010
73	7,290.97	1.00	49.44	0.01	-0.07	7,637.01	1.00	0.00	73.00	6.19	0.00	1.00	0.01	7,290.97	0.010
74	7,340.40	1.00	49.44	0.01	-0.07	7,686.45	1.00	0.00	74.00	6.21	0.00	1.00	0.01	7,340.40	0.010
75	7,389.84	1.00	49.44	0.01	-0.07	7,735.89	1.00	0.00	75.00	6.23	0.00	1.00	0.01	7,389.84	0.010
76	7,439.27	1.00	49.44	0.01	-0.07	7,785.32	1.00	0.00	76.00	6.25	0.00	1.00	0.01	7,439.27	0.010
77	7,488.71	1.00	49.44	0.01	-0.07	7,834.76	1.00	0.00	77.00	6.27	0.00	1.00	0.01	7,488.71	0.010
78	7,538.14	1.00	49.44	0.01	-0.07	7,884.19	1.00	0.00	78.00	6.29	0.00	1.00	0.01	7,538.14	0.010
79	7,587.58	1.00	49.44	0.01	-0.07	7,933.63	1.00	0.00	79.00	6.30	0.00	1.00	0.01	7,587.58	0.010
80	7,637.01	1.00	49.44	0.01	-0.07	7,983.06	1.00	0.00	80.00	6.32	0.00	1.00	0.01	7,637.01	0.010

81	7,686.45	1.00	49.44	0.01	-0.07	8,032.50	1.00	0.00	81.00	6.34	0.00	1.00	0.01	7,686.45	0.010
82	7,735.89	1.00	49.44	0.01	-0.07	8,081.93	1.00	0.00	82.00	6.36	0.00	1.00	0.01	7,735.89	0.010
83	7,785.32	1.00	49.44	0.01	-0.07	4,028.24	0.97	0.03	82.97	6.38	0.18	1.00	0.01	7,785.32	0.010
84	7,834.76	1.00	49.44	0.01	-0.07	8,131.37	0.96	0.01	83.93	6.39	0.08	0.99	0.01	7,834.76	0.010
85	7,884.19	1.00	49.44	0.01	-0.07	8,180.80	0.87	0.09	84.80	6.41	0.56	0.98	0.01	7,884.19	0.010
86	7,933.63	1.00	49.44	0.01	-0.07	3,978.80	0.81	0.06	85.61	6.43	0.40	0.97	0.01	7,933.63	0.010
87	7,983.06	1.00	49.44	0.01	-0.07	8,230.24	0.79	0.02	86.40	6.45	0.16	0.96	0.01	7,983.06	0.010
88	8,032.50	1.00	49.44	0.01	-0.07	8,279.67	0.70	0.09	87.10	6.47	0.56	0.95	0.01	8,032.50	0.010
89	8,081.93	1.00	49.44	0.01	-0.07	3,929.37	0.65	0.05	87.74	6.50	0.32	0.94	0.01	8,081.93	0.010
90	8,131.37	0.96	48.44	0.01	-0.07	8,329.11	0.61	0.04	88.36	6.52	0.24	0.93	0.01	8,131.37	0.010
91	8,180.80	0.87	45.28	0.01	-0.07	8,378.54	0.52	0.09	88.88	6.54	0.57	0.91	0.01	8,180.80	0.010
92	8,230.24	0.79	40.97	0.01	-0.06	3,879.93	0.49	0.04	89.36	6.57	0.25	0.90	0.01	8,230.24	0.010
93	8,279.67	0.70	36.65	0.01	-0.06	8,427.98	0.44	0.05	89.80	6.59	0.33	0.88	0.01	8,279.67	0.010
94	8,329.11	0.61	32.34	0.01	-0.05	8,477.41	0.35	0.09	90.15	6.61	0.58	0.85	0.01	8,329.11	0.010
95	8,378.54	0.52	28.03	0.01	-0.05	3,830.50	0.32	0.02	90.47	6.64	0.17	0.84	0.01	8,378.54	0.009
96	8,427.98	0.44	23.72	0.01	-0.04	8,526.85	0.26	0.06	90.74	6.67	0.42	0.82	0.01	8,427.98	0.009
97	8,477.41	0.35	19.41	0.00	-0.03	8,576.29	0.17	0.09	90.91	6.69	0.58	0.77	0.01	8,477.41	0.009
98	8,526.85	0.26	15.09	0.00	-0.03	3,781.06	0.16	0.01	91.07	6.72	0.08	0.76	0.01	8,526.85	0.008
99	8,576.29	0.17	10.78	0.00	-0.02	8,625.72	0.09	0.07	91.16	6.75	0.50	0.69	0.01	8,576.29	0.008
100	8,625.72	0.09	6.47	0.00	-0.01	8,675.16	0.00	0.09	91.16	6.78	0.59	0.01	0.00	8,625.72	0.007
101	8,675.16	0.00	2.16	0.00	-0.01	3,731.63	0.00	0.00	91.16	6.81	0.00	0.00	0.00	8,675.16	0.000
			4,506.49	1	-6.58						**6.577**	97.13022			1
				HP	6.581										
				K=	0.999										

Appendix 11:

Test result for traditional model

Appendix 11.0: Test result for Scenari1 traditional FV model

S/No	Data centre	Incidence	Unit Quantity	Rate	Amount in Millions	DURATION IN YEARS 0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	450	4,979.89	2.24	2.24	-	0	0	0	0	0	0
1B	Finance	Annual	212	8,049.24	1.71	0	1.95	1.46	0.97	0.49			
2	**Income:**	Annual	212	6,000.75	1.27	0	(1.36)	(1.46)	(1.57)	(1.69)	(1.81)	(1.94)	(2.08)
3	**Construction cost**												
3A	Building:	Initial	212	20,488.53	4.34	4.34		0	0	0	0	0	0
3B	External works:	Initial	238	4,646.21	1.11	1.11		0	0	0	0	0	0
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38		0	0	0	0	0	0
3D	Design fees:	Initial	212	3,694.40	0.78	0.78		0	0	0	0	0	0
4	**Operations:**	Annual	212	1,489.07	0.32	0	0.34	0.36	0.39	0.42	0.45	0.48	0.52
5	**Maintenance:**	Annual	212	311.78	0.07	0	0.07	0.08	0.08	0.09	0.09	0.10	0.11
6	**End-of-life:**	Terminal	450	6,060.27	2.73	0							
	Annual totals					**8.86**	**0.99**	**0.44**	**(0.13)**	**(0.69)**	**(1.27)**	**(1.36)**	**(1.46)**

DURATION IN YEARS 8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(2.23)	(2.40)	(2.57)	(2.76)	(2.96)	(3.18)	(3.41)	(3.66)	(3.93)	(4.21)	(4.52)	(4.85)	(5.20)	(5.58)	(5.99)	(6.43)	(6.90)	(7.40)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.55	0.59	0.64	0.68	0.73	0.79	0.85	0.91	0.97	1.05	1.12	1.20	1.29	1.39	1.49	1.59	1.71	1.84
0.12	0.12	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.22	0.23	0.25	0.27	0.29	0.31	0.33	0.36	0.38
(1.56)	**(1.68)**	**(1.80)**	**(1.93)**	**(2.07)**	**(2.22)**	**(2.39)**	**(2.56)**	**(2.75)**	**(2.95)**	**(3.16)**	**(3.39)**	**(3.64)**	**(3.91)**	**(4.19)**	**(4.50)**	**(4.83)**	**(5.18)**

Appendix11.0 cont.

DURATION IN YEARS															
26	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**
0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
(7.94)	(8.52)	(9.14)	(9.81)	(10.52)	(11.29)	(12.11)	(13.00)	(13.94)	(14.96)	(16.05)	(17.22)	(18.48)	(19.83)	(21.28)	(22.83)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.97	2.11	2.27	2.43	2.61	2.80	3.01	3.22	3.46	3.71	3.98	4.27	4.59	4.92	5.28	5.66
0.41	0.44	0.47	0.51	0.55	0.59	0.63	0.68	0.72	0.78	0.83	0.89	0.96	1.03	1.11	1.19
(5.56)	**(5.96)**	**(6.40)**	**(6.86)**	**(7.36)**	**(7.90)**	**(8.48)**	**(9.10)**	**(9.76)**	**(10.47)**	**(11.24)**	**(12.06)**	**(12.94)**	**(13.88)**	**(14.89)**	**(15.98)**

DURATION IN YEARS									**SECTION**
42	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**TOTALS**
-	-	-	-	-	-	-	-	-	**2.24**
									4.87
(24.49)	(26.28)	(28.20)	(30.26)	(32.46)	(34.83)	(37.37)	(40.10)	(43.03)	**(614.05)**
0	0	0	0	0	0	0	0	0	**4.34**
0	0	0	0	0	0	0	0	0	**1.11**
0	0	0	0	0	0	0	0	0	**0.38**
0	0	0	0	0	0	0	0	0	**0.78**
6.08	6.52	7.00	7.51	8.06	8.64	9.27	9.95	10.68	**152.37**
1.27	1.37	1.47	1.57	1.69	1.81	1.94	2.08	2.24	**31.90**
								(92.24)	**(92.24)**
(17.14)	**(18.39)**	**(19.74)**	**(21.18)**	**(22.72)**	**(24.38)**	**(26.16)**	**(28.07)**	**(122.35)**	**(508.28)**

Appendix 11.1: Test result for Scenario2 traditional FV model

S/No	Data centre	Incidence	Unit Quantity	Rate	Amount in Millions	DURATION IN YEARS 0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	450	4,979.89	2.24	2.24	-	0	0	0	0	0	0
1B	Finance	Annual	180	8,049.24		0							
2	**Income:**	Annual	180	6,000.75	1.27	0	(1.36)	(1.46)	(1.57)	(1.69)	(1.81)	(1.94)	(2.08)
3	**Construction cost**												
3A	Building:	Initial	180	20,488.53	4.34	4.34		0	0	0	0	0	0
3B	External works:	Initial	238	4,646.21	1.11	1.11		0	0	0	0	0	0
3C	Preliminaries:	Initial	180	1,807.43	0.38	0.38		0	0	0	0	0	0
3D	Design fees:	Initial	180	3,694.40	0.78	0.78		0	0	0	0	0	0
4	**Operations:**	Annual	180	1,489.07	0.32	0	0.34	0.36	0.39	0.42	0.45	0.48	0.52
5	**Maintenance:**	Annual	180	311.78	0.07	0	0.07	0.08	0.08	0.09	0.09	0.10	0.11
6	**End-of-life:**	Terminal	450	6,060.27	2.73	0							
	Annual totals					**8.86**	**(0.96)**	**(1.03)**	**(1.10)**	**(1.18)**	**(1.27)**	**(1.36)**	**(1.46)**

DURATION IN YEARS 8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(2.23)	(2.40)	(2.57)	(2.76)	(2.96)	(3.18)	(3.41)	(3.66)	(3.93)	(4.21)	(4.52)	(4.85)	(5.20)	(5.58)	(5.99)	(6.43)	(6.90)	(7.40)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.55	0.59	0.64	0.68	0.73	0.79	0.85	0.91	0.97	1.05	1.12	1.20	1.29	1.39	1.49	1.59	1.71	1.84
0.12	0.12	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.22	0.23	0.25	0.27	0.29	0.31	0.33	0.36	0.38
(1.56)	**(1.68)**	**(1.80)**	**(1.93)**	**(2.07)**	**(2.22)**	**(2.39)**	**(2.56)**	**(2.75)**	**(2.95)**	**(3.16)**	**(3.39)**	**(3.64)**	**(3.91)**	**(4.19)**	**(4.50)**	**(4.83)**	**(5.18)**

Appendix 11.1: Cont.

DURATION IN YEARS															
26	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(7.94)	(8.52)	(9.14)	(9.81)	(10.52)	(11.29)	(12.11)	(13.00)	(13.94)	(14.96)	(16.05)	(17.22)	(18.48)	(19.83)	(21.28)	(22.83)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.97	2.11	2.27	2.43	2.61	2.80	3.01	3.22	3.46	3.71	3.98	4.27	4.59	4.92	5.28	5.66
0.41	0.44	0.47	0.51	0.55	0.59	0.63	0.68	0.72	0.78	0.83	0.89	0.96	1.03	1.11	1.19
(5.56)	**(5.96)**	**(6.40)**	**(6.86)**	**(7.36)**	**(7.90)**	**(8.48)**	**(9.10)**	**(9.76)**	**(10.47)**	**(11.24)**	**(12.06)**	**(12.94)**	**(13.88)**	**(14.89)**	**(15.98)**

DURATION IN YEARS									SECTION
42	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**TOTALS**
0	0	0	0	0	0	0	0	0	**2.24**
(24.49)	(26.28)	(28.20)	(30.26)	(32.46)	(34.83)	(37.37)	(40.10)	(43.03)	**(614.05)**
0	0	0	0	0	0	0	0	0	**4.34**
0	0	0	0	0	0	0	0	0	**1.11**
0	0	0	0	0	0	0	0	0	**0.38**
0	0	0	0	0	0	0	0	0	**0.78**
6.08	6.52	7.00	7.51	8.06	8.64	9.27	9.95	10.68	**152.37**
1.27	1.37	1.47	1.57	1.69	1.81	1.94	2.08	2.24	**31.90**
								(92.24)	**(92.24)**
(17.14)	**(18.39)**	**(19.74)**	**(21.18)**	**(22.72)**	**(24.38)**	**(26.16)**	**(28.07)**	**(122.35)**	**(513.15)**

Appendix 11.2: Test result for Scenario1 traditional PV model

						DURATION IN YEARS							
S/No	Data centre	Incidence	Unit Quantity	Rate	Amount in Millions	0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	450	4,979.89	2.24	2.24	-	0	0	0	0	0	0
1B	Finance	Annual	212	8,049.24	1.71	0	1.95	1.46	0.97	0.49			
2	**Income:**	Annual	212	6,000.75	1.27	0	(1.24)	(1.20)	(1.16)	(1.13)	(1.10)	(1.07)	(1.03)
3	**Construction cost**												
3A	Building:	Initial	212	20,488.53	4.34	4.34		0	0	0	0	0	0
3B	External works:	Initial	238	4,646.21	1.11	1.11		0	0	0	0	0	0
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38		0	0	0	0	0	0
3D	Design fees:	Initial	212	3,694.40	0.78	0.78		0	0	0	0	0	0
4	**Operations:**	Annual	212	1,489.07	0.32	0	0.31	0.30	0.29	0.28	0.27	0.26	0.26
5	**Maintenance:**	Annual	212	311.78	0.07	0	0.06	0.06	0.06	0.06	0.06	0.06	0.05
6	**End-of-life:**	Terminal	450	6,060.27	2.73	0							
	Annual totals					**8.86**	**1.08**	**0.62**	**0.16**	**(0.30)**	**(0.77)**	**(0.75)**	**(0.72)**

DURATION IN YEARS																	
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(1.00)	(0.97)	(0.95)	(0.92)	(0.89)	(0.87)	(0.84)	(0.82)	(0.79)	(0.77)	(0.75)	(0.72)	(0.70)	(0.68)	(0.66)	(0.64)	(0.63)	(0.61)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.17	0.17	0.16	0.16	0.16	0.15
0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03
(0.70)	**(0.68)**	**(0.66)**	**(0.64)**	**(0.62)**	**(0.61)**	**(0.59)**	**(0.57)**	**(0.55)**	**(0.54)**	**(0.52)**	**(0.51)**	**(0.49)**	**(0.48)**	**(0.46)**	**(0.45)**	**(0.44)**	**(0.42)**

Appendix 11.2: Cont.

DURATION IN YEARS																	
26	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**
0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(0.59)	(0.57)	(0.56)	(0.54)	(0.52)	(0.51)	(0.49)	(0.48)	(0.47)	(0.45)	(0.44)	(0.43)	(0.41)	(0.40)	(0.39)	(0.38)	(0.37)	(0.36)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.15	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
(0.41)	**(0.40)**	**(0.39)**	**(0.38)**	**(0.37)**	**(0.36)**	**(0.35)**	**(0.34)**	**(0.33)**	**(0.32)**	**(0.31)**	**(0.30)**	**(0.29)**	**(0.28)**	**(0.27)**	**(0.26)**	**(0.26)**	**(0.25)**

DURATION IN YEARS							SECTION
44	**45**	**46**	**47**	**48**	**49**	**50**	**TOTALS**
-	-	-	-	-	-	-	**2.24**
							4.87
(0.35)	(0.34)	(0.33)	(0.32)	(0.31)	(0.30)	(0.29)	**(32.71)**
0	0	0	0	0	0	0	**4.34**
0	0	0	0	0	0	0	**1.11**
0	0	0	0	0	0	0	**0.38**
0	0	0	0	0	0	0	**0.78**
0.09	0.08	0.08	0.08	0.08	0.07	0.07	**8.12**
0.02	0.02	0.02	0.02	0.02	0.02	0.02	**1.70**
						(2.73)	**(2.73)**
(0.24)	**(0.24)**	**(0.23)**	**(0.22)**	**(0.22)**	**(0.21)**	**(2.93)**	**(11.89)**

Appendix 11.3: Test result for Scenario2 traditional PV model

						DURATION IN YEARS							
S/No	Data centre	Incidence	Unit Quantity	Rate	Amount in Millions	0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	450	4,979.89	2.24	2.24	-	0	0	0	0	0	0
1B	Finance	Annual	212	8,049.24		0							
2	**Income:**	Annual	212	3,500.00	1.27	0	(1.24)	(1.20)	(1.16)	(1.13)	(1.10)	(1.07)	(1.03)
3	**Construction cost**												
3A	Building:	Initial	212	20,488.53	4.34	4.34		0	0	0	0	0	0
3B	External works:	Initial	238	4,646.21	1.11	1.11		0	0	0	0	0	0
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38		0	0	0	0	0	0
3D	Design fees:	Initial	212	3,694.40	0.78	0.78		0	0	0	0	0	0
4	**Operations:**	Annual	212	1,489.07	0.32	0	0.31	0.30	0.29	0.28	0.27	0.26	0.26
5	**Maintenance:**	Annual	212	311.78	0.07	0	0.06	0.06	0.06	0.06	0.06	0.06	0.05
6	**End-of-life:**	Terminal	450	6,060.27	2.73	0							
	Annual totals					8.86	(0.86)	(0.84)	(0.81)	(0.79)	(0.77)	(0.75)	(0.72)

DURATION IN YEARS																	
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(1.00)	(0.97)	(0.95)	(0.92)	(0.89)	(0.87)	(0.84)	(0.82)	(0.79)	(0.77)	(0.75)	(0.72)	(0.70)	(0.68)	(0.66)	(0.64)	(0.63)	(0.61)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.17	0.17	0.16	0.16	0.16	0.15
0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03
(0.70)	(0.68)	(0.66)	(0.64)	(0.62)	(0.61)	(0.59)	(0.57)	(0.55)	(0.54)	(0.52)	(0.51)	(0.49)	(0.48)	(0.46)	(0.45)	(0.44)	(0.42)

Appendix 11.3: Cont.

DURATION IN YEARS																	
26	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(0.59)	(0.57)	(0.56)	(0.54)	(0.52)	(0.51)	(0.49)	(0.48)	(0.47)	(0.45)	(0.44)	(0.43)	(0.41)	(0.40)	(0.39)	(0.38)	(0.37)	(0.36)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.15	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
(0.41)	(0.40)	(0.39)	(0.38)	(0.37)	(0.36)	(0.35)	(0.34)	(0.33)	(0.32)	(0.31)	(0.30)	(0.29)	(0.28)	(0.27)	(0.26)	(0.26)	(0.25)

DURATION IN YEARS							SECTION
44	**45**	**46**	**47**	**48**	**49**	**50**	**TOTALS**
0	0	0	0	0	0	0	
							-
(0.35)	(0.34)	(0.33)	(0.32)	(0.31)	(0.30)	(0.29)	**(32.71)**
							-
0	0	0	0	0	0	0	
0	0	0	0	0	0	0	**1.11**
0	0	0	0	0	0	0	**0.38**
0	0	0	0	0	0	0	**0.78**
0.09	0.08	0.08	0.08	0.08	0.07	0.07	**8.12**
0.02	0.02	0.02	0.02	0.02	0.02	0.02	**1.70**
						(2.73)	**(2.73)**
(0.24)	(0.24)	(0.23)	(0.22)	(0.22)	(0.21)	(2.93)	**(16.76)**

Appendix 12:

Test result for modified traditional future worth model

Appendix 12.0: Test result for Scenari1 Modified traditional FV model

						DURATION IN YEARS							
S/No	Data centre	Incidence	Unit Quantity	Rate	Amount in Millions	0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	450	4,979.89	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
1B	Finance	Annual	212	8,049.24	1.71	0	1.95	3.41	4.38	4.87	4.87	4.87	4.87
2	**Income:**	Annual	212	6,000.75	1.27	0	(1.31)	(2.66)	(4.05)	(5.48)	(6.96)	(8.48)	(10.04)
3	**Construction cost**												
3A	Building:	Initial	212	20,488.53	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
3B	External works:	Initial	238	4,646.21	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
3D	Design fees:	Initial	212	3,694.40	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
4	**Operations:**	Annual	212	1,489.07	0.32	0	0.33	0.66	1.01	1.36	1.73	2.10	2.49
5	**Maintenance:**	Annual	212	311.78	0.07	0	0.07	0.14	0.21	0.28	0.36	0.44	0.52
6	**End-of-life:**	Terminal	450	6,060.27	2.73								
	Total costs					8.86	11.20	13.06	14.46	15.37	15.81	16.27	16.74
	Total Income						1.31	2.66	4.05	5.48	6.96	8.48	10.04
	Cummulative Annual totals					**8.86**	**9.89**	**10.40**	**10.41**	**9.89**	**8.86**	**7.79**	**6.70**

DURATION IN YEARS															
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87
(11.65)	(13.31)	(15.02)	(16.79)	(18.60)	(20.47)	(22.40)	(24.38)	(26.42)	(28.53)	(30.69)	(32.93)	(35.23)	(37.59)	(40.03)	(42.55)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
2.89	3.30	3.73	4.17	4.62	5.08	5.56	6.05	6.56	7.08	7.62	8.17	8.74	9.33	9.93	10.56
0.61	0.69	0.78	0.87	0.97	1.06	1.16	1.27	1.37	1.48	1.59	1.71	1.83	1.95	2.08	2.21
17.22	17.72	18.24	18.76	19.31	19.87	20.45	21.04	21.66	22.29	22.94	23.61	24.30	25.01	25.74	26.50
11.65	13.31	15.02	16.79	18.60	20.47	22.40	24.38	26.42	28.53	30.69	32.93	35.23	37.59	40.03	42.55
5.57	**4.41**	**3.21**	**1.98**	**0.71**	**(0.60)**	**(1.95)**	**(3.34)**	**(4.77)**	**(6.24)**	**(7.76)**	**(9.32)**	**(10.93)**	**(12.59)**	**(14.29)**	**(16.05)**

Appendix 12.0: Cont.

DURATION IN YEARS															
24	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87
(45.14)	(47.80)	(50.55)	(53.38)	(56.29)	(59.29)	(62.39)	(65.57)	(68.85)	(72.23)	(75.71)	(79.29)	(82.99)	(86.79)	(90.71)	(94.74)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
11.20	11.86	12.54	13.25	13.97	14.71	15.48	16.27	17.08	17.92	18.79	19.68	20.59	21.54	22.51	23.51
2.35	2.48	2.63	2.77	2.92	3.08	3.24	3.41	3.58	3.75	3.93	4.12	4.31	4.51	4.71	4.92
27.27	28.07	28.90	29.75	30.62	31.52	32.45	33.40	34.39	35.40	36.45	37.52	38.63	39.77	40.95	42.16
45.14	47.80	50.55	53.38	56.29	59.29	62.39	65.57	68.85	72.23	75.71	79.29	82.99	86.79	90.71	94.74
(17.86)	**(19.73)**	**(21.65)**	**(23.63)**	**(25.67)**	**(27.77)**	**(29.94)**	**(32.17)**	**(34.46)**	**(36.83)**	**(39.26)**	**(41.77)**	**(44.36)**	**(47.02)**	**(49.76)**	**(52.58)**

DURATION IN YEARS										
40	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87
(98.90)	(103.18)	(107.59)	(112.14)	(116.81)	(121.63)	(126.60)	(131.71)	(136.98)	(142.41)	(147.99)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
24.54	25.60	26.70	27.83	28.99	30.18	31.42	32.68	33.99	35.34	36.72
5.14	5.36	5.59	5.83	6.07	6.32	6.58	6.84	7.12	7.40	7.69
										(11.98)
43.41	44.69	46.02	47.38	48.78	50.23	51.72	53.25	54.83	56.46	58.14
98.90	103.18	107.59	112.14	116.81	121.63	126.60	131.71	136.98	142.41	159.97
(55.49)	**(58.49)**	**(61.58)**	**(64.76)**	**(68.03)**	**(71.40)**	**(74.88)**	**(78.46)**	**(82.14)**	**(85.94)**	**(101.83)**

Appendix 12.1: Test result for Scenari2 Modified traditional FV model

						DURATION IN YEARS							
S/No	Data centre	Incidence	Unit Quantity	Rate	Amount in Millions	0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	450	4,979.89	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
1B	Finance	Annual	212	8,049.24									
2	**Income:**	Annual	212	6,000.75	1.27	0	(1.31)	(2.66)	(4.05)	(5.48)	(6.96)	(8.48)	(10.04)
3	**Construction cost**												
3A	Building:	Initial	212	20,488.53	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
3B	External works:	Initial	238	4,646.21	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
3D	Design fees:	Initial	212	3,694.40	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
4	**Operations:**	Annual	212	1,489.07	0.32	0	0.33	0.66	1.01	1.36	1.73	2.10	2.49
5	**Maintenance:**	Annual	212	311.78	0.07	0	0.07	0.14	0.21	0.28	0.36	0.44	0.52
6	**End-of-life:**	Terminal	450	6,060.27	2.73	0							
	Total costs					8.86	9.25	9.66	10.07	10.50	10.94	11.40	11.87
	Total Income						1.31	2.66	4.05	5.48	6.96	8.48	10.04
	Cummulative Annual totals					**8.86**	**7.94**	**6.99**	**6.02**	**5.02**	**3.99**	**2.92**	**1.83**

DURATION IN YEARS															
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
(11.65)	(13.31)	(15.02)	(16.79)	(18.60)	(20.47)	(22.40)	(24.38)	(26.42)	(28.53)	(30.69)	(32.93)	(35.23)	(37.59)	(40.03)	(42.55)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
2.89	3.30	3.73	4.17	4.62	5.08	5.56	6.05	6.56	7.08	7.62	8.17	8.74	9.33	9.93	10.56
0.61	0.69	0.78	0.87	0.97	1.06	1.16	1.27	1.37	1.48	1.59	1.71	1.83	1.95	2.08	2.21
12.35	12.85	13.37	13.89	14.44	15.00	15.58	16.17	16.79	17.42	18.07	18.74	19.43	20.14	20.87	21.63
11.65	13.31	15.02	16.79	18.60	20.47	22.40	24.38	26.42	28.53	30.69	32.93	35.23	37.59	40.03	42.55
0.70	**(0.46)**	**(1.66)**	**(2.89)**	**(4.16)**	**(5.47)**	**(6.82)**	**(8.21)**	**(9.64)**	**(11.11)**	**(12.63)**	**(14.19)**	**(15.80)**	**(17.46)**	**(19.16)**	**(20.92)**

Appendix 12.1: Cont.

DURATION IN YEARS															
24	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
(45.14)	(47.80)	(50.55)	(53.38)	(56.29)	(59.29)	(62.39)	(65.57)	(68.85)	(72.23)	(75.71)	(79.29)	(82.99)	(86.79)	(90.71)	(94.74)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
11.20	11.86	12.54	13.25	13.97	14.71	15.48	16.27	17.08	17.92	18.79	19.68	20.59	21.54	22.51	23.51
2.35	2.48	2.63	2.77	2.92	3.08	3.24	3.41	3.58	3.75	3.93	4.12	4.31	4.51	4.71	4.92
22.40	23.20	24.03	24.88	25.75	26.65	27.58	28.53	29.52	30.53	31.58	32.65	33.76	34.90	36.08	37.29
45.14	47.80	50.55	53.38	56.29	59.29	62.39	65.57	68.85	72.23	75.71	79.29	82.99	86.79	90.71	94.74
(22.73)	**(24.60)**	**(26.52)**	**(28.50)**	**(30.54)**	**(32.64)**	**(34.81)**	**(37.04)**	**(39.33)**	**(41.70)**	**(44.13)**	**(46.64)**	**(49.23)**	**(51.89)**	**(54.63)**	**(57.45)**

DURATION IN YEARS										
40	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
(98.90)	(103.18)	(107.59)	(112.14)	(116.81)	(121.63)	(126.60)	(131.71)	(136.98)	(142.41)	(147.99)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
24.54	25.60	26.70	27.83	28.99	30.18	31.42	32.68	33.99	35.34	36.72
5.14	5.36	5.59	5.83	6.07	6.32	6.58	6.84	7.12	7.40	7.69
										(11.98)
38.54	39.82	41.15	42.51	43.91	45.36	46.85	48.38	49.96	51.59	53.27
98.90	103.18	107.59	112.14	116.81	121.63	126.60	131.71	136.98	142.41	159.97
(60.36)	**(63.36)**	**(66.45)**	**(69.63)**	**(72.90)**	**(76.27)**	**(79.75)**	**(83.33)**	**(87.01)**	**(90.81)**	**(106.70)**

Appendix 13:

Test result for modified traditional present worth model

Appendix 13.0: Test result for Scenario1 Modified traditional PV model

						DURATION IN YEARS							
S/No	Data centre	Incidence	Unit Qty	Rate	Amount in Millions	0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	450	4,979.89	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
1B	Finance	Annual	212	8,049.24	1.71	-	1.95	3.41	4.38	4.87	4.87	4.87	4.87
2	**Income:**	Annual	212	6,000.75	1.27	-	(1.24)	(2.43)	(3.60)	(4.73)	(5.83)	(6.89)	(7.92)
3	**Construction cost**												
3A	Building:	Initial	212	20,488.53	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
3B	External works:	Initial	238	4,646.21	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
3D	Design fees:	Initial	212	3,694.40	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
4	**Operations:**	Annual	212	1,489.07	0.32	0	0.31	0.60	0.89	1.17	1.45	1.71	1.97
5	**Maintenance:**	Annual	212	311.78	0.07	0	0.06	0.13	0.19	0.25	0.30	0.36	0.41
6	**End-of-life:**	Terminal	450	6,060.27	2.73								
	Total costs					8.86	11.18	13.00	14.32	15.15	15.48	15.80	16.11
	Total Income						1.24	2.43	3.60	4.73	5.83	6.89	7.92
	Cummulative Annual totals					**8.86**	**9.94**	**10.56**	**10.72**	**10.42**	**9.65**	**8.91**	**8.18**

DURATION IN YEARS															
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87
(8.93)	(9.90)	(10.85)	(11.77)	(12.66)	(13.53)	(14.37)	(15.18)	(15.97)	(16.74)	(17.49)	(18.22)	(18.92)	(19.60)	(20.27)	(20.91)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
2.22	2.46	2.69	2.92	3.14	3.36	3.56	3.77	3.96	4.15	4.34	4.52	4.69	4.86	5.03	5.19
0.46	0.51	0.56	0.61	0.66	0.70	0.75	0.79	0.83	0.87	0.91	0.95	0.98	1.02	1.05	1.09
16.41	16.70	16.98	17.26	17.53	17.79	18.04	18.28	18.52	18.75	18.98	19.19	19.41	19.61	19.81	20.00
8.93	9.90	10.85	11.77	12.66	13.53	14.37	15.18	15.97	16.74	17.49	18.22	18.92	19.60	20.27	20.91
7.48	**6.80**	**6.13**	**5.49**	**4.87**	**4.26**	**3.67**	**3.10**	**2.55**	**2.01**	**1.49**	**0.98**	**0.49**	**0.01**	**(0.46)**	**(0.91)**

Appendix 13.0: Cont.

DURATION IN YEARS															
24	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87
(21.53)	(22.14)	(22.73)	(23.30)	(23.86)	(24.40)	(24.92)	(25.43)	(25.92)	(26.40)	(26.87)	(27.32)	(27.76)	(28.18)	(28.59)	(29.00)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
5.34	5.49	5.64	5.78	5.92	6.05	6.18	6.31	6.43	6.55	6.67	6.78	6.89	6.99	7.10	7.20
1.12	1.15	1.18	1.21	1.24	1.27	1.29	1.32	1.35	1.37	1.40	1.42	1.44	1.46	1.49	1.51
20.19	20.37	20.55	20.72	20.89	21.05	21.21	21.36	21.51	21.65	21.79	21.93	22.06	22.19	22.31	22.43
21.53	22.14	22.73	23.30	23.86	24.40	24.92	25.43	25.92	26.40	26.87	27.32	27.76	28.18	28.59	29.00
(1.34)	**(1.77)**	**(2.18)**	**(2.58)**	**(2.97)**	**(3.35)**	**(3.71)**	**(4.07)**	**(4.42)**	**(4.75)**	**(5.08)**	**(5.39)**	**(5.70)**	**(6.00)**	**(6.29)**	**(6.57)**

DURATION IN YEARS										
40	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87
(29.39)	(29.76)	(30.13)	(30.49)	(30.83)	(31.17)	(31.49)	(31.81)	(32.12)	(32.42)	(32.71)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
7.29	7.39	7.48	7.57	7.65	7.73	7.82	7.89	7.97	8.04	8.12
1.53	1.55	1.57	1.58	1.60	1.62	1.64	1.65	1.67	1.68	1.70
										(2.73)
22.55	22.66	22.77	22.88	22.98	23.08	23.18	23.27	23.37	23.46	23.54
29.39	29.76	30.13	30.49	30.83	31.17	31.49	31.81	32.12	32.42	35.43
(6.84)	**(7.10)**	**(7.36)**	**(7.61)**	**(7.85)**	**(8.09)**	**(8.31)**	**(8.54)**	**(8.75)**	**(8.96)**	**(11.89)**

Appendix 13.1: Test result for Scenario2 Modified traditional PV model

S/No	Data centre	Incidence	Unit Quantity	Rate	Amount in Millions	DURATION IN YEARS 0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	450	4,979.89	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
1B	Finance	Annual	212	8,049.24									
2	**Income:**	Annual	212	6,000.75	1.27	0	(1.24)	(2.43)	(3.60)	(4.73)	(5.83)	(6.89)	(7.92)
3	**Construction cost**												
3A	Building:	Initial	212	20,488.53	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
3B	External works:	Initial	238	4,646.21	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
3D	Design fees:	Initial	212	3,694.40	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
4	**Operations:**	Annual	212	1,489.07	0.32	0	0.31	0.60	0.89	1.17	1.45	1.71	1.97
5	**Maintenance:**	Annual	212	311.78	0.07	0	0.06	0.13	0.19	0.25	0.30	0.36	0.41
6	**End-of-life:**	Terminal	450	6,060.27	2.73								
	Total costs					8.86	9.23	9.59	9.94	10.28	10.60	10.92	11.23
	Total Income						1.24	2.43	3.60	4.73	5.83	6.89	7.92
	Cummulative Annual totals					**8.86**	**7.99**	**7.15**	**6.34**	**5.55**	**4.78**	**4.03**	**3.31**

DURATION IN YEARS 8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
(8.93)	(9.90)	(10.85)	(11.77)	(12.66)	(13.53)	(14.37)	(15.18)	(15.97)	(16.74)	(17.49)	(18.22)	(18.92)	(19.60)	(20.27)	(20.91)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
2.22	2.46	2.69	2.92	3.14	3.36	3.56	3.77	3.96	4.15	4.34	4.52	4.69	4.86	5.03	5.19
0.46	0.51	0.56	0.61	0.66	0.70	0.75	0.79	0.83	0.87	0.91	0.95	0.98	1.02	1.05	1.09
11.54	11.83	12.11	12.39	12.66	12.92	13.17	13.41	13.65	13.88	14.11	14.32	14.53	14.74	14.94	15.13
8.93	9.90	10.85	11.77	12.66	13.53	14.37	15.18	15.97	16.74	17.49	18.22	18.92	19.60	20.27	20.91
2.61	**1.93**	**1.26**	**0.62**	**(0.00)**	**(0.61)**	**(1.20)**	**(1.77)**	**(2.32)**	**(2.86)**	**(3.38)**	**(3.89)**	**(4.38)**	**(4.86)**	**(5.33)**	**(5.78)**

Appendix 13.1: Cont.

DURATION IN YEARS															
24	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
(21.53)	(22.14)	(22.73)	(23.30)	(23.86)	(24.40)	(24.92)	(25.43)	(25.92)	(26.40)	(26.87)	(27.32)	(27.76)	(28.18)	(28.59)	(29.00)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
5.34	5.49	5.64	5.78	5.92	6.05	6.18	6.31	6.43	6.55	6.67	6.78	6.89	6.99	7.10	7.20
1.12	1.15	1.18	1.21	1.24	1.27	1.29	1.32	1.35	1.37	1.40	1.42	1.44	1.46	1.49	1.51
15.32	15.50	15.68	15.85	16.02	16.18	16.34	16.49	16.64	16.78	16.92	17.05	17.19	17.31	17.44	17.56
21.53	22.14	22.73	23.30	23.86	24.40	24.92	25.43	25.92	26.40	26.87	27.32	27.76	28.18	28.59	29.00
(6.22)	**(6.64)**	**(7.05)**	**(7.45)**	**(7.84)**	**(8.22)**	**(8.59)**	**(8.94)**	**(9.29)**	**(9.62)**	**(9.95)**	**(10.26)**	**(10.57)**	**(10.87)**	**(11.16)**	**(11.44)**

DURATION IN YEARS										
40	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
(29.39)	(29.76)	(30.13)	(30.49)	(30.83)	(31.17)	(31.49)	(31.81)	(32.12)	(32.42)	(32.71)
4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
7.29	7.39	7.48	7.57	7.65	7.73	7.82	7.89	7.97	8.04	8.12
1.53	1.55	1.57	1.58	1.60	1.62	1.64	1.65	1.67	1.68	1.70
										(2.73)
17.68	17.79	17.90	18.01	18.11	18.21	18.31	18.40	18.50	18.58	18.67
29.39	29.76	30.13	30.49	30.83	31.17	31.49	31.81	32.12	32.42	35.43
(11.71)	**(11.97)**	**(12.23)**	**(12.48)**	**(12.72)**	**(12.96)**	**(13.19)**	**(13.41)**	**(13.62)**	**(13.83)**	**(16.76)**

Appendix 14:

Test result for present worth of option to develop model

Appendix 14.0: Test result for Scenario1 Option to develop PV model

						DURATION IN YEARS							
S/No	Data centre	Incidence	Unit Qty	Rate	Amount in	0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	450	4,979.89	2.24	2.24	2.18	2.11	2.05	1.99	1.93	1.88	1.82
1B	Finance	Annual	212	8,049.24	1.71	4.87	4.73	4.59	4.46	4.33	4.20	4.08	3.96
2	Income:	Annual	212	6,000.75	1.27	(32.71)	(31.75)	(30.83)	(29.93)	(29.05)	(28.21)	(27.38)	(26.58)
3	**Construction cost**												
3A	Building:	Initial	212	20,488.53	4.34	4.34	4.22	4.09	3.97	3.86	3.75	3.64	3.53
3B	External works:	Initial	238	4,646.21	1.11	1.11	1.07	1.04	1.01	0.98	0.95	0.93	0.90
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38	0.37	0.36	0.35	0.34	0.33	0.32	0.31
3D	Design fees:	Initial	212	3,694.40	0.78	0.78	0.76	0.74	0.72	0.70	0.68	0.66	0.64
4	**Operations:**	Annual	212	1,489.07	0.32	8.12	7.88	7.65	7.43	7.21	7.00	6.80	6.60
5	**Maintenance:**	Annual	212	311.78	0.07	1.70	1.65	1.60	1.55	1.51	1.47	1.42	1.38
7	**End-of-life:**	Terminal	450	6,060.27	2.73	(2.73)	(2.65)	(2.57)	(2.50)	(2.42)	(2.35)	(2.28)	(2.22)
				Total cost		**23.54**	**22.86**	**22.19**	**21.54**	**20.91**	**20.30**	**19.71**	**19.14**
				Total Income		**35.43**	**34.40**	**33.40**	**32.42**	**31.48**	**30.56**	**29.67**	**28.80**
				NPV		**11.89**	**11.54**	**11.21**	**10.88**	**10.56**	**10.26**	**9.96**	**9.67**
				d1		3E+27	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00
				d2		3E+27	6E-01	3E-01	1E-01	3E-02	-6E-02	-1E-01	-2E-01
				N(d1)		1E+00	9E-01	8E-01	8E-01	8E-01	9E-01	9E-01	9E-01
				N(d2)		1E+00	7E-01	6E-01	6E-01	5E-01	5E-01	4E-01	4E-01
				Option Value		**11.89**	**13.14**	**14.44**	**15.35**	**16.00**	**16.46**	**16.77**	**16.98**
				BCR		**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**
				PI of NPV		**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**
				PI of Option Value		**0.51**	**0.57**	**0.65**	**0.71**	**0.77**	**0.81**	**0.85**	**0.89**

Appendix 14.0:

DURATION IN YEARS															
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1.77	1.72	1.67	1.62	1.57	1.53	1.48	1.44	1.40	1.35	1.32	1.28	1.24	1.20	1.17	1.13
3.84	3.73	3.62	3.52	3.41	3.31	3.22	3.12	3.03	2.94	2.86	2.78	2.69	2.62	2.54	2.47
(25.81)	(25.06)	(24.33)	(23.62)	(22.93)	(22.26)	(21.61)	(20.98)	(20.37)	(19.77)	(19.20)	(18.64)	(18.09)	(17.57)	(17.05)	(16.56)
3.43	3.33	3.23	3.14	3.04	2.96	2.87	2.79	2.70	2.63	2.55	2.48	2.40	2.33	2.26	2.20
0.87	0.85	0.82	0.80	0.78	0.75	0.73	0.71	0.69	0.67	0.65	0.63	0.61	0.59	0.58	0.56
0.30	0.29	0.28	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.19
0.62	0.60	0.58	0.57	0.55	0.53	0.52	0.50	0.49	0.47	0.46	0.45	0.43	0.42	0.41	0.40
6.40	6.22	6.04	5.86	5.69	5.52	5.36	5.21	5.05	4.91	4.76	4.62	4.49	4.36	4.23	4.11
1.34	1.30	1.26	1.23	1.19	1.16	1.12	1.09	1.06	1.03	1.00	0.97	0.94	0.91	0.89	0.86
(2.15)	(2.09)	(2.03)	(1.97)	(1.91)	(1.86)	(1.80)	(1.75)	(1.70)	(1.65)	(1.60)	(1.55)	(1.51)	(1.46)	(1.42)	(1.38)
18.58	**18.04**	**17.51**	**17.00**	**16.50**	**16.02**	**15.55**	**15.10**	**14.66**	**14.23**	**13.82**	**13.41**	**13.02**	**12.64**	**12.28**	**11.92**
27.96	**27.15**	**26.35**	**25.59**	**24.84**	**24.11**	**23.41**	**22.73**	**22.07**	**21.42**	**20.80**	**20.19**	**19.60**	**19.03**	**18.48**	**17.94**
9.38	**9.11**	**8.84**	**8.59**	**8.34**	**8.09**	**7.86**	**7.63**	**7.41**	**7.19**	**6.98**	**6.78**	**6.58**	**6.39**	**6.20**	**6.02**
1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00
-2E-01	-3E-01	-3E-01	-4E-01	-4E-01	-5E-01	-5E-01	-5E-01	-6E-01	-6E-01	-6E-01	-6E-01	-7E-01	-7E-01	-7E-01	-7E-01
9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	1E+00
4E-01	4E-01	4E-01	4E-01	3E-01	3E-01	3E-01	3E-01	3E-01	3E-01	3E-01	3E-01	3E-01	2E-01	2E-01	2E-01
17.09	**17.13**	**17.11**	**17.04**	**16.92**	**16.78**	**16.60**	**16.40**	**16.18**	**15.95**	**15.70**	**15.44**	**15.17**	**14.89**	**14.61**	**14.33**
1.51	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**
0.51	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**
0.92	**0.95**	**0.98**	**1.00**	**1.03**	**1.05**	**1.07**	**1.09**	**1.10**	**1.12**	**1.14**	**1.15**	**1.16**	**1.18**	**1.19**	**1.20**

Appendix 14.0: Cont.

DURATION IN YEARS															
24	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
1.10	1.07	1.04	1.01	0.98	0.95	0.92	0.90	0.87	0.84	0.82	0.80	0.77	0.75	0.73	0.71
2.39	2.32	2.26	2.19	2.13	2.06	2.00	1.95	1.89	1.83	1.78	1.73	1.68	1.63	1.58	1.54
(16.07)	(15.60)	(15.15)	(14.71)	(14.28)	(13.86)	(13.46)	(13.06)	(12.68)	(12.31)	(11.95)	(11.61)	(11.27)	(10.94)	(10.62)	(10.31)
2.13	2.07	2.01	1.95	1.90	1.84	1.79	1.74	1.68	1.64	1.59	1.54	1.50	1.45	1.41	1.37
0.54	0.53	0.51	0.50	0.48	0.47	0.46	0.44	0.43	0.42	0.40	0.39	0.38	0.37	0.36	0.35
0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.12
0.38	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.30	0.29	0.29	0.28	0.27	0.26	0.25	0.25
3.99	3.87	3.76	3.65	3.54	3.44	3.34	3.24	3.15	3.06	2.97	2.88	2.80	2.71	2.64	2.56
0.84	0.81	0.79	0.76	0.74	0.72	0.70	0.68	0.66	0.64	0.62	0.60	0.59	0.57	0.55	0.54
(1.34)	(1.30)	(1.26)	(1.23)	(1.19)	(1.16)	(1.12)	(1.09)	(1.06)	(1.03)	(1.00)	(0.97)	(0.94)	(0.91)	(0.89)	(0.86)
11.57	**11.23**	**10.90**	**10.59**	**10.28**	**9.98**	**9.69**	**9.40**	**9.13**	**8.86**	**8.61**	**8.35**	**8.11**	**7.87**	**7.64**	**7.42**
17.41	**16.91**	**16.41**	**15.93**	**15.47**	**15.02**	**14.58**	**14.15**	**13.74**	**13.34**	**12.95**	**12.57**	**12.21**	**11.85**	**11.51**	**11.17**
5.84	**5.67**	**5.51**	**5.35**	**5.19**	**5.04**	**4.89**	**4.75**	**4.61**	**4.48**	**4.35**	**4.22**	**4.10**	**3.98**	**3.86**	**3.75**
2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00
-8E-01	-8E-01	-8E-01	-8E-01	-9E-01	-9E-01	-9E-01	-9E-01	-9E-01	-9E-01	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00
1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00
2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	1E-01	1E-01
14.04	**13.75**	**13.46**	**13.17**	**12.88**	**12.59**	**12.30**	**12.02**	**11.74**	**11.46**	**11.18**	**10.91**	**10.65**	**10.38**	**10.13**	**9.87**
1.51	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**
0.51	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**
1.21	**1.22**	**1.23**	**1.24**	**1.25**	**1.26**	**1.27**	**1.28**	**1.29**	**1.29**	**1.30**	**1.31**	**1.31**	**1.32**	**1.32**	**1.33**

Appendix 14.0: Cont.

DURATION IN YEARS										
40	41	42	43	44	45	46	47	48	49	50
0.69	0.67	0.65	0.63	0.61	0.59	0.57	0.56	0.54	0.53	0.51
1.49	1.45	1.40	1.36	1.32	1.29	1.25	1.21	1.18	1.14	1.11
(10.01)	(9.72)	(9.43)	(9.16)	(8.89)	(8.63)	(8.38)	(8.14)	(7.90)	(7.67)	(7.44)
1.33	1.29	1.25	1.22	1.18	1.15	1.11	1.08	1.05	1.02	0.99
0.34	0.33	0.32	0.31	0.30	0.29	0.28	0.28	0.27	0.26	0.25
0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.09	0.09
0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.19	0.19	0.18	0.18
2.48	2.41	2.34	2.27	2.21	2.14	2.08	2.02	1.96	1.90	1.85
0.52	0.50	0.49	0.48	0.46	0.45	0.44	0.42	0.41	0.40	0.39
(0.83)	(0.81)	(0.79)	(0.76)	(0.74)	(0.72)	(0.70)	(0.68)	(0.66)	(0.64)	(0.62)
7.20	**6.99**	**6.79**	**6.59**	**6.40**	**6.21**	**6.03**	**5.86**	**5.69**	**5.52**	**5.36**
10.84	**10.53**	**10.22**	**9.92**	**9.63**	**9.35**	**9.08**	**8.81**	**8.56**	**8.31**	**8.07**
3.64	**3.53**	**3.43**	**3.33**	**3.23**	**3.14**	**3.05**	**2.96**	**2.87**	**2.79**	**2.71**
2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00
-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00
1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00
1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01
9.62	**9.38**	**9.14**	**8.90**	**8.67**	**8.45**	**8.23**	**8.01**	**7.80**	**7.59**	**7.39**
1.51	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**	**1.51**
0.51	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**
1.34	**1.34**	**1.35**	**1.35**	**1.36**	**1.36**	**1.36**	**1.37**	**1.37**	**1.38**	**1.38**

Appendix 14.1: Test result for Scenario2 Option to develop PV model

						DURATION IN YEARS							
S/No	External works:	Incidence	Unit Qty	Rate	Amount in	0	1	2	3	4	5	6	7
1	**Non-construction cost:**												
1A	Land	Initial	212	4,979.89	2.24	2.24	2.18	2.11	2.05	1.99	1.93	1.88	1.82
1B	Finance	Annual	212	8,049.24	1.71		-	-	-	-	-	-	-
2	Income:	Annual	212	6,000.75	1.27	(32.71)	(31.75)	(30.83)	(29.93)	(29.05)	(28.21)	(27.38)	(26.58)
3	**Construction cost**												
3A	Building:	Initial	212	20,488.53	4.34	4.34	4.22	4.09	3.97	3.86	3.75	3.64	3.53
3B	External works:	Initial	238	4,646.21	1.11	1.11	1.07	1.04	1.01	0.98	0.95	0.93	0.90
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38	0.37	0.36	0.35	0.34	0.33	0.32	0.31
3D	Design fees:	Initial	212	3,694.40	0.78	0.78	0.76	0.74	0.72	0.70	0.68	0.66	0.64
4	**Operations:**	Annual	212	1,489.07	0.32	8.12	7.88	7.65	7.43	7.21	7.00	6.80	6.60
5	**Maintenance:**	Annual	212	311.78	0.07	1.70	1.65	1.60	1.55	1.51	1.47	1.42	1.38
7	**End-of-life:**	Terminal	450	6,060.27	2.73	(2.73)	(2.65)	(2.57)	(2.50)	(2.42)	(2.35)	(2.28)	(2.22)
				Total cost		**18.67**	**18.13**	**17.60**	**17.09**	**16.59**	**16.10**	**15.63**	**15.18**
				Total Income		**35.43**	**34.40**	**33.40**	**32.42**	**31.48**	**30.56**	**29.67**	**28.80**
				NPV		**16.76**	**16.27**	**15.80**	**15.34**	**14.89**	**14.46**	**14.03**	**13.62**
				d1		4E+27	2E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00
				d2		4E+27	1E+00	6E-01	4E-01	3E-01	1E-01	6E-02	-2E-02
				N(d1)		1E+00	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01
				N(d2)		1E+00	9E-01	7E-01	7E-01	6E-01	6E-01	5E-01	5E-01
				Option Value		**16.76**	**16.85**	**17.42**	**17.89**	**18.21**	**18.42**	**18.53**	**18.56**
				BCR		1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
				PI of NPV		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
				PI of Option Value		0.90	0.93	0.99	1.05	1.10	1.14	1.19	1.22

Appendix 14.1:Cont.

DURATION IN YEARS															
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1.77	1.72	1.67	1.62	1.57	1.53	1.48	1.44	1.40	1.35	1.32	1.28	1.24	1.20	1.17	1.13
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(25.81)	(25.06)	(24.33)	(23.62)	(22.93)	(22.26)	(21.61)	(20.98)	(20.37)	(19.77)	(19.20)	(18.64)	(18.09)	(17.57)	(17.05)	(16.56)
3.43	3.33	3.23	3.14	3.04	2.96	2.87	2.79	2.70	2.63	2.55	2.48	2.40	2.33	2.26	2.20
0.87	0.85	0.82	0.80	0.78	0.75	0.73	0.71	0.69	0.67	0.65	0.63	0.61	0.59	0.58	0.56
0.30	0.29	0.28	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.19
0.62	0.60	0.58	0.57	0.55	0.53	0.52	0.50	0.49	0.47	0.46	0.45	0.43	0.42	0.41	0.40
6.40	6.22	6.04	5.86	5.69	5.52	5.36	5.21	5.05	4.91	4.76	4.62	4.49	4.36	4.23	4.11
1.34	1.30	1.26	1.23	1.19	1.16	1.12	1.09	1.06	1.03	1.00	0.97	0.94	0.91	0.89	0.86
(2.15)	(2.09)	(2.03)	(1.97)	(1.91)	(1.86)	(1.80)	(1.75)	(1.70)	(1.65)	(1.60)	(1.55)	(1.51)	(1.46)	(1.42)	(1.38)
14.73	**14.31**	**13.89**	**13.48**	**13.09**	**12.71**	**12.34**	**11.98**	**11.63**	**11.29**	**10.96**	**10.64**	**10.33**	**10.03**	**9.74**	**9.45**
27.96	**27.15**	**26.35**	**25.59**	**24.84**	**24.11**	**23.41**	**22.73**	**22.07**	**21.42**	**20.80**	**20.19**	**19.60**	**19.03**	**18.48**	**17.94**
13.23	**12.84**	**12.47**	**12.10**	**11.75**	**11.41**	**11.07**	**10.75**	**10.44**	**10.13**	**9.84**	**9.55**	**9.27**	**9.00**	**8.74**	**8.48**
1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00
-8E-02	-1E-01	-2E-01	-2E-01	-3E-01	-3E-01	-4E-01	-4E-01	-4E-01	-5E-01	-5E-01	-5E-01	-6E-01	-6E-01	-6E-01	-6E-01
9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	9E-01	1E+00	1E+00	1E+00	1E+00	1E+00
5E-01	4E-01	4E-01	4E-01	4E-01	4E-01	4E-01	3E-01	3E-01	3E-01	3E-01	3E-01	3E-01	3E-01	3E-01	3E-01
18.52	**18.43**	**18.30**	**18.13**	**17.93**	**17.71**	**17.46**	**17.20**	**16.92**	**16.63**	**16.33**	**16.03**	**15.72**	**15.40**	**15.09**	**14.77**
1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
1.26	1.29	1.32	1.34	1.37	1.39	1.42	1.44	1.45	1.47	1.49	1.51	1.52	1.54	1.55	1.56

Appendix 14.1:Cont.

DURATION IN YEARS															
24	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
1.10	1.07	1.04	1.01	0.98	0.95	0.92	0.90	0.87	0.84	0.82	0.80	0.77	0.75	0.73	0.71
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(16.07)	(15.60)	(15.15)	(14.71)	(14.28)	(13.86)	(13.46)	(13.06)	(12.68)	(12.31)	(11.95)	(11.61)	(11.27)	(10.94)	(10.62)	(10.31)
2.13	2.07	2.01	1.95	1.90	1.84	1.79	1.74	1.68	1.64	1.59	1.54	1.50	1.45	1.41	1.37
0.54	0.53	0.51	0.50	0.48	0.47	0.46	0.44	0.43	0.42	0.40	0.39	0.38	0.37	0.36	0.35
0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.12
0.38	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.30	0.29	0.29	0.28	0.27	0.26	0.25	0.25
3.99	3.87	3.76	3.65	3.54	3.44	3.34	3.24	3.15	3.06	2.97	2.88	2.80	2.71	2.64	2.56
0.84	0.81	0.79	0.76	0.74	0.72	0.70	0.68	0.66	0.64	0.62	0.60	0.59	0.57	0.55	0.54
(1.34)	(1.30)	(1.26)	(1.23)	(1.19)	(1.16)	(1.12)	(1.09)	(1.06)	(1.03)	(1.00)	(0.97)	(0.94)	(0.91)	(0.89)	(0.86)
9.18	**8.91**	**8.65**	**8.40**	**8.15**	**7.91**	**7.68**	**7.46**	**7.24**	**7.03**	**6.83**	**6.63**	**6.43**	**6.25**	**6.06**	**5.89**
17.41	**16.91**	**16.41**	**15.93**	**15.47**	**15.02**	**14.58**	**14.15**	**13.74**	**13.34**	**12.95**	**12.57**	**12.21**	**11.85**	**11.51**	**11.17**
8.24	**8.00**	**7.76**	**7.54**	**7.32**	**7.10**	**6.90**	**6.70**	**6.50**	**6.31**	**6.13**	**5.95**	**5.77**	**5.61**	**5.44**	**5.28**
2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00
-7E-01	-7E-01	-7E-01	-7E-01	-8E-01	-8E-01	-8E-01	-8E-01	-8E-01	-9E-01	-9E-01	-9E-01	-9E-01	-9E-01	-1E+00	-1E+00
1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00
3E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01	2E-01
14.45	**14.13**	**13.82**	**13.50**	**13.19**	**12.88**	**12.58**	**12.28**	**11.98**	**11.69**	**11.40**	**11.11**	**10.83**	**10.56**	**10.29**	**10.03**
1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
1.57	1.59	1.60	1.61	1.62	1.63	1.64	1.65	1.65	1.66	1.67	1.68	1.68	1.69	1.70	1.70

Appendix 14.1:Cont

DURATION IN YEARS										
40	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
0.69	0.67	0.65	0.63	0.61	0.59	0.57	0.56	0.54	0.53	0.51
-	-	-	-	-	-	-	-	-	-	-
(10.01)	(9.72)	(9.43)	(9.16)	(8.89)	(8.63)	(8.38)	(8.14)	(7.90)	(7.67)	(7.44)
1.33	1.29	1.25	1.22	1.18	1.15	1.11	1.08	1.05	1.02	0.99
0.34	0.33	0.32	0.31	0.30	0.29	0.28	0.28	0.27	0.26	0.25
0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.09	0.09
0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.19	0.19	0.18	0.18
2.48	2.41	2.34	2.27	2.21	2.14	2.08	2.02	1.96	1.90	1.85
0.52	0.50	0.49	0.48	0.46	0.45	0.44	0.42	0.41	0.40	0.39
(0.83)	(0.81)	(0.79)	(0.76)	(0.74)	(0.72)	(0.70)	(0.68)	(0.66)	(0.64)	(0.62)
5.71	**5.55**	**5.39**	**5.23**	**5.08**	**4.93**	**4.78**	**4.65**	**4.51**	**4.38**	**4.25**
10.84	**10.53**	**10.22**	**9.92**	**9.63**	**9.35**	**9.08**	**8.81**	**8.56**	**8.31**	**8.07**
5.13	**4.98**	**4.83**	**4.69**	**4.56**	**4.42**	**4.29**	**4.17**	**4.05**	**3.93**	**3.82**
2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00	2E+00
-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00	-1E+00
1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00
2E-01	2E-01	2E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01
9.77	**9.52**	**9.27**	**9.03**	**8.79**	**8.56**	**8.33**	**8.11**	**7.89**	**7.68**	**7.47**
1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
1.71	1.72	1.72	1.73	1.73	1.74	1.74	1.75	1.75	1.75	1.76

Appendix 15:

Test result for future worth of option to develop model

Appendix 15.0: Test result for Scenario1 Option to develop FV model

						DURATION IN YEARS					
S/No	Data centre	Incidence	Unit Qty	Rate	Amount in M	0	1	2	3	4	5
1	**Non-construction cost:**										
1A	Land	Initial	450	4,979.89	2.24	2.24	2.31	2.38	2.45	2.52	2.60
1B	Finance	Annual	212	8,049.24	1.71	4.50	4.64	4.77	4.92	5.07	5.22
2	Income:	Annual	212	6,000.75	1.27	**(32.71)**	**(33.69)**	**(34.70)**	**(35.74)**	**(36.82)**	**(37.92)**
3	**Construction cost**										
3A	Building:	Initial	212	20,488.53	4.34	4.34	4.47	4.61	4.75	4.89	5.04
3B	External works:	Initial	238	4,646.21	1.11	1.11	1.14	1.17	1.21	1.24	1.28
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38	0.39	0.41	0.42	0.43	0.44
3D	Design fees:	Initial	212	3,694.40	0.78	0.78	0.81	0.83	0.86	0.88	0.91
4	**Operations:**	Annual	212	1,489.07	0.32	**8.12**	0.33	0.33	0.34	0.36	0.37
5	**Maintenance:**	Annual	212	311.78	0.07	**1.70**	0.07	0.07	0.07	0.07	0.08
7	**End-of-life:**	Terminal	450	6,060.27	2.73	(2.73)	(2.81)	(2.89)	(2.98)	(3.07)	(3.16)
				Total cost		**23.17**	**14.15**	**14.58**	**15.01**	**15.47**	**15.93**
				Total Income		**35.43**	**36.50**	**37.59**	**38.72**	**39.89**	**41.08**
				NPV		**12.26**	**22.35**	**23.02**	**23.71**	**24.42**	**25.15**
				d1		2.7E+27	2.20496	1.77841	1.63109	1.56761	1.54079
				d2		2.7E+27	1.70496	1.0713	0.76507	0.56761	0.42275
				N(d1)		1	0.98627	0.96233	0.94856	0.94151	0.93832
				N(d2)		1	0.9559	0.85798	0.77788	0.71485	0.66376
				Option Value		**12.26**	**22.47**	**23.67**	**25.05**	**26.50**	**27.98**
				BCR		1.53	2.58	2.58	2.58	2.58	2.58
				PI of NPV		0.53	1.58	1.58	1.58	1.58	1.58
				PI of Option Value		0.53	1.59	1.62	1.67	1.71	1.76

Appendix 15.0:

DURATION IN YEARS														
6	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
2.68	2.76	2.84	2.93	3.01	3.10	3.20	3.29	3.39	3.49	3.60	3.71	3.82	3.93	4.05
5.37	5.54	5.70	5.87	6.05	6.23	6.42	6.61	6.81	7.02	7.23	7.44	7.67	7.90	8.13
(39.06)	**(40.24)**	**(41.44)**	**(42.69)**	**(43.97)**	**(45.29)**	**(46.65)**	**(48.06)**	**(49.50)**	**(50.99)**	**(52.52)**	**(54.10)**	**(55.72)**	**(57.40)**	**(59.12)**
5.19	5.34	5.50	5.67	5.84	6.02	6.20	6.38	6.57	6.77	6.97	7.18	7.40	7.62	7.85
1.32	1.36	1.40	1.44	1.49	1.53	1.58	1.62	1.67	1.72	1.78	1.83	1.88	1.94	2.00
0.46	0.47	0.49	0.50	0.52	0.53	0.55	0.56	0.58	0.60	0.62	0.63	0.65	0.67	0.69
0.94	0.96	0.99	1.02	1.05	1.08	1.12	1.15	1.19	1.22	1.26	1.30	1.33	1.37	1.42
0.38	0.39	0.40	0.41	0.42	0.44	0.45	0.46	0.48	0.49	0.51	0.52	0.54	0.55	0.57
0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.12
(3.26)	(3.35)	(3.46)	(3.56)	(3.67)	(3.78)	(3.89)	(4.01)	(4.13)	(4.25)	(4.38)	(4.51)	(4.65)	(4.79)	(4.93)
16.41	**16.90**	**17.41**	**17.93**	**18.47**	**19.03**	**19.60**	**20.19**	**20.79**	**21.42**	**22.06**	**22.72**	**23.41**	**24.11**	**24.83**
42.32	**43.59**	**44.90**	**46.25**	**47.64**	**49.07**	**50.54**	**52.06**	**53.63**	**55.24**	**56.90**	**58.61**	**60.37**	**62.18**	**64.05**
25.91	**26.69**	**27.49**	**28.32**	**29.17**	**30.04**	**30.95**	**31.88**	**32.83**	**33.82**	**34.84**	**35.88**	**36.96**	**38.07**	**39.22**
1.53313	1.53661	1.54699	1.56188	1.57979	1.59976	1.62117	1.64357	1.66666	1.69021	1.71406	1.73809	1.76221	1.78635	1.81045
0.30839	0.21373	0.13278	0.06188	-0.0013	-0.0585	-0.1109	-0.1592	-0.2042	-0.2463	-0.2859	-0.3235	-0.3591	-0.3931	-0.4256
0.93738	0.93781	0.93907	0.94084	0.94292	0.94517	0.94751	0.94987	0.95221	0.95451	0.95674	0.9589	0.96098	0.96298	0.96489
0.62111	0.58462	0.55282	0.52467	0.49946	0.47666	0.45586	0.43676	0.41911	0.40273	0.38746	0.37317	0.35976	0.34712	0.33519
29.48	**31.00**	**32.54**	**34.10**	**35.69**	**37.31**	**38.96**	**40.64**	**42.35**	**44.10**	**45.89**	**47.72**	**49.59**	**51.51**	**53.48**
2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58
1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
1.80	1.83	1.87	1.90	1.93	1.96	1.99	2.01	2.04	2.06	2.08	2.10	2.12	2.14	2.15

Appendix 15.0: Cont.

DURATION IN YEARS														
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
4.17	4.30	4.43	4.56	4.70	4.84	4.98	5.13	5.29	5.45	5.61	5.78	5.95	6.13	6.31
8.38	8.63	8.89	9.16	9.43	9.72	10.01	10.31	10.62	10.94	11.26	11.60	11.95	12.31	12.68
(60.90)	**(62.72)**	**(64.61)**	**(66.55)**	**(68.55)**	**(70.61)**	**(72.73)**	**(74.92)**	**(77.17)**	**(79.48)**	**(81.87)**	**(84.33)**	**(86.87)**	**(89.48)**	**(92.16)**
8.09	8.33	8.58	8.84	9.10	9.38	9.66	9.95	10.25	10.56	10.87	11.20	11.54	11.88	12.24
2.06	2.12	2.18	2.25	2.32	2.39	2.46	2.53	2.61	2.69	2.77	2.85	2.94	3.03	3.12
0.71	0.73	0.76	0.78	0.80	0.83	0.85	0.88	0.90	0.93	0.96	0.99	1.02	1.05	1.08
1.46	1.50	1.55	1.59	1.64	1.69	1.74	1.79	1.85	1.90	1.96	2.02	2.08	2.14	2.21
0.59	0.61	0.62	0.64	0.66	0.68	0.70	0.72	0.74	0.77	0.79	0.81	0.84	0.86	0.89
0.12	0.13	0.13	0.13	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.18	0.18	0.19
(5.08)	(5.23)	(5.39)	(5.55)	(5.72)	(5.89)	(6.06)	(6.25)	(6.43)	(6.63)	(6.83)	(7.03)	(7.24)	(7.46)	(7.68)
25.58	**26.35**	**27.14**	**27.96**	**28.80**	**29.66**	**30.55**	**31.47**	**32.41**	**33.39**	**34.39**	**35.42**	**36.49**	**37.59**	**38.71**
65.97	**67.96**	**70.00**	**72.10**	**74.27**	**76.50**	**78.80**	**81.16**	**83.60**	**86.11**	**88.70**	**91.36**	**94.11**	**96.94**	**99.85**
40.39	**41.61**	**42.86**	**44.14**	**45.47**	**46.84**	**48.24**	**49.69**	**51.19**	**52.72**	**54.31**	**55.94**	**57.62**	**59.35**	**61.13**
1.83449	1.85842	1.88223	1.90589	1.9294	1.95275	1.97592	1.99892	2.02173	2.04437	2.06681	2.08908	2.11116	2.13306	2.15478
-0.4568	-0.4868	-0.5157	-0.5436	-0.5706	-0.5968	-0.6222	-0.6468	-0.6708	-0.6942	-0.7171	-0.7393	-0.7611	-0.7824	-0.8033
0.96671	0.96845	0.9701	0.97167	0.97316	0.97458	0.97592	0.97719	0.9784	0.97954	0.98062	0.98165	0.98262	0.98354	0.98441
0.32391	0.3132	0.30304	0.29336	0.28414	0.27533	0.26692	0.25887	0.25116	0.24376	0.23667	0.22985	0.22329	0.21699	0.21091
55.49	**57.56**	**59.68**	**61.86**	**64.09**	**66.39**	**68.74**	**71.16**	**73.65**	**76.21**	**78.84**	**81.55**	**84.33**	**87.19**	**90.13**
2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58
1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
2.17	2.18	2.20	2.21	2.23	2.24	2.25	2.26	2.27	2.28	2.29	2.30	2.31	2.32	2.33

Appendix 15.0: Cont.

DURATION IN YEARS														
36	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
6.50	6.70	6.90	7.11	7.32	7.54	7.77	8.00	8.24	8.49	8.75	9.01	9.28	9.56	9.84
13.06	13.45	13.86	14.27	14.70	15.15	15.60	16.07	16.55	17.05	17.56	18.09	18.63	19.19	19.77
(94.93)	**(97.78)**	**(100.72)**	**(103.75)**	**(106.87)**	**(110.08)**	**(113.38)**	**(116.79)**	**(120.30)**	**(123.91)**	**(127.63)**	**(131.47)**	**(135.42)**	**(139.49)**	**(143.68)**
12.61	12.99	13.38	13.78	14.19	14.62	15.06	15.51	15.98	16.46	16.95	17.46	17.98	18.52	19.08
3.21	3.31	3.41	3.51	3.61	3.72	3.83	3.95	4.07	4.19	4.32	4.45	4.58	4.72	4.86
1.11	1.15	1.18	1.22	1.25	1.29	1.33	1.37	1.41	1.45	1.50	1.54	1.59	1.63	1.68
2.27	2.34	2.41	2.48	2.56	2.64	2.72	2.80	2.88	2.97	3.06	3.15	3.24	3.34	3.44
0.92	0.94	0.97	1.00	1.03	1.06	1.09	1.13	1.16	1.20	1.23	1.27	1.31	1.35	1.39
0.19	0.20	0.20	0.21	0.22	0.22	0.23	0.24	0.24	0.25	0.26	0.27	0.27	0.28	0.29
(7.92)	(8.15)	(8.40)	(8.65)	(8.91)	(9.18)	(9.45)	(9.74)	(10.03)	(10.33)	(10.64)	(10.96)	(11.29)	(11.63)	(11.98)
39.88	**41.08**	**42.31**	**43.58**	**44.89**	**46.24**	**47.63**	**49.06**	**50.53**	**52.05**	**53.61**	**55.23**	**56.88**	**58.59**	**60.35**
102.85	**105.94**	**109.12**	**112.40**	**115.78**	**119.25**	**122.84**	**126.53**	**130.33**	**134.24**	**138.28**	**142.43**	**146.71**	**151.12**	**155.66**
62.97	**64.86**	**66.81**	**68.82**	**70.89**	**73.02**	**75.21**	**77.47**	**79.80**	**82.19**	**84.66**	**87.21**	**89.83**	**92.52**	**95.30**
2.17633	2.19769	2.218887	2.239908	2.260761	2.281448	2.301971	2.322335	2.34254	2.36259	2.382489	2.402237	2.421839	2.441297	2.460614
-0.8237	-0.8437	-0.86332	-0.88259	-0.90152	-0.92011	-0.9384	-0.95638	-0.97408	-0.99151	-1.00868	-1.02559	-1.04226	-1.0587	-1.07492
0.98523	0.98601	0.986753	0.987452	0.988113	0.988739	0.989332	0.989893	0.990424	0.990926	0.991402	0.991852	0.992279	0.992683	0.993065
0.20506	0.19942	0.193981	0.188729	0.183657	0.178757	0.17402	0.169439	0.165007	0.160718	0.156565	0.152542	0.148645	0.144868	0.141205
93.15	**96.27**	**99.47**	**102.76**	**106.16**	**109.65**	**113.24**	**116.94**	**120.74**	**124.66**	**128.69**	**132.85**	**137.12**	**141.52**	**146.06**
2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58
1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
2.34	2.34	2.35	2.36	2.36	2.37	2.38	2.38	2.39	2.39	2.40	2.41	2.41	2.42	2.42

Appendix 15.0: Test result for Scenario2 Option to develop FV model

						DURATION IN YEARS					
S/No	External works:	Incidence	Unit Qty	Rate	Amount in M	0	1	2	3	4	5
1	**Non-construction cost:**										
1A	Land	Initial	212	4,979.89	2.24	2.24	2.31	2.38	2.45	2.52	2.60
1B	Finance	Annual	212	8,049.24	1.71		-	-	-	-	-
2	Income:	Annual	212	6,000.75	1.27	**(32.71)**	**(33.69)**	**(34.70)**	**(35.74)**	**(36.82)**	**(37.92)**
3	**Construction cost**										
3A	Building:	Initial	212	20,488.53	4.34	4.34	4.47	4.61	4.75	4.89	5.04
3B	External works:	Initial	238	4,646.21	1.11	1.11	1.14	1.17	1.21	1.24	1.28
3C	Preliminaries:	Initial	212	1,807.43	0.38	0.38	0.39	0.41	0.42	0.43	0.44
3D	Design fees:	Initial	212	3,694.40	0.78	0.78	0.81	0.83	0.86	0.88	0.91
4	**Operations:**	Annual	212	1,489.07	0.32	**8.12**	0.33	0.33	0.34	0.36	0.37
5	**Maintenance:**	Annual	212	311.78	0.07	**1.70**	0.07	0.07	0.07	0.07	0.08
7	**End-of-life:**	Terminal	450	6,060.27	2.73	(2.73)	(2.81)	(2.89)	(2.98)	(3.07)	(3.16)
				Total cost		**18.67**	**9.52**	**9.80**	**10.10**	**10.40**	**10.71**
				Total Income		**35.43**	**36.50**	**37.59**	**38.72**	**39.89**	**41.08**
				NPV		**16.76**	**26.98**	**27.79**	**28.63**	**29.49**	**30.37**
				d1		4.1E+27	2.99861	2.3396	2.0893	1.96443	1.89572
				d2		4.1E+27	2.49861	1.63249	1.22328	0.96443	0.77768
				N(d1)		1	0.99864	0.99035	0.98166	0.97526	0.971
				N(d2)		1	0.99377	0.94871	0.88939	0.83259	0.78162
				Option Value		**16.76**	**26.99**	**27.93**	**29.03**	**30.24**	**31.52**
				BCR		1.90	3.84	3.84	3.84	3.84	3.84
				PI of NPV		0.90	2.84	2.84	2.84	2.84	2.84
				PI of Option Value		0.90	2.84	2.85	2.88	2.91	2.94

Appendix 15.1:Cont.

DURATION IN YEARS														
6	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
2.68	2.76	2.84	2.93	3.01	3.10	3.20	3.29	3.39	3.49	3.60	3.71	3.82	3.93	4.05
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(39.06)	**(40.24)**	**(41.44)**	**(42.69)**	**(43.97)**	**(45.29)**	**(46.65)**	**(48.06)**	**(49.50)**	**(50.99)**	**(52.52)**	**(54.10)**	**(55.72)**	**(57.40)**	**(59.12)**
5.19	5.34	5.50	5.67	5.84	6.02	6.20	6.38	6.57	6.77	6.97	7.18	7.40	7.62	7.85
1.32	1.36	1.40	1.44	1.49	1.53	1.58	1.62	1.67	1.72	1.78	1.83	1.88	1.94	2.00
0.46	0.47	0.49	0.50	0.52	0.53	0.55	0.56	0.58	0.60	0.62	0.63	0.65	0.67	0.69
0.94	0.96	0.99	1.02	1.05	1.08	1.12	1.15	1.19	1.22	1.26	1.30	1.33	1.37	1.42
0.38	0.39	0.40	0.41	0.42	0.44	0.45	0.46	0.48	0.49	0.51	0.52	0.54	0.55	0.57
0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.12
(3.26)	(3.35)	(3.46)	(3.56)	(3.67)	(3.78)	(3.89)	(4.01)	(4.13)	(4.25)	(4.38)	(4.51)	(4.65)	(4.79)	(4.93)
11.03	**11.37**	**11.71**	**12.06**	**12.42**	**12.79**	**13.18**	**13.57**	**13.98**	**14.40**	**14.83**	**15.28**	**15.74**	**16.21**	**16.70**
42.32	**43.59**	**44.90**	**46.25**	**47.64**	**49.07**	**50.54**	**52.06**	**53.63**	**55.24**	**56.90**	**58.61**	**60.37**	**62.18**	**64.05**
31.29	**32.23**	**33.19**	**34.19**	**35.22**	**36.28**	**37.37**	**38.49**	**39.64**	**40.84**	**42.06**	**43.33**	**44.63**	**45.97**	**47.35**
1.85714	1.83658	1.82759	1.82643	1.83076	1.83906	1.85028	1.86369	1.87877	1.89513	1.91247	1.93058	1.94927	1.96842	1.98792
0.63239	0.5137	0.41338	0.32643	0.24962	0.18075	0.11823	0.06092	0.00794	-0.0414	-0.0875	-0.131	-0.172	-0.211	-0.2482
0.96835	0.96686	0.96619	0.96611	0.96643	0.96705	0.96786	0.96882	0.96986	0.97096	0.97209	0.97323	0.97437	0.97549	0.97659
0.73643	0.69627	0.66033	0.62795	0.59856	0.57172	0.54706	0.52429	0.50317	0.4835	0.46513	0.4479	0.4317	0.41643	0.40201
32.85	**34.23**	**35.65**	**37.11**	**38.60**	**40.14**	**41.71**	**43.32**	**44.97**	**46.67**	**48.41**	**50.19**	**52.03**	**53.91**	**55.84**
3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84
2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84
2.98	3.01	3.05	3.08	3.11	3.14	3.17	3.19	3.22	3.24	3.26	3.28	3.31	3.32	3.34

Appendix 15.1:Cont.

DURATION IN YEARS														
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
4.17	4.30	4.43	4.56	4.70	4.84	4.98	5.13	5.29	5.45	5.61	5.78	5.95	6.13	6.31
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(60.90)	**(62.72)**	**(64.61)**	**(66.55)**	**(68.55)**	**(70.61)**	**(72.73)**	**(74.92)**	**(77.17)**	**(79.48)**	**(81.87)**	**(84.33)**	**(86.87)**	**(89.48)**	**(92.16)**
8.09	8.33	8.58	8.84	9.10	9.38	9.66	9.95	10.25	10.56	10.87	11.20	11.54	11.88	12.24
2.06	2.12	2.18	2.25	2.32	2.39	2.46	2.53	2.61	2.69	2.77	2.85	2.94	3.03	3.12
0.71	0.73	0.76	0.78	0.80	0.83	0.85	0.88	0.90	0.93	0.96	0.99	1.02	1.05	1.08
1.46	1.50	1.55	1.59	1.64	1.69	1.74	1.79	1.85	1.90	1.96	2.02	2.08	2.14	2.21
0.59	0.61	0.62	0.64	0.66	0.68	0.70	0.72	0.74	0.77	0.79	0.81	0.84	0.86	0.89
0.12	0.13	0.13	0.13	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.18	0.18	0.19
(5.08)	(5.23)	(5.39)	(5.55)	(5.72)	(5.89)	(6.06)	(6.25)	(6.43)	(6.63)	(6.83)	(7.03)	(7.24)	(7.46)	(7.68)
17.20	**17.72**	**18.25**	**18.80**	**19.36**	**19.95**	**20.54**	**21.16**	**21.80**	**22.45**	**23.13**	**23.82**	**24.54**	**25.27**	**26.03**
65.97	**67.96**	**70.00**	**72.10**	**74.27**	**76.50**	**78.80**	**81.16**	**83.60**	**86.11**	**88.70**	**91.36**	**94.11**	**96.94**	**99.85**
48.77	**50.24**	**51.75**	**53.30**	**54.90**	**56.55**	**58.25**	**60.00**	**61.80**	**63.66**	**65.57**	**67.54**	**69.57**	**71.66**	**73.81**
2.00768	2.02763	2.04771	2.0679	2.08813	2.1084	2.12866	2.1489	2.16911	2.18926	2.20936	2.22938	2.24932	2.26917	2.28894
-0.2836	-0.3176	-0.3502	-0.3816	-0.4119	-0.4411	-0.4694	-0.4968	-0.5235	-0.5493	-0.5745	-0.599	-0.623	-0.6463	-0.6691
0.97766	0.9787	0.97971	0.98068	0.98161	0.9825	0.98336	0.98418	0.98496	0.98571	0.98643	0.98711	0.98775	0.98837	0.98896
0.38835	0.3754	0.36309	0.35138	0.34022	0.32957	0.31939	0.30965	0.30032	0.29138	0.28281	0.27457	0.26665	0.25904	0.25171
57.82	**59.86**	**61.95**	**64.10**	**66.31**	**68.59**	**70.92**	**73.33**	**75.80**	**78.34**	**80.95**	**83.65**	**86.41**	**89.26**	**92.19**
3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84
2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84
3.36	3.38	3.39	3.41	3.42	3.44	3.45	3.47	3.48	3.49	3.50	3.51	3.52	3.53	3.54

Appendix 15.1:Cont.

DURATION IN YEARS														
36	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
6.50	6.70	6.90	7.11	7.32	7.54	7.77	8.00	8.24	8.49	8.75	9.01	9.28	9.56	9.84
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(94.93)	**(97.78)**	**(100.72)**	**(103.75)**	**(106.87)**	**(110.08)**	**(113.38)**	**(116.79)**	**(120.30)**	**(123.91)**	**(127.63)**	**(131.47)**	**(135.42)**	**(139.49)**	**(143.68)**
12.61	12.99	13.38	13.78	14.19	14.62	15.06	15.51	15.98	16.46	16.95	17.46	17.98	18.52	19.08
3.21	3.31	3.41	3.51	3.61	3.72	3.83	3.95	4.07	4.19	4.32	4.45	4.58	4.72	4.86
1.11	1.15	1.18	1.22	1.25	1.29	1.33	1.37	1.41	1.45	1.50	1.54	1.59	1.63	1.68
2.27	2.34	2.41	2.48	2.56	2.64	2.72	2.80	2.88	2.97	3.06	3.15	3.24	3.34	3.44
0.92	0.94	0.97	1.00	1.03	1.06	1.09	1.13	1.16	1.20	1.23	1.27	1.31	1.35	1.39
0.19	0.20	0.20	0.21	0.22	0.22	0.23	0.24	0.24	0.25	0.26	0.27	0.27	0.28	0.29
(7.92)	(8.15)	(8.40)	(8.65)	(8.91)	(9.18)	(9.45)	(9.74)	(10.03)	(10.33)	(10.64)	(10.96)	(11.29)	(11.63)	(11.98)
26.82	**27.62**	**28.45**	**29.31**	**30.19**	**31.09**	**32.03**	**32.99**	**33.98**	**35.00**	**36.05**	**37.14**	**38.25**	**39.40**	**40.59**
102.85	**105.94**	**109.12**	**112.40**	**115.78**	**119.25**	**122.84**	**126.53**	**130.33**	**134.24**	**138.28**	**142.43**	**146.71**	**151.12**	**155.66**
76.03	**78.32**	**80.67**	**83.09**	**85.59**	**88.16**	**90.81**	**93.54**	**96.35**	**99.24**	**102.22**	**105.29**	**108.46**	**111.72**	**115.07**
2.3086	2.32817	2.347633	2.366993	2.386248	2.405395	2.424434	2.443364	2.462187	2.4809	2.499505	2.518002	2.536392	2.554675	2.572852
-0.6914	-0.7132	-0.73457	-0.75551	-0.77603	-0.79617	-0.81594	-0.83535	-0.85444	-0.8732	-0.89166	-0.90982	-0.92771	-0.94532	-0.96268
0.98952	0.99005	0.990553	0.991033	0.991489	0.991922	0.992334	0.992724	0.993095	0.993447	0.993782	0.994099	0.9944	0.994686	0.994957
0.24466	0.23786	0.2313	0.224973	0.218866	0.212967	0.207268	0.201759	0.196431	0.191277	0.186288	0.181457	0.176779	0.172247	0.167854
95.21	**98.31**	**101.51**	**104.80**	**108.18**	**111.67**	**115.26**	**118.95**	**122.75**	**126.67**	**130.70**	**134.85**	**139.13**	**143.53**	**148.06**
3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84
2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84
3.55	3.56	3.57	3.58	3.58	3.59	3.60	3.61	3.61	3.62	3.63	3.63	3.64	3.64	3.65