TESTING CALCULATION ENGINES USING INPUT SPACE PARTITIONING AND AUTOMATION

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Sciences at George Mason University

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DEDICATION

To Cherry and Vinnu

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TABLE OF CONTENTS

Page
List of Tables ix
List of Figures xi
Abstract xii

1 Introduction 1

2 Characteristics of the Calculation Engines 4

2.1 Controllability Factors of Testability 5
2.2 Observability Factors of Testability 5
2.3 Specification Formats for Calculation Engines 5
2.3.1 Precision, Truncation, and Rounding 6
2.4 Design or Implementation Characteristics 7
2.4.1 Pricing Grids 7
2.4.2 Data Flow 8
2.4.3 Conditional Events 8
2.4.4 Calculation Algorithms 8
2.4.5 Architecture 9
2.4.6 Important Attributes 9
2.4.7 Intermediate Values 9
2.4.8 Business Cycles 10

3 Test Approach 11

3.1 Step #1: Applying the Technique 16
3.1.1 Input Space Partitioning (ISP) 16
3.1.2 Requirements Modeling 21
3.1.3 Overview of the Process 26
3.1.4 Modeling Technique 27
3.1.5 Requirements and Specifications 29
3.1.6 Rationale Behind This Modeling Design 33
3.1.7 Coverage Criterion 35
3.2 Step #2: Generating Test Requirements 37
3.3 Step #3: Generating Test Data 38
3.4 Step #4: Simulating Calculation Engine and Inputting the Test Data 38
3.5 Step #5: Collecting Expected Results 39
3.6 Step #6: Input Test Data to the System-Under-Test 40

3.7 Step #7: Collecting Actual Results ... 41
3.8 Step #8: Comparing Actual and Expected Results Using a Comparator ... 42

4 Case Study #1: Contract Pricing ... 43

4.1 Step #1: Input Space Partitioning ... 44
4.1.1 Base Choice Coverage ... 49
4.1.2 Multiple Base Choice Coverage ... 50
4.1.3 Pair-Wise Coverage ... 52
4.2 Step # 1: Modeling Technique ... 53
4.3 Step #2: Generating Test Requirements ... 55
4.4 Step #3: Generating Test Data ... 55
4.5 Step #4: Building the Simulator and Inputting Test Data ... 55
4.6 Step #5: Input Test Data Into System-Under-Test ... 55
4.7 Steps # 6, 7, and 8: Collecting Expected Results, Actual Results, and Comparing the Results ... 56

5 Case Study #2: Loan Pricing ... 57

5.1 Step #1: Input Space Partitioning ... 59
5.1.1 Base Choice Coverage ... 60
5.1.2 Multiple Base Choice Coverage ... 61
5.1.3 Pair-Wise Coverage ... 64
5.2 Step #1: Modeling Technique ... 66
5.3 Other Steps in the Process ... 67

6 Case Study # 3: Amortization ... 68

6.1 Step #1: Input Space Partitioning ... 69
6.1.1 Testable Functions ... 70
6.1.2 Base Choice Coverage ... 79
6.1.3 Multiple Base Choice Coverage ... 79
6.1.4 Pair-Wise Coverage ... 80
6.2 Step # 1 Modeling Technique ... 80
6.3 Step # 2: Generating Test Requirements ... 80
6.4 Step # 3: Generating Test Data ... 80
6.5 Steps # 4 and 5: Building the Simulator and Inputting Test Data and Collecting Expected Results ... 81
6.6 Steps # 6 and 7: Inputting Test Data Into System-Under-Test and Collecting Actual Results ... 81
6.7 Step # 8: Comparing Actual and Expected Results ... 82

7 Case Study # 4 ... 83

7.1 Input Space Partitioning ... 83

7.1.1 Testable Functions 84
7.1.2 Base Choice Coverage 91
7.1.3 Multiple Base Choice Coverage 92
7.1.4 Pair-Wise Coverage 92
7.2 Modeling Technique 92
7.3 Application of the Framework 93
7.3.1 Step # 1: Identify the Functionality to Be Tested – Define Scope 93
7.3.2 Step # 2: Identify the Testable Functions 93
7.3.3 Step # 3: Identify the Entities and Attributes - Partitions 93
7.3.4 Step # 4: Identify Distinct Values – Blocks 93
7.3.5 Step # 5: Apply Base Choice Criteria to Filter the Invalid Values 94
7.3.6 Steps # 6, 7, 8, and 9: Eliminate Invalid Values and Combinations 94
7.3.7 Step #10: Ensure the Functional Coverage With RTM 95
7.3.8 Steps # 11 and 12: Prefix the Test Cases and Provide Real Values 95
7.3.9 Step #13: Build the Calculation Simulator 95
7.3.10 Step #14: Collect the Actual Results 95
7.3.11 Step # 15: Compare the Actual and Expected Results 96

8 Results 97

8.1 Case Study #1: Contract Pricing 98
8.1.1 Requirements Coverage 99
8.1.2 Code Coverage 99
8.1.3 Observations 101
8.2 Case Study #2: Loan Pricing 103
8.2.1 Requirements Coverage 103
8.2.2 Code Coverage 103
8.2.3 Observations 104
8.3 Case Study #3 105
8.3.1 Requirements Coverage 105
8.3.2 Code Coverage 105
8.3.3 Observations 106
8.4 Case Study #4 107
8.4.1 Requirements Coverage 107
8.4.2 Code Coverage 107
8.4.3 Observations 108

9 Advantage and Disadvantages 110

9.1 Pros and Cons of Modeling 110
9.1.1 Advantages of Modeling 110
9.1.2 Disadvantages of Modeling 111
9.2 Pros and Cons of ISP 113
9.2.1 Advantages of ISP 113
9.2.2 Disadvantages of ISP 117

10 Conclusions and Recommendations 118

10.1 Conclusion 118

10.2 Recommendations 120
10.3 Further Work 123
10.3.1 Automatic Generation of Test Data for ISP tests 123
10.3.2 Filter the Conflicting Combinations Automatically 124
10.3.3 Build the Tool With a User Interface 124
10.3.4 Auto Detection of the Requirements Coverage and Building Traceability 124
10.3.5 Testable Functions as an Estimation Technique 125

Appendix A 125
Appendix B 150
Appendix C 154
REFERENCES 155

LIST OF TABLES

Table Page
Table 1: *Contract Partitions and Blocks* 45
Table 2: *Contract Pricing Partitions and Blocks* 48
Table 3: *Contract Pricing Base Test #1* 49
Table 4: *Contract Pricing Base Test #2* 49
Table 5: *Contract Pricing Base Choice Tests* 50
Table 6: *Contract Pricing Multiple Base Choice Tests* 51
Table 7: *Contract Pricing Pair-Wise Tests* 53
Table 8: *Contract Pricing Test Inputs From Modeling* 54
Table 9: *Loan Pricing Partitions and Blocks* 58
Table 10: *Loan Pricing Base Test #1* 59
Table 11: *Loan Pricing Base Test #2* 59
Table 12: *Loan Pricing Base Choice Tests* 60
Table 13: *Loan Pricing Multiple Base Choice Tests* 62
Table 14: *Loan Pricing Pair-Wise Tests* 65
Table 15: *Partitions and Blocks for TF # 1* 71
Table 16: *Partitions and Blocks for TF # 2* 71
Table 17: *Partitions and Blocks for TF # 3* 72
Table 18: *Partitions and Blocks for TF # 4* 72
Table 19: *Partitions and Blocks for TF # 5* 72
Table 20: *Partitions and Blocks for TF # 6* 73
Table 21: *Partitions and Blocks for TF # 7* 74
Table 22: *Partitions and Blocks for TF # 8* 74
Table 23: *Partitions and Blocks for TF # 9* 75
Table 24: *Partitions and Blocks for TF # 10* 75
Table 25: *Partitions and Blocks for TF # 11* 76
Table 26: *Partitions and Blocks for TF # 12* 76
Table 27: *Partitions and Blocks for TF # 13* 77
Table 28: *Partitions and Blocks for TF # 14* 77
Table 29: *Partitions and Blocks for TF # 15* 78
Table 30: *Partitions and Blocks for TF # 16* 78
Table 31: *SEY IRR - TF # 1 – Partitions and Blocks* 84
Table 32: *SEY IRR - TF #1 Base Choice Tests* 85
Table 33: *SEY IRR - TF #2 Partitions and Blocks* 86
Table 34: *SEY IRR - TF #2 Base Choice Tests* 86
Table 35: *SEY IRR - TF # 3 Partitions and Blocks* 87

Table 36: *SEY IRR - TF # 3 Base Choice Tests* 87
Table 37: *SEY IRR - TF # 4 Partitions and Blocks*.. 88
Table 38: *SEY IRR - TF #4 Base Choice Tests* 88
Table 39: *SEY IRR Partitions and Blocks for Loops* 89
Table 40: *SEY IRR - TF # 5 Partitions and Blocks*.. 90
Table 41: *SEY IRR - TF #6 Partitions and Blocks*... 90
Table 42: *SEY IRR - TF # 7 Partitions and Blocks*.. 91
Table 43: *Partitions and Blocks for loops* 92
Table 44: *Case Study #1 - Statement Coverage Results* 100
Table 45: *Case Study #2 - Statement Coverage Results* 104
Table 46: *Case Study #3 - Statement Coverage Results* 106
Table 47: *Case Study # 4 - Statement Coverage Results* 108

LIST OF FIGURES

Figure Page

Figure 1. Process to test calculation engines. 16

Figure 2. Input Space Partitioning (ISP) process to test calculation engines. 17

Figure 3. Tree example. 26

Figure 4. Modeling process to test calculation engines. 27

Figure 5. Modeling example #1 using Fusion Test Modeler.. 30

Figure 6. Modeling example #2 using Fusion Test Modeler.. 32

Figure 7. Sample outputs from Fusion Test Modeler. 33

ABSTRACT

TESTING CALCULATION ENGINES USING INPUT SPACE PARTITIONING AND AUTOMATION

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George Mason University, 2008

Thesis Director: Dr. Jeff Offutt

This thesis proposes a solution to test calculation engines in financial services applications such as banking, mortgage, insurance, and trading. Calculation engines form the heart of financial applications, as the results are very sensitive to the business and can cause severe damage if wrong. But controllability and observability of these calculations are low. In order to test these calculations, more robust and sophisticated methods are required. In this thesis, input space partitioning, along with automation, were applied with the help of tools. Case studies were conducted to validate the effectiveness of this approach. Finally, a framework is recommended to test the calculation engines.

1 Introduction

Financial services like banking, mortgage, and insurance consist of several subsystems that involve complex calculations. Pricing loans, amortizing loans, asset valuations, accounting rules, interest calculations, pension calculations, and generating the insurance quotes are some of the familiar calculations involved in these applications. Calculations embedded into these systems for different business objectives differ in their calculation algorithms. In a particular application, multiple calculations may need to be performed by different calculators to achieve the business's objective. These calculators together can be termed the ***calculation engine***. In most cases, several calculations need to be performed in sequence or in parallel to get the final output. The logic for these calculations will be designed to reside in the business layer of an architecture, which makes them more complex to test.

Financial models are another form of calculation engine. Financial modeling is the process by which an organization/firm constructs a financial representation of some, or all, of its financial aspects. The model is built by performing calculations, and then recommendations are made for the model. The model may also summarize particular events for the user and provide direction regarding possible actions or alternatives.

Financial models can be constructed in many ways, either by computer software or with a pen and paper. What is most important, however, is not the kind of technology used, but the underlying logic that encompasses the model. A model, for example, can summarize investment management returns, such as the Sortino ratio, or it may help estimate market direction, such as the Fed model.

It is essential to test financial models thoroughly as they are business sensitive and may cause enormous side effects to the business if wrong. Currently test requirements at the system and integration testing level are derived from black box testing techniques such as equivalence partitioning, boundary value analysis, and error guessing—and these are not always effective as the test requirements should be tested in relation with each other. Effective test methods need to be employed to overcome the calculations' low observability and controllability. A comprehensive solution that addresses the variables' transformation and interdependency in calculators is presented in this thesis.

System testing and user acceptance testing are crucial to testing, as the calculations need to be tested in conjunction with the system's other functionalities. There are numerous approaches available to perform system testing, but most falls short of offering comprehensive solution for testing calculation engines.

In this thesis, characteristics of calculation engines are analyzed and then different techniques are applied to offer a robust and comprehensive solution for testing calculation engines.

The thesis statement for this research is that calculation engines in financial services applications can be tested effectively and efficiently using input space partitioning and with automation. This research evaluates the thesis statement with a case study approach by using automation to apply input space partitioning to several actual calculation engines of Freddie Mac.

2 Characteristics of the Calculation Engines

In the applications that have calculation engines, calculation logic is implemented in the business layer. All calculations are performed on the server side; the client side of the application is abstracted from the processing. Therefore the user does not observe any processing behind the graphical user interface (GUI). For example, a user supplies inputs for an insurance quote and the application generates the insurance quote by performing various calculations on the server. Then the user enters different characteristics of the borrower and the application generates the interest rate by applying different rules on the server. The application takes different inputs from taxpayers and generates the tax owed by performing several calculations on the server.

By virtue of the implementation, calculation engines feature some of the characteristics of component-based applications. This makes testing calculation engines more complex and challenging.

Testability is used to describe how adequately a particular set of tests will cover the product. Software testability is simply how easily software or a computing program can be tested. Bach (2003) determined a set of characteristics to measure the testability of software, including controllability and observability.

2.1 Controllability Factors of Testability

- All possible outputs can be generated through some combination of inputs.
- All code is executable through some combination of inputs.
- Software and hardware states and variables can be controlled directly by the test engineer.
- Input and output formats are consistent and structured.
- Tests can be conveniently specified, automated, and reproduced.

2.2 Observability Factors of Testability

- Distinct outputs are generated for each input.
- System states and variables are visible or queriable during execution.
- Past system states and variables are queriable or visible (e.g., transaction logs).
- All factors affecting the output are visible.
- Incorrect output is easily identified.
- Internal errors are automatically detected through self-testing mechanisms.
- Internal errors are automatically reported.

Due to the factor that calculations occur on server, factors that determine the testability of the software with respect to controllability and observability are obscured in calculation engines, which challenge the test engineers.

2.3 Specification Formats for Calculation Engines

When studying different applications that have calculation engines, I found requirements are specified in various forms and in combinations of the following:

requirements in plain English, use cases, mathematical expressions, logical expressions, business rules, procedural design, and mathematical formulae.

Businesses are sensitive to the defects in calculation engines. They not only lead to interruptions in the business's continuity, but also can lead corporations to legal battles and liabilities. These incidents create headlines in newspapers, causing severe damage to the subject corporations' reputations. Therefore, strict IT controls are put into place around these applications, and they are subjected to regular auditing. The following subsections define some of the commonalities in calculation engine specifications and design.

2.3.1 Precision, Truncation, and Rounding

Incorrect handling of specifications with respect to precision, truncation, and rounding leads to distorted values. In many applications it is desirable to maintain constant word size through the basic arithmetic operations of add, subtract, multiply, and divide. Of these operations, multiplication is the biggest concern as multiplying two n-bit data items yields a 2n-bit product. Forming the full product and rounding it to the desired precision is mathematically attractive, but the complexity is high. Forming a portion of the bit product reduces the complexity, but incurs potentially large errors. Truncation limits should be defined in the specifications.

The other component of the format specification is the precision specification, which specifies a nonnegative decimal integer, preceded by a period (**.**), which specifies the number of characters to be printed, the number of decimal places, and the number of significant digits. Unlike the width specification, the precision specification can cause either truncation of the output value or rounding of a floating-point value. For example, if *precision* is specified as 0 and the value to be converted is 0, the result is no output.

Rounding the values is another key specification. Intermediate rounding applies when data items are retrieved for inclusion in an arithmetic operation or arithmetic expression, and during the execution of arithmetic operators to produce an intermediate result. When the intermediate value can be represented exactly in the appropriate intermediate format, the exact value is used. Final rounding applies to forming the final result of the expression or statement, at the completion of evaluating the statement or expression, immediately before the result is placed in the destination.

Price values or any other values should be stored with all the decimal places, however big the values are. Therefore, when a database is designed, this factor should be considered. Although a database stores all the decimal places, the business’s rules may ask to use only up to certain number of decimal places in calculations. Tests should be carefully designed to evaluate precision, truncation, and rounding of the calculated values.

2.4 Design or Implementation Characteristics

2.4.1 Pricing Grids

Values such as interest rates, S&P index, NYMEX index, etc., change constantly during a business day depending on various market factors. The calculations use some of these values in their computations. These values are updated constantly into tables which are called *pricing grids*. Calculation systems have interfaces to these grids and pull the current values when required. While designing the tests, this factor can be abstracted or discounted, as this need not be tested every time.

2.4.2 Data Flow

Attributes for calculations may be received from external systems (upstream). The systems under test process the calculations and may send the data to external (downstream) systems that consume the outcome. For example, Asset valuation calculations receive inputs from Sourcing systems and pass the data to the Subledger and General Ledger downstream systems, where accounting calculations (principles) are applied and the final result will be reflected in financial reports at the end of the period. These chains of systems use mainframe systems to batch processes. Yet the requirements may not clearly specify the source of the data for calculations. Understanding the technical specifications helps to determine better tests. This is essential—especially in determining the preconditions, and later to "prefix the test data."

2.4.3 Conditional Events

Understanding the events and conditions that determine the flow in the calculations helps derive effective tests. For example, the Interest Rate type (Fixed, ARM, or Balloon) determines which path to follow. Based on these inputs, calculations take different paths.

2.4.4 Calculation Algorithms

Algorithms for amortization, pricing, insurance quotations, asset valuations, and accounting principles are standard. For example, amortization methods could be based on the diminishing balance or flat rate over a preset duration. Knowing these algorithms greatly helps in determining the expected outputs. For example, MS-Excel has standard amortization functions, which can be used as a calculation simulator instead of building simulator programs.

2.4.5 Architecture

In almost all the applications, most of these calculations are implemented either as a batch process or an online transaction that occurs in the business layer. Understanding the architecture helps isolate the testable requirements from non-testable requirements.

2.4.6 Important Attributes

Even though the entities that participate in the calculations have many attributes, only a few attributes will be involved in the calculations. For example, the loan pricing calculation has 2 entities, Loan and Master Commitment, which have 140 and 35 attributes respectively that participate in the calculations but only 7 attributes are involved in the calculations. Identifying the influential attributes is important in building effective tests. This simplifies the task of testing by understanding the constraints among these attributes. The acceptable values for each attribute and their constraints are defined in the form of business rules. When tests are built, test inputs need to be prefixed with the remaining attributes to make a test case executable.

2.4.7 Intermediate Values

Calculation engines are formed from calculators that input/output the values to one another. In many cases, debugging the incorrect output is a tedious process as it involves checking all the intermediate values in the flow. The same set of inputs may yield different outputs when the calculations are performed at different time periods. The reasons could be: (a) input values are interpreted differently, (b) interest values could be changed in different time periods, (c) intermediate values could have changed, (d) business rules would have changed in the due course, etc. The systems do not store the intermediate values, but intermediate values are essential in diagnosing problems.

2.4.8 Business Cycles

Applications that involve these calculations need to be tested for different business cycles such as daily, monthly, quarterly, and annually. Therefore, the same tests may need to be executed for different business cycles. Understanding this aspect of the requirements and system helps in planning the data. Data cloning mechanisms can be implemented to reuse the same data for different periods.

3 Test Approach

A robust test approach that determines the input from the client side of the software and affects different paths of calculations on the component or server software is required. To offer comprehensive testing, problem analysis needs to be performed systematically, which forms the core of this approach. Although many such techniques exist, they fall short of being comprehensive. In this thesis, problem analysis is conducted using both requirements modeling and input space partitioning. In Chapter 2 and specifically in Section 2.4 of this thesis, design and implementation characteristics of the calculation engines were discussed. Modeling some of these characteristics simplifies the process of generating the test requirements. On the other hand, when the testable functions are identified, input space partitioning with appropriate coverage criterion consistently provides the test requirements.

Pressman (2005) states that any engineered product can be tested in one of two ways. Knowing the specified function that a product has been designed to perform, tests can be conducted that demonstrate each function is fully operational while at the same time searching for errors in each function. Or, knowing the internal workings of the product, tests can be conducted to ensure that “all gears mesh,” that is, internal operations are performed according to specifications and all internal components have been adequately exercised. The first approach is called black box testing, and the second, white box testing. Black box testing alludes to tests that are conducted at the software interface. Although they are designed to uncover errors, black box tests are used to demonstrate that software functions are operational: that input is properly accepted and output is correctly produced. White box testing of software requires looking at the source code. Logical paths of the software are tested by test cases that exercise specific sets of conditions and/or loops.

The attributes of both black box and white box testing can be combined to provide an approach that validates the software interface and selectively ensures the software's internal workings are correct. This thesis applies requirements modeling and input space partitioning (ISP) by choosing appropriate coverage criteria.

In general, calculations reside in the business layer behind the client and are invoked by inputs from the client. Inputs largely determine which calculations to trigger and what paths in the calculations will be parsed. In this context, the problem directly correlates to the controllability and observability problem.

Ammann and Offutt (2008) define software observability and controllability as follows.

- *Software Observability:* How easy it is to observe the behavior of a program in terms of its outputs, effects on the environment, and other hardware and software components.
- *Software Controllability:* How easy it is to provide a program with the needed inputs in terms of values, operations, and behaviors.

Ammann and Offutt illustrated the ideas of observability and controllability in the context of embedded software. Embedded software often does not produce output for human consumption, but affects the behavior of some piece of hardware. Thus, observability will be quite low. Likewise, software for which all inputs are the values entered from a keyboard is easy to control. But an embedded program that gets its inputs from hardware sensors is more difficult to control and some inputs may be difficult, dangerous, or impossible to supply. Many observability and controllability problems can be addressed with simulation, by extra software built to “bypass” the hardware or software components that interfere with testing. Other applications that sometimes have low observability and controllability include component-based software, distributed software, and web applications.

The calculation engines draw the similarities of the applications that have low controllability and observability, making it difficult to derive the appropriate inputs. Depending on the software, the level of testing, and the source of the tests, the tester may need to supply other inputs to the software to affect controllability or observability. Two common practical problems associated with software testing are how to provide the right values to the software, and observing details of the software’s behavior. Offutt and Amman (2008) used these two ideas to refine the definition of a test case as follows.

- *Prefix Values:* Any inputs necessary to put the software into the appropriate state to receive the test case values.
- *Postfix Values:* Any inputs that need to be sent to the software after the test case values are sent.

Two types of postfix values exist.

- *Verification Values:* Values necessary to see the results of the test case.
- *Exit Commands:* Values needed to terminate the program or otherwise return it to a stable state.

A test case is the combination of all these components (test case values, expected results, prefix values, and postfix values). When it is clear from context, however, we will follow tradition and use the term “test case” in place of “test case values.”

- *Test Case:* A test case is comprised of the test case values, expected results, prefix values, and postfix values necessary for a complete execution and valuation of the software under test.
- *Test Set:* A test set is simply a set of test cases.

Test analysts can automate as many test activities as possible. A crucial way to automate testing is to prepare the test inputs as executable tests for the software. This may be done using Unix shell scripts, input files, or through the use of a tool that can control the software or software component being tested. Ideally, the execution should be complete in the sense of running the software with the test case values, getting the results, comparing the results with the expected results, and preparing a clear report for the test analyst.

- *Executable Test Script:* A test case that is prepared in a form to be executed automatically on the test software and produce a report.

Throughout this thesis, these terms defined in the Ammann and Offutt (2008) textbook will be used for consistency.

The proposed solution is intended to apply testing at the system and integration levels, but can also be extended to the unit and user acceptance testing levels. Calculation engines are tested using two different methods: input space partitioning and a modeling technique. This was a project decision, made by the test manager. If the project was designed as a research project, it may have been done differently. But the goal was to test the software and evaluate the testing in a case study fashion.

Processes to apply and test calculation engines using these two techniques are shown in Figure 2 and Figure 4. Each process shown in the figures has 9 steps. Steps 2 to 9 are common in both the techniques and are detailed in sections 3.2 to 3.8.

Figure 1 shows the overall process to test calculation engines. This is a 9-step process in which the first step is to apply the technique. In this thesis, modeling and ISP are applied to derive the test requirements.

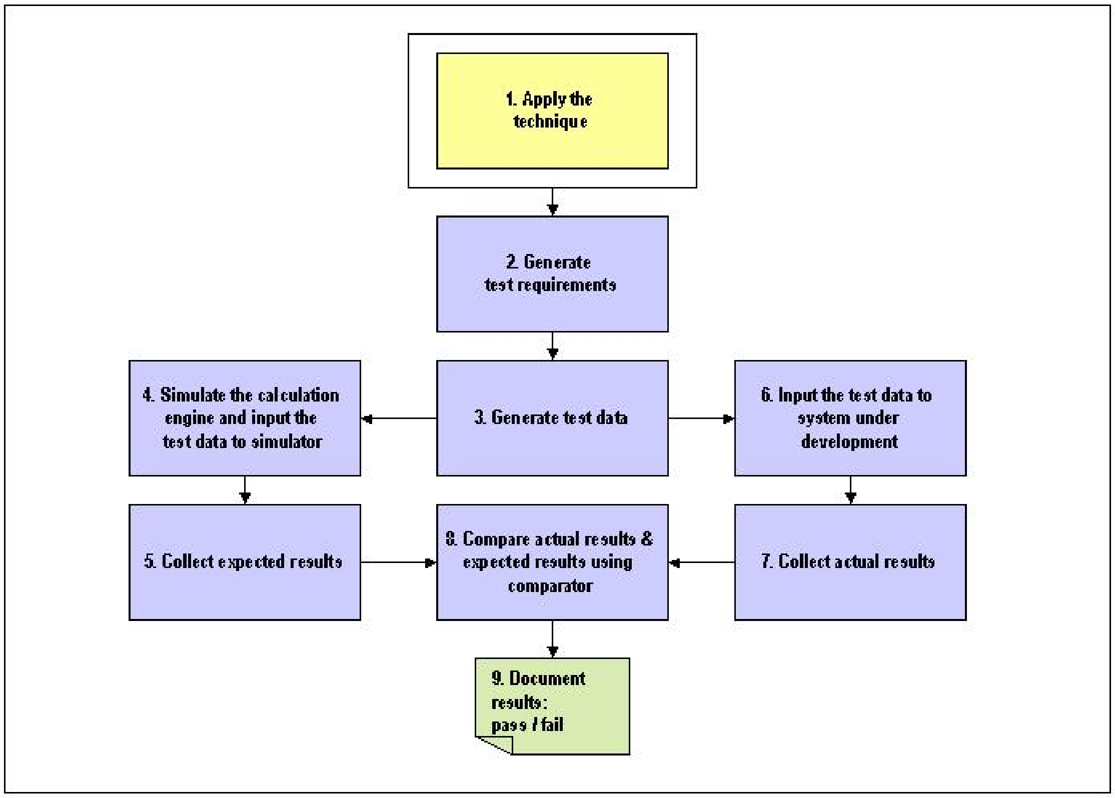

1. Apply the technique
2. Generate test requirements
3. Generate test data
4. Simulate the calculation engine and input the test data to simulator
5. Collect expected results
6. Input the test data to system under development
7. Collect actual results
8. Compare actual results & expected results using comparator
9. Document results: pass / fail

Figure 1. Process to test calculation engines.

3.1 Step #1: Applying the Technique

3.1.1 Input Space Partitioning (ISP)

Ammann and Offutt (2008) categorized black box testing in terms of input space partitioning and discussed different criteria to cover the input space. The process to test the calculation engines using ISP is shown in Figure 2.

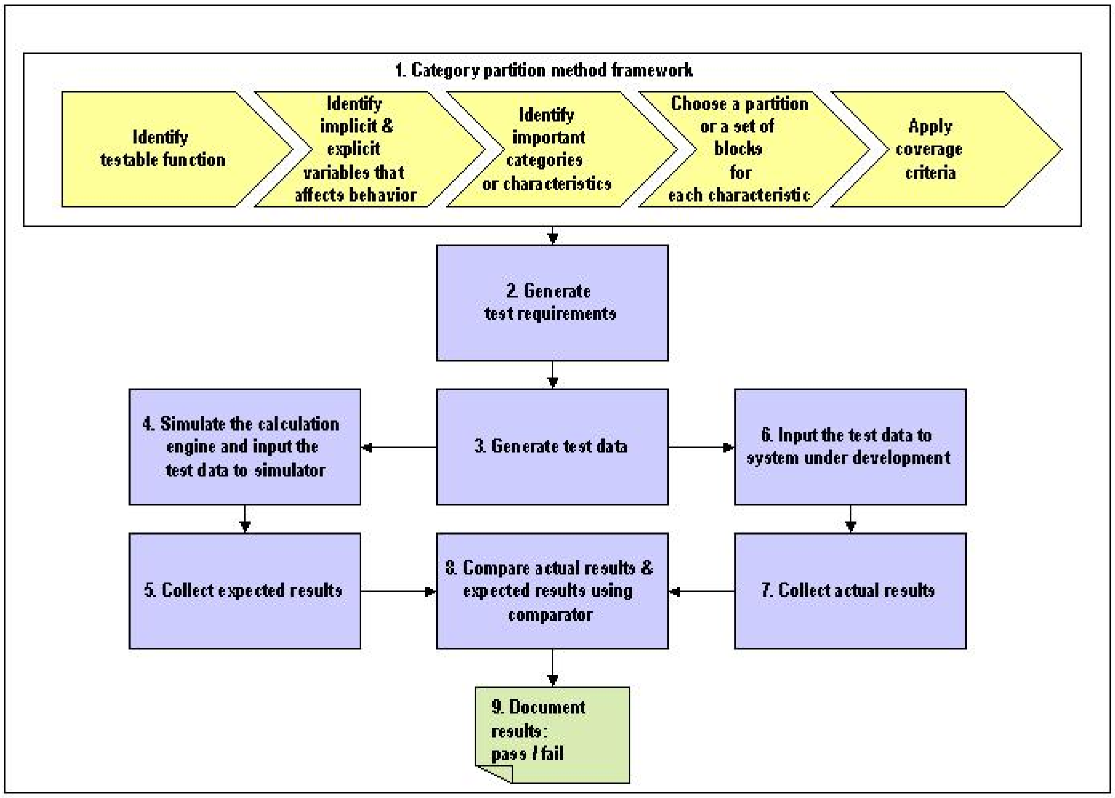

1. Category partition method framework
Identify testable function
Identify implicit & explicit variables that affects behavior
Identify important categories or characteristics
Choose a partition or a set of blocks for each characteristic
Apply coverage criteria
2. Generate test requirements
3. Generate test data
4. Simulate the calculation engine and input the test data to simulator
5. Collect expected results
6. Input the test data to system under development
7. Collect actual results
8. Compare actual results & expected results using comparator
9. Document results: pass / fail

Figure 2. Input Space Partitioning (ISP) process to test calculation engines.

In chapter 4 of Ammann and Offutt's 2008 textbook *Introduction to Software Testing*, an input space is divided into different partitions and each partition consists of different blocks.

In a fundamental way, all testing is about choosing elements from the input space of the software being tested. This criterion can be viewed as defining ways to divide the space according to test requirements. The input domain is defined in terms of possible values that the input parameters can have. The input domain is then partitioned into regions that are assumed to contain equally useful values from a testing perspective.

Consider a partition q over some domain D. The partition q defines the set of equivalence classes, which are called blocks Bq that are pairwise disjoint, that is:

$$bi \cap bj = \varnothing, i \neq j; bi, bj \in Bq$$

and together the blocks cover the domain D, that is:

$$\bigcup_{b \in Bq} b = D$$

3.1.1.1 The Category Partition Method

The category partition method provides a process framework in which to partition the input space. It consists of 6 manual steps to identify input space partitions and convert them to test cases.

1. Identify functionalities that are called testable functions and can be tested separately.
2. For each testable function, identify the explicit and implicit variables that can affect its behavior.
3. For each testable function, identify characteristics or categories that, in the judgment of the test engineer, are important factors to consider in testing the function. This is the most creative step in this method and also varies depending on the expertise of the test engineer.
4. Choose a partition, or set of blocks, for each characteristic. Each block represents a set of values on which the test engineer expects the software to behave identically. Well-designed characteristics often lead to straightforward partitions.

5. Choose a test criterion and generate the test requirements. Each partition contributes exactly one block to a given test requirement.
6. Refine each test requirement into a test case by choosing appropriate values for the explicit and implicit variables.

3.1.1.2 Coverage Criterion for Input Space Partitioning

Amman and Offutt (2008) discussed the All Combinations, Each Choice, Pair-Wise, t-Wise, Base Choice, and Multiple Base Choices coverage criteria for the input space partitioning. Pair-Wise, Base Choice, and Multiple Base Choices coverage criteria were used to derive the test cases for this thesis's case studies.

3.1.1.2.1 Pair-Wise (PW)

A value from each block for each partition must be combined with a value from every block for each other partition. For example, if there are three partitions with blocks [A, B], [1, 2, 3], and [x, y], then PW will need tests to cover the following combinations:

(A, 1) (B, 1) (1, x)

(A, 2) (B, 2) (1, y)

(A, 3) (B, 3) (2, x)

(A, x) (B, x) (2, y)

(A, y) (B, y) (3, x)

(3, y)

PW allows the same test case to cover more than one unique pair of values. So the above combinations can be combined in several ways, including:

(A, 1, x) (B, 1, y)

(A, 2, x) (B, 2, y)

(A, 3, x) (B, 3, y)

(A, ~, y) (B, ~, x)

The tests with “~” mean that any block can be used. A test suite that satisfies PW will pair each value with each other value.

3.1.1.2.2 Base Choice (BC)

A base choice block is chosen for each partition, and a base test is formed by using the base choice for each partition. Subsequent tests are chosen by holding all but one base choice constant and using each non-base choice in each other parameter.

We actually use domain knowledge to choose the base blocks. The base choice criterion depends on a crucial piece of domain knowledge: Which block from each partition determines the base choice test. This choice is called the “base choice.”

If there are three partitions with blocks [A, B], [1, 2, 3], and [x, y], suppose base choice blocks are ‘A’, ‘1’ and ‘x.’ Then the base choice test is (A, 1, x), and the following tests would need to be used:

(B, 1, x)

(A, 2, x)

(A, 3, x)

(A, 1, y)

A test suite that satisfies BC will have one base test, plus one test for each remaining block for each partition.

The base choice can be the simplest, the smallest, the first in some ordering, or the most likely from an end-user point of view. Combining more than one invalid value is usually not useful because the software often recognizes one value and then negative effects of the others are masked. Which blocks are chosen for the base choices becomes a crucial step in test design that can greatly impact the resulting test. It is important to document the strategy that was used so that further testing can reevaluate that decision.

3.1.1.2.3 Multiple Base Choices (MBC)

At least one, and possibly more, base choice blocks are chosen for each partition, and base tests are formed by using each base choice for each partition at least once. Subsequent tests are chosen by holding all but one base choice constant for each base test and using each non-base choice in each other parameter.

The MBC criterion sometimes results in duplicate tests, which should, of course, be eliminated.

3.1.2 Requirements Modeling

Modeling the behavior of the software to analyze and derive the tests is known and has been used for the past four decades. Beizer (1990), Myers, and many others extensively discussed behavioral testing with the help of models such as control-flow graphs, transaction-flow graphs, data flow graphs, and finite state machines.

Engineering disciplines use models to develop the products they intend to build. Requirements models are used to discover and clarify the functional and data requirements for software and business systems. Additionally, requirements models are used as specifications for the system’s designers, builders, and testers.

Beizer (1990) states that analysis is the engineering process by which a design evolves to fulfill the requirements. It may be wholly intuitive or formal. Intuitive analysis, while often effective, cannot be communicated to others easily and, consequently, some kind of formal, often mathematical, analysis is needed—even if only retroactively.

Pressman (2005) states that one important step in black box or behavioral testing is to understand the objects that are modeled in the software and the relationships that connect those objects. Once this has been accomplished, the next step is to define a series of tests that verify the statement "All objects have the expected relationship to one another." Stated in another way, software testing begins by creating a graph of important objects and their relationships and then devising a series of tests that will cover the graph so that each object and relationship is exercised and errors are uncovered.

The idea of modeling different aspects of the system using different modeling tools is gaining momentum at present. It is also very conventional that test engineers build mental models as a part of the problem analysis. These models can further be used to derive the test conditions. Therefore, one objective of modeling the requirements is to generate the test requirements and then refine the test requirements into test cases by choosing appropriate values for both the explicit and implicit variables.

Binder (2000) states that software testing requires the use of a model to guide the efforts in test selection and test verification. Often, such models are implicit, existing only in the head of a human tester, applying test inputs in an ad hoc fashion. The mental models testers build encapsulate application behavior, allowing testers to understand the application’s capabilities and more effectively test its range of possible behaviors. When these models are written down, they become sharable, reusable testing artifacts.

Simply put, a model of software describes behavior. Behavior can be described in terms of input sequences accepted by the system, the actions, conditions, and output logic, or the flow of data through the application’s modules and routines. In order for a model to be useful for groups of testers and for multiple testing tasks, it needs to be taken out of the mind of those who understand what the software is supposed to accomplish and written down in an easily understandable form. It is also generally preferable that a model be as formal as it is practical. With these properties, the model becomes a shareable, reusable, precise description of the system under test.

There are many such models, and each describes different aspects of software behavior. For example, control-flow, data-flow, and program dependency graphs express how the implementation behaves by representing its source code structure. Decision tables, transaction-flows, and state machines, on the other hand, are used to describe external so-called black box behavior. The system testing community today tends to think in terms of such black box models. Finite state machines, state charts, UML models, grammars, decision tables, and decision trees are some of the popular models used to represent the software behavior.

In general, test models are designed as part of problem analysis.

The criterion for model testability is an algorithm that can be devised and programmed that will produce ready-to-run test cases with only the information in the model. The model should support both manual and auto test generation. Binder (2000) describes that a testable model must meet the following requirements:

- The model should be a complete and accurate reflection of the kind of implementation to be tested. The model must represent all features to be exercised.
- The model should abstract the details that would make the cost of testing prohibitive.
- The model should preserve the details that are essential for revealing faults and demonstrating conformance.
- The model should represent all possible events so that we can generate these events, typically as messages sent to the system under test.
- The model should represent all possible actions so that we can determine whether a required action has been produced.
- The model should represent the state so that we have an executable means to determine what state has been achieved.

Models also reveal controllability and observability by tracing different paths that information can flow through in the system. In addition, models provide the visual representations of the information flow, thus allowing the requirements engineers, development engineers, and test engineers to have the same understanding of the requirements.

When multiple projects related to the calculation engines in financial services are studied, requirements specifications follow a certain pattern when modeled in the form of a graph; if appropriate graph coverage criterion is applied, paths in a graph produce different test requirements.

There are several techniques available to model the requirements and then to generate the test requirements from the models. I developed the tool called the Fusion Test Modeler (FTM) to facilitate modeling the requirements related to calculation engines. This tool helped test analysts in requirements modeling and then in tracing back the test cases to the requirements.

The requirements of the calculation engines are captured in the form of sequences of events, sequences of actions, business rules, use cases, plain text in English, logical expressions, and mathematical expressions. For example, pricing a loan or a contract occurs when some events occur, such as creation of the loan, change in time period, change in the interest rates, and/or change in fee rates. Amortization calculations depend on the time period of the loan and characteristics of the loan such as ARM or fixed. Asset valuation triggers a different set of calculations based on the Asset type, e.g. whole loans, swaps, or bonds.

In some cases, specifications for the calculations are defined in the form of pseudo-code and procedural design, especially for financial models, which are bought as third-party tools and are integrated into the Freddie Mac systems. In other cases, complex calculations are embedded in the sequence of steps in use cases mentioning when to trigger the calculations.

The modeling design chosen in this thesis is a Tree. Requirements can be analyzed in the form of models. These models can be further extended and then could be decomposed to trace different paths in the models. These decomposed paths simplify the complex or obscure behavior of the calculation engines. Each path in the models can be refined to a unique test case mapping to the test requirement.

Graph G_1 in ***Figure 3*** is an example of Tree.

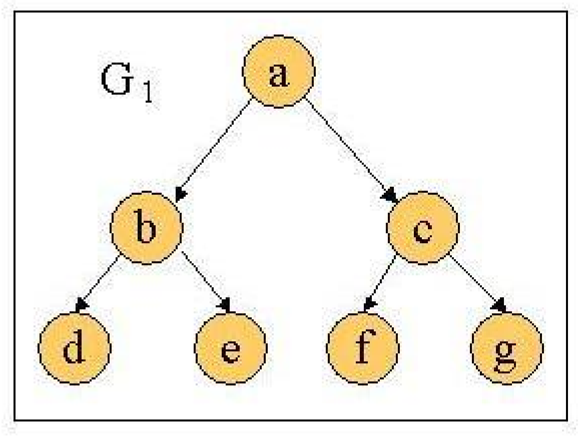


Figure 3. Tree example.

In general, for any graph-based coverage criterion, the idea is to identify the test requirements in terms of various structures in the graph.

A typical test requirement is met by visiting a particular node or edge or by touring a particular path. T = {a, b, d}, {a, b, e}, {a, c, f}, {a, c, g} are the four test requirements that cover the graph G_1 in ***Figure 3***.

3.1.3 Overview of the Process

Figure 4 shows the high level process to test the calculation engines using the modeling technique. The first and second steps are crucial in this process to model the requirements. The Fusion Test Modeler facilitates in modeling the requirements. The second step in this process is to derive the test scenarios from the model. FTM automatically generates these test scenarios. Steps 4, 5, and 8 are automated with the help of other tools.

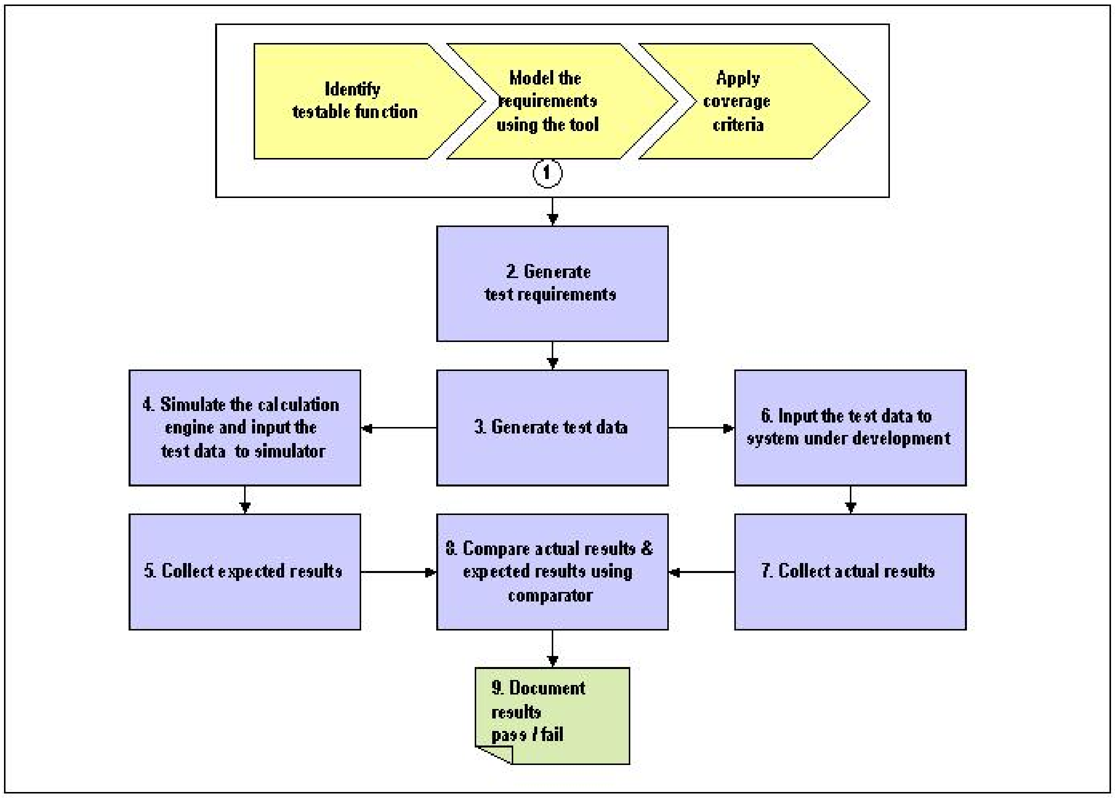

Identify testable function
Model the requirements using the tool
Apply coverage criteria
1
2. Generate test requirements
3. Generate test data
4. Simulate the calculation engine and input the test data to simulator
6. Input the test data to system under development
5. Collect expected results
8. Compare actual results & expected results using comparator
7. Collect actual results
9. Document results pass / fail

Figure 4. Modeling process to test calculation engines.

3.1.4 Modeling Technique

The technique defined here is the definitive procedure to be followed in modeling the requirements to accomplish the goal of deriving the test requirements. These steps follow Beizer’s (1990) advice of modeling and are extended to help modeling using FTM.

1. Identify the testable functions. This is a manual step; guidelines will be provided to define the testable function.
2. Examine the requirements and analyze them for operationally satisfactory completeness and self-consistency.
3. Confirm that the specification correctly reflects the requirements, and correct the specification if it does not.
4. Rewrite the specification as a sequence of short sentences. This can be done using FTM.
5. Model the specifications using FTM. Modeling is explained in the subsections with the examples.
6. Verify the model.
7. Select the test paths. This step is automated.
8. Sensitize the selected test paths. That is, select input values that would cause the software to do the equivalent of traversing the selected paths.
9. Record the expected outcome for each test. Expected results can be specified in FTM, which is one of the advantages of the tool.
10. Confirm the path. This step is automated. The prime path coverage criterion is applied to traverse the model’s paths.

3.1.5 Requirements and Specifications

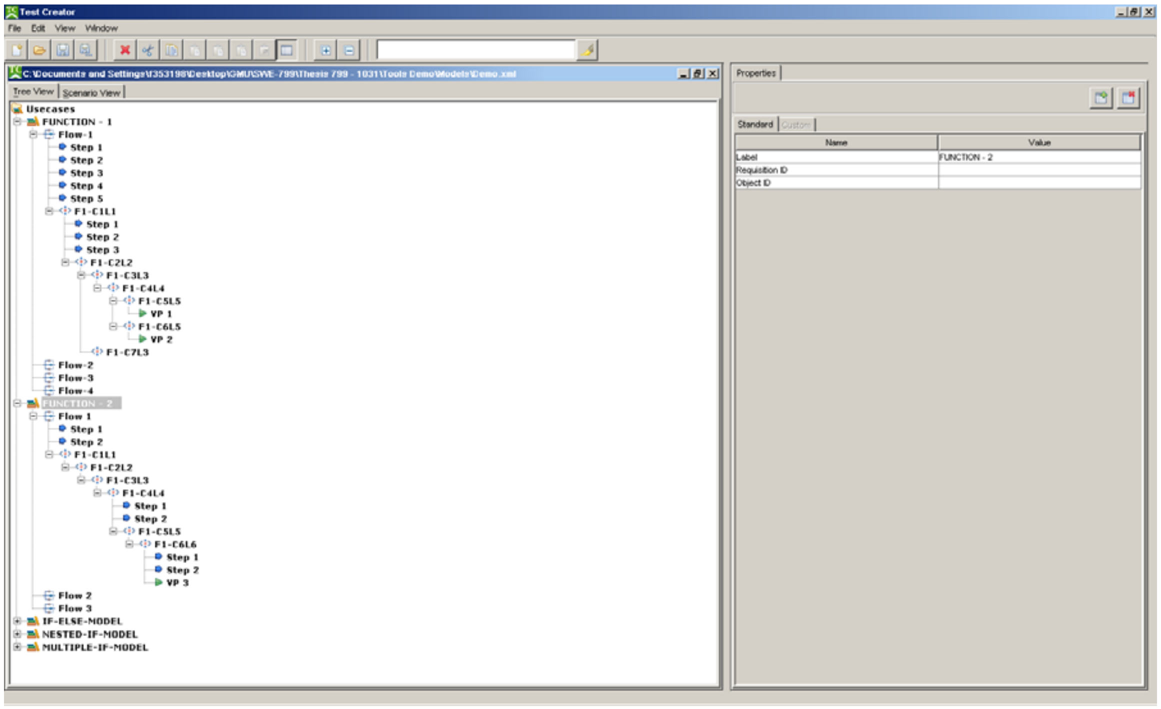
Calculation engines are specified in a variety of formats. Requirements are translated into functional specifications, which are more formal. In the case of calculation engines, specifications can take the form of finite state machines, state-transition diagrams, control flows, process models, data flows, etc. Financial models are sometimes in the form of the source code; if systems are to be implemented to replicate the financial models, then the source code becomes the specifications to test. For example, algorithms defined in the VB language for financial models are to be tested for their implementation in Java. They are also expressed in combination of all the above, such as logical expression, use cases, program structures, sequence of events, and sequence of actions.

3.1.5.1 Logical Expressions

Logical expressions generally consist of predicates and clauses. Predicates require special attention. Compound predicates can be broken down to equivalent sequences of simple predicates or to disjunctive normal form. Logical expressions can be modeled in the form of directed acyclic graphs. Clause coverage and predicate coverage criteria can be used to test the logical expressions. If there are n clauses in the predicate, then combinatorial coverage leads to 2^n truth-values. Applying appropriate predicate and clause coverage criteria would result in $n+1$ truth-values. Ammann and Offutt discussed specification-based logic coverage with examples in chapter 3 of their book (2008).

Predicates in the programs can be taken from *if* statements, *case/switch* statements, *for* loops, *while* loops, and *do-until* loops.

Logical expression can be modeled with the help of the tree shown in Figure 5.



```
Usecases
  FUNCTION - 1
    Flow-1
      Step 1
      Step 2
      Step 3
      Step 4
      Step 5
      F1-C1L1
        Step 1
        Step 2
        Step 3
        F1-C2L2
          F1-C3L3
            F1-C4L4
              F1-C5L5
                VP 1
              F1-C6L5
                VP 2
          F1-C7L3
    Flow-2
    Flow-3
    Flow-4
  FUNCTION - 2
    Flow 1
      Step 1
      Step 2
      F1-C1L1
        F1-C2L2
          F1-C3L3
            F1-C4L4
              Step 1
              Step 2
              F1-C5L5
                F1-C6L6
                  Step 1
                  Step 2
                  VP 3
    Flow 2
    Flow 3
  IF-ELSE-MODEL
  NESTED-IF-MODEL
  MULTIPLE-IF-MODEL
```

Name	Value
Label	FUNCTION - 2
Requisition ID	
Object ID	

Figure 5. Modeling example #1 using Fusion Test Modeler.

3.1.5.2 Use Cases

UML use cases are being widely used to clarify and express software requirements. They are meant to describe sequences of actions that software performs as a result of inputs from the users; that is, they help express the workflow of a computer application. Because use cases are developed early in software development, they can be valuable in helping the tester start testing activities early.

Use cases are described textually, and can be expressed as graphs. These graphs can be viewed as transaction flows. Activity diagrams can also be used to express transaction flows. FTM can be used to model a variety of things, including state changes, returning values, and computations.

For use cases, complete path coverage is often feasible and sometimes reasonable. It is also rare to find a complicated predicate that contains multiple clauses. This is because the use case is usually expressed in terms that the users can understand.

Users try to deduce use case scenarios which are instances of, or complete paths through, a use case. Each scenario should constitute some transaction by the users and is often derived when the use cases are constructed. If the use case graph is finite, then it is possible to list all possible scenarios. However, domain knowledge can be used to reduce the number of scenarios that are useful or interesting from either a modeling or test case perspective.

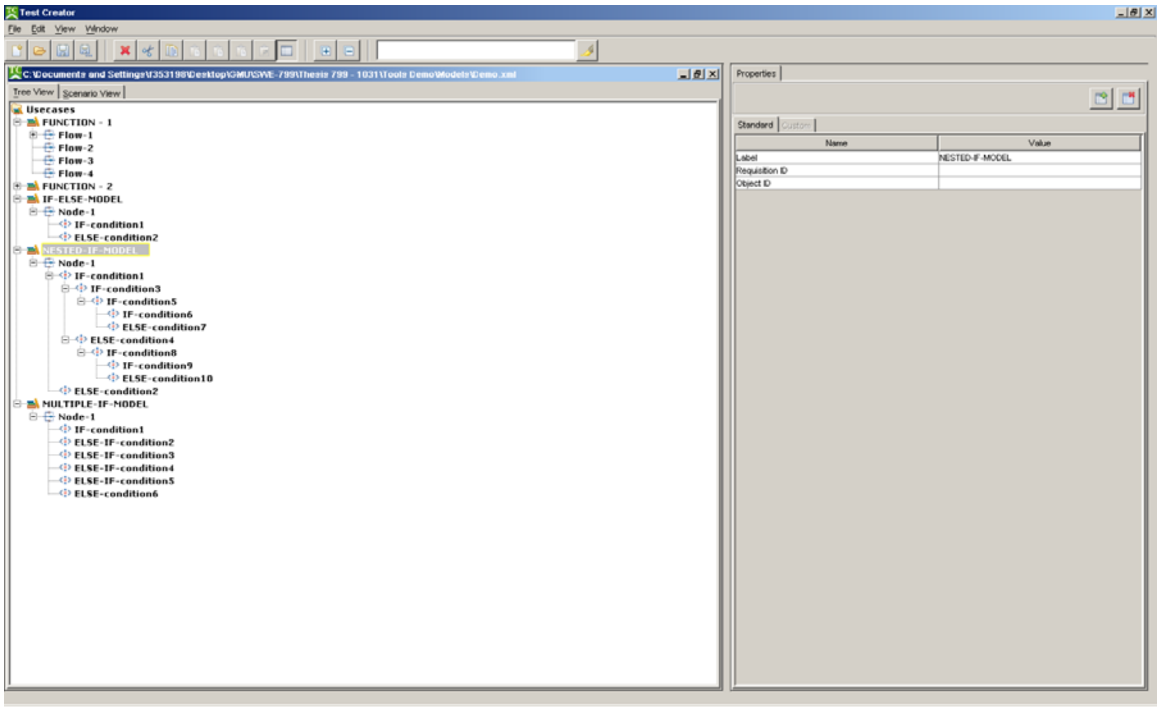
3.1.5.3 Loops

The loops themselves are not important for the purpose of modeling, but loop control variables are important in the cases of both deterministic and non-deterministic loops. This thesis applied boundary value techniques for the loop control variables. Deriving these values will help in path sensitization of the processing to be tested within the loops. This also applies to nested loops.

3.1.5.4 Other Common Elements in Specifications

Various program structures that are commonly seen in the specifications are *if-else* structures, *nested-if* structures, decision tree structures, and *case/switch* structures. Conditional expressions are composed of expressions combined with relational and/or logical operators. A condition is an expression that can be evaluated to be true or false. A sequence of events, also called preconditions to satisfy, as well as a sequence of actions, relations or constraints defined among different parameters, are some common observations in the specifications.

All of these structures can be modeled with the help of a tree, as shown in Figure 6.

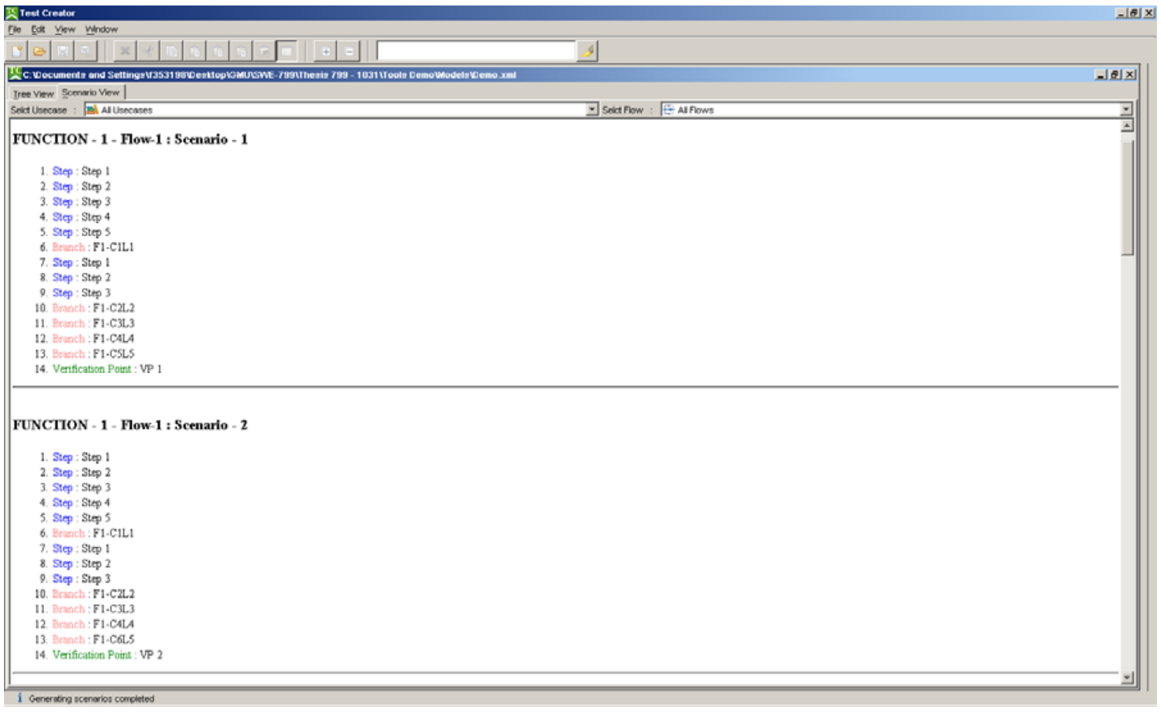

Test Creator
File
Edit
View
Window
C:\Documents and Settings\I353198\Desktop\GMU\SWE-799\Thesis 799 - 1031\Tools Demo\Models\Demo.xml
Tree View
Scenario View
Properties
Standard
Custom

```
Usecases
⊟ FUNCTION - 1
    ⊞ Flow-1
      Flow-2
      Flow-3
      Flow-4
⊞ FUNCTION - 2
⊟ IF-ELSE-MODEL
    ⊟ Node-1
        IF-condition1
        ELSE-condition2
⊟ NESTED-IF-MODEL
    ⊟ Node-1
        ⊟ IF-condition1
            ⊟ IF-condition3
                ⊟ IF-condition5
                    IF-condition6
                    ELSE-condition7
            ⊟ ELSE-condition4
                ⊟ IF-condition8
                    IF-condition9
                    ELSE-condition10
        ELSE-condition2
⊟ MULTIPLE-IF-MODEL
    ⊟ Node-1
        IF-condition1
        ELSE-IF-condition2
        ELSE-IF-condition3
        ELSE-IF-condition4
        ELSE-IF-condition5
        ELSE-condition6
```

Name	Value
Label	NESTED-IF-MODEL
Requisition ID	
Object ID	

Figure 6. Modeling example #2 using Fusion Test Modeler.

Requirements modeled as shown in Figures 5 and 6 are transformed into tests as shown in Figure 7. This process is explained and documented in detail with help of a case study in Chapters 6 and 9.



```
FUNCTION - 1 - Flow-1 : Scenario - 1

 1. Step : Step 1
 2. Step : Step 2
 3. Step : Step 3
 4. Step : Step 4
 5. Step : Step 5
 6. Branch : F1-C1L1
 7. Step : Step 1
 8. Step : Step 2
 9. Step : Step 3
10. Branch : F1-C2L2
11. Branch : F1-C3L3
12. Branch : F1-C4L4
13. Branch : F1-C5L5
14. Verification Point : VP 1

FUNCTION - 1 - Flow-1 : Scenario - 2

 1. Step : Step 1
 2. Step : Step 2
 3. Step : Step 3
 4. Step : Step 4
 5. Step : Step 5
 6. Branch : F1-C1L1
 7. Step : Step 1
 8. Step : Step 2
 9. Step : Step 3
10. Branch : F1-C2L2
11. Branch : F1-C3L3
12. Branch : F1-C4L4
13. Branch : F1-C6L5
14. Verification Point : VP 2

Generating scenarios completed
```

Figure 7. Sample outputs from Fusion Test Modeler.

3.1.6 Rationale Behind This Modeling Design

The test approach defined here is more appropriate to system testing and acceptance testing, but can also be applied to unit testing. There are numerous testing techniques available for black box testing that are insufficient to test calculation engines. Because controllability and observability are very low for calculation engines, reachability of a statement or condition can be achieved with the help of modeling.

At present, many commercially available tools expect testers to possess strong logical, analytical, and critical thinking skills. Unfortunately, this is not always true. Technology should adequately address the competence of a majority of its users. A number of modeling techniques and tools are also available on the market that take a longer time to learn and apply, which is not practical. Also, these modeling techniques are associated with notations and steps to follow. There is a lot of research in generating test requirements from formal specifications; however, the outcome depends on the degree of formalism in the specifications.

The trees, on the other hand, are simple structures that can be easily understood and modeling can be done with ease. FTM is developed to meet the following seven essential needs.

3.1.6.1 Requirements Traceability

The model's traceability to the requirements is an essential element that not only provides the coverage but also helps in impact analysis when requirements change. Factory tools/modeling languages such as Visio and UML do not help build traceability into the model. FTM provides traceability of the requirements from the test models.

3.1.6.2 Audit Requirements

Internal audits require testing processes to be transparent. Test cases should be well documented, and changes should be applied in a controlled manner. FTM allows test analysts to keep track of changes, and also captures information related to who executed the tests and when they were executed. Models are saved in XML format and the XML files can be put under configuration management.

3.1.6.3 Specification Formats

As discussed in Section 2.3, requirements are specified in different formats. FTM allows modeling multiple kinds of specifications (with some exceptions).

3.1.6.4 Easy to Learn

The modeling technique chosen is simple so that the business community, testers, and analysts from non-engineering backgrounds can learn and model the requirements with minimal training. They can also analyze the requirements with the help of models.

3.1.6.5 Preserving the Models

It is common for testers to build mental models and then destroy the models once they understand the requirements. The FTM tool allows users to build rough drafts of the test models and preserve them for future analysis. The tool helps the users evolve their analysis into a model that captures the testable requirements. In later stages, it supports the impact analysis. These models also help in transitioning the knowledge when new team members arrive into the project.

3.1.6.6 Complementing the Existing Tools to Manage Testing

Freddie Mac has a set of tools that complements its software development methodology. Any homegrown tools should be tightly integrated with the existing tools. The FTM tool complements the TestManager tool, which is used to manage the test assets.

3.1.7 Coverage Criterion

Directed graphs form the foundation for many coverage criteria. For example, the most common graph abstraction for source code maps code is to a control flow graph. It is important to understand that the graph is not the same as the artifact; indeed, artifacts typically have several useful, but nonetheless quite different, graph abstractions. The same abstraction that produces the graph from the artifact also maps test cases for the artifact to paths in the graph. Accordingly, a graph-based coverage criterion evaluates a test set for an artifact in terms of how the paths corresponding to the test cases "cover" the artifact's graph abstraction.

The basic notion of a graph and necessary additional structures is given below. A graph G formally is:

- a set N of nodes
- a set N_o of initial nodes, where $N_o \subseteq$ N
- a set N_f of final nodes, where $N_f \subseteq$ N
- a set E of edges, where E is a subset of N × N

The term "node" or "vertex" is often identified with a statement or a basic block. The term "edge" or "arc" is often identified with a branch.

Test criteria require inputs that start at one node and end at another. This is only possible if a path connects those nodes.

Ammann and Offutt (2008) presented different graph coverage criteria for the structural graphs and data flow graphs. The Node coverage, Edge coverage, Edge-Pair coverage, Prime Path coverage, Simple Round Trip coverage, Complete Round Trip coverage, Complete Path coverage, and Specified Path coverage are applicable for the structural graphs. The All-DU-Paths coverage, All-Uses coverage, and All-Defs coverage are applicable for the data flow graphs.

The logical expressions, conditional expressions, and control structures such as if statements, if-else statements, nested if-else statements, switch statements, and use cases are modeled in the form of trees using the Fusion Test Modeler (FTM). The tree structures do not have loops. Traversing the tree from root to leaf leads to the prime path coverage criterion. When there are no loops, the prime path coverage criterion is equivalent to the all-paths coverage. Therefore, in this case, applying prime path coverage criterion generates all the distinct paths in the model, which in turn are the test cases.

3.1.7.1 Prime Path Coverage

A path from n_i to n_j is *simple* if no node appears more than once on the path, with the exception that the first and last nodes may be identical.

A path from n_i to n_j is a *prime path* if it is a simple path and it does not appear as a proper subpath of any other simple path.

Prime Path Coverage (PPC): TR contains each prime path in G.

3.2 Step #2: Generating Test Requirements

The test requirements for the calculation engines are generated from the models that are built using FTM. Prime path coverage is applied to derive the test requirements. This process of generating test requirements is automated, which means when requirements are modeled using FTM, test requirements are automatically generated. This process is explained in detail in this thesis's case studies.

For ISP, test requirements for the testable functions are derived by applying Base Choice (BC), Multiple Base Choice (MBC), and Pair-Wise (PW) coverage criteria. Testable functions are identified and then their partitions and blocks are derived following the guidelines in the category partition method framework. Guidelines are provided to list the partitions and blocks in the spreadsheet. Java utilities are written to read and generate the base choice and multiple base choice test requirements from the spreadsheet. Bach's PERL program is used to read and generate the pairwise test requirements from the spreadsheet.

This step is completely automated.

3.3 Step #3: Generating Test Data

In order to execute the test requirements derived from step #2, test data is required. This test data is refined from the input space partitioning and modeling technique.

As discussed in earlier sections, calculation engines usually do not receive inputs directly from the GUI. Calculations will be triggered only after the inputs are validated at the presentation layer, which means invalid inputs are unlikely to be input to the calculation engines. In this process, test data will be associated with the test requirements and prepared test cases will be executable.

When there are constraints among the attributes, then the test requirements may contain attribute values such as "Less than," "Greater than," or something similar. Actual values to these attributes are provided. This step currently involves manual intervention and is explained in detail in the case studies.

3.4 Step #4: Simulating Calculation Engine and Inputting the Test Data

A simulator is used to generate the expected results. Simulators can be written in any programming language the test analyst is comfortable with. Freddie Mac often uses MS-Excel to write the functions using built-in functions of Excel. VB Macros also can be used.

In End User Computing (EUC) applications, most calculations should already be in place, built with the help of VB Macros or Excel functions. When new information system applications are built to replace these EUCs per Sarbanes Oxley (SOX) requirements, system upgrades, or any other compliance requirements, existing programs can be used as simulators.

Simulators provide challenges with respect to correctness. It is difficult to judge whether the output of the simulator or the output of the system-under-testing is correct. Differences in these two outcomes should be resolved with the knowledge of a calculation engine specialist or a requirements analyst.

Simulators should be simple in nature compared to the implementation of the same logic in system-under-testing. Test inputs derived in step #3 should be inputted to the simulator. Inputs are generated in large numbers; therefore, automated programs can be developed to read the inputs and input them to the simulator.

Pemmaraju (1998) states that if multiple calculations performed by different calculators work in combination to produce the final output, it is beneficial to log the outputs of each calculator. This will help in two ways. One is to understand the data flows among these calculators. The second is to know the internal states of these values. In addition, logging helps to debug the problem if the expected and actual results differ.

3.5 Step #5: Collecting Expected Results

Once the test data is derived and is associated with the test requirements, the test case now becomes ready to execute. When these test cases are executed against the simulator built in the previous step, the simulator produces the expected results.

The automation process helps generate the tests and execute them in a reasonable amount of time. Since the models are developed early in the life cycle and undergo frequent changes, expected results tend to change. A mechanism needs to be established to capture the expected results. In this thesis's case studies, expected results are captured in the spreadsheets under different columns for each test requirement and this placeholder always remains the same.

In EUC applications in Freddie Mac, when systems are already in place these expected results are already available in the reference spreadsheets. VB Macros in the spreadsheets contain the same functionality as the system-under-test. This also comes with a price, as the reference spreadsheet is just a current form of implementation of a complex application and therefore could be as faulty as the new implementation of the system-under-test. Nevertheless, the reference spreadsheet proved to be very useful for automated verification of results, as it was possible to write scripts to read the spreadsheet and obtain results from it. Moreover, the reference spreadsheet was the only specification for the backend calculations in one case study.

3.6 Step #6: Input Test Data to the System-Under-Test

Once the test data is generated and is associated with the test requirements, test cases are ready to execute against the system-under-test. This process of deriving the inputs using the ISP method, and designing the test requirements from the test model, may generate a large number of test cases—making them cumbersome and time consuming to execute manually. Therefore, an automation tool must be considered to feed the test data of the test cases to the system under development. In Rational

TestManager this test data is stored in data pools. A data-driven testing technique is applied to automatically enter the test data into the system by the tool. Logic validation is not added to the automation scripts in order to maximize the processing time of the data entry. Automation scripts are just simulated to enter the data and are scheduled on different machines to enter data in parallel. When the test data is inputted to the system, calculation-triggering events are identified and automation scripts are programmed to trigger the calculations. Events to trigger the calculations are also incorporated into the script, so that every time the event triggers, the calculation engine is activated and performs calculations at the business layer, storing the results in the database.

3.7 Step #7: Collecting Actual Results

All the actual results are stored in the database. It is essential for the test analysts to understand the data model of the system so they can locate the actual results. In general, the final state of the actual results generated by the calculation engines will be stored in the database, and the internal states of the results may be logged into the execution logs for debugging. It may be required to refer to the execution logs for the internal states and values of the actual results in case of deviation from the expected results. In one case study, where there are 9 calculators involved and each calculator receives the inputs from one or more calculators, it was suggested to programmers to generate the execution logs with the intermediate values of the calculation variables. This helped in debugging the incorrect expected output. A Java utility was written to search all the intermediate states of calculation variables for each and every instance of them. The program scanned 10 MB of the execution logs in less than 10 seconds and wrote the expected intermediate outputs in a tabular format in an Excel spreadsheet.

3.8 Step #8: Comparing Actual and Expected Results Using a Comparator

Because the calculations performed by the backend often produced hundreds of outputs, an automated comparison tool was developed to examine and compare the backend results with those of the spreadsheet. Also, these results need to be compared more frequently. The comparator compares the results, showing the differences in cases of failures and showing success in cases of passes. Expected results are saved in the Excel sheet and actual results may be obtained from the database or execution logs. The comparator is built with the capability to compare the left-hand side and right-hand side of the results in different forms: spreadsheet, spreadsheet; spreadsheet, database; and spreadsheet, text file.

In some cases, actual results (intermediate) are obtained from the program execution logs. These logs store values for intermediate results and final results are stored in the database. The comparator searches for the desired text in the execution logs and required fields in the database. The comparator tool discards unneeded text strings before making comparisons of the output results. Actual and expected results may not always be the same. As long as they are with in the tolerance limits, the result is deemed correct. For example, a variation of at most one dollar in a million is acceptable if the variation is caused due to drifts in floating point accuracy in Java or Microsoft Excel.

4 Case Study #1: Contract Pricing

"Contract Pricing" is an important feature in the pricing subsystem of the selling system. The system prices the contracts when contracts are created in the Loan Purchase Contract (LPC) subsystem and reprices the contracts when contracts are modified or upon a request from the user.

The contracts are of two types: cash contracts and swap contracts. This case study represents swap contract pricing. The requirements for the pricing calculations of swap contracts are specified in the form of use cases. This use case calculates the swap GFee, Buyup max, Buydown max, and Total adjusted GFee for fixed rate, Guarantor, and Multilender ARM swap contracts.

This thesis is focused on the approach to test the calculation engines; however, this case study also shows how to isolate and test the testable functions related to calculations in the system. Freddie Mac's selling system consists of different subsystems: LPC, NCM, TPA, Pooling, Pricing, and OIM. Each subsystem contains multiple features and is designed to abstract their functionalities from the other. The "contract pricing" feature in the pricing subsystem receives the inputs from the "import contracts" feature of the LPC subsystem that facilitates importing the contracts. This feature is tested in two stages. In the first stage, the import contracts feature is tested so that the system accepts only the valid contracts for pricing. In the second stage, contract attributes are isolated to test the contract pricing feature of the system.

4.1 Step #1: Input Space Partitioning

The contract entity has 29 attributes. Therefore, the contract domain is divided into 29 partitions. These partitions and their blocks are shown in Table 1.

Table 1: *Contract Partitions and Blocks*

Partition	Partition Name	Partition Blocks
1	Execution Option	{GU, ML, NULL_EO, *EO}
2	Rate Option	{FI, AR, NULL_RO, *RO}
3	Master Commitment	{9CHAR, 10CHAR, 8CHAR,NULL_MC, TBD}
4	Security Product	{NUMBER, NULL_SP, *SP}
5	Security Amount	{DOLLAR_ROUND, *DOLLAR_FRACTION, *>100B, NULL_SA}
6	Contract Name	{CHAR (26), CHAR (25), CHAR (1), NULL_CONT}
7	Settlement Date	{MMDDYYYY, *SD, NULL_SD}
8	Settlement Cycle Days	{1,3,4,5, *6, *2, NULL_SCD}
9	Security Coupon	{XX.XXX, XXX.XX, NULL_SC, 26.000}
10	Servicing Option	{RE, CT, *SO, NULL_SO}
11	Designated Servicer Number	{NULL_DS, DS, *DS}
12	Minimum Required Servicing Spread	{XX.XXX, NULL_MRSS, XXX.XX}
13	Minimum Servicing Spread Coupon	{XX.XXX, NULL_MSSC, XXX.XX}
14	Minimum Servicing Spread Margin	{XX.XXX, NULL_MSSM, XXX.XX}
15	Minimum Servicing Spread Lifetime Ceiling	{XX.XXX, NULL_MSSLC, XXX.XX}
16	Remittance Option	{AR, SU, FT, GO, *RT, NULL_RT}
17	Super ARC Remittance Due day	{0,1,2,14,15,16,NULL_SARD}
18	Required Spread GFee	{NULL_RSG, *RSG, RSG}
19	BUBD Program Type	{CL, NL, LL, *BUBD_PT, NULL}
20	BUBD Request Type	{NULL_BUBD_RT, BO, BU, BD, NO, *BUBD_RT}
21	Contract Level Buyup/Buydown	{NULL_CL_BUBD, *CL_BUBD, BU, BD, NO}
22	BUBD Grid Type	{NULL_BUBD_GT, *BUBD_GT, A, A-Minus, Negotiated 1 Grid}
23	BU Max Amount	{0, *BU_MAX_AMT, NULL_BU_MAX_AMT, XXX.XXX}
24	BD Max Amount	{0, *BD_MAX_AMT, NULL_BD_MAX_AMT, XXX.XXX}
25	Pool Number	{NULL_PNO, PNO, *PNO}
26	Index Look Back Period	{NULL_ILP, *ILP, ILP}
27	Fee Type	{FT, *FT, NULL_FT}
28	Fee Payment Method	{Delivery Fee, GFee Add On, *FTM, NULL_FTM}
29	Prepayment Penalty Indicator	{Y, N}

The system validates the properties for each attribute before creating a contract and generates an error message if any invalid inputs or invalid combination of inputs are passed to the system.

The blocks for each partition are derived based on the system specifications. The standard conventions are followed in defining the abstract values for these blocks. For example, for the first partition, Execution Option, the set of blocks are: {GU, ML, NULL_EO, *EO}. GU and ML are valid values for this partition. Invalid values are represented by *EO, which means the user can pass any satisfying value in the place of *EO. NULL_EO is another invalid value per the specifications. When the values for *EO, and NULL_EO are inputted, the system is expected to generate error messages informative to the user. This feature is tested in two stages.

First Stage

In the first stage, each attribute of the contract is validated using the base choice coverage criterion and constraints among the attributes are validated using the pair-wise coverage criterion.

The base contract is chosen to create the base choice contracts using different values of the blocks from each partition. A Java utility was written to create the base choice contracts.

When each block of every partition needs to be validated, the base choice coverage works well. Each base choice contract is targeted to validate one of the business rules in case of valid values, or will be targeted to generate error or informative messages in case of invalid values.

Even though one test input or a base contract addresses more than one requirement, independent tests are created to satisfy each requirement. This not only helps in traceability of the requirements, but also helps minimize the changes in test cases.

In the first stage, all the attributes or partitions of the contract are treated as being independent even though the constraints exist.

The constraints among the parameters are tested as follows: The Rate option, BUBD eligibility type, and BUBD request type of the contract are interdependent and also depend on the values of another entity called a master commitment. The master commitment has 30 partitions but MC LLBUBD eligibility and MC GFee add on eligibility are the only partitions within the scope of this testable function.

The pair-wise coverage criterion is applied to derive test cases to test the constraints among these parameters. Other partitions of the contract are prefixed with the base test value of the contract.

Each and every distinct value chosen for the blocks are traced to different error messages and an error code associated with it. Inputs are derived based on the functional specifications and not from the implementation details. Some tests are infeasible, as the design does not allow them. It is also a good practice to derive the inputs based on the functional specifications instead of implementation details, as the tests may uncover the errors in implementation (Grindal, Offut & Mellin, 2006).

Applying the base choice technique produced 120 test cases for contracts; pair-wise produced 207 test cases. A Java utility was built to generate base choice test cases and Bach's Perl program was used to generate the pair-wise test cases.

The contract entity has close to 200 business rules defined for the import contracts feature in the LPC subsystem. Test inputs are derived in the above process by applying the base choice and pair-wise coverage criteria to satisfy each and every business rule.

Second Stage

In the second stage, partitions required for "contract pricing" calculations were separated and then base choice, multiple base choice, and pair-wise criteria are applied. Problem analysis shows that among the inputs defined earlier, only Rate option, GFee, Remittance option type, GFee grid remittance option, LLGFee eligibility, BUBD Eligibility, and Max Buyup determine the controllability of the calculations. Therefore, only these partitions are considered to derive the tests. Partitions and blocks of the Contract Pricing are shown in Table 2.

.

Table 2: *Contract Pricing Partitions and Blocks*

Partitions	Rate Option	GFee	Remittance Option Type	GFee Grid Remittance Option	MC LLGFee Eligibility	BUBD Eligibility	Max Buyup
Blocks	{FIXED, ARM}	{NOT_NULL, NULL}	{GOLD, FIRST_TUESDAY, ARC, SUPER_ARC}	{GOLD, FIRST_TUESDAY, ARC, SUPER_ARC}	{Y, N}	{PROHIBITED, REQUIRED, OPTIONAL}	{LT_12.5, EQ_12.5, GT_12.5, NULL}

Base test #1, selected to generate base choice tests, is shown in Table 3.

Table 3: *Contract Pricing Base Test #1*

Partitions	Rate Option	GFee	Remittance Option Type	GFee Grid Remittance Option	MC LLGFee Eligibility	BUBD Eligibility	Max Buyup
Blocks	FIXED	NOT_ NULL	GOLD	GOLD	Y	PROHIBIT ED	LT_12. 5

Base test #2, selected to generate base choice tests, is shown in Table 4.

Table 4: *Contract Pricing Base Test #2*

Partitions	Rate Option	GFee	Remittance Option Type	GFee Grid Remittance Option	MC LLGFee Eligibility	BUBD Eligibility	Max Buyup
Blocks	ARM	NOT_ NULL	SUPER_A RC	GOLD	N	PROHIBIT ED	EQ_12 .5

4.1.1 Base Choice Coverage

Table 5 shows the base choice tests generated using base choice test #1.

Table 5: *Contract Pricing Base Choice Tests*

Test #	Rate Option	GFee	Remittance Option Type	GFee Grid Remittance Option	MC LLGFee Eligibility	BUBD Eligibility	Max Buyup
1	ARM	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	LT_12.5
2	FIXED	NULL	GOLD	GOLD	Y	PROHIBITED	LT_12.5
3	FIXED	NOT_NULL	FIRST_ TUESDAY	GOLD	Y	PROHIBITED	LT_12.5
4	FIXED	NOT_NULL	ARC	GOLD	Y	PROHIBITED	LT_12.5
5	FIXED	NOT_NULL	SUPER_ARC	GOLD	Y	PROHIBITED	LT_12.5
6	FIXED	NOT_NULL	GOLD	FIRST_TUE SDAY	Y	PROHIBITED	LT_12.5
7	FIXED	NOT_NULL	GOLD	ARC	Y	PROHIBITED	LT_12.5
8	FIXED	NOT_NULL	GOLD	SUPER_AR C	Y	PROHIBITED	LT_12.5
9	FIXED	NOT_NULL	GOLD	GOLD	N	PROHIBITED	LT_12.5
10	FIXED	NOT_NULL	GOLD	GOLD	Y	REQUIRED	LT_12.5
11	FIXED	NOT_NULL	GOLD	GOLD	Y	OPTIONAL	LT_12.5
12	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	EQ_12.5
13	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	GT_12.5
14	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	NULL
15	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	LT_12.5

4.1.2 Multiple Base Choice Coverage

Table 6 shows the multiple base choice tests using base choice test #1 and base choice test #2.

Table 6: *Contract Pricing Multiple Base Choice Tests*

Test #	**Rate Option**	**GFee**	**Remittance Option Type**	**GFee Grid Remittance Option**	**MC LLGFee Eligibility**	**BUBD Eligibility**	**Max Buyup**
1	ARM	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	LT_12.5
2	FIXED	NULL	GOLD	GOLD	Y	PROHIBITED	LT_12.5
3	FIXED	NOT_NULL	FIRST_ TUESDAY	GOLD	Y	PROHIBITED	LT_12.5
4	FIXED	NOT_NULL	ARC	GOLD	Y	PROHIBITED	LT_12.5
5	FIXED	NOT_NULL	SUPER_ ARC	GOLD	Y	PROHIBITED	LT_12.5
6	FIXED	NOT_NULL	GOLD	FIRST_ TUESDAY	Y	PROHIBITED	LT_12.5
7	FIXED	NOT_NULL	GOLD	ARC	Y	PROHIBITED	LT_12.5
8	FIXED	NOT_NULL	GOLD	SUPER_ ARC	Y	PROHIBITED	LT_12.5
9	FIXED	NOT_NULL	GOLD	GOLD	N	PROHIBITED	LT_12.5
10	FIXED	NOT_NULL	GOLD	GOLD	Y	REQUIRED	LT_12.5
11	FIXED	NOT_NULL	GOLD	GOLD	Y	OPTIONAL	LT_12.5
12	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	EQ_12.5
13	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	GT_12.5
14	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	NULL
15	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	LT_12.5
16	FIXED	NOT_NULL	SUPER_ ARC	GOLD	N	PROHIBITED	EQ_12.5
17	ARM	NULL	SUPER_ ARC	GOLD	N	PROHIBITED	EQ_12.5
18	ARM	NOT_NULL	GOLD	GOLD	N	PROHIBITED	EQ_12.5
19	ARM	NOT_NULL	FIRST_ TUESDAY	GOLD	N	PROHIBITED	EQ_12.5
20	ARM	NOT_NULL	ARC	GOLD	N	PROHIBITED	EQ_12.5
21	ARM	NOT_NULL	SUPER_ ARC	FIRST_ TUESDAY	N	PROHIBITED	EQ_12.5
22	ARM	NOT_NULL	SUPER_ ARC	ARC	N	PROHIBITED	EQ_12.5
23	ARM	NOT_NULL	SUPER_ ARC	SUPER_ ARC	N	PROHIBITED	EQ_12.5
24	ARM	NOT_NULL	SUPER_ ARC	GOLD	Y	PROHIBITED	EQ_12.5
25	ARM	NOT_NULL	SUPER_ ARC	GOLD	N	REQUIRED	EQ_12.5

Test #	Rate Option	GFee	Remittance Option Type	GFee Grid Remittance Option	MC LLGFee Eligibility	BUBD Eligibility	Max Buyup
26	ARM	NOT_NULL	SUPER_ ARC	GOLD	N	OPTIONAL	EQ_12.5
27	ARM	NOT_NULL	SUPER_ ARC	GOLD	N	PROHIBITED	LT_12.5
28	ARM	NOT_NULL	SUPER_ ARC	GOLD	N	PROHIBITED	GT_12.5
29	ARM	NOT_NULL	SUPER_ ARC	GOLD	N	PROHIBITED	NULL
30	ARM	NOT_NULL	SUPER_ ARC	GOLD	N	PROHIBITED	EQ_12.5

4.1.3 Pair-Wise Coverage

Table 7 shows the pair-wise tests derived using Bach’s PERL program.

Table 7: *Contract Pricing Pair-Wise Tests*

Test #	Rate Option	GFee	Remittance Option Type	GFee Grid Remittance Option	MC LLGFee Eligibility	BUBD Eligibility	Max Buyup
1	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	LT_12.5
2	ARM	NULL	FIRST_ TUESDAY	GOLD	N	REQUIRED	EQ_12.5
3	FIXED	NULL	FIRST_ TUESDAY	FIRST_ TUESDAY	Y	OPTIONAL	LT_12.5
4	ARM	NOT_NULL	GOLD	FIRST_ TUESDAY	N	PROHIBITED	EQ_12.5
5	FIXED	NOT_NULL	ARC	ARC	N	REQUIRED	GT_12.5
6	ARM	NOT_NULL	SUPER_ ARC	ARC	Y	OPTIONAL	NULL
7	FIXED	NULL	SUPER_ ARC	SUPER_ARC	N	PROHIBITED	GT_12.5
8	ARM	NULL	ARC	SUPER_ARC	Y	REQUIRED	NULL
9	ARM	NULL	GOLD	ARC	N	REQUIRED	LT_12.5
10	FIXED	NOT_NULL	FIRST_ TUESDAY	SUPER_ARC	Y	OPTIONAL	EQ_12.5
11	ARM	~NULL	GOLD	GOLD	Y	OPTIONAL	GT_12.5
12	FIXED	~NOT_NUL L	FIRST_ TUESDAY	FIRST_ TUESDAY	N	PROHIBITED	NULL
13	~ARM	~NOT_NUL L	ARC	FIRST_ TUESDAY	N	OPTIONAL	GT_12.5
14	~FIXED	~NULL	ARC	ARC	~Y	PROHIBITED	EQ_12.5
15	~FIXED	~NOT_NUL L	SUPER_ ARC	GOLD	~N	REQUIRED	NULL
16	~ARM	~NOT_NUL L	SUPER_ ARC	SUPER_ARC	~N	~PROHIBITED	LT_12.5
17	~FIXED	~NULL	SUPER_ ARC	FIRST_ TUESDAY	~Y	REQUIRED	GT_12.5
18	~FIXED	~NULL	GOLD	GOLD	~N	~OPTIONAL	NULL
19	~ARM	~NOT_NUL L	ARC	GOLD	~Y	~PROHIBITED	LT_12.5
20	~ARM	~NOT_NUL L	FIRST_ TUESDAY	ARC	~Y	~REQUIRED	EQ_12.5
21	~FIXED	~NULL	GOLD	SUPER_ARC	~N	~OPTIONAL	EQ_12.5
22	~ARM	~NULL	FIRST_ TUESDAY	~FIRST_ TUESDAY	~Y	~PROHIBITED	GT_12.5
23	~ARM	~NULL	SUPER_ ARC	~ARC	~N	~OPTIONAL	EQ_12.5

4.2 Step # 1: Modeling Technique

The testable function for the Contract Pricing is modeled using the FTM tool. Detailed outputs of the model are shown in Appendix A. Test cases are shown in Table 8.

Table 8: *Contract Pricing Test Inputs From Modeling*

Test #	Rate Option	GFee	Remittance Option Type	GFee Grid Remittance Option	MC LLGFee Eligibility	BUBD Eligibility	Max Buyup
1	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	GT_12.5
2	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	LE_12.5
3	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	GT_12.5
4	FIXED	NOT_NULL	GOLD	GOLD	Y	PROHIBITED	LE_12.5
5	FIXED	NOT_NULL	GOLD	SUPER_ ARC	Y	PROHIBITED	GT_12.5
6	FIXED	NOT_NULL	GOLD	SUPER_ ARC	Y	PROHIBITED	GT_12.5
7	FIXED	NOT_NULL	GOLD	FIRST_ TUESDAY	Y	PROHIBITED	LE_12.5
8	FIXED	NOT_NULL	GOLD	ARC	Y	PROHIBITED	LE_12.5
9	FIXED	NOT_NULL	GOLD	FIRST_ TUESDAY	Y	PROHIBITED	LE_12.5
10	FIXED	NOT_NULL	GOLD	FIRST_ TUESDAY	Y	PROHIBITED	GT_12.5
11	FIXED	NOT_NULL	GOLD	ARC	Y	PROHIBITED	LE_12.5
12	FIXED	NOT_NULL	GOLD	FIRST_ TUESDAY	Y	PROHIBITED	LE_12.5
13	FIXED	NOT_NULL	GOLD	GOLD	N	PROHIBITED	GT_12.5
14	FIXED	NOT_NULL	GOLD	GOLD	N	PROHIBITED	LE_12.5
15	FIXED	NOT_NULL	GOLD	SUPER_ ARC	N	PROHIBITED	GT_12.5
16	FIXED	NOT_NULL	GOLD	SUPER_ ARC	N	PROHIBITED	LE_12.5
17	FIXED	NOT_NULL	GOLD	SUPER_ ARC	N	PROHIBITED	GT_12.5
18	FIXED	NOT_NULL	GOLD	SUPER_ ARC	N	PROHIBITED	LE_12.5
19	ARM	NOT_NULL	FIRST_ TUESDAY	FIRST_ TUESDAY	Y	PROHIBITED	GT_25
20	ARM	NOT_NULL	FIRST_ TUESDAY	FIRST_ TUESDAY	Y	PROHIBITED	LE_25
21	ARM	NOT_NULL	FIRST_ TUESDAY	ARC	Y	PROHIBITED	GT_25
22	ARM	NOT_NULL	FIRST_ TUESDAY	ARC	Y	PROHIBITED	LE_25
23	ARM	NOT_NULL	FIRST_ TUESDAY	SUPER_ ARC	Y	PROHIBITED	GT_25
24	ARM	NOT_NULL	FIRST_ TUESDAY	SUPER_ ARC	Y	PROHIBITED	LE_25
25	ARM	NOT_NULL	FIRST_ TUESDAY	FIRST_ TUESDAY	N	PROHIBITED	GT_12.5
26	ARM	NOT_NULL	FIRST_ TUESDAY	ARC	N	PROHIBITED	EQ_12.5
27	ARM	NOT_NULL	FIRST_ TUESDAY	ARC	N	PROHIBITED	EQ_12.5

4.3 Step #2: Generating Test Requirements

Sections 4.1 and 4.2 shows the test cases generated by both the ISP and modeling technique for the contract pricing feature. The remaining attributes of the contract are prefixed to make these test cases executable.

4.4 Step #3: Generating Test Data

Test data is built by passing actual values in place of abstract values such as EQ_12.5, LE_25.

4.5 Step #4: Building the Simulator and Inputting Test Data

The contract pricing calculation simulator was built in Java. This simulator program reads inputs from the spreadsheet, performs the calculations, and then outputs the calculation results into another spreadsheet at a defined location. Test inputs derived from the modeling and ISP techniques are then inputted to the calculation simulator. The calculation simulator performs the calculations and generates the expected results for each and every test input. The simulator program also writes the expected results into a spreadsheet.

4.6 Step #5: Input Test Data Into System-Under-Test

Test inputs derived from the modeling and ISP techniques are then inputted to the system-under-test. Because we have too many tests to enter them manually, a data-driven automation technique is applied using the Rational’s robot tool. The system has another feature called “import contracts” with which all these test inputs can be bundled into a flat file and imported at once. Both methods are chosen to input the contracts into the system-under-test, as they follow different paths of processing. When the contract is successfully created, the system automatically prices the contracts and stores the pricing results in the database. These pricing results are the actual results.

4.7 Steps # 6, 7, and 8: Collecting Expected Results, Actual Results, and Comparing the Results

Expected results are stored in a spreadsheet and actual results are stored in a DB2 database. The comparator program written in Java compares the expected results with actual results. The program uses the contract number as the unique ID; it parses the expected results in the spreadsheet row by row, picks up each contract ID and values of its attributes, then searches the corresponding values of attributes for the same contract ID in the database, and compares both the values. If the values match, the program flags the test case as “Pass,” otherwise as “Fail.” In the calculations, tolerance will be defined for rounding and is taken into account if the expected and actual results deviate within the determined tolerance range.

Results and observations are discussed in Chapter 8.

5 Case Study #2: Loan Pricing

The “Loan Pricing” feature in the pricing subsystem prices the loans when the loans are newly created in the system or upon a reprice request by the business users.

In release 7.0, price recalculation for swap loans is triggered by a data correction to one or more data elements that are used in the price calculation performed at the time of settlement. These data corrections can be one or both of the following changes: internal FM price definition terms (grid data), or seller delivered loan/contract data for price affecting fields. Either type of data correction will trigger a total price recalculation of all price components that apply to the loan, including GFEE/LLGFEE, BUBD and Delivery Fees.

The Price recalculation can be approved either automatically or manually. Manual approval of the price recalculation results is applicable only when the recalculation is isolated solely to changes in either the BUBD and contract GFEE fee grid definition changes.

Any data change to loan and/or delivery fee data will trigger a recalculation and reprice *all* price component data that is effective at the time of settlement. This includes any changes to BUBD or contract GFEE grid definition terms.

The mortgage loan entity has nearly 150 attributes, but only a few of those attributes are relevant to “Loan Pricing” as described in the requirements. Following are

12 partitions that are identified in this testable function and shown in Table 9. Among the 12, values for loan interest rate (3), and servicing fee rate (4) are received from the price grids. These values are updated in the grids based on the current market. Max BU (9), Max BD (11), and user requested Max Buy Up (12) are intermediate parameters whose values are used in the final calculations. Even though they participate in the calculations, their values depend on the values of the other attributes that are input for the loan.

Table 9: *Loan Pricing Partitions and Blocks*

Partition #	Partition Name	Partition Blocks
1	BUBD Request Type	{ NLBUBD, LLBUBD, CLBU, CLBD, NONE }
2	Current Loan Family Type	{ ARM, FIXED, BALLOON }
3	Loan Interest Rate	
4	Servicing Fee Rate	
5	Total Adjusted GFee	{ GT_MAXBD, LT_MAXBD, EQ_MAXBD }
6	BUBD Basis Points	{ GT_Z, LT_Z, EQ_Z, GT_SSBU, LT_SSBU, EQ_SSBU, GT_URMP, LT_URMP, EQ_URMP, GT_MAXBD, LT_MAXBD, EQ_MAXBD }
7	Investor Pass Thru Rate	
8	Seller Specified Buy Up (SSBU)	{ GT_MAXBU, LT_MAXBU, EQ_MAXBU }
9	MAX BU	
10	Seller Specified Buy Down (SSBD)	{ GT_TGF, LT_TGF, EQ_TGF, GT_BUBDBP, LT_BUBDBP, EQ_BUBDBP,
11	MAX BD	
12	User Requested Max Buy Up	

Among the 140 attributes of the loan, only the 12 partitions shown in Table 9 are involved in the pricing calculations. Among these 12 partitions, only 6 partitions (1, 2, 5, 6, 8, and 10) influence the controllability of the pricing calculations. The remaining 6 partitions influence the observability of the calculations.

5.1 Step #1: Input Space Partitioning

Test cases are derived based on the base choice, multiple-base choice, and pair-wise coverage criteria taking the partitions that influence the controllability of the loan pricing calculations. Values for the remaining partitions are prefixed with default values.

The base tests shown in Tables 10 and 11 are used to generate base choice tests and multiple base choice tests with the help of a Java utility.

Table 10: *Loan Pricing Base Test #1*

BUBD Request Type	**Loan Type**	**Total Adjusted GFee**	**BUBD Basis points**	**Seller Specified Buy Up**	**Seller Specified Buy Down**
NLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF

Table 11: *Loan Pricing Base Test #2*

BUBD Request Type	**Loan Type**	**Total Adjusted GFee**	**BUBD Basis points**	**Seller Specified Buy Up**	**Seller Specified Buy Down**
NLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF

5.1.1 Base Choice Coverage

Table 12 shows the base choice tests using base test #1.

Table 12: *Loan Pricing Base Choice Tests*

Test #	BUBD Request Type	Loan Type	Total Adjusted GFee	BUBD Basis Points	Seller Specified Buy Up	Seller Specified Buy Down
1	NLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
2	CLBU	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
3	CLBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
4	NONE	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
5	LLBUBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
6	LLBUBD	FIXED	LT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
7	LLBUBD	FIXED	EQ_MAXBD	GT_Z	GT_MAXBU	GT_TGF
8	LLBUBD	FIXED	GT_MAXBD	EQ_Z	GT_MAXBU	GT_TGF
9	LLBUBD	FIXED	GT_MAXBD	LT_Z	GT_MAXBU	GT_TGF
10	LLBUBD	FIXED	GT_MAXBD	GT_SSBU	GT_MAXBU	GT_TGF
11	LLBUBD	FIXED	GT_MAXBD	LT_SSBU	GT_MAXBU	GT_TGF
12	LLBUBD	FIXED	GT_MAXBD	EQ_SSBU	GT_MAXBU	GT_TGF
13	LLBUBD	FIXED	GT_MAXBD	GT_URMP	GT_MAXBU	GT_TGF
14	LLBUBD	FIXED	GT_MAXBD	LT_URMP	GT_MAXBU	GT_TGF
15	LLBUBD	FIXED	GT_MAXBD	EQ_URMP	GT_MAXBU	GT_TGF
16	LLBUBD	FIXED	GT_MAXBD	GT_MAXBD	GT_MAXBU	GT_TGF
17	LLBUBD	FIXED	GT_MAXBD	LT_MAXBD	GT_MAXBU	GT_TGF
18	LLBUBD	FIXED	GT_MAXBD	EQ_MAXBD	GT_MAXBU	GT_TGF

Test #	BUBD Request Type	Loan Type	Total Adjusted GFee	BUBD Basis Points	Seller Specified Buy Up	Seller Specified Buy Down
19	LLBUBD	FIXED	GT_MAXBD	GT_Z	LT_MAXBU	GT_TGF
20	LLBUBD	FIXED	GT_MAXBD	GT_Z	EQ_MAXBU	GT_TGF
21	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	LT_TGF
22	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	EQ_TGF
23	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_BUBDBP
24	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	LT_BUBDBP
25	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	EQ_BUBDBP
26	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF

5.1.2 Multiple Base Choice Coverage

The test cases in Table 13 are generated using multiple base choice coverage criteria.

Table 13: *Loan Pricing Multiple Base Choice Tests*

Test #	BUBD Request Type	Loan Type	Total Adjusted GFee	BUBD Basis Points	Seller Specified Buy Up	Seller Specified Buy Down
1	NLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
2	CLBU	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
3	CLBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
4	NONE	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
5	LLBUBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
6	LLBUBD	FIXED	LT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
7	LLBUBD	FIXED	EQ_MAXBD	GT_Z	GT_MAXBU	GT_TGF
8	LLBUBD	FIXED	GT_MAXBD	EQ_Z	GT_MAXBU	GT_TGF
9	LLBUBD	FIXED	GT_MAXBD	LT_Z	GT_MAXBU	GT_TGF
10	LLBUBD	FIXED	GT_MAXBD	GT_SSBU	GT_MAXBU	GT_TGF
11	LLBUBD	FIXED	GT_MAXBD	LT_SSBU	GT_MAXBU	GT_TGF
12	LLBUBD	FIXED	GT_MAXBD	EQ_SSBU	GT_MAXBU	GT_TGF
13	LLBUBD	FIXED	GT_MAXBD	GT_URMP	GT_MAXBU	GT_TGF
14	LLBUBD	FIXED	GT_MAXBD	LT_URMP	GT_MAXBU	GT_TGF
15	LLBUBD	FIXED	GT_MAXBD	EQ_URMP	GT_MAXBU	GT_TGF
16	LLBUBD	FIXED	GT_MAXBD	GT_MAXBD	GT_MAXBU	GT_TGF
17	LLBUBD	FIXED	GT_MAXBD	LT_MAXBD	GT_MAXBU	GT_TGF
18	LLBUBD	FIXED	GT_MAXBD	EQ_MAXBD	GT_MAXBU	GT_TGF
19	LLBUBD	FIXED	GT_MAXBD	GT_Z	LT_MAXBU	GT_TGF
20	LLBUBD	FIXED	GT_MAXBD	GT_Z	EQ_MAXBU	GT_TGF
21	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	LT_TGF

Test #	BUBD Request Type	Loan Type	Total Adjusted GFee	BUBD Basis Points	Seller Specified Buy Up	Seller Specified Buy Down
22	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	EQ_TGF
23	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_BUBDBP
24	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	LT_BUBDBP
25	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	EQ_BUBDBP
26	LLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
27	LLBUBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
28	CLBU	ARM	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
29	CLBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
30	NONE	ARM	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
31	NLBUBD	FIXED	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
32	NLBUBD	ARM	LT_MAXBD	GT_Z	GT_MAXBU	GT_TGF
33	NLBUBD	ARM	EQ_MAXBD	GT_Z	GT_MAXBU	GT_TGF
34	NLBUBD	ARM	GT_MAXBD	EQ_Z	GT_MAXBU	GT_TGF
35	NLBUBD	ARM	GT_MAXBD	LT_Z	GT_MAXBU	GT_TGF
36	NLBUBD	ARM	GT_MAXBD	GT_SSBU	GT_MAXBU	GT_TGF
37	NLBUBD	ARM	GT_MAXBD	LT_SSBU	GT_MAXBU	GT_TGF
38	NLBUBD	ARM	GT_MAXBD	EQ_SSBU	GT_MAXBU	GT_TGF
39	NLBUBD	ARM	GT_MAXBD	GT_URMP	GT_MAXBU	GT_TGF
40	NLBUBD	ARM	GT_MAXBD	LT_URMP	GT_MAXBU	GT_TGF
41	NLBUBD	ARM	GT_MAXBD	EQ_URMP	GT_MAXBU	GT_TGF
42	NLBUBD	ARM	GT_MAXBD	GT_MAXBD	GT_MAXBU	GT_TGF
43	NLBUBD	ARM	GT_MAXBD	LT_MAXBD	GT_MAXBU	GT_TGF
44	NLBUBD	ARM	GT_MAXBD	EQ_MAXBD	GT_MAXBU	GT_TGF
45	NLBUBD	ARM	GT_MAXBD	GT_Z	LT_MAXBU	GT_TGF

Test #	BUBD Request Type	Loan Type	Total Adjusted GFee	BUBD Basis Points	Seller Specified Buy Up	Seller Specified Buy Down
46	NLBUBD	ARM	GT_MAXBD	GT_Z	EQ_MAXBU	GT_TGF
47	NLBUBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	LT_TGF
48	NLBUBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	EQ_TGF
49	NLBUBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	GT_BUBDBP
50	NLBUBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	LT_BUBDBP
51	NLBUBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	EQ_BUBDBP
52	NLBUBD	ARM	GT_MAXBD	GT_Z	GT_MAXBU	GT_TGF

5.1.3 Pair-Wise Coverage

Table 14 shows the pair-wise tests generated with the help of Bach's PERL utility.

Table 14: *Loan Pricing Pair-Wise Tests*

Test #	**BUBD Request Type**	**Loan Type**	**Total Adjusted GFee**	**BUBD Basis Points**	**Seller Specified Buy Up**	**Seller Specified Buy Down**
1	NLBUBD	ARM	GT_maxBD	GT_0	GT_maxBU	GT_Tgfee
2	LLBUBD	FIXED	LT_maxBD	GT_0	LT_maxBU	LT_Tgfee
3	LLBUBD	ARM	EQ_maxBD	EQ_0	EQ_maxBU	GT_Tgfee
4	NLBUBD	FIXED	GT_maxBD	EQ_0	LT_maxBU	LT_Tgfee
5	CLBU	FIXED	LT_maxBD	LT_0	GT_maxBU	GT_Tgfee
6	CLBD	ARM	EQ_maxBD	LT_0	EQ_maxBU	LT_Tgfee
7	CLBU	ARM	EQ_maxBD	GT_ssBU	LT_maxBU	EQ_Tgfee
8	CLBD	FIXED	LT_maxBD	GT_ssBU	EQ_maxBU	GT_BUBDbp
9	NONE	FIXED	GT_maxBD	LT_ssBU	EQ_maxBU	EQ_Tgfee
10	NLBUBD	ARM	EQ_maxBD	LT_ssBU	GT_maxBU	GT_BUBDbp
11	NONE	ARM	LT_maxBD	EQ_ssBU	GT_maxBU	LT_BUBDbp
12	NLBUBD	FIXED	EQ_maxBD	EQ_ssBU	EQ_maxBU	EQ_BUBDbp
13	LLBUBD	FIXED	GT_maxBD	GT_Urmp	GT_maxBU	LT_BUBDbp
14	CLBU	ARM	GT_maxBD	GT_Urmp	LT_maxBU	EQ_BUBDbp
15	CLBD	ARM	LT_maxBD	LT_Urmp	GT_maxBU	EQ_Tgfee
16	NONE	FIXED	EQ_maxBD	LT_Urmp	LT_maxBU	GT_BUBDbp
17	CLBD	FIXED	GT_maxBD	EQ_Urmp	LT_maxBU	LT_BUBDbp
18	LLBUBD	ARM	LT_maxBD	EQ_Urmp	GT_maxBU	EQ_BUBDbp
19	CLBU	FIXED	EQ_maxBD	GT_maxBD	EQ_maxBU	LT_BUBDbp
20	NONE	ARM	GT_maxBD	GT_maxBD	LT_maxBU	GT_Tgfee
21	NLBUBD	ARM	LT_maxBD	LT_maxBD	GT_maxBU	LT_Tgfee
22	LLBUBD	FIXED	GT_maxBD	LT_maxBD	EQ_maxBU	GT_BUBDbp
23	CLBD	FIXED	EQ_maxBD	EQ_maxBD	GT_maxBU	GT_Tgfee
24	NLBUBD	ARM	LT_maxBD	EQ_maxBD	EQ_maxBU	EQ_Tgfee
25	LLBUBD	~FIXED	EQ_maxBD	GT_0	EQ_maxBU	EQ_Tgfee
26	CLBU	~ARM	LT_maxBD	EQ_0	GT_maxBU	GT_BUBDbp
27	NLBUBD	~ARM	GT_maxBD	LT_0	LT_maxBU	LT_BUBDbp
28	NONE	~FIXED	GT_maxBD	GT_ssBU	GT_maxBU	EQ_BUBDbp
29	CLBU	~FIXED	LT_maxBD	LT_ssBU	LT_maxBU	LT_Tgfee
30	CLBD	~ARM	GT_maxBD	EQ_ssBU	LT_maxBU	LT_Tgfee
31	NONE	~ARM	EQ_maxBD	GT_Urmp	EQ_maxBU	LT_Tgfee
32	CLBU	~ARM	GT_maxBD	LT_Urmp	EQ_maxBU	EQ_BUBDbp
33	NONE	~FIXED	EQ_maxBD	EQ_Urmp	EQ_maxBU	GT_Tgfee
34	CLBD	~FIXED	LT_maxBD	GT_maxBD	GT_maxBU	EQ_BUBDbp
35	NONE	~FIXED	EQ_maxBD	LT_maxBD	LT_maxBU	EQ_Tgfee
36	LLBUBD	~ARM	GT_maxBD	EQ_maxBD	LT_maxBU	GT_BUBDbp
37	NLBUBD	~FIXED	LT_maxBD	GT_Urmp	~LT_maxBU	GT_Tgfee
38	NONE	~ARM	~LT_maxBD	GT_0	~EQ_maxBU	LT_BUBDbp
39	CLBD	~FIXED	~GT_maxBD	EQ_0	~GT_maxBU	EQ_Tgfee
40	LLBUBD	~FIXED	~EQ_maxBD	LT_0	~LT_maxBU	EQ_BUBDbp
41	LLBUBD	~ARM	~EQ_maxBD	GT_ssBU	~GT_maxBU	LT_Tgfee
42	CLBD	~ARM	~EQ_maxBD	LT_ssBU	~LT_maxBU	LT_BUBDbp
43	CLBU	~FIXED	~GT_maxBD	EQ_ssBU	~EQ_maxBU	GT_Tgfee

Test #	BUBD Request Type	Loan Type	Total Adjusted GFee	BUBD Basis Points	Seller Specified Buy Up	Seller Specified Buy Down
44	LLBUBD	~FIXED	~LT_maxBD	LT_Urmp	~LT_maxBU	GT_Tgfee
45	CLBU	~ARM	~EQ_maxBD	EQ_Urmp	~GT_maxBU	LT_Tgfee
46	NLBUBD	~ARM	~GT_maxBD	GT_maxBD	~EQ_maxBU	LT_Tgfee
47	CLBU	~ARM	~LT_maxBD	LT_maxBD	~EQ_maxBU	LT_BUBDbp
48	NONE	~FIXED	~LT_maxBD	EQ_maxBD	~GT_maxBU	LT_BUBDbp
49	CLBD	~ARM	~GT_maxBD	GT_0	~LT_maxBU	GT_BUBDbp
50	CLBU	~FIXED	~EQ_maxBD	GT_0	~GT_maxBU	EQ_BUBDbp
51	NONE	~ARM	~LT_maxBD	EQ_0	~LT_maxBU	EQ_BUBDbp
52	NONE	~ARM	~GT_maxBD	LT_0	~GT_maxBU	EQ_Tgfee
53	NLBUBD	~FIXED	~LT_maxBD	GT_ssBU	~EQ_maxBU	LT_BUBDbp
54	LLBUBD	~FIXED	~GT_maxBD	LT_ssBU	~EQ_maxBU	EQ_BUBDbp
55	LLBUBD	~FIXED	~LT_maxBD	EQ_ssBU	~GT_maxBU	GT_BUBDbp
56	CLBD	~ARM	~LT_maxBD	GT_Urmp	~EQ_maxBU	EQ_Tgfee
57	NLBUBD	~FIXED	~EQ_maxBD	LT_Urmp	~GT_maxBU	LT_BUBDbp
58	NLBUBD	~FIXED	~GT_maxBD	EQ_Urmp	~EQ_maxBU	GT_BUBDbp
59	LLBUBD	~ARM	~EQ_maxBD	GT_maxBD	~LT_maxBU	EQ_Tgfee
60	CLBD	~ARM	~EQ_maxBD	LT_maxBD	~LT_maxBU	GT_Tgfee
61	CLBU	~ARM	~GT_maxBD	EQ_maxBD	~EQ_maxBU	LT_Tgfee
62	~LLBUBD	~ARM	~EQ_maxBD	EQ_0	~EQ_maxBU	LT_BUBDbp
63	~CLBU	~FIXED	~LT_maxBD	LT_0	~EQ_maxBU	GT_BUBDbp
64	~NLBUBD	~FIXED	~GT_maxBD	GT_ssBU	~LT_maxBU	GT_Tgfee
65	~CLBD	~ARM	~LT_maxBD	LT_ssBU	~GT_maxBU	GT_Tgfee
66	~NLBUBD	~FIXED	~EQ_maxBD	EQ_ssBU	~LT_maxBU	EQ_Tgfee
67	~NONE	~FIXED	~EQ_maxBD	GT_Urmp	~GT_maxBU	GT_BUBDbp
68	~NONE	~ARM	~GT_maxBD	LT_Urmp	~EQ_maxBU	LT_Tgfee
69	~CLBU	~ARM	~LT_maxBD	EQ_Urmp	~LT_maxBU	EQ_Tgfee
70	~CLBD	~FIXED	~LT_maxBD	GT_maxBD	~GT_maxBU	GT_BUBDbp
71	~CLBD	~FIXED	~GT_maxBD	LT_maxBD	~GT_maxBU	EQ_BUBDbp
72	~NLBUBD	~FIXED	~EQ_maxBD	EQ_maxBD	~LT_maxBU	EQ_BUBDbp

5.2 Step #1: Modeling Technique

The requirements model generated 131 test cases. Most of these test cases are redundant because the same flow of information is duplicated for Fixed, ARM, and Balloon contracts. In the requirements modeling, the scope of the testable function chosen is larger than that of ISP.

5.3 Other Steps in the Process

Steps 2 to 8 are very similar to Case Study #3 (in the next chapter). Tests derived using ISP and the modeling technique are updated with real values by replacing the arbitrary values chosen in generating the tests. The simulator program is developed in Java and tests are passed to the simulator to generate the expected results. The LPC subsystem of the Selling System has the option of importing the maximum of 5000 (configurable) loans in bulk. All the tests are imported at the same time with no need for automation to input these into the system. A comparator program is used to compare the values expected from the spreadsheet and the actual results in the DB2 database. Results and observations are discussed in Chapter 8.

6 Case Study # 3: Amortization

The Amortization calculator is a modular section of code that calculates the amortized cash flows of a given loan. Calculation the Loan Amortization requires the following 11 steps.

1. Calculate Intermediate Results: This step calculates several intermediate timing outputs (in months) from loan level data inputs. These intermediate outputs will later be used as inputs to steps that follow.
2. Calculate Monthly Interest Rates: This step calculates the Monthly Interest Rate used in later calculations.
3. Calculate Beginning Balances: This step calculates the unpaid principal balance at the beginning of Period_t.
4. Calculate Total Mortgage Payments: This step calculates the mortgage payment in Period_t.
5. Calculate Scheduled Interest Payments: This step calculates the portion of the Total Mortgage Payment attributable to interest in Period_t.
6. Calculate Scheduled Principal Payments: This step calculates the portion of the Total Mortgage Payment attributable to principal in Period_t.
7. Calculate Prepayments: This step calculates the value attributed to the probability that the borrower will make a prepayment.

8. Calculate Balloons: This step calculates a one-time balloon payment that only occurs in the Final Cash Flow Period when Remaining Amortization Period is greater than the Remaining Term.
9. Calculate Total Principal Cash Flows: This step calculates the total principal paid in Period_t.
10. Calculate Ending Balances: This step calculates the unpaid principal balance at the end of Period_t.
11. Calculate Weighted Average Life (WAL): This step calculates the measure of how fast the principal is being paid back for a loan (in years).

This case study is a typical example of how different calculations will be triggered upon the preceding conditions. There are a total of 15 calculations that follow one another in a sequence and feed their outputs to the following calculator. Five of them are preliminary calculations. The remaining 10 calculations occur recursively until the end of the loan's term. For example, the ending balance of the loan changes from month to month, i.e. if the loan's life is 30 years, the loan will have 360 installments and when amortized it will have 360 records with varying ending balances for each month. For a given loan, the same types of calculations occur 360 times. Therefore, when defining the scope of each testable function, the loop is considered as one of the partitions and critical characteristics of loops are included as the blocks.

6.1 Step #1: Input Space Partitioning

The amortization of whole loans, structured bonds, and unstructured bond instruments are the scope of this use case. Each instrument consists of nearly 160 attributes and receives the reference values such as interest rates from multiple grids for the calculations.

Among the 160 attributes, the following are the 14 attributes (with their short form in parentheses) which contribute to these calculations: loan type (LT1), prepayment function (PPF2), conditional prepayment rate (CPR3), term cap (TC4), yield maintenance cap (YMC5), mortgage note rate (MR6), unpaid principal balance (UPB7), loan age (LA8), months to funding (MTF9), original term (OT10), original amortization period (OAP11), original yield maintenance period (OYMP12), original interest only period (OIOP13), and original amortization after interest only period (OAIOP14).

6.1.1 Testable Functions

All 16 calculations are treated as 16 testable functions for this case study. The first 6 are the preliminary calculations, which means the values or outputs from these calculations are necessary for the next 9 calculations. These are also called *intermediate calculations*. The next 9 calculations are performed for each period of the loan until the end of its term. The last calculator needs all the amortized values for each time period of the loan’s term.

Preliminary Calculations

Remaining term (RT-P1), remaining amortization period (RAP-P2), remaining YM period (RYMP-P3), remaining IO period (RIOP-P4), final cash flow period (FCP-P5), and prepay window (PPW-P6) are the preliminary calculations and they are represented as short forms in parentheses. They are also represented as the abstract outputs from these calculations, which are used in the final calculations.

6.1.1.1 TF #1: Calculate Remaining Term (RT-PC1)

Table 15 shows the partitions and blocks for TF #1.

The partitions TC4, and LA8 have only one block. The value for the Term cap (TC4) is pulled from the grids and the value for the loan age is always a constant value for a particular business cycle.

Table 15: *Partitions and Blocks for TF # 1*

No	Partitions	Blocks
1	OT10	GT_TC4, LT_TC4, EQ_TC4
2	TC4	TC4
3	LA8	LA8

6.1.1.2 TF #2: Calculate Remaining Amortization Period (RAP-PC2)

Table 16 shows the partitions and blocks for TF #2.

Table 16: *Partitions and Blocks for TF # 2*

No	Partitions	Blocks
1	OOIP13	GT_0, EQ_0, LT_0
2	RIOP-P4	GT_0, EQ_0, LT_0
3	LA8	LA8

6.1.1.3 TF #3: Calculate Remaining Yield Maintenance Period (RYMP-PC3)

Table 17 shows the partitions and blocks for TF #3.

Table 17: *Partitions and Blocks for TF # 3*

No	Partitions	Blocks
1	OYMP12	GT_YMC5, EQ_YMC5, LT_YMC5
2	YMC5	YMC5
3	LA8	LA8

6.1.1.4 TF #4: Calculate Remaining Interest Only Period (RIOP-PC4)

Table 18 shows the partitions and blocks for TF #4.

Table 18: *Partitions and Blocks for TF # 4*

No	Partitions	Blocks
1	OOIP13	EQ_0, GT_0
2	LA8	LA8

6.1.1.5 TF #5: Calculate Final Cash Flow Period (FCP-PC5)

This calculation does not have any preconditions. Table 19 shows the partitions and blocks for TF #5.

Table 19: *Partitions and Blocks for TF # 5*

No	Partitions	Blocks
1	RT-PC1	RT-PC1
2	MTF9	MTF9

6.1.1.6 TF #6: Calculate Prepayment Window (PPW-PC6)

This calculation does not have any preconditions. Table 20 shows the partitions and blocks for TF #6. The output of TF #1 and TF # 3 are inputs to the two partitions of this testable function.

Table 20: *Partitions and Blocks for TF # 6*

No	Partitions	Blocks
1	RT-PC1	RT-PC1
2	RYMP-PC3	RYMP-PC3

Loops

The calculations in the following 9 testable functions occur recursively to the end of the instrument's term starting from the current period in the term. Therefore, loop characteristics such as initial period, current period, final period, and reference periods with other partitions (greater than final cash flow period, less than, or equal to final cash flow period) are included as the blocks for the partition "period." This can be observed in all of the following 9 testable functions from TF #7 to TF # 15.

The calculations in following testable functions occur in a sequence. Each calculation in a testable function results in the output. The output is represented in a short form in parentheses. Their output is eventually used in the following calculators, which can be observed in their respective blocks and partitions.

6.1.1.7 TF #7: Calculate Monthly Interest Rates (MIR-FC1)

Table 21 shows the partitions and blocks for TF #7. The output of TF #8: BB-FC2 is one of the inputs to this calculation.

Table 21: *Partitions and Blocks for TF # 7*

No	Partitions	Blocks
1	MR6	MR6
2	FCP-P5	FCP-P5
3	Period $_t$	GT_FCP-P5, LT_FCP-P5, EQ_FCP-P5, Period $_i$, Period $_f$
4	BB-FC2	BB-FC2

6.1.1.8 TF #8: Calculate Beginning Balances (BB-FC2)

Table 22 shows the partitions and blocks for TF # 8.

Table 22: *Partitions and Blocks for TF # 8*

No	Partitions	Blocks
1	FCP-P5	FCP-P5
2	MTF9	MTF9
3	UPB7	UPB7
4	Period $_t$	GT_FCP-P5, LT_FCP-P5, EQ_FCP-P5, GT_MTF9, LT_MTF9, EQ_MTF9, EQ_MTF9+1, Period $_i$, Period $_f$

6.1.1.9 TF # 9: Calculate Total Mortgage Payments (TMP-FC3)

Table 23 shows the partitions and blocks for TF #9.

Table 23: *Partitions and Blocks for TF # 9*

No	Partitions	Blocks
1	FCP-P5	FCP-P5
2	MTF9	MTF9
3	RIOP-P4	RIOP-P4
4	Period $_t$	GT_FCP-P5, LT_FCP-P5, EQ_FCP-P5, GT_(RIOP-P4 +MTF9+1), LT_(RIOP-P4 +MTF9+1), EQ_(RIOP-P4 +MTF9+1), Period $_i$, Period $_f$
5	MIR-FC1	MIR-FC1
6	BB-FC2	BB-FC2
7	RAP-PC2	RAP-PC2

6.1.1.10 TF # 10: Calculate Scheduled Interest Payments (SIP-FC4)

Table 24 shows the partitions and blocks for TF #10.

Table 24: *Partitions and Blocks for TF # 10*

No	Partitions	Blocks
1	MR6	MR6
2	FCP-P5	FCP-P5
3	Period $_t$	GT_FCP-P5, LT_FCP-P5, EQ_FCP-P5, Period $_i$, Period $_f$
4	MTF9	MTF9
5	BB-FC2	BB-FC2

6.1.1.11 TF # 11: Calculate Scheduled Principal Payments (SPP-FC5)

Table 25 shows the partitions and blocks for TF #11.

Table 25: *Partitions and Blocks for TF # 11*

No	Partitions	Blocks
1	FCP-P5	FCP-P5
2	MTF9	MTF9
3	RIOP-P4	RIOP-P4
4	Period $_t$	GT_FCP-P5, LT_FCP-P5, EQ_FCP-P5, GT_(RIOP-P4 +MTF9+1), LT_(RIOP-P4 +MTF9+1), EQ_(RIOP-P4 +MTF9+1), Period $_i$, Period $_f$
5	SIP-FC4	SIP-FC4
6	TMP-FC3	TMP-FC3

6.1.1.12 TF # 12: Calculate Prepayments (PP-FC6)

Table 26 shows the partitions and blocks for TF #12.

Table 26: *Partitions and Blocks for TF # 12*

No	Partitions	Blocks
1	FCP-P5	FCP-P5
2	MTF9	MTF9
3	RYMP-P3	RYMP-P3
4	Period $_t$	GT_FCP-P5, LT_FCP-P5, EQ_FCP-P5, GT_(RYMP-P3 +MTF9), LT_(RYMP-P3 +MTF9), EQ_(RYMP-P3 +MTF9), Period $_i$, Period $_f$
5	BB-FC2	BB-FC2
6	SIP-FC4	SIP-FC4
7	CPR3	CPR3

6.1.1.13 TF # 13: Calculate Balloons (BP-FC7)

Table 27 shows the partitions and blocks for TF #13.

Table 27: *Partitions and Blocks for TF # 13*

No	Partitions	Blocks
1	FCP-P5	FCP-P5
2	Period $_t$	GT_FCP-P5, LT_FCP-P5, EQ_FCP-P5, Period $_i$, Period $_f$
3	UPB7	UPB7
4	SPP-FC5	SPP-FC5
5	PP-FC6	PP-FC6

6.1.1.14 TF #14: Calculate Total Principal Cash Flows (TPCF-FC8)

Table 28 shows the partitions and blocks for TF #14.

Table 28: *Partitions and Blocks for TF # 14*

No	Partitions	Blocks
1	FCP-P5	FCP-P5
2	Period $_t$	GT_FCP-P5, LT_FCP-P5, EQ_FCP-P5, Period $_i$, Period $_f$
3	SPP-FC5	SPP-FC5
4	PP-FC6	PP-FC6
5	BP-FC7	BP-FC7

6.1.1.15 TF # 15: Calculate Ending Balance (EB-FC9)

Table 29 shows the partitions and blocks for TF #15.

Table 29: *Partitions and Blocks for TF # 15*

No	Partitions	Blocks
1	FCP-P5	FCP-P5
2	Period $_t$	GT_FCP-P5, LT_FCP-P5, EQ_FCP-P5, Period $_i$, Period $_f$
3	TPCF-FC8	TPCF-FC8
4	BB-FC2	BB-FC2

6.1.1.16 TF #16: Calculate WAL (WAL-FC10)

The following table shows the partitions and blocks for TF #16. The previous 9 calculations produce the values for all the terms of the instrument beginning from its current period. Then this calculator averages all the beginning balances and calculates the weighted average life (WAL) of a loan or an instrument. Therefore, the blocks for the partition period consist of all the periods as shown in Table 30.

Table 30: *Partitions and Blocks for TF # 16*

No	Partitions	Blocks
1	BB-FC2	BB-FC2
2	Period $_t$	Period $_i$ to Period $_f$
3	UPB7	UPB7

6.1.2 Base Choice Coverage

The number of base choice tests from each testable function is as follows: TF #1, 3; TF #2, 5; TF #3, 3; TF #4, 2; TF #5, 1; TF #6, 1; TF #7, 5; TF #8, 9; TF #9, 8; TF #10, 5; TF #11, 8; TF #12, 8; TF #13, 5; TF #14, 5; TF #15, 5; and TF #16, 1. The total number of base choice tests is 74.

The base choice tests are not shown because they are relatively simple and can be easily understood from the blocks. In the majority of the testable functions, only the period partition has more than one block, and the other partitions have only one value. Domain knowledge is required to determine the values for the blocks. The invalid values and invalid combinations for each partition are not considered, because the entities come from other external systems and the project assumed that it would always receive valid entities for amortization.

The period partition will have more blocks than are required to test the loop conditions because the calculation at each period also depends on the final cash flow period and remaining months to funding. For example, the calculator in the testable function TF #13 uses a different formula to calculate balloons based on the current period whether the period is greater than or less than the final cash flow period. Therefore, the same inputs at different time periods result in different outputs.

6.1.3 Multiple Base Choice Coverage

The Multiple base choice coverage criterion does not offer any additional coverage, as the partitions chosen are the same for all the instruments, such as whole loans, structured bonds, and unstructured bonds. The same set of base choice tests can be cloned for all three types of instruments. Therefore, the multiple base choice coverage criterion is not applied for this case study.

6.1.4 Pair-Wise Coverage

The pairwise coverage also does not offer any extra coverage. The constraints among different blocks of the partitions are limited to two at the most. Base choice coverage offers all the combinations in this case. Therefore the pair-wise coverage criterion is not applied.

6.2 Step # 1 Modeling Technique

The modeling technique was not applied for this case study. At the time this case study was conducted, the tool was not built.

6.3 Step # 2: Generating Test Requirements

The tests discussed in Section 6.1 are automatically generated using the Java utility.

6.4 Step # 3: Generating Test Data

The abstract values chosen to generate the tests are replaced with the real values. The other attributes for whole loans, structured, and unstructured bonds are prefixed to the test cases to make them executable. Amortization is part of the asset valuations. Asset valuations in Multifamily are calculated every month. Assets of three categories—whole loans, structured bonds, and unstructured bonds—number in the thousands. When test data is prefixed, all three categories are considered to produce test data with good variation. Also, the same data is cloned to run the tests for different time periods such as monthly, quarterly, and annually.

6.5 Steps # 4 and 5: Building the Simulator and Inputting Test Data and Collecting Expected Results

In this case study the simulator is built using VB macros in an MS-Excel spreadsheet. This is one of the end user computing (EUC) application that needs to be implemented as a robust system. All of these calculations are being performed using the spreadsheets. The testing team used these spreadsheets as the simulators with some changes. Although it eased the process of building the simulators, it came with a price, as the test team went back and forth with the development team to determine whether the output of the simulator was correct or that of the system-under-test. In some cases, output of the simulator was proved correct.

Another challenge in generating the expected results is to pass the output of one calculator to another calculator for the same period of the loan's term. This process of collecting the output for a term, and passing it as the input to another calculator for the same term, is automated.

6.6 Steps # 6 and 7: Inputting Test Data Into System-Under-Test and Collecting Actual Results

This application receives all the input data from external systems. In other words, the system does have a user interface, but it prompts the user to enter a start date and an end date for which valuations need to run for different kinds of instruments. The testing team used SQL scripts to input test data into the database by satisfying all the database entity constraints. When a user enters a start date, an end date, and runs the valuation, the system picks the data within the date range from the database, performs the calculations, and stores the actual results into the database in different tables.

6.7 Step # 8: Comparing Actual and Expected Results

Actual results are pulled into a spreadsheet and the comparator program is run to compare the actual and expected results. It took quite a few cycles to reconcile small differences between expected and actual results. Most of these differences stemmed from the previous implementation of the logic in Excel and the current implementation of the logic in Java. The business team determined the tolerance levels and later results are considered “Passes” if the differences are within the tolerance limits.

7 Case Study # 4

Freddie Mac intends to change the methodology for amortizing GOs such that a GO is amortized at the greater of the cumulative amortization calculated with the Static Effective Yield (SEY) method or the cumulative amortization calculated with the Declining UPB method. Specifications to calculate SEY IRR, which is used in GO Amortization to calculate SEY amortization for pools and in segment reporting to calculate SEY amortization for cohorts of whole loans, are described in the form of use cases. A use case can be found in Appendix B of this thesis.

Specifications of this use case encompass many characteristics for the calculation engines mentioned in Chapter 2 Section 2.4 of this thesis. The problem analysis is conducted with the help of the standard framework recommended in this thesis. Amortization calculation functions are recursive in nature.

7.1 Input Space Partitioning

This use case document has 9 sections. Sections 7 and 8 consist of the functional requirements that are important for this case study. The other sections contain technical and business details of the functionality such as introduction, references, description, process flow diagrams, data elements, and table structures of the database.

7.1.1 Testable Functions

SEY-IRR calculation methods choose the loan or any other structured instrument for GO amortization or segment reporting, get the PSA values or prepayment factors, and then perform the calculations. The testing team identified 8 testable functions, sections 7 and 8 of which are discussed in the following subsections 7.1.1 to 7.1.9.

7.1.1.1 TF # 1: Choose Instruments for GO Amortization

The testable function TF #1 covers the requirements described in 7.3.1, 7.3.3, 7.3.4, and 7.3.5.

Expected output: The testable function TF #1 should eliminate the invalid instruments going into GO Amortization calculations.

The partitions and blocks for TF #1 are listed in Tables 31 and 32.

Table 31: *SEY IRR - TF # 1 – Partitions and Blocks*

Test #	Partitions	Blocks
1	Amortization Purpose	GO_GAAP, INVALID_VALUE (*GO_GAAP)
2	Amortization Effective Begin Date	First day of current GL cycle month (MON), INVALID VALUE (*MON)
3	Date of Inception	Month prior to current GL cycle month (MON - 1), INVALID VALUE (*MON - 1)
4	Amortization Method	SEY, *SEY
5	Original UPB Amount	NULL, <=0, NOT NULL
6	Original Base Fee	NULL, NOT NULL

Table 32: *SEY IRR - TF #1 Base Choice Tests*

Test #	Amortization Purpose	Begin Date	Inception Date	Amortization Method	Original UPB	Original Base Fee	A/R
1	GO_GAAP	MON	MON – 1	SEY	NOT NULL	NOT NULL	A
2	*GO_GAAP	MON	MON – 1	SEY	NOT NULL	NOT NULL	R
3	GO_GAAP	*MON	MON – 1	SEY	NOT NULL	NOT NULL	R
4	GO_GAAP	MON	*MON – 1	SEY	NOT NULL	NOT NULL	R
5	GO_GAAP	MON	MON – 1	*SEY	NOT NULL	NOT NULL	R
6	GO_GAAP	MON	MON – 1	SEY	NULL	NOT NULL	R
7	GO_GAAP	MON	MON – 1	SEY	<=0	NOT NULL	R
8	GO_GAAP	MON	MON – 1	SEY	NOT NULL	NULL	R

7.1.1.2 TF # 2: Choose Instruments for Segment Reporting

This testable function covers requirements described in 7.3.2, 7.3.3, 7.3.4, and 7.3.5.

Expected output: Testable function TF #2 should eliminate the invalid instruments going for segment reporting.

Partitions and blocks for TF #2 are listed in Tables 33 and 34.

Table 33: *SEY IRR - TF #2 Partitions and Blocks*

Test #	Partitions	Blocks
1	Amortization purpose	SR, *SR
2	Amortization effective begin date	First day of current GL cycle month (MON), INVALID VALUE (*MON)
3	Date funding begin period date	Month prior to current GL cycle month (MON-1), INVALID VALUE (*MON-1)
4	Accounting level process name	COHORT, *COHORT
5	Amortization method	SEY, *SEY
6	Original UPB Amount	NULL, <=0, NOT NULL
7	Original Base Fee	NULL, NOT NULL

Table 34: *SEY IRR - TF #2 Base Choice Tests*

S #	Amortization Purpose	Begin Date	Funding Date	Accounting Process	Amorti-zation Method	Original UPB	Original Base Fee	A/R
1	GO_GAAP	MON	MON – 1	COHORT	SEY	NOT NULL	NOT NULL	A
2	*GO_GAAP	MON	MON – 1	COHORT	SEY	NOT NULL	NOT NULL	R
3	GO_GAAP	*MON	MON – 1	COHORT	SEY	NOT NULL	NOT NULL	R
4	GO_GAAP	MON	*MON – 1	COHORT	SEY	NOT NULL	NOT NULL	R
5	GO_GAAP	MON	MON – 1	*COHORT	SEY	NOT NULL	NOT NULL	R
6	GO_GAAP	MON	MON – 1	COHORT	*SEY	NOT NULL	NOT NULL	R
7	GO_GAAP	MON	MON – 1	COHORT	SEY	NULL	NOT NULL	R
8	GO_GAAP	MON	MON – 1	COHORT	SEY	<=0	NOT NULL	R
9	GO_GAAP	MON	MON – 1	COHORT	SEY	NOT NULL	NULL	R

7.1.1.3 TF # 3: Chose Prepayment Factors

This testable function covers the requirements described in 7.4.1, 7.4.2, and 7.4.3.

Expected output: Testable function TF #3 should choose the appropriate prepayment factors for each instrument based on the instrument's characteristics shown as partitions in Table 35.

Partitions and blocks for TF #3 are shown in Tables 35 and 36.

Table 35: *SEY IRR - TF # 3 Partitions and Blocks*

S #	Partitions	Blocks
1	Amortization Effective Begin Date	First day of current GL cycle month (MON), INVALID VALUE (*MON)
2	CD Scenario	Current CD, Non current CD
3	Prepayment Identifier	= Prepayment ID of the chosen record, *PID

Table 36: *SEY IRR - TF # 3 Base Choice Tests*

S #	Amortization Begin date	CD Scenario	Prepayment ID	A / R
1	MON	Current	= PID	A
2	*MON	Current	= PID	R
3	MON	Non Current CD	= PID	R
4	MON	Current	<> PID	R

7.1.1.4

7.1.1.5 TF #4: Choose PSA - Speed Values

This testable function covers the requirements described in 7.5.1.

Expected output: Testable function TF #4 should choose the appropriate PSA speed values for each instrument based on the instrument's characteristics shown as partitions in Table 37.

Partitions and blocks for TF #4 are shown in Tables 37 and 38.

Table 37: *SEY IRR - TF # 4 Partitions and Blocks*

S #	Partitions	Blocks
1	Amortization Effective Begin Date	First day of current GL cycle month (FD), *FD
2	Amortization Run Parameter	Starts with PSA *PSA

Table 38: *SEY IRR - TF #4 Base Choice Tests*

S #	Amortization Begin Date	Amortization Run Parameter	A/R
1	FD	LIKE PSA%	A
2	*FD	LIKE PSA%	R
3	FD	*LIKE PSA%	R

Loops

In the amortization, initial period, first period, current period, and final period of the instrument are important. Unpaid principal balance (UPB) will be the original UPB for the initial period. In many cases the amortization amount for the initial month will be set to 0, for the convenience of the customer. Amortization starts a month after the instrument is funded. Application of the SEY IRR calculation can occur at any time during the life of the loan, therefore, current period is an important block in this partition. At the end of the final period, the amortization amount should be equal to 0.

Partitions and blocks for loops are shown in Table 39.

Table 39: *SEY IRR Partitions and Blocks for Loops*

S #	Partitions	Blocks
1	Current Period	0, First Period, Current Period, Final Period

The following 4 testable functions, TF #5, 6, 7, and 8, are calculation related. All of these calculations are performed recursively for each time period of the instrument's life until the end time period. Therefore these 4 blocks should always be considered, at minimum, for the loops.

7.1.1.6 TF #5: Calculate UPB - Prepayment Factor = NOT NULL

The testable function TF #5 covers the requirements described at 7.6.2.1 and 7.6.2.2.

Expected output: The system should calculate UPB and set default cash flow flag = N.

Partitions and blocks for TF #5 are shown in Table 40.

Table 40: *SEY IRR - TF # 5 Partitions and Blocks*

S #	Partitions	Blocks
1	UPB Value	Value from TF # 1 or TF # 2
2	Prepayment factor	< 0, > 1, Between 0 and 1

7.1.1.7 TF # 6: Calculate UPB Using PSA Speed Values - Prepayment Factor = NULL

This testable function covers requirements described at 7.6.3.1, 7.6.3.2, and 7.6.3.3.

Expected output: The system should calculate UPB and set default cash flow flag = Y.

Partitions and blocks for TF #6 are shown in Table 41.

Table 41: *SEY IRR - TF #6 Partitions and Blocks*

S #	Partitions	Blocks
1	Prepayment Factor	Null
2	Original Term	> 20 Years, < = 20 Years, NULL

7.1.1.8 TF #7: Calculate Cash Flow for Each Period

This testable function covers the requirement described at 7.6.6.

Expected output: The system calculates cash flow as follows:

Cash flow = UPB or prior month – UPB of current month.

Partitions and blocks for TF #7 are shown in Table 42.

Table 42: *SEY IRR - TF # 7 Partitions and Blocks*

S #	Partitions	Blocks
1	Unpaid Principal Balance (UPB)	UPB of prior month, UPB of current month

7.1.1.9 TF #8: Calculate SEY IRR for Each Period

This testable function covers the requirement described in 7.6.7.1.

Expected output: If SEY IRR value = NULL, < 0, or > 1, then generate an exception with the error message.

7.1.2 Base Choice Coverage

Applying the base choice coverage criterion to TF #1 gives 8 base choice tests; TF #2 gives 9 base choice tests. TF #3 and TF #4 cover the specifications for pulling the current values from the grids and give 4 and 3 base choice tests respectively. The blocks of these partitions mentioned in these testable functions should serve as search conditions or where clauses combined with the ‘and’ operator in the SQL query. The number of base choice tests for TF #5, 6, 7, and 8 are 3, 3, 1, and 1.

Calculations in TF #5, 6, 7, and 8 are recursive in nature, which means the same calculations are performed repetitively beginning from the current period of the instrument until the end of its life period.

The base choice tests derived from TF #5, TF #6, TF #7, and TF #8 should be tested for different time periods of the loan instrument. The blocks for this loop characteristic are shown Table 43.

Table 43: *Partitions and Blocks for loops*

S #	Partitions	Blocks
1	Period	0, First Period, Current Period, Final Period

Applying the base choice tests at the periods mentioned in Table 43 gives a total of 12, 12, 4, and 4 base choice tests for the testable functions TF #5, TF #6, TF #7, and TF #8.

7.1.3 Multiple Base Choice Coverage

The multiple base choice coverage criterion does not achieve any additional coverage. Therefore this was not applied.

7.1.4 Pair-Wise Coverage

The pair-wise coverage criterion was not applied, as the blocks of the partitions do not have complex dependencies. The combination of calculations with different time periods of the loan's term is tested with the help of base choice tests as mentioned in Section 7.1.2: Base Choice Coverage.

7.2 Modeling Technique

The requirements are classified as 8 testable functions in the previous section of this thesis. When modeling, the requirements are grouped together into 3 testable functions. Modeling produced 12 test cases. The modeling of these requirements and the test cases are shown in Appendix B.

7.3 Application of the Framework

7.3.1 Step # 1: Identify the Functionality to Be Tested – Define Scope

In the first step, the requirements document is analyzed and the functionality to test is identified. The document has 9 sections, but only sections 7 and 8 contain the functional requirements. This step is to define the scope of the functionality.

7.3.2 Step # 2: Identify the Testable Functions

In this step testable functions are identified as discussed in subsections 7.1.1 to 7.1.9.

7.3.3 Step # 3: Identify the Entities and Attributes - Partitions

Requirements define how to select the whole loan instrument for amortization, as well as segment reporting, and how to perform the calculations. The whole loan instrument is identified as the entity and its attributes are identified. Partitions of this entity are identified in TF #1, Section 7.1.1 and TF #2, Section 7.1.2. The loan instrument has nearly 150 attributes, but only a few attributes are key to test the functionality identified in Step #1.

7.3.4 Step # 4: Identify Distinct Values – Blocks

Distinct values for each partition, which are called blocks, are derived from the requirements within each testable function. Partitions and blocks tables in Sections 7.1.1 to 7.1.9 show these distinct values.

7.3.5 Step # 5: Apply Base Choice Criteria to Filter the Invalid Values

Calculations most often will be performed only with valid values, which means testable functions related to the calculations are to be tested with valid values. The system should reject the invalid records or entities and only accept the entities with valid values and then perform the calculations. The Base choice criterion is applied to generate the base choice tests, which are shown in the base choice tests tables in Sections 7.1.1 and 7.1.2. Each base choice test is tagged with the value A or R in the last column of these tables. Tests tagged with A should be accepted by the system and test tagged with R should be rejected by the system.

7.3.6 Steps # 6, 7, 8, and 9: Eliminate Invalid Values and Combinations

Steps 6, 7, 8, and 9 tell how to eliminate the invalid values and combinations. Base choice criteria can be applied again only on the valid values. Pair-wise can be applied to derive the tests for combinational requirements and multiple base choice coverage criterion can be applied to derive the tests emphasizing different characteristics of a partition.

In this case study, the base choice coverage criterion generates all the required tests. This is because testable functions are chosen as small units. If there are dependencies between only 2 partitions, base choice coverage can determine all the combinations between the 2 partitions. Therefore, other coverage criteria are not applied.

7.3.7 Step #10: Ensure the Functional Coverage With RTM

The RTM is built manually with requirements in the first column and the corresponding base choice tests in the other column. All the testable requirements have at least one test case and a majority of the requirements have more than one test case.

7.3.8 Steps # 11 and 12: Prefix the Test Cases and Provide Real Values

The test cases derived above have abstract values and only the active attributes are chosen from 150 attributes of the loan instrument. In order to make these tests executable, real values must be passed and the other values of the excluded attributes should be prefixed. The test environment should be configured such that the system pulls either PSA values from grids or uses prepayment factors for SEY-IRR calculations. The test environment and data are configured appropriately.

7.3.9 Step #13: Build the Calculation Simulator

The calculation simulator is built using the spreadsheet functions and the expected results are stored in the spreadsheet.

7.3.10 Step #14: Collect the Actual Results

The test cases derived in the earlier steps are executed against the system-under-test. Actual results are stored in the database. SQL queries are written to collect the actual results of the calculations from the database. The actual results are then copied into the spreadsheet manually.

7.3.11 Step # 15: Compare the Actual and Expected Results

The expected and actual results are stored in the spreadsheet. These values are compared using spreadsheet functions with the loan identification number as the unique key. The results are discussed in Chapter 8.

8 Results

Each case study chosen for this thesis possesses different characteristics. They differ in the nature of the calculations as well as in their implementations. In this section, results of each case study are analyzed, and observations are documented. The effectiveness of this approach is measured in terms of percentage of coverage on the requirements as well as code.

The case studies documented here are only part of the entire applications on which this approach is applied. The results obtained here refer only to the scope of the functionality used for this thesis.

Martin, Ruud, and Veenendall (2000), Chapter 15 defines test “coverage” as a measure of the degree to which the software has been exercised by the executed tests.

In this thesis, two types of coverage measures are used to determine the effectiveness of the test cases: functional coverage and structural coverage. Functional coverage is a measure of the number of functional requirements executed within the testable function. Structural coverage is a proportional measure of the logical code structures that are executed within the testable functions.

Functional coverage is evaluated from a requirements traceability matrix (RTM), which is the list of requirements and their corresponding test cases. The RTM document shows each requirement is covered by at least one test case.

The structural coverage is evaluated using jTest tool. However, it should be noted that structural testing could often miss logical errors, so it is not safe to assume that better structural coverage equates to good quality software. The evaluation or measurement of the structural coverage requires the use of tools called coverage analyzers or monitors. Structural coverage analysis is a useful mechanism for identifying the gaps or the redundancies in the test cases.

I had 2 limitations in determining the structural coverage: (1) I am not authorized to the access the code and (2) the programs really cannot be isolated for the scope of this case study.

Case study # 1 and 2 belongs to the Selling System that has ~1200 java files and the size of the compiled code is ~600 MB.

Freddie Mac uses Parasoft’s jTest tool for unit testing. This tool offers the statistics for only statement coverage and method coverage. Therefore, branch coverage is not determined. The program’s logical correctness is determined by comparing the output of the system-under-test and a simulator.

In addition, the defects logged in the defect management system were analyzed for the past 8 releases and identified that this approach would have eliminated 75% of the defects in the functionality of case study # 1 and 2.

8.1 Case Study #1: Contract Pricing

The ISP method was applied to derive the testable functions. This case study was conducted in two stages. In the first stage, all the parameters or attributes of the entity “Contract” were tested to validate their individual characteristics. Contract has 29 attributes. Base Choice (BC) coverage was applied assuming all the attributes are independent and have no conflicts.

In the second stage, attributes that only participate in the calculations were isolated and then Base Choice, Multiple Base Choice, and Pair-Wise coverage criteria were applied.

8.1.1 Requirements Coverage

Base choice coverage criterion produced 205 test cases. This feature has 89 requirements for business rules, 22 system-specific requirements, and 92 requirements to generate error messages, for a total of 203 requirements. The application also has 22 requirements for different combinations of the attributes. The 205 test cases generated by the BC criterion covered all of the 203 requirements. The tests also covered some of the requirements more than once. Base choice tests also covered 8 of 22 combinational requirements. The rest are covered by the pair-wise tests.

Base choice tests, multiple base choice tests, and pair-wise tests together offered 100% functional coverage of the requirements for the testable functions chosen to test contract pricing.

8.1.2 Code Coverage

Contract pricing is chosen as one of the testable functions using the ISP technique. Both implicit and explicit attributes for this testable function are identified. Possible values are derived for each attribute. BC, MBC, and PW coverage criteria are applied to derive the test cases. Requirements of this testable function are modeled using the FTM tool. The number of test cases generated for each method is as follows: BC, 15; MBC, 30; PW, 23; and Requirements Model, 27.

Table 44: *Case Study #1 - Statement Coverage Results*

	Base Choice	**Multiple Base Choice**	**Pair-Wise**	**Pair-Wise – Refined**	**Requirements Model**
Number of Tests	15	30	23	23	27
SwapContractService Coverage	86%	92%	85%	92%	92%
SwapContractCalculator Coverage	85%	90%	79%	90%	82%

The following 6 Java programs contain the logic for this case study. The LOC for each program appear in the parenthesis.

1. SwapBUBDDetail.java – (461 LOC)
2. SwapContractCalculator.java – (166 LOC)
3. SwapContractService.Java – (258 LOC)
4. SwapDetailPriceResult.java – (757 LOC)
5. SwapPriceResult.java – (1343 LOC)
6. SwapService.java – (4040 LOC)

In the above programs, program # 1 gets the inputs for calculations from buy-up and buy-down (BUBD) grids. Program # 3 gets pricing attributes for the contract from LPC subsystem. Program # 4 displays the pricing results on the user interface and # 5 save the results in the database. Program # 6 distinguishes the swap contracts from cash contracts.

In addition, there are other files in which contract attributes are defined and are initialized. There are also separate programs that are initialized to catch the exceptions and throw the error messages defined in the XML files. The statement coverage is measured on the programs 2 and 3.

The contract entity has 203 business rules defined for its 29 attributes. There are 16 programs to handle the logic for the business rules.

ISP is applied in 2 stages for this case study. In the first stage, all the business rules are verified using BC coverage and PW-coverage. Since this scope is not part of the calculation engines, only the functional coverage of the tests is mentioned and not the structural coverage.

The statement coverage achieved by the test cases from each method is shown in Table 44

8.1.3 Observations

Base choice coverage achieved good coverage of the functional requirements for the characteristics defined for each and every attribute. Characteristics of these attributes are validated at the client layer of the application, which means that the application filters any invalid values for each attribute, before saving the entity in the database. This may not be true in all cases, as the data for calculations will be received from external systems that were implemented decades ago and may be defective.

Contracts are fundamentally of three types: Fixed Contract, Balloon Contract, or ARM Contract. Fixed and Balloon contracts possess the same characteristics. Therefore, the MBC criterion is applied by choosing the value for Contract type as “Fixed” in base test #1 and “ARM” in base test # 2.

When the implementation is inspected, the information flow for the Fixed and ARM Contracts is the same for the most part. This is also clear from the coverage results, as BC offered 86% of the coverage and MBC offered 92% of the coverage.

When the PW criterion was applied, the program generated the test cases with “default” or “do not care” values after all the combinations of that attribute with others were fulfilled. When a default value is accepted as the input, the coverage is 82%. When the default value was replaced test case #16 by “FIXED,” it achieved 91% coverage.

When the individual characteristics of each attribute need to be tested, BC test cases offer good coverage of the functional requirements. It is relatively easy to trace the test cases to the requirements, as each characteristic defined for the attribute will have one test case from BC.

The PW criterion does not help when the characteristics have a large number of attributes because it is difficult to map the PW test cases to the requirements where traceability is an important factor to determine the coverage. Using pair-wise is also cumbersome, because mapping tests to the requirements is hard with too many partitions. The pair-wise criterion definitely helps in reducing or eliminating the duplicate pairs of inputs and hence is used to eliminate the constraints that do not coexist. If the implementation is such that it will not allow these combinations to be input, then almost all of the pair-wise tests become infeasible from a design perspective. Grindal, Offutt, and Mellin (2006) proposed a submodel strategy to handle the constraints between the partitions. Later, I found it is more helpful than the pair-wise strategy. As mentioned earlier, this case study is tested in 2 stages. In the first stage only, out of 230 requirements, base choice did not cover 16 requirements. Pair-wise covered these 16 requirements, but it took a very long time to filter these 16 from 172 pair-wise tests. Instead of applying the pair-wise criterion, a submodel strategy would have helped.

8.2 Case Study #2: Loan Pricing

The ISP method is applied to determine the testable functions for the Loan Pricing feature. The testable function in this feature has the following three entities involved: Loan, Contract, and Master Commitment, which have 140, 29, and 35 attributes respectively. Out of these only 6 attributes contribute to the calculations. BC, MBC, and PW coverage criteria are applied to generate the test cases. The requirements of this testable function are also modeled using the FTM tool. Coverage of these test cases against the requirements as well as code are described in the following sections.

8.2.1 Requirements Coverage

Loan pricing functionality in this case study is captured in the form of a use case that has one main flow, one alternate flow, and three exception flows. Other flows are ignored for this case study. BC, MBC, and PW together covered 100% of the functional requirements.

8.2.2 Code Coverage

Logic for loan pricing was captured in three Java classes namely, SwapLoanService.java, SwapLoanCalculator.Java, and SwapLoanBase.java. The LOC for each program are 549, 194, and 139 respectively.

A method priceLoan () was added to SwapLoanService.java to receive the inputs directly from the spreadsheet. Parasoft's jTest tool was used to determine the code coverage. The test configuration was created in the tool that takes the inputs from spreadsheet. The tests were run using the inputs from BC, MBC, PW, and Requirements Modeling. Java classes were modified/commented without altering the behavior of the programs. Code coverage is shown in Table 45.

Table 45: *Case Study #2 - Statement Coverage Results*

	Base Choice	**Multiple Base Choice**	**Pair-Wise**	**Requirements Model**
Number of Tests	26	52	72	131
Statement Coverage	86%	89%	92%	97%

8.2.3 Observations

Requirements coverage achieved by the BC and MBC are quite different, as the loans are broadly classified as Fixed loans and ARM loans. Even though they share some functional requirements, they are duplicated for the most part. Therefore, functional coverage by the BC tests and the MBC tests are very different, even though code coverage on same tests was only slightly higher with the MBC tests.

Attributes that are chosen in this testable function have a number of constraints. The PW tests had good coverage, but have a lot of test cases when compared to BC. To manually determine which pair-wise tests actually filled the gaps left by base choice coverage took very long time.

The requirements model generated 131 test cases. Most of these test cases are redundant because the same flow of the information is duplicated for Fixed, ARM, and Balloon contracts. In the requirements modeling, the testable function chosen has more scope than the function considered for ISP.

8.3 Case Study #3

The testable function of the Amortization feature has very distinct characteristics. For each loan or instrument, the system should generate amortized payments for every month until the end of the loan’s life. This testable function involves a series of calculations that occur sequentially; output of one calculation is sent to the next calculation. When this testable function is considered, loops are isolated and tested separately. The loop characteristics are considered as a separate testable function and are tested separately.

8.3.1 Requirements Coverage

Base choice tests had good functional requirements coverage: 100% of the functional requirements are covered with base choice tests.

8.3.2 Code Coverage

The base choice tests had statement coverage of 100%, as shown in Table 46.

The logic in this case study is captured in seven programs. It was relatively easy to isolate the programs, as this is the new system. Among the seven programs, three are related to declaration, initialization, and obtaining the data from the external systems. Two programs capture the logic of persisting the amortized data to the database. The remaining two programs compute the amortization on different conditions. These two programs had 1733 and 1521 LOC.

This entire application has ~80K LOC. This application has 630 base choice tests for the entire functionality.

Table 46: *Case Study #3 - Statement Coverage Results*

	Base Choice	**Multiple Base choice**	**Pair-Wise**	**Requirements Model**
Number of Tests	74	N/A	N/A	N/A
Statement Coverage	100%	0	0	0

8.3.3 Observations

This case study contains 16 different calculations that occur sequentially to generate the final result. I did this case study in two ways: (a) all 16 calculators are wrapped in a single testable function, and (b) each calculator is considered as one testable function.

In the first case, I applied base choice, pair-wise, and multiple base choice criteria. Each criterion achieved 20, 41, and 36 tests and 81%, 81%, and 68% of the statement coverage. Although the pair-wise has a greater number of tests, they resulted in infeasible tests. However, this method of choosing the testable function is not correct in this type of calculation application.

In the second case, I applied base choice criteria to all 16 testable functions. The 74 base choice tests not only achieved 100% functional coverage on requirements, but also achieved 100% statement coverage.

8.4 Case Study #4

Specifications for this case study are very typical for the calculation engines as discussed in Chapter 2 Section 2.4. Amortization calculations in this case study are similar to those of Case Study #3. The framework recommended in the Chapter 10 of this thesis is applied to validate whether the steps defined in the framework provide proper guidance in applying ISP. The base choice tests alone offered the required coverage of the requirements. Therefore, multiple base choice coverage and pair-wise coverage were not applied.

8.4.1 Requirements Coverage

Base choice tests achieved 100% functional coverage of the requirements. The 8 testable functions have a total number of 32 base choice tests. The testable functions TF #5, 6, 7, and 8 should be tested at different periods of the loop conditions. Therefore, 8 base choice tests of these testable functions should be repeated at the initial period, first period, current period, and the final period of the loan instrument and they result in 32 tests. These 32 tests are in addition to 24 base choice tests of the testable functions TF #1, 2, 3, and 4, which covered all the functional requirements within the scope.

8.4.2 Code Coverage

Code coverage is summarized in Table 47.

The logic in this case study is captured in three programs, excluding the programs to access the data from external systems and save it to the database after processing. These programs have 212, 1243, and 119 LOC.

The total LOC is not known for this application.

Table 47: *Case Study # 4 - Statement Coverage Results*

	Base Choice	**Multiple Base Choice**	**Pair-Wise**	**Requirements Model**
Number of Tests	56	N/A	N/A	N/A
Statement Coverage	100%	0	0	0

8.4.3 Observations

The 8 testable functions have a total of 32 base choice tests. The testable functions TF #5, 6, 7, and 8 should be tested at different periods of the loop conditions. Therefore, 8 base choice tests of these testable functions should be repeated at the initial period, first period, current period, and the final period of the loan instrument and they result in 32 tests.

The requirements were modeled with a different approach. The model produced 12 tests as shown in Appendix B. Because these test cases required a lot of rework in the prefixing, later the idea of using the modeling to test this use case was dropped. However, if the testable functions deduced in this case study are used for modeling, then modeling would have certainly achieved good coverage.

The systematic/methodical application of the standard framework defined in this thesis simplified the complexity in analyzing the requirements. Base choice coverage not only achieved complete coverage on the requirements, but also achieved 100% statement coverage on the code.

9 Advantage and Disadvantages

This chapter analyzes the results and observations of Chapter 8 and presents the pros and cons of each method applied to test the calculation engines.

9.1 Pros and Cons of Modeling

Test models provide a straightforward representation of the requirements where a testable function, particular response, or response subset is to be selected by evaluating many related conditions. The test models are effective for revealing defects in their implementation and their specification. They can also support test design at any scope, from methods at the unit level to a system in its entirety. The FTM supports automated generation of test cases. The following subsections explain the advantages and disadvantages of modeling.

9.1.1 Advantages of Modeling

- Requirements modeling using FTM instantly generates the test cases from the model. When modeled early in the life cycle, the requirements provide the test analyst an idea of the number of test cases that need to be tested, which can be used to measure or estimate the time needed to test.
- FTM helps to map the test cases to the requirements. The traceability of the test cases to the specifications is simultaneously achieved along with the modeling.

- Audit requirements for the test cases are: (a) test cases should be repeatable, (b) test cases should contain enough level of detail, and (c) test cases should be mapped to the requirements. These 3 audit requirements are met using the FTM.
- FTM allows users to mark the critical paths in a tree. These paths help in identifying the regression testing suite or the smoke-testing suite.
- Models bring common understanding of the requirements among the business analysts, the programmers, and the test analysts.
- When the requirements are changed, and when the changes are applied to the tests, the FTM is designed to highlight the impacted paths, easing impact analysis.
- When the relations or constraints among the attributes are modeled carefully, modeling precludes unnecessary or infeasible combinations.

9.1.2 Disadvantages of Modeling

A model's success largely depends on the following factors.

- Skill set: Modeling requires the personnel to understand software engineering concepts in order to be efficient. For example, if the test analysts understand different UML diagrams, it helps them to transform use cases, sequence diagrams, and activity diagrams into test models using FTM, which in turn helps them to derive test cases. In an environment where all the resources including business analysts are used to conduct testing, it is optimal to expect the required skill set.

- Domain knowledge: The effectiveness of the test model largely depends on the domain knowledge of the test analysts. For example, in Case Study #1 and Case Study #2, the requirements state that a calculator should pull the price values from grids. In this case, if the test analyst understands the domain and nature of the application, this step can be ignored in modeling. It is difficult to decide what to model and what to omit from modeling unless the modelers are experienced and trained.
- Model's inconsistency: In spite of the guidance on modeling, different test analysts model the same requirements differently. In some cases test analysts are obsessed with modeling, leading them to modeling analysis paralysis. Analysis Paralysis is a term given to the situation where a team of otherwise intelligent and well-meaning analysts enters into a phase of analysis that only ends when the project is cancelled (Analysis Paralysis). In Case Study #2 users were unable to confine themselves to the scope of the testable function. The model generated 131 test cases, but most of them are redundant.
- Consistency in practice: In large organizations, a consistent way of developing the software is very important. Freddie Mac is hugely disadvantaged by accounting mistakes in the past. The methodology and controls insist on consistency in practice. Any new tool has to complement the existing tools. TestManager is used to manage the test cases. Test cases generated by FTM have to be translated into a format that the TestManager tool can understand. Changes in requirements leads to changes in the test models, and therefore

changes in test cases. This incurred an extra burden on the teams. Flux in the requirements also leads to problems in maintaining the models. These problems lead to less management support.

9.2 Pros and Cons of ISP

Case studies are discussed in Chapters 4, 5, 6, and 7. Chapter 8 details the results and observations of the case studies. The following section explains the pros and cons of the ISP technique.

9.2.1 Advantages of ISP

- Test analysts are knowledgeable about the fundamentals of the equivalence partitioning, boundary value analysis, error guessing and other techniques of black box testing. The ISP technique can easily be understood with such a background.
- ISP gives good guidance when deriving the testable functions: Steps defined in the recommended framework provide clear guidance on how to isolate the set of requirements that can form a testable function. This method of exploring the requirements unfolds the complexity in an application. For example, in Case Study #4, although calculations appear to be receiving the inputs from four different external systems, this analysis of identifying the testable function simplified the complex look of the requirements.
- Test cases to satisfy different coverage criteria are automated. What is established with the help of case studies is the fact that these test cases, when executed, achieved good coverage of the requirements as well as the statement

coverage. This coverage provided more assurance to adapt this framework and implement the suggested approach.

- Test cases can be generated early in the cycle. Soon after the objects are identified, entities are defined, and their relations are specified, test case design can be started using this approach. In Case Study #2, test analysts designed and completed the test cases even before developers completed coding the requirements. Developers used these tests to test their implementation in addition to their unit tests. When system testing is conducted, fewer functional defects were found.
- It is easy to trace BC and MBC test cases to the requirements, which is the essential part of Freddie Mac’s methodology.
- Freddie Mac’s methodology requires test cases to be repeatable, contain enough level of detail, and then they should be mapped to the requirements. Test cases derived using this technique satisfy the methodology requirements.
- The majority of the applications in Freddie Mac, or any other financial service, are data intensive, which means the same scenario may need to be executed by multiple sets of data. For example, Freddie Mac has hundreds of products for Fixed and ARM categories. All of the products in each category share most of their properties and differ in some. In many test cases derived using the BC and MBC, the same requirement is covered more than once. In this case, when the test cases need prefixing of the values, they are varied with

different products. Therefore, not only are requirements well covered, but tests have a rich variety in data.

- Controllability: The case studies discussed in this thesis show that test cases derived using ISP offer good coverage not only of the requirements but also on the code.
- Observability: When there are multiple calculations occurring in a series or in parallel, all the requirements are broken into multiple testable functions for each calculation. While generating the expected results, all the intermediate values of the attributes are logged. The test team suggested the development team follow the same approach, which means to save the intermediate values of these variables into traces, while persisting the final values in the database. This approach simplified the process of diagnosing the differences in expected and actual results.
- Data aging: Test data that is used for one reporting cycle may not be useful for another reporting cycle. For example, when a loan is created in the system in January with the settlement date in April, the same loan data cannot be reused to test the February month cycle. This problem is called *data aging*. In test case design, only abstract values are used so that actual values can be applied periodically and with the current data. Automation is also applied to keep the data current. This approach simplified and resolved the data aging problem by keeping the test case design abstract from passing the real values during the test case design.

- Changes in requirements: When the requirements were changed, the traceability matrix allowed test analysts to quickly identify the impacted test cases. As the entire process of test case design was automated, it became easy to quickly generate a new set of test cases. The test analyst needed to simply identify the impacted testable function, change the partitions and/or values in the blocks to reflect the changes in requirements, and follow through the test case design steps.
- Submodeling: If the constraints among the attributes in a testable function span more than 2 attributes and their relations are complex in nature, then any one of the following actions can be taken to reduce the complexity: (a) the testable function can be further separated into small testable functions, or (b) a subset of attributes in the testable function can be chosen to apply the coverage criteria in the first stage, and in the second stage outputs of the first stage can be tested in conjunction with the outputs of the second stage (Grindal, Offutt, & Mellin, 2006).
- Business rules: A business rule is a requirement that is expressed in non-procedural and non-technical form, which implies specific constraints on data or business processes (i.e. valid values, calculations, timing ranges, etc.). The base choice criterion is best suited to test the business rules. For example, in Case Study #1, there are 180 business rules to test in a feature. The first part of the case study demonstrates how effective and efficient ISP was at testing the business rules. In another instance, where there are 1359 business rules,

application of BC coverage criterion coupled with automation reduced the testing cycle time from 5 business days to less than 2 hours. Also, the maintenance time was reduced drastically.

- Business cycles testing: In some applications, all the calculations in an application need to be tested for different business cycles: weekly, monthly, quarterly, and annually. Test data, along with the environment, needs to be changed to simulate these cycles. The ISP technique with automation offered this dynamism with the test data, keeping the process compliant with audit requirements.

9.2.2 Disadvantages of ISP

- The success of ISP largely depends on how well the testable functions are identified and how discrete they are. For example, Case Study #3 considered all the calculators as 1 single testable function instead of 11 testable functions. When these 11 calculations are considered as individual testable functions, they become very simple and straightforward. Case Study #4 demonstrates the effectiveness of choosing testable function at a unit level.
- ISP generates a large number of test cases across the entire application. ISP is more efficient if complemented by automation.
- The pair-wise criterion needs to be chosen carefully, otherwise more tests will be invalid. It is difficult to determine which tests are invalid.

10 Conclusions and Recommendations

10.1 Conclusion

Calculation engines are similar in their characteristics with respect to their specifications, architecture, and implementation. In this thesis's case studies, a common observation is that not all the attributes of the entities are important for the calculations. Problem analysis is the first step in finding the solution, and identifying the testable functions is a critical part in the problem analysis. Complexity in testing the calculations can be reduced by identifying the testable functions that are part of the calculations. A testable function can be a single requirement or a set of requirements that can be tested as a single unit. Each testable function should be independent of the other and should be testable in isolation. Functional and structural coverage of the requirements largely depends on the identified testable functions.

The framework recommended in Section 10.2 explains a way to identify the testable functions. Using automation, these sets of testable functions can be executed at once.

Thus, this thesis proposes a framework to test calculation engines. The framework provides guidance on deriving the testable functions and deriving the test cases. Case studies demonstrated the effectiveness of the approach by using common applications in the calculation engines and covering different characteristics.

- Case Study #1 explains how to isolate and test the calculation engines at different layers.
- Case Study #2 demonstrates how to analyze and simplify the calculation requirements and then how to test them.
- Case Study #3 demonstrates testing the very common amortization application in the financial services industry using ISP and automation.
- Case Study #4 shows a practical application of this framework.

This thesis began with addressing the problem with the help of modeling requirements. Although comparing the results of modeling with ISP was not an initial goal, the ISP technique was found to be better and to produce more consistent results. The outcome of the modeling approach largely depends on the skill set of the test analyst.

Systematic application of the technique to the problem is necessary. All four case studies confirm that BC and MBC, if applied according to the steps defined in the framework, offer good functional and structural coverage. It was also found that BC and MBC cover a large number of combinations among the attributes.

In the case studies # 1 and # 2, the statement coverage gaps, are traced to the exceptions. Programs handle the additional exceptions that are not in the scope of the functionality under tests. But when inputs are derived using ISP, blocks for the exceptions are not considered, as these exceptions are already filtered in the client layer.

The FTM framework is best applicable at the integration, system, and user acceptance test levels. In Case Study #3, test inputs were derived in advance to the coding and were given to the development team to satisfy these tests. This helped improve the software, as there were relatively few functional defects observed during system testing.

Tests derived following this framework and using the BC or MBC coverage criterion offer simple traceability to the requirements, which is an important requirement in the Freddie Mac's methodology.

This framework can easily be adapted to different development methodologies such as waterfall, spiral model, and RAD.

In all the cases examined, this framework not only proved to be effective in terms of coverage, but also very efficient. In Case Study #3, the entire application has 11 use cases and the total number of tests is close to 600. The application first runs with these 600 tests with a clean pass. Subsequently this application is tested with monthly cycle data that has 17,000 records with 0 defects. This entire process eventually was reduced to 0.5 days from 5 days.

10.2 Recommendations

The following framework, when used to test the calculation engines using the ISP technique, achieved consistency and offered repeatability. The steps below describe the process framework to test the calculation engines and extend the category partition method framework defined by Ostrand and Balcer (1998).

Step 1 Problem analysis is a crucial part of the ISP. In the first step, identify the problem to be addressed.

Step 2 Identify the testable functions. The testable functions could be a calculation set, a characteristic of a single attribute, a set of characteristics of multiple attributes that can be tested together, a set of conditions that triggers calculations, or a set of combination of values that triggers calculations.

Step 3 Identify explicit and the implicit attributes of the testable function. Many entities may take part in the testable function, but only a few attributes influence the objective of the testable function.

Step 4 Identify all the possible distinct values that are both valid and invalid for each attribute. Design specifications for the attributes of the testable function can help identify these values. In this step, real values may not be possible to consider. Therefore, any abstract values such as < 0, >0, and =0 can be chosen as distinct values. Amortization calculations occur recursively until the end of their term. Derive the blocks for loop characteristics carefully. In addition, Grindal and Offutt’s (2007) guidance on choosing the distinct values for the blocks using equivalence partitioning and boundary value analysis helps in determining the values.

Step 5 Apply the BC criteria with the invalid values and to derive the test cases to test all the error conditions.

Step 6 After testing the invalid conditions, eliminate the invalid values from each partition.

Step 7 Apply base choice, multiple base choice, and pair-wise coverage criteria appropriately to the remaining valid values of each partition to generate test cases with the valid values. Constraints may exist among these valid values. If the constraints exist only between 2 partitions, then base choice criterion covers critical constraints. If constraints exist among more than 2 partitions, then pair-wise criterion helps in reducing the number of tests, but it is very cumbersome to identify which combinations are valid. Grindal, Offutt, and Mellin (2006) suggested different strategies for conflict handling. The submodels strategy is relatively simple and easy to apply, and can be used in place of the pair-wise criterion to test the constraints among the partitions.

Step 8 Analyze requirements in the testable function and then identify the constraints among the partitions. These constraints can be of two types: either two or more attributes can coexist together with certain values, or they do not coexist.

Step 9 Test cases derived in Step 7 should be manually inspected for the conditions described in Step 8. Test cases that cannot be used should be excluded from the test suite or can be included as negative test cases.

Step 10 Ensure that test cases cover all the functional requirements in the testable function with the help of the Requirements Traceability Matrix (RTM). Each requirement can be covered by more than one test case by applying different coverage criteria as mentioned in Step 7. If the coverage is not sufficient, then choose more values for each partition and repeat from Step 3 to Step 10.

Step 11 Prefix the test cases with other attribute values that are trivial in this testable function but are required to execute the test case. In Step 3, if any of the other trivial attributes of the entities that are excluded in deriving the test cases are described in Step 7, prefix the test cases with these excluded attributes.

Step 12 Provide the real values for each attribute of the test cases, in place of arbitrary values chosen in the Step 3. Now the test case becomes executable.

Step 13 Build the calculation simulator, and then execute the test cases against the simulator to derive expected results.

Step 14 Execute the test cases against the system-under-test and get the actual results.

Step 15 Compare actual results with expected results to determine whether the test case passes or fails.

10.3 Further Work

10.3.1 Automatic Generation of Test Data for ISP tests

Abstract values are used to generate the ISP tests. Later, real values are added in place of arbitrary values. If the ranges of values for each partition/block and their constraints of other values in different partitions/blocks are known, then automatic test data generation is possible. If the automation is coupled with auto generation of the test data, this will further improve the efficiency of testing the calculation engines.

10.3.2 Filter the Conflicting Combinations Automatically

In the first two case studies, the pair-wise criterion is applied to derive the combinatorial tests. In both the cases, a number of pair-wise tests are invalid and more time is spent in filtering the valid tests from the pair-wise tests. I found it is more efficient to apply the submodels strategy instead of pair-wise tests. Grindal, Offutt, and Mellon (2006) discussed several strategies in managing the conflicts. The dependencies or conflicts between the partitions can be identified and the tests can be filtered accordingly using the automation.

10.3.3 Build the Tool With a User Interface

A Java utility was written to automatically generate the Base Choice and Multiple Base Choice test cases. Bach's PERL program is used to generate the pair-wise tests. These utilities read the inputs from spreadsheet and write the outputs to spreadsheet or a word processor. Freddie Mac's methodology requires proper documentation of the practice. A tool with the help of a user interface to define the partitions, blocks, and input the values will greatly enhance and ease the process of deriving the test inputs. This approach can then be incorporated in their test strategy.

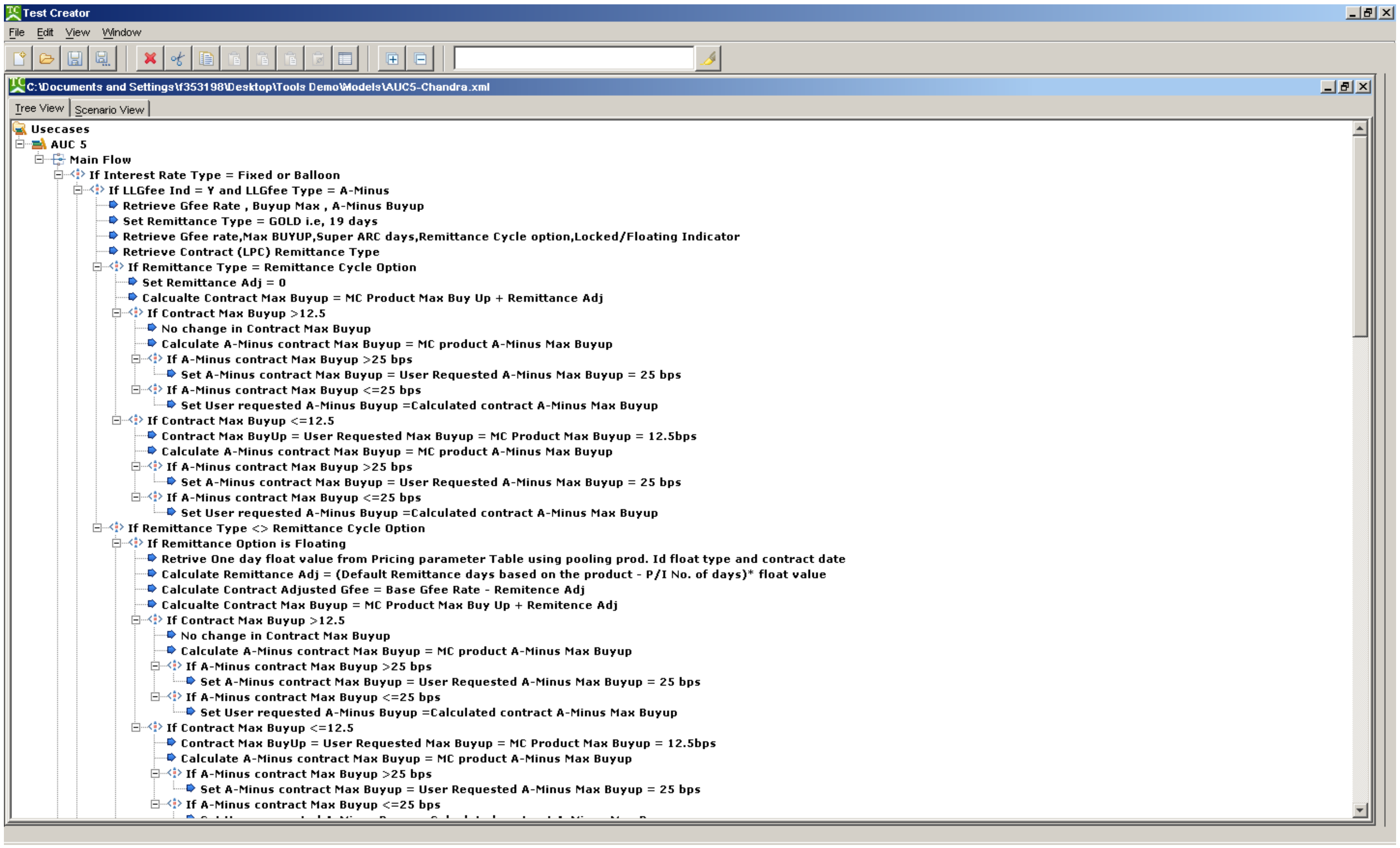
10.3.4 Auto Detection of the Requirements Coverage and Building Traceability

Requirements within the scope of testing can be divided into multiple testable functions. When a testable function is chosen to derive the test inputs, and if the corresponding requirement numbers are associated with each test input, then functional coverage of the requirements can be analyzed. For example, Bach's PERL program generates the test inputs along with the pairs of attributes that are covered in each test input. When the same requirement is covered multiple times, it will help in varying the values of the inputs. For example, when the partition "product type" is covered multiple times, different products—30 Y FIXED, 40 Y FIXED, etc.—are passed as real values. This not only improves coverage, but also provides rich variation in the test data. At present, this identification is done manually. Automating this detection of the coverage could greatly enhance the testing efficiency.

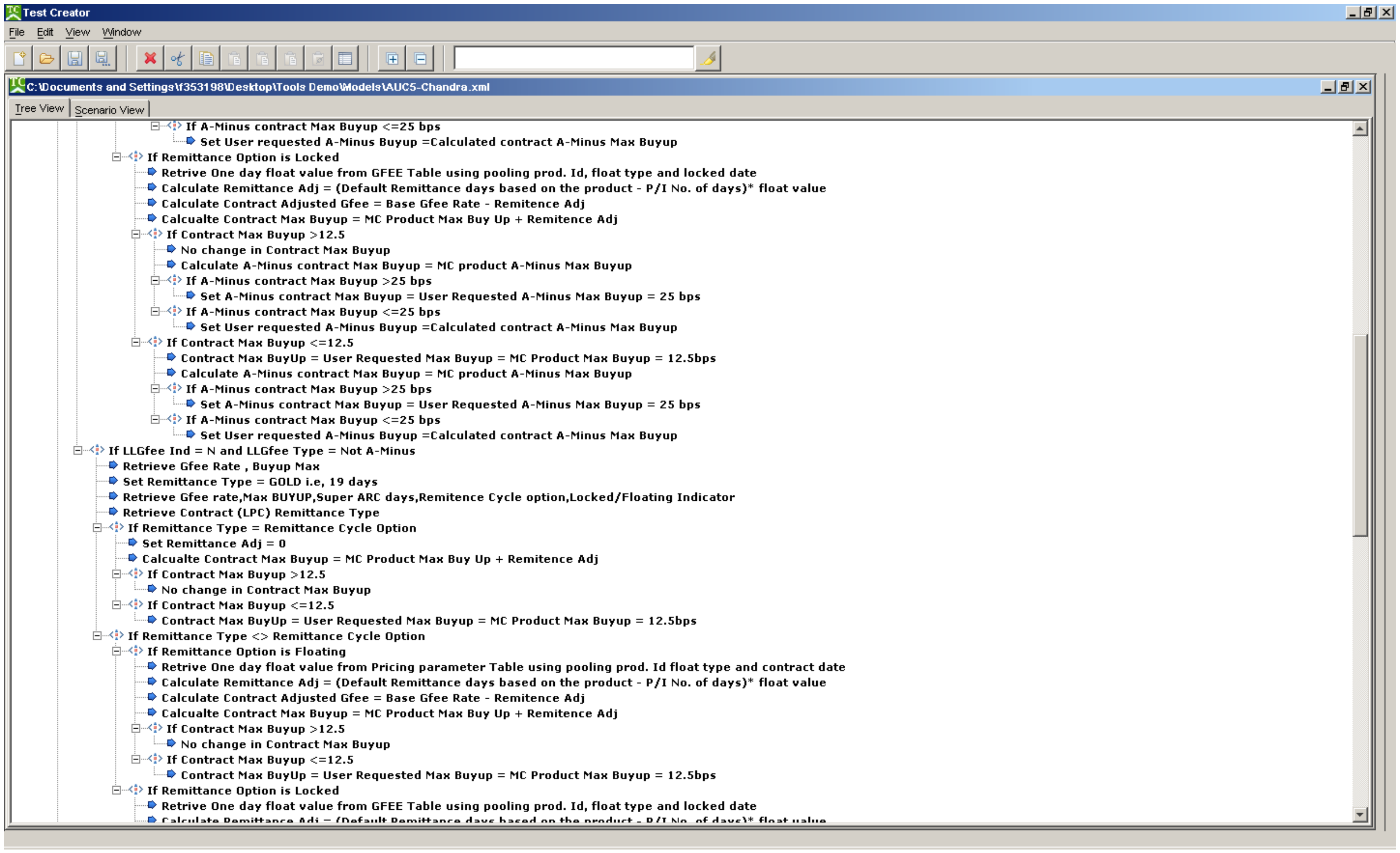
10.3.5 Testable Functions as an Estimation Technique

Test analysts are able to quickly identify the testable functions after analyzing a few use cases or a subset of the requirements. They are also able to recognize the testable functions that can be tested and executed together. Derived testable functions can be categorized as low, medium, and high by the number of characteristics of each attribute and constraints among the attributes. It is possible to predict the number of test inputs for each testable function. This information, if obtained early in the life cycle of the project, could help estimate the testing efforts of the project.

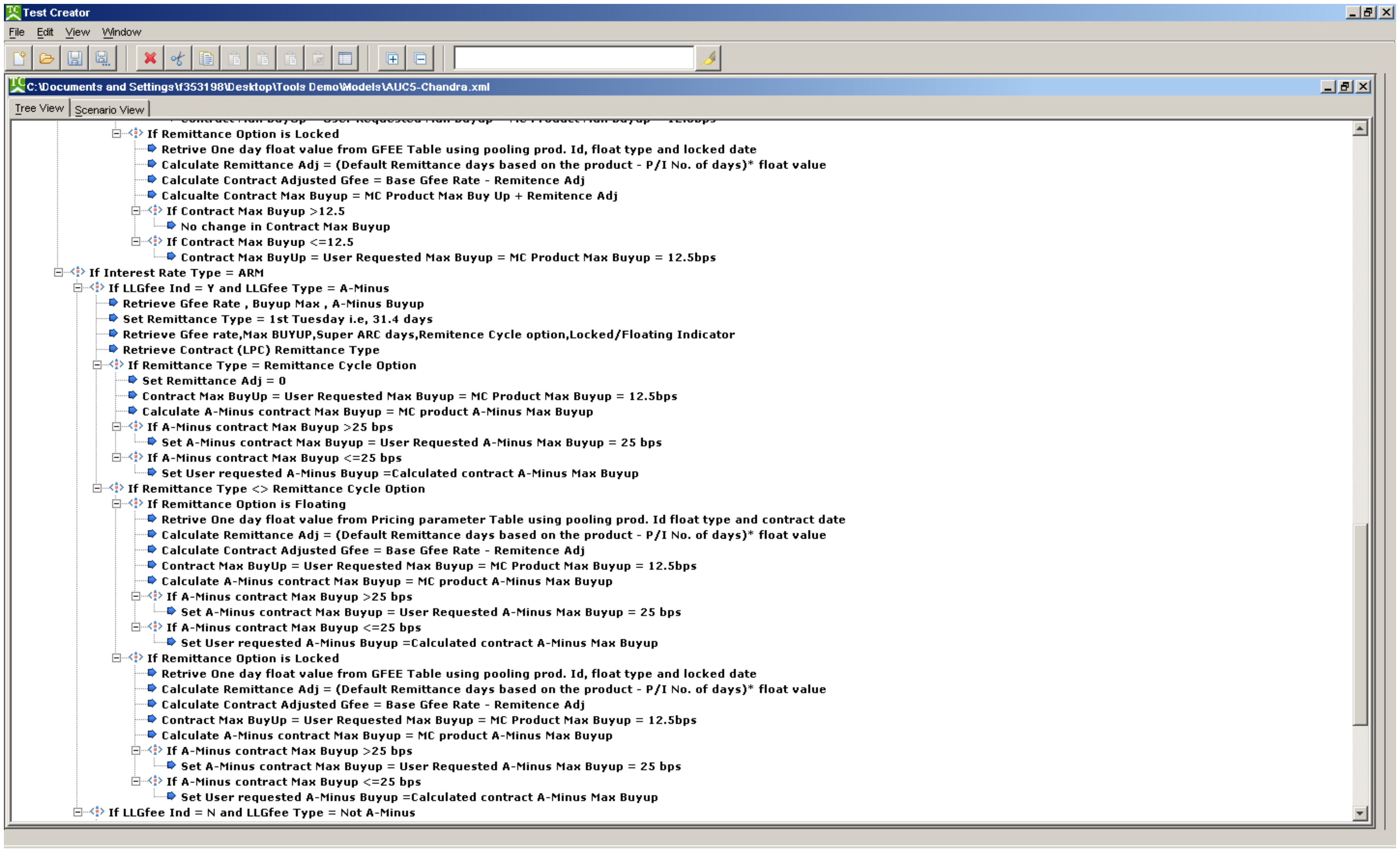
Appendix A. Modeling Outputs for Case Study # 1


Test Creator
File Edit View Window
C:\Documents and Settings\f353198\Desktop\Tools Demo\Models\AUC5-Chandra.xml
Tree View
Scenario View

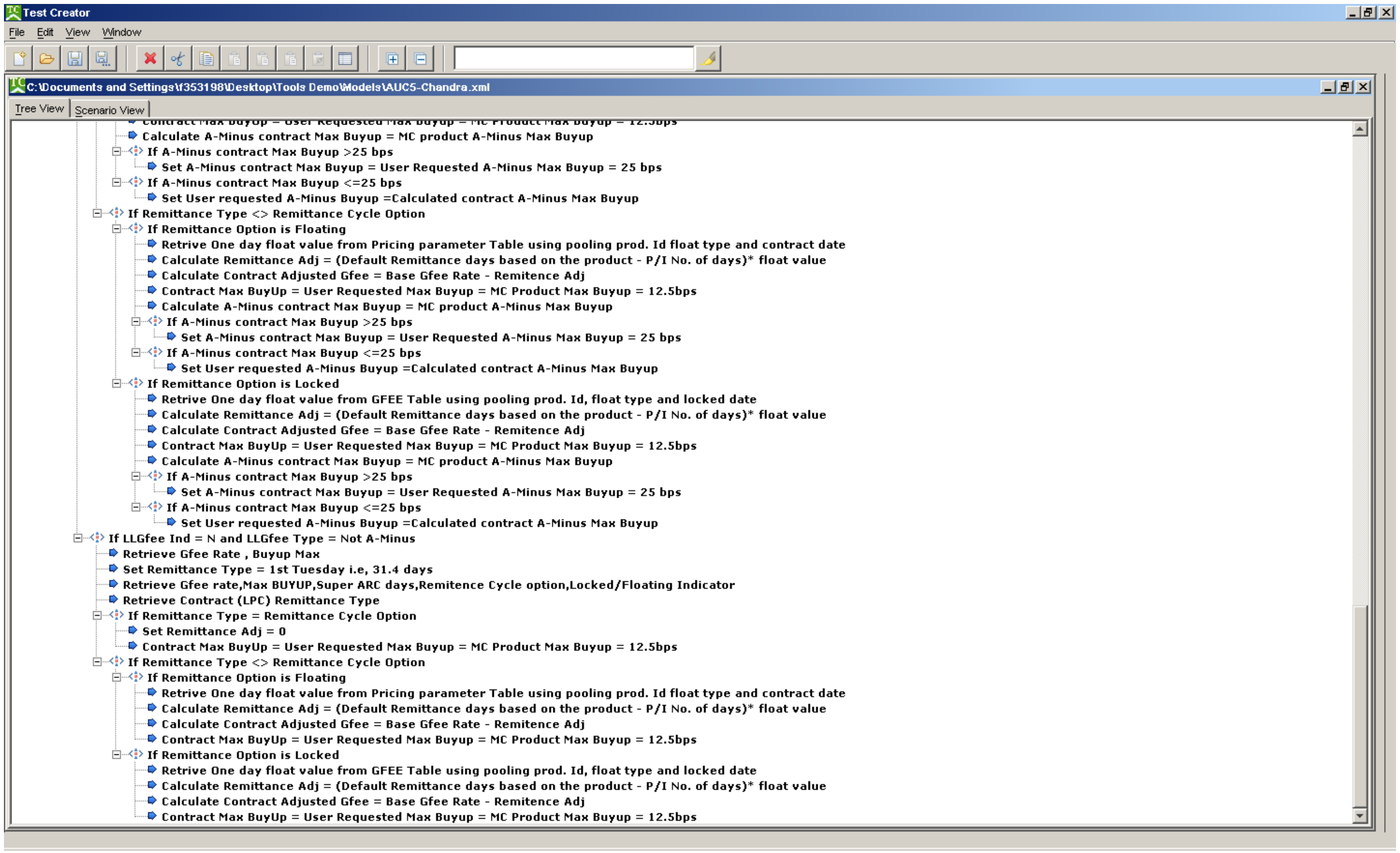
```
Usecases
  AUC 5
    Main Flow
      If Interest Rate Type = Fixed or Balloon
        If LLGfee Ind = Y and LLGfee Type = A-Minus
          Retrieve Gfee Rate , Buyup Max , A-Minus Buyup
          Set Remittance Type = GOLD i.e, 19 days
          Retrieve Gfee rate,Max BUYUP,Super ARC days,Remittance Cycle option,Locked/Floating Indicator
          Retrieve Contract (LPC) Remittance Type
          If Remittance Type = Remittance Cycle Option
            Set Remittance Adj = 0
            Calcualte Contract Max Buyup = MC Product Max Buy Up + Remittance Adj
            If Contract Max Buyup >12.5
              No change in Contract Max Buyup
              Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
              If A-Minus contract Max Buyup >25 bps
                Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
              If A-Minus contract Max Buyup <=25 bps
                Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
            If Contract Max Buyup <=12.5
              Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
              Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
              If A-Minus contract Max Buyup >25 bps
                Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
              If A-Minus contract Max Buyup <=25 bps
                Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
          If Remittance Type <> Remittance Cycle Option
            If Remittance Option is Floating
              Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
              Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
              Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
              Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
              If Contract Max Buyup >12.5
                No change in Contract Max Buyup
                Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
                If A-Minus contract Max Buyup >25 bps
                  Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
                If A-Minus contract Max Buyup <=25 bps
                  Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
              If Contract Max Buyup <=12.5
                Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
                Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
                If A-Minus contract Max Buyup >25 bps
                  Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
                If A-Minus contract Max Buyup <=25 bps
```


Test Creator
File Edit View Window
C:\Documents and Settings\f353198\Desktop\Tools Demo\Models\AUC5-Chandra.xml
Tree View
Scenario View

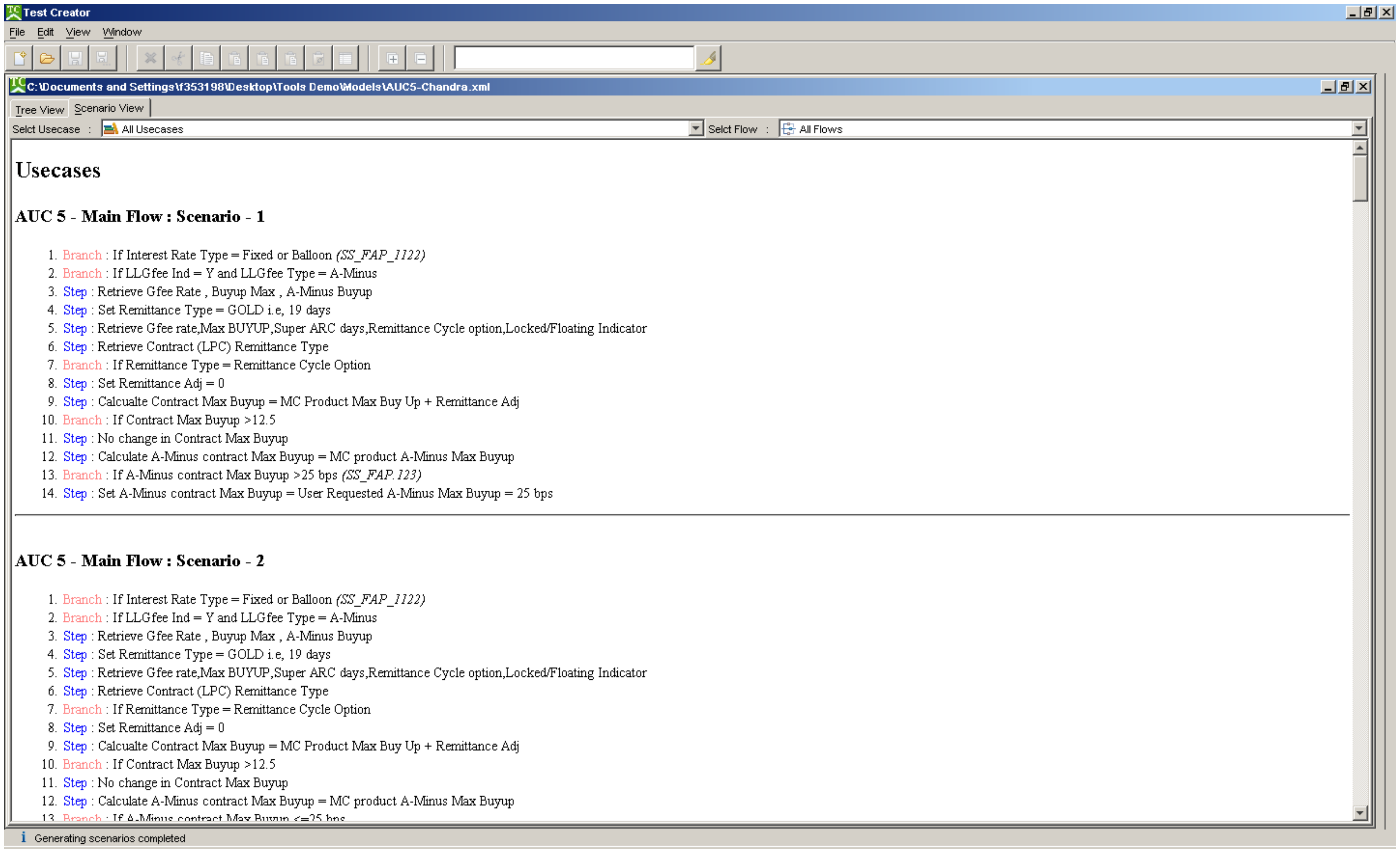
```
        If A-Minus contract Max Buyup <=25 bps
          Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
    If Remittance Option is Locked
      Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
      Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
      Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
      Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
      If Contract Max Buyup >12.5
        No change in Contract Max Buyup
        Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
        If A-Minus contract Max Buyup >25 bps
          Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
        If A-Minus contract Max Buyup <=25 bps
          Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
      If Contract Max Buyup <=12.5
        Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
        Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
        If A-Minus contract Max Buyup >25 bps
          Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
        If A-Minus contract Max Buyup <=25 bps
          Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
If LLGfee Ind = N and LLGfee Type = Not A-Minus
  Retrieve Gfee Rate , Buyup Max
  Set Remittance Type = GOLD i.e, 19 days
  Retrieve Gfee rate,Max BUYUP,Super ARC days,Remitence Cycle option,Locked/Floating Indicator
  Retrieve Contract (LPC) Remittance Type
  If Remittance Type = Remittance Cycle Option
    Set Remittance Adj = 0
    Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
    If Contract Max Buyup >12.5
      No change in Contract Max Buyup
    If Contract Max Buyup <=12.5
      Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
  If Remittance Type <> Remittance Cycle Option
    If Remittance Option is Floating
      Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
      Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
      Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
      Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
      If Contract Max Buyup >12.5
        No change in Contract Max Buyup
      If Contract Max Buyup <=12.5
        Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
    If Remittance Option is Locked
      Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
      Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
```



```
      If Remittance Option is Locked
        Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
        Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
        Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
        Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
        If Contract Max Buyup >12.5
          No change in Contract Max Buyup
        If Contract Max Buyup <=12.5
          Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
If Interest Rate Type = ARM
  If LLGfee Ind = Y and LLGfee Type = A-Minus
    Retrieve Gfee Rate , Buyup Max , A-Minus Buyup
    Set Remittance Type = 1st Tuesday i.e, 31.4 days
    Retrieve Gfee rate,Max BUYUP,Super ARC days,Remitence Cycle option,Locked/Floating Indicator
    Retrieve Contract (LPC) Remittance Type
    If Remittance Type = Remittance Cycle Option
      Set Remittance Adj = 0
      Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
      Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
      If A-Minus contract Max Buyup >25 bps
        Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
      If A-Minus contract Max Buyup <=25 bps
        Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
    If Remittance Type <> Remittance Cycle Option
      If Remittance Option is Floating
        Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
        Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
        Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
        Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
        Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
        If A-Minus contract Max Buyup >25 bps
          Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
        If A-Minus contract Max Buyup <=25 bps
          Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
      If Remittance Option is Locked
        Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
        Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
        Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
        Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
        Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
        If A-Minus contract Max Buyup >25 bps
          Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
        If A-Minus contract Max Buyup <=25 bps
          Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
  If LLGfee Ind = N and LLGfee Type = Not A-Minus
```


Test Creator
File
Edit
View
Window
C:\Documents and Settings\f353198\Desktop\Tools Demo\Models\AUC5-Chandra.xml
Tree View
Scenario View

```
        Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
        Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
        If A-Minus contract Max Buyup >25 bps
          Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
        If A-Minus contract Max Buyup <=25 bps
          Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
      If Remittance Type <> Remittance Cycle Option
        If Remittance Option is Floating
          Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
          Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
          Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
          Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
          Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
          If A-Minus contract Max Buyup >25 bps
            Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
          If A-Minus contract Max Buyup <=25 bps
            Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
        If Remittance Option is Locked
          Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
          Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
          Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
          Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
          Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
          If A-Minus contract Max Buyup >25 bps
            Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps
          If A-Minus contract Max Buyup <=25 bps
            Set User requested A-Minus Buyup =Calculated contract A-Minus Max Buyup
    If LLGfee Ind = N and LLGfee Type = Not A-Minus
      Retrieve Gfee Rate , Buyup Max
      Set Remittance Type = 1st Tuesday i.e, 31.4 days
      Retrieve Gfee rate,Max BUYUP,Super ARC days,Remitence Cycle option,Locked/Floating Indicator
      Retrieve Contract (LPC) Remittance Type
      If Remittance Type = Remittance Cycle Option
        Set Remittance Adj = 0
        Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
      If Remittance Type <> Remittance Cycle Option
        If Remittance Option is Floating
          Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
          Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
          Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
          Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
        If Remittance Option is Locked
          Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
          Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
          Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
          Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
```



C:\Documents and Settings\f353198\Desktop\Tools Demo\Models\AUC5-Chandra.xml

Usecases

AUC 5 - Main Flow : Scenario - 1

1. Branch : If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch : If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step : Retrieve Gfee Rate , Buyup Max , A-Minus Buyup
4. Step : Set Remittance Type = GOLD i.e, 19 days
5. Step : Retrieve Gfee rate,Max BUYUP,Super ARC days,Remittance Cycle option,Locked/Floating Indicator
6. Step : Retrieve Contract (LPC) Remittance Type
7. Branch : If Remittance Type = Remittance Cycle Option
8. Step : Set Remittance Adj = 0
9. Step : Calcualte Contract Max Buyup = MC Product Max Buy Up + Remittance Adj
10. Branch : If Contract Max Buyup >12.5
11. Step : No change in Contract Max Buyup
12. Step : Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
13. Branch : If A-Minus contract Max Buyup >25 bps *(SS_FAP.123)*
14. Step : Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

AUC 5 - Main Flow : Scenario - 2

1. Branch : If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch : If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step : Retrieve Gfee Rate , Buyup Max , A-Minus Buyup
4. Step : Set Remittance Type = GOLD i.e, 19 days
5. Step : Retrieve Gfee rate,Max BUYUP,Super ARC days,Remittance Cycle option,Locked/Floating Indicator
6. Step : Retrieve Contract (LPC) Remittance Type
7. Branch : If Remittance Type = Remittance Cycle Option
8. Step : Set Remittance Adj = 0
9. Step : Calcualte Contract Max Buyup = MC Product Max Buy Up + Remittance Adj
10. Branch : If Contract Max Buyup >12.5
11. Step : No change in Contract Max Buyup
12. Step : Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
13. Branch : If A-Minus contract Max Buyup <=25 bps

Generating scenarios completed

AUC 5 - Main Flow: Scenario - 1

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e., 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type = Remittance Cycle Option
8. Step: Set Remittance Adj = 0
9. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remittance Adj
10. Branch: If Contract Max Buyup >12.5
11. Step: No change in Contract Max Buyup
12. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
13. Branch: If A-Minus contract Max Buyup >25 bps *(SS_FAP.123)*
14. Step: Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

---

AUC 5 - Main Flow: Scenario - 2

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e., 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type = Remittance Cycle Option

8. Step: Set Remittance Adj = 0
9. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remittance Adj
10. Branch: If Contract Max Buyup >12.5
11. Step: No change in Contract Max Buyup
12. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
13. Branch: If A-Minus contract Max Buyup <=25 bps
14. Step: Set User requested A-Minus Buyup = Calculated contract A-Minus Max Buyup

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AUC 5 - Main Flow: Scenario - 3

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type = Remittance Cycle Option
8. Step: Set Remittance Adj = 0
9. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remittance Adj
10. Branch: If Contract Max Buyup <=12.5
11. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
12. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
13. Branch: If A-Minus contract Max Buyup >25 bps

14. Step: Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

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AUC 5 - Main Flow: Scenario - 4

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type = Remittance Cycle Option
8. Step: Set Remittance Adj = 0
9. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remittance Adj
10. Branch: If Contract Max Buyup <=12.5
11. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
12. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
13. Branch: If A-Minus contract Max Buyup <=25 bps
14. Step: Set User requested A-Minus Buyup = Calculated contract A-Minus Max Buyup

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AUC 5 - Main Flow: Scenario - 5

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days

5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Floating
9. Step: Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup >12.5
14. Step: No change in Contract Max Buyup
15. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
16. Branch: If A-Minus contract Max Buyup >25 bps
17. Step: Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

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AUC 5 - Main Flow: Scenario - 6

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option

8. Branch: If Remittance Option is Floating
9. Step: Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup >12.5
14. Step: No change in Contract Max Buyup
15. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
16. Branch: If A-Minus contract Max Buyup <=25 bps
17. Step: Set User requested A-Minus Buyup = Calculated contract A-Minus Max Buyup

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AUC 5 - Main Flow: Scenario - 7

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Floating
9. Step: Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value

11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup <=12.5
14. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
15. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
16. Branch: If A-Minus contract Max Buyup >25 bps
17. Step: Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

---

AUC 5 - Main Flow: Scenario - 8

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Floating
9. Step: Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup <=12.5

14. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
15. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
16. Branch: If A-Minus contract Max Buyup <=25 bps
17. Step: Set User requested A-Minus Buyup = Calculated contract A-Minus Max Buyup

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AUC 5 - Main Flow: Scenario - 9

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Locked
9. Step: Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup >12.5
14. Step: No change in Contract Max Buyup
15. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
16. Branch: If A-Minus contract Max Buyup >25 bps

17. 17. Step: Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

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AUC 5 - Main Flow: Scenario - 10

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Locked
9. Step: Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup >12.5
14. Step: No change in Contract Max Buyup
15. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
16. Branch: If A-Minus contract Max Buyup <=25 bps
17. Step: Set User requested A-Minus Buyup = Calculated contract A-Minus Max Buyup

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AUC 5 - Main Flow: Scenario - 11

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*

2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Locked
9. Step: Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup <=12.5
14. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
15. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
16. Branch: If A-Minus contract Max Buyup >25 bps
17. Step: Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

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AUC 5 - Main Flow: Scenario - 12

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = GOLD i.e, 19 days

5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Locked
9. Step: Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup <=12.5
14. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
15. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
16. Branch: If A-Minus contract Max Buyup <=25 bps
17. Step: Set User requested A-Minus Buyup = Calculated contract A-Minus Max Buyup

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AUC 5 - Main Flow: Scenario - 13

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = N and LLGfee Type = Not A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type = Remittance Cycle Option

8. Step: Set Remittance Adj = 0
9. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
10. Branch: If Contract Max Buyup >12.5
11. Step: No change in Contract Max Buyup

AUC 5 - Main Flow: Scenario - 14

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = N and LLGfee Type = Not A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type = Remittance Cycle Option
8. Step: Set Remittance Adj = 0
9. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
10. Branch: If Contract Max Buyup <=12.5
11. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

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AUC 5 - Main Flow: Scenario - 15

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = N and LLGfee Type = Not A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator

6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Floating
9. Step: Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup >12.5
14. Step: No change in Contract Max Buyup

AUC 5 - Main Flow: Scenario - 16

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = N and LLGfee Type = Not A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Floating
9. Step: Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj

12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj

13. Branch: If Contract Max Buyup <=12.5

14. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

---

AUC 5 - Main Flow: Scenario - 17

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = N and LLGfee Type = Not A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max
4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Locked
9. Step: Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup >12.5
14. Step: No change in Contract Max Buyup

AUC 5 - Main Flow: Scenario - 18

1. Branch: If Interest Rate Type = Fixed or Balloon *(SS_FAP_1122)*
2. Branch: If LLGfee Ind = N and LLGfee Type = Not A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max

4. Step: Set Remittance Type = GOLD i.e, 19 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Locked
9. Step: Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj
12. Step: Calcualte Contract Max Buyup = MC Product Max Buy Up + Remitence Adj
13. Branch: If Contract Max Buyup <=12.5
14. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

---

AUC 5 - Main Flow: Scenario - 19

1. Branch: If Interest Rate Type = ARM
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = 1st Tuesday i.e, 31.4 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type = Remittance Cycle Option
8. Step: Set Remittance Adj = 0
9. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

10. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup

11. Branch: If A-Minus contract Max Buyup >25 bps

12. Step: Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

---

AUC 5 - Main Flow: Scenario - 20

1. Branch: If Interest Rate Type = ARM
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = 1st Tuesday i.e, 31.4 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type = Remittance Cycle Option
8. Step: Set Remittance Adj = 0
9. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps
10. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup
11. Branch: If A-Minus contract Max Buyup <=25 bps
12. Step: Set User requested A-Minus Buyup = Calculated contract A-Minus Max Buyup

---

AUC 5 - Main Flow: Scenario - 21

1. Branch: If Interest Rate Type = ARM
2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup
4. Step: Set Remittance Type = 1st Tuesday i.e, 31.4 days

5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator

6. Step: Retrieve Contract (LPC) Remittance Type

7. Branch: If Remittance Type <> Remittance Cycle Option

8. Branch: If Remittance Option is Floating

9. Step: Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date

10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value

11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remitence Adj

12. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

13. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup

14. Branch: If A-Minus contract Max Buyup >25 bps

15. Step: Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

---

AUC 5 - Main Flow: Scenario - 22

1. Branch: If Interest Rate Type = ARM

2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus

3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup

4. Step: Set Remittance Type = 1st Tuesday i.e, 31.4 days

5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator

6. Step: Retrieve Contract (LPC) Remittance Type

7. Branch: If Remittance Type <> Remittance Cycle Option

8. Branch: If Remittance Option is Floating

9. Step: Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date

10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value

11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remittance Adj

12. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

13. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup

14. Branch: If A-Minus contract Max Buyup <=25 bps

15. Step: Set User requested A-Minus Buyup = Calculated contract A-Minus Max Buyup

---

AUC 5 - Main Flow: Scenario - 23

1. Branch: If Interest Rate Type = ARM

2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus

3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup

4. Step: Set Remittance Type = 1st Tuesday i.e, 31.4 days

5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator

6. Step: Retrieve Contract (LPC) Remittance Type

7. Branch: If Remittance Type <> Remittance Cycle Option

8. Branch: If Remittance Option is Locked

9. Step: Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date

10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value

11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remittance Adj

12. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

13. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup

14. Branch: If A-Minus contract Max Buyup >25 bps

15. Step: Set A-Minus contract Max Buyup = User Requested A-Minus Max Buyup = 25 bps

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AUC 5 - Main Flow: Scenario - 24

1. Branch: If Interest Rate Type = ARM

2. Branch: If LLGfee Ind = Y and LLGfee Type = A-Minus

3. Step: Retrieve Gfee Rate, Buyup Max, A-Minus Buyup

4. Step: Set Remittance Type = 1st Tuesday i.e, 31.4 days

5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator

6. Step: Retrieve Contract (LPC) Remittance Type

7. Branch: If Remittance Type <> Remittance Cycle Option

8. Branch: If Remittance Option is Locked

9. Step: Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date

10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value

11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remittance Adj

12. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

13. Step: Calculate A-Minus contract Max Buyup = MC product A-Minus Max Buyup

14. Branch: If A-Minus contract Max Buyup <=25 bps

15. Step: Set User requested A-Minus Buyup = Calculated contract A-Minus Max Buyup

---

AUC 5 - Main Flow: Scenario - 25

1. Branch: If Interest Rate Type = ARM

2. Branch: If LLGfee Ind = N and LLGfee Type = Not A-Minus

3. Step: Retrieve Gfee Rate, Buyup Max
4. Step: Set Remittance Type = 1st Tuesday i.e, 31.4 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type = Remittance Cycle Option
8. Step: Set Remittance Adj = 0
9. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

---

AUC 5 - Main Flow: Scenario - 26

1. Branch: If Interest Rate Type = ARM
2. Branch: If LLGfee Ind = N and LLGfee Type = Not A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max
4. Step: Set Remittance Type = 1st Tuesday i.e, 31.4 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Floating
9. Step: Retrive One day float value from Pricing parameter Table using pooling prod. Id float type and contract date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remittance Adj
12. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

---

AUC 5 - Main Flow: Scenario - 27

1. Branch: If Interest Rate Type = ARM

2. Branch: If LLGfee Ind = N and LLGfee Type = Not A-Minus
3. Step: Retrieve Gfee Rate, Buyup Max
4. Step: Set Remittance Type = 1st Tuesday i.e, 31.4 days
5. Step: Retrieve Gfee rate, Max BUYUP, Super ARC days, Remittance Cycle option, Locked/Floating Indicator
6. Step: Retrieve Contract (LPC) Remittance Type
7. Branch: If Remittance Type <> Remittance Cycle Option
8. Branch: If Remittance Option is Locked
9. Step: Retrive One day float value from GFEE Table using pooling prod. Id, float type and locked date
10. Step: Calculate Remittance Adj = (Default Remittance days based on the product - P/I No. of days)* float value
11. Step: Calculate Contract Adjusted Gfee = Base Gfee Rate - Remittance Adj
12. Step: Contract Max BuyUp = User Requested Max Buyup = MC Product Max Buyup = 12.5bps

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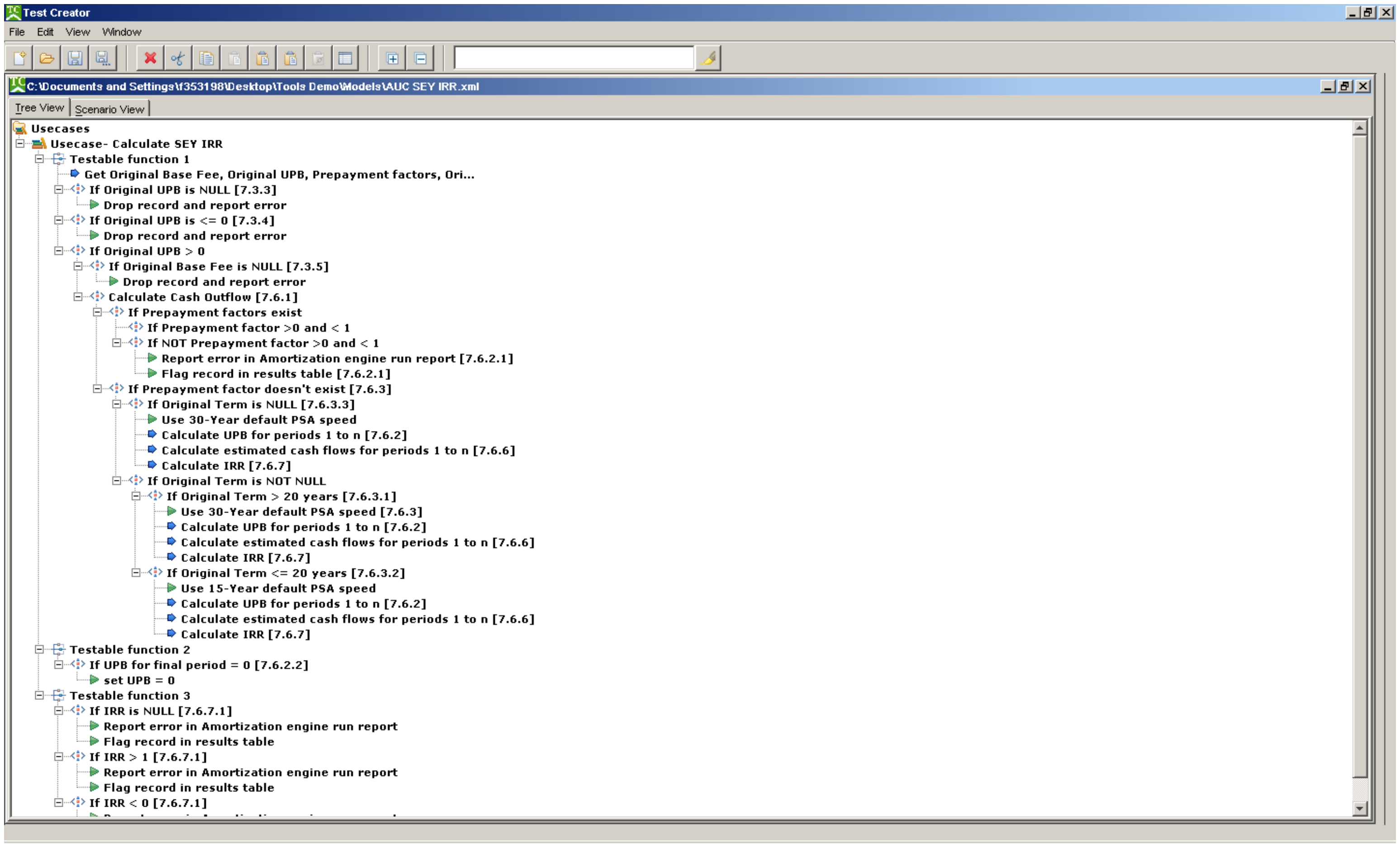
Appendix B. Modeling Outputs for Case Study # 4



Test Creator
File Edit View Window
C:\Documents and Settings\f353198\Desktop\Tools Demo\Models\AUC SEY IRR.xml
Tree View
Scenario View

```
Usecases
  Usecase- Calculate SEY IRR
    Testable function 1
      Get Original Base Fee, Original UPB, Prepayment factors, Ori...
      If Original UPB is NULL [7.3.3]
        Drop record and report error
      If Original UPB is <= 0 [7.3.4]
        Drop record and report error
      If Original UPB > 0
        If Original Base Fee is NULL [7.3.5]
          Drop record and report error
        Calculate Cash Outflow [7.6.1]
          If Prepayment factors exist
            If Prepayment factor >0 and < 1
            If NOT Prepayment factor >0 and < 1
              Report error in Amortization engine run report [7.6.2.1]
              Flag record in results table [7.6.2.1]
          If Prepayment factor doesn't exist [7.6.3]
            If Original Term is NULL [7.6.3.3]
              Use 30-Year default PSA speed
              Calculate UPB for periods 1 to n [7.6.2]
              Calculate estimated cash flows for periods 1 to n [7.6.6]
              Calculate IRR [7.6.7]
            If Original Term is NOT NULL
              If Original Term > 20 years [7.6.3.1]
                Use 30-Year default PSA speed [7.6.3]
                Calculate UPB for periods 1 to n [7.6.2]
                Calculate estimated cash flows for periods 1 to n [7.6.6]
                Calculate IRR [7.6.7]
              If Original Term <= 20 years [7.6.3.2]
                Use 15-Year default PSA speed
                Calculate UPB for periods 1 to n [7.6.2]
                Calculate estimated cash flows for periods 1 to n [7.6.6]
                Calculate IRR [7.6.7]
    Testable function 2
      If UPB for final period = 0 [7.6.2.2]
        set UPB = 0
    Testable function 3
      If IRR is NULL [7.6.7.1]
        Report error in Amortization engine run report
        Flag record in results table
      If IRR > 1 [7.6.7.1]
        Report error in Amortization engine run report
        Flag record in results table
      If IRR < 0 [7.6.7.1]
```

Usecase- Calculate SEY IRR - Testable function 1: Scenario - 1

1. Step: Get Original Base Fee, Original UPB, Prepayment factors, Original Term
2. Branch: If Original UPB is NULL [7.3.3]
3. Verification Point: Drop record and report error

Usecase- Calculate SEY IRR - Testable function 1: Scenario - 2

1. Step: Get Original Base Fee, Original UPB, Prepayment factors, Original Term
2. Branch: If Original UPB is <= 0 [7.3.4]
3. Verification Point: Drop record and report error

Usecase- Calculate SEY IRR - Testable function 1: Scenario - 3

1. Step: Get Original Base Fee, Original UPB, Prepayment factors, Original Term
2. Branch: If Original UPB > 0
3. Branch: If Original Base Fee is NULL [7.3.5]
4. Verification Point: Drop record and report error

Usecase- Calculate SEY IRR - Testable function 1: Scenario - 4

1. Step: Get Original Base Fee, Original UPB, Prepayment factors, Original Term
2. Branch: If Original UPB > 0
3. Branch: Calculate Cash Outflow [7.6.1]
4. Branch: If Prepayment factors exist
5. Branch: If Prepayment factor >0 and < 1

Usecase- Calculate SEY IRR - Testable function 1: Scenario - 5

1. Step: Get Original Base Fee, Original UPB, Prepayment factors, Original Term
2. Branch: If Original UPB > 0
3. Branch: Calculate Cash Outflow [7.6.1]
4. Branch: If Prepayment factors exist
5. Branch: If NOT Prepayment factor >0 and < 1

6. Verification Point: Report error in Amortization engine run report [7.6.2.1]
7. Verification Point: Flag record in results table [7.6.2.1]

Usecase- Calculate SEY IRR - Testable function 1: Scenario - 6

1. Step: Get Original Base Fee, Original UPB, Prepayment factors, Original Term
2. Branch: If Original UPB > 0
3. Branch: Calculate Cash Outflow [7.6.1]
4. Branch: If Prepayment factor doesn&apost exist [7.6.3]
5. Branch: If Original Term is NULL [7.6.3.3]
6. Verification Point: Use 30-Year default PSA speed
7. Step: Calculate UPB for periods 1 to n [7.6.2]
8. Step: Calculate estimated cash flows for periods 1 to n [7.6.6]
9. Step: Calculate IRR [7.6.7]

Usecase- Calculate SEY IRR - Testable function 1: Scenario - 7

1. Step: Get Original Base Fee, Original UPB, Prepayment factors, Original Term
2. Branch: If Original UPB > 0
3. Branch: Calculate Cash Outflow [7.6.1]
4. Branch: If Prepayment factor doesn&apost exist [7.6.3]
5. Branch: If Original Term is NOT NULL
6. Branch: If Original Term > 20 years [7.6.3.1]
7. Verification Point: Use 30-Year default PSA speed [7.6.3]
8. Step: Calculate UPB for periods 1 to n [7.6.2]
9. Step: Calculate estimated cash flows for periods 1 to n [7.6.6]
10. Step: Calculate IRR [7.6.7]

Usecase- Calculate SEY IRR - Testable function 1: Scenario - 8

1. Step: Get Original Base Fee, Original UPB, Prepayment factors, Original Term

2. Branch: If Original UPB > 0
3. Branch: Calculate Cash Outflow [7.6.1]
4. Branch: If Prepayment factor doesn&apost exist [7.6.3]
5. Branch: If Original Term is NOT NULL
6. Branch: If Original Term <= 20 years [7.6.3.2]
7. Verification Point: Use 15-Year default PSA speed
8. Step: Calculate UPB for periods 1 to n [7.6.2]
9. Step: Calculate estimated cash flows for periods 1 to n [7.6.6]
10. Step: Calculate IRR [7.6.7]

Usecase- Calculate SEY IRR - Testable function 2: Scenario - 9

1. Branch: If UPB for final period = 0 [7.6.2.2]
2. Verification Point: set UPB = 0

Usecase- Calculate SEY IRR - Testable function 3: Scenario - 10

1. Branch: If IRR is NULL [7.6.7.1]
2. Verification Point: Report error in Amortization engine run report
3. Verification Point: Flag record in results table

Usecase- Calculate SEY IRR - Testable function 3: Scenario - 11

1. Branch: If IRR > 1 [7.6.7.1]
2. Verification Point: Report error in Amortization engine run report
3. Verification Point: Flag record in results table

Usecase- Calculate SEY IRR - Testable function 3: Scenario - 12

1. Branch: If IRR < 0 [7.6.7.1]
2. Verification Point: Report error in Amortization engine run report
3. Verification Point: Flag record in results table

Appendix C. Glossary

Selling System: Freddie Mac's Web-based selling system integrates all secondary marketing functions—from pricing through delivery, certification and funding—into one system. The system provides a seamless secondary marketing process that incorporates pricing, contracting, loan allocation, purchase edits, note certification, contract settlement, and funding. By tying all the secondary marketing functions together, Freddie Mac eliminated the need to interact with multiple systems or to complete tasks through fax and phone.

Business Rules: A business rule is a requirement that is expressed in non-procedural and non-technical form, which implies specific constraints on data or business processes (i.e. valid values, calculations, timing ranges, etc.).

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